Conference Proceedings

15th International Conference on Information Systems for Crisis Response and Management

ISCRAM 2018

ISCRAM 2018

Rochester Institute of Technology
Rochester, NY, USA

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1. About the Conference

ISCRAM is a global community of academic researchers and practitioners. The annual international conference is a premier international venue for the dissemination of peer-reviewed research and lessons learned from all aspects of information systems for crisis response and management. Topics of interest to ISCRAM include, but are not limited to: crisis informatics, geographic information systems, human-computer interaction, humanitarian information management, situation awareness, visual analytics, social media, serious games and more. ISCRAM particularly interested in conference participation from students and attendees from developing countries.

The 2018 International Association for Information Systems for Crisis Response and Management (ISCRAM) World Conference Organizing Committee was pleased to announce that the 2018 ISCRAM World Conference being held May 20-23, 2018 in Rochester, NY, USA (https://iscram2018.rit.edu) was been approved for In-Cooperation with ACM SIGCAS.

The ACM (Association for Computing Machinery - https://www.acm.org/) is a non-profit organization that is the world's largest scientific and educational computing society. SIGCAS is the ACM Special Interest Group on Computers and Society. The In-Cooperation agreement between ACM SIGCAS and ISCRAM was designed to encourage collaboration and cooperation between the ISCRAM and ACM SIGCAS communities through publicity and ISCRAM conference participation and paper contribution by ACM SIGCAS and other ACM SIGs.

Some additional points to communicate about this exciting new aspect of the ISCRAM World Conference:

(1) The ISCRAM World Conference remained a conference run by the ISCRAM society – ACM In-Cooperation does not makes ISCRAM an ACM-sponsored conference;
(2) Proceedings of the 2018 ISCRAM World Conference will remain freely and openly available via the ISCRAM digital library (http://idl.iscram.org/). Additionally, the ISCRAM paper template will not be changed to the ACM template;
(3) As per the agreement to have ACM In-Cooperation status, a current ACM member can register to the 2018 ISCRAM World Conference with the ISCRAM member rate.

2. Host Institution

2.1 Rochester Institute of Technology

Founded in 1829, RIT is a privately endowed, coeducational university with nine colleges emphasizing career education and experiential learning. There are over 15,000 undergraduates and 3,200 graduate students from all 50 states and more than 100 countries. World-class research and teaching in imaging science, engineering, and computing are hallmarks of RIT's

portfolio. A diverse and interdisciplinary group of researchers interested in crisis management topics make RIT well suited for hosting the ISCRAM 2018 conference.

2.2 B. Thomas Golisano College of Computing and Information Sciences

The Golisano College of Computing and Information Sciences (GCCIS) is one of the nation's premier computing colleges and research facilities. From life-saving software applications to cutting edge technology for humanitarian purposes, every day Golisano College faculty and students are changing the world in exciting new ways. Golisano College is home to RIT's Computer Science, Computing Security, Information Sciences and Technologies, and Software Engineering departments, as well as our Ph.D. program in Computing and Information Sciences, and the School of Interactive Games & Media. The college has approximately 3,800 full-time students including 3,000 undergraduate students and 800 graduate students.

3. Conference Theme

Each year, ISCRAM brings together top researchers and practitioners working in the area of information systems and crisis management. The conference provides an excellent opportunity to exchange information and knowledge on new research and discuss best practices. The overarching theme for ISCRAM 2018 is Visualizing Crisis, which aims at the interdisciplinary development and design of information systems that enable better crisis planning, response, mitigation, recovery and training by using integrated approaches that combine organizational, behavioral, technical, economic and environmental aspects through visual representation and reasoning.

4. ISCRAM 2018 Committees

4.1 Conference Chairs

Brian Tomaszewski, Ph.D., Rochester Institute of Technology, USA.
Kim Shearer, Rochester Institute of Technology, USA.

4.2 Scientific Program Committee

4.2.1 Program Chair

Kees Boersma, Vrije Universiteit, Amsterdam

4.3 Local Organizing Committee

Jennifer L. Schneider, Rochester Institute of Technology, USA.
Kimberly McGann, Rochester Institute of Technology, USA.
J. Scott Hawker, Rochester Institute of Technology, USA.
Danielle Smith, Rochester Institute of Technology, USA.
Rita McCarthy, Rochester Institute of Technology, USA.
Wendy Ford, Rochester Institute of Technology, USA.

4.4 Communications Chair

Fran Broderick, Rochester Institute of Technology, USA.

4.5 Social Media Chair

Apoorva Chauhan, Utah State University, USA.

4.6 Paper Track Chairs

Christopher Zobel, Virginia Tech, USA.
Josey Chacko, Mount St. Mary's University, USA.
Björn JE Johansson, Linköping University, Sweden.
Peter Berggren, Linköping University, Sweden.
Nicoletta Baroutsi, Swedish Defence University/ Lund's University, Sweden.
Monika Büscher, Lancaster University, England.
Katrina Petersen, Trilateral Research, EU.
Hayley Watson, Trilateral Research, EU.
Caroline Rizza, Télécom Paristech, France.
Bernd Hellingrath, University of Münster, Germany.
Gyöngyi Kovács, Hanken School of Economics, Finland.
Adam Widera, University of Münster, Germany.
Tim Clark, Aptima, USA.
Vitaveska Lanfranchi, University of Sheffield, England.
Ryan Mullins, Aptima, USA.
João Porto de Albuquerque, University of Warwick, UK.
Alexander Zipf, University of Heidelberg, Germany.
Flávio E. A. Horita, University of São Paulo, Brazil.
Victor A. Bañuls, Pablo de Olavide University, Spain.
Murray Turoff, New Jersey Institute of Technology, USA.
José H. Canós, Universitat Politècnica de València, Spain.
Roxanne Hiltz, New Jersey Institute of Technology, USA.
Amanda Lee Hughes, Utah State University, USA.
Imran Muhammad, Qatar Computing Research Institute, Qatar.
Christian Reuter, Technische Universität Darmstadt, Germany.
Terje Gjøsæter, Oslo and Akershus University College, Norway.
Jaziar Radianti, University of Agder, Norway.
Weiqin Chen, Oslo and Akershus University College, Norway.
Bart van Leeuwen, Netage, Amsterdam, the Netherlands.

Zeno Franco, Medical College of Wisconsin, & Marquette University, USA.
Bas Lijnse, Radboud University, the Netherlands.
Reem Abbasl, Auckland University of Technology, New Zealand.
Sheikh Iqbal Ahamed, Marquette University, USA.
Tony Norris, Auckland University of Technology, New Zealand.
Jeroen Wolbers, Vrije Universiteit, Amsterdam, the Netherlands.
Louise Comfort, University of Pittsburgh, USA.
Anouck Adrot, Paris-Dauphine University, France.
Kees Boersma, Vrije Universiteit, Amsterdam, the Netherlands.
Danielle Smith, Rochester Institute of Technology, USA.

4.7 Workshop and Tutorial Chairs

Anastasios Karakostas, Information Technologies Institute - Centre for Research and Technology Hellas, Greece.
Claudio Rossi, Istituto Superiore Mario Boella, Italy.
Daniel Sempere Torres, UPC Civil Engineering School.
Stefanos Vrochidis, Information Technologies Institute - Centre for Research and Technology Hellas, Greece.
Hussein S. Al-Olimat, Wright State University, USA.
Amir Hossein Yazdavar, Wright State University, USA.
Krishnaprasad Thirunarayan, Wright State University, USA.
Amit Sheth, Wright State University, USA.

4.8 Doctoral Colloquium Chairs

Fiona McNeill, Heriot-Watt University, Scotland.
Kathleen Moore, James Madison University, USA.

5. ISCRAM 2018 Sponsors

GIS/SIG
Genesee | Finger Lakes Region, NY

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B. Thomas Golisano
College of Computing and
Information Sciences

RIT Office of the Provost

6. ISCRAM 2018 Tracks and Chairs

T1 - Analytical Modeling and Simulation
Chairs: Christopher Zobel and Josey Chacko

T2 - Command & Control Studies
Chairs: Björn JE Johansson, Peter Berggren, and Nicoletta Baroutsi

T3 - Ethical, Legal, and Social Issues (ELSI)
Chairs: Monika Büscher, Katrina Petersen, and Caroline Rizza

T4 - Logistics and Supply Chain Management in Crisis Response
Chairs: Bernd Hellingrath, Gyöngyi Kovács, and Adam Widera

T5 - Cybersecurity Issues and Innovations for Crisis Response
Chairs: Tim Clark, Vitaveska Lanfranchi, and Ryan Mullins

T6 - Geospatial Technologies and Geographic Information Science for Crisis Management (GIS)
Chairs: João Porto de Albuquerque, Alexander Zipf, and Flávio E. A. Horita

T7 - Planning, Foresight and Risk Analysis
Chairs: Victor A. Bañuls, Murray Turoff, and José H. Canós

T8 - Social Media Studies
Chairs: Roxanne Hiltz, Amanda Lee Hughes, Imran Muhammad, and Christian Reuter

T9 - Universal Design of ICT in Emergency Management
Chairs: Terje Gjøsæter, Jaziar Radianti, and Weiqin Chen

T10 - Case studies and reflections from practice
Chairs: Kees Boersma and Bart van Leeuwen

T11 - Community Engagement & Healthcare Systems
Chairs: Zeno Franco, Bas Lijnse, Reem Abbas, and Sheikh Iqbal Ahamed,

T12 - Designing for Resilience
Chairs: Jeroen Wolbers, Louise Comfort, Anouck Adrot, and Kees Boersma

T13- Open Track
Chair: Danielle Smith

7. Workshops and Tutorials

1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
Chairs: Anastasios Karakostas, Claudio Rossi, Daniel Sempere Torres, and Stefanos Vrochidis

Location Extraction and Georeferencing in Social Media: Challenges, Techniques, and Applications
Chairs: Hussein S. Al-Olimat, Amir Hossein Yazdavar, Krishnaprasad Thirunarayan, and Amit Sheth

Doctoral Colloquium
Chairs: Fiona McNeill and Kathleen Moore

8. ISCRAM 2018 Keynote Speakers

As anchors to this year's program we have three keynote speakers.

8.1 Andrej Verity

Andrej Verity is an information management officer at the United Nations (UN) Office for the Coordination of Humanitarian Affairs (OCHA) in New York and a co-founder of the Digital Humanitarian Network. Between responding to emergencies, he leads OCHA's multi-skilled Digital Services team providing strategic end-to-end service development, integrating and promoting standards and taxonomies, and managing platform-as-a-service support to a variety of sites ranging from ReliefWeb to the Humanitarian Data Exchange to the Financial Tracking Service to unocha.org. Verity has been working in the information management field for over 15 years, with the last 12 in the humanitarian realm. He has responded to many of the recent, major sudden onset emergencies - the 2010 Haiti earthquake, the 2010 Pakistan floods, the 2013-14 Philippines typhoon and the 2015 Nepal earthquake.

8.2 Dr. Andrea H. Tapia

Dr. Andrea H. Tapia is an Associate Professor of Information Sciences and Technology at the Pennsylvania State University in the United States of America. Dr. Tapia is a scholar of Crisis Informatics. She studies information discovery, needs, use and sharing in disaster settings. She also develops and studies information analysis tools, information devices and services in disaster settings. Dr. Tapia seeks to develop information and communication technology solutions that promote better decision-making across all responders. Dr. Tapia's most recent work focuses on making data generated by individuals or social networks via mobile information technologies useful to decision-makers within large institutions. At ISCRAM 2018, Dr. Tapia will present Developing for the Last Mile of Crisis: Where Analytics End and Community and Organization Begin.

8.3 Irene Omondi

) Irene Omondi is the Head of Office with United Nations High Commissioner for Refugees (UNHCR) sub-office located in Mafraq, Jordan which oversees 158,000 persons of concern from nearby Syria. In particular, her office covers the Zaatari Syrian refugee camp – currently home to over 78,000 Syrian refugees, making it one of the largest refugee camps in the world. She has fourteen years of professional humanitarian experience having served the UN in many humanitarian emergencies that include Yemen, Afghanistan, Liberia and Egypt. In her role, she has lead the implementation and partnership of rapid-refugee crisis response and research efforts to support community empowerment and mobilization, innovation, and service development. Additionally, Ms. Omondi has continued to serve as a leading expert in community based protection, education and solutions, and conflict management and negotiation in support of

vulnerable persons. Since 2014, she took a significant leadership role to advance UNHCR's innovative approaches to community based information management in Zaatari camp.

9. ISCRAM 2018 Papers and Posters Summary

We are pleased to present the accepted papers for ISCRAM 2018, which represent excellent contributions to a wide range of topics related to the use of information for the full cycle of emergency management. In total we received 132 papers. 54 were CoRe (full) papers, of which 30 have been accepted (55%). We received 78 WiPe (shorter) papers, of which 54 have been accepted (69%).

- 54 long research papers were submitted 30 of which were accepted—55% acceptance rate
- 78 short research papers were submitted, 54 of which we accepted. ---69% acceptance rate
- 25 posters were accepted.

For this year, ISCRAM defined two types of paper: Research and Insight. Research papers are intended to meet the needs of researchers by being peer reviewed to the highest academic standards. The primary aim of an academic paper is to make a contribution to the scientific body of knowledge. By contrast, Insight papers are intended to meet the needs of practitioners, managers, professionals, experts, and policy makers by being peer reviewed to high practical standards. The primary aim is to give an insight into what real-world problems arise during emergencies, disasters, and crises, and how such problems can be solved with the help of information systems.

9.1 Reviewing Criteria

The same five **criteria** (relevance, significance, originality, validity, and clarity) are used to judge all types of ISCRAM papers whether the paper is Research or Insight, CoRe or WiPe. However, some of these criteria are defined differently between Research and Insight papers, as shown in the table below. To select a score for each criterion, the reviewer should use the following 6-point scale: 0 = strongly disagree; 1 = disagree; 2=rather disagree; 3 = rather agree; 4 = agree; 5 = strongly agree.

Criterion	**Research paper**	**Insight paper**
Relevance	Relates both to information systems ***and*** the management of crises, emergencies or disasters. Relevance to special themes (if any) and to the track for which it is submitted.	
Significance	Presents knowledge about a way of designing, developing or deploying ISCRAM, about a way of managing crises, emergencies or disasters using information systems, or about the individual, organizational, or social consequences of ISCRAM that could open up or close off a line of academic research (for *Research* papers) or that improve the understanding or design of ISCRAM or ways of using ISCRAM by practitioners (for *Insight* papers).	
Originality	Ideas that are new to researchers, timely, non-	Ideas that are new, timely, and non-trivial to those who

	trivial, and well-grounded in the existing academic body of knowledge.	design, implement, or use of information systems for crisis management.
Validity	Research is based on appropriate theory, methods and approaches. References are suitable and relevant to content. Conclusions are reached by complete and logically correct argumentation.	Content is grounded in the actual experiences and realities of practitioners, professionals, experts, and/or policy makers.
Clarity	Paper is well structured, language is easy to read, figures and diagrams are easy to see, and any jargon and abbreviations used will be understandable by the audience at the ISCRAM event.	

Both types of papers were submitted in Full or Short form. A full paper reports on a completed project or piece of work, including validation of the results. Only full papers may be candidates for selection for the Best Research Paper, Best Student Paper, and Best Insight Paper awards. By contrast, a short paper is intended for the reporting of part of a complete project or piece of work. For example, a short paper may describe a project or research plan, a literature survey, the design of an information system, the development and testing of software, user evaluation of developed software, deployment, a real incident, a proposed new policy.

All authors of the papers in these proceedings have agreed to the ISCRAM 2018 Proceedings copyright agreement. This copyright agreement and use license state that an author retains copyright. It also permits any user – for any noncommercial purpose, including unlimited classroom and distance learning use – to download, print out, extract, archive, distribute and make derivative works of an article published in the ISCRAM 2018 Proceedings, as long as appropriate credit is given to the authors and the source of the work and all derivative works are placed under the same license.

9.2 ISCRAM 2018 Best Paper Awards

The Best Paper Award honors the author(s) of a paper of exceptional merit dealing with a subject related to the ISCRAM. We have three categories: best research, insight and student paper. Here we specify the criteria for eligibility in each category:

Long Research papers

- Significance of the paper to the field of ISCRAM
- Contribution to ISCRAM academic community
- Use of appropriate methodological rigor
- Clarity of writing

Long Insight papers

- Significance of the paper to the field of ISCRAM
- Contribution to ISCRAM practitioner's community
- Novelty and innovation
- Practical relevance and applicability
- Clarity of writing

Long Student papers (Research or Insight)

- Significance of the paper to the field of ISCRAM
- Level of contribution of the student in the paper
- Theoretical/Practical contribution to ISCRAM community
- Use of appropriate methodological rigor
- Clarity of writing

Process

A first set of candidate papers in each category has been proposed by the attending to the reviewers/track chairs ratings and recommendations. This first selection of the candidate papers has been made by the Papers and Conference Chairs. Then, the ISCRAM Publication and Standards Committee (PASC) takes the lead and proposes a committee for each category. The committee is mostly drawn from PASC, with one Program Committee representative. The review process is blind. After receiving their feedback, The Best Paper Committee decides which paper will receive the award. The rest of the papers can be recognized as finalists in the ISCRAM2018 Conference Proceedings.

9.3 Best Research Paper Committee

Chair: Hans Jochen Scholl
Committee: José H. Canós; Starr Roxanne Hiltz; Christopher Zobel

Paper Category / Award Candidate	Paper Title	Authors
CoRe Theoretical #144 First author = student Best Paper Candidate	Modeling Threats of Mass Incidents Using Scenario-based Bayesian Network Reasoning	Lida Huang Guoray Cai Hongyong Yuan Jianguo Chen Yan Wang Feng Sun
Core #112 theoretical. First author = student Best Paper Candidate	Situation Detection based on Activity Recognition in Disaster Scenarios	Patrick Lieser Hosam Nima Sanja Huhle Alaa Alhamoud

		Björn Richerzhagen Doreen Böhnstedt Ralf Steinmetz
Core practical #117 Best Paper Candidate	The sensor to decision chain in crisis management	Jürgen Moßgraber Hylke van der Schaaf Philipp Hertweck Efstratios Kontopoulos Panagiotis Mitzias Anastasios Karakostas Stefanos Vrochidis Ioannis Kompatsiaris
CoRe #111 theoretical Best Insight Paper Candidate	Crowding of Various Facilities Relevant to Supporting People Who Have Difficulty Returning Home after a Large Earthquake	Toshihiro Osaragi
Core #137 theoretical Best Insight Paper Candidate	Simulation of The Urban Waterlogging and Emergency Response Strategy at Subway Station's Entry-exit Platform in Heavy Rainstorm	Xiaoyong Ni Hong Huang Shiwei Zhou Boni Su Jianchun Zheng Wei Zhu
Core Practical #132 First author = student Best Insight Paper Candidate	Evaluation results for a Social Media Analyst Responding Tool	Mahshid Marbouti Craig Anslow Frank Maurer
Core theoretical #115 First author = student Best Doctoral Student Paper Candidate	Decision Support for the Optimal Coordination of Spontaneous Volunteers in Disaster Relief	Gerhard Rauchecker Guido Schryen
CoRe theoretical #152 First author = student Best Insight Paper Candidate	Social Media Resources Named after a Crisis Event	Apoorva Chauhan Amanda Lee Hughes

10. ISCRAM 2018 Book of Papers

All ISCRAM2018 papers and posters are available at the ISCRAM Digital Library

http://idl.iscram.org/

All presented papers will be submitted for indexing in:

• Scopus
• Compendex
• DBLP
• Google Scholar

*Disclaimer***:** All effort has been made to ensure the proceedings accurately represent all submitted and registered papers for the 2018 ISCRAM Conference. Any discrepancies with this document will be corrected in the ISCRAM Digital Library - http://idl.iscram.org/.

10.1 Acknowledgements

There are a huge number of people who have helped in producing this conference. First of all the members of the Conference and Program Committee and representatives of the ISCRAM board and their helpers. But we want to thank all the (c Track Chairs, Track Co-Chairs and reviewers, as well as all the member of the Scientific Committee for their help in the review process and organizing the tracks and special sessions.

We hope that you enjoy what we expect to be a lively conference!

Brian Tomaszewski, Kim Shearer and Kees Boersma
Conference and Programme Chairs

11. ISCRAM 2018 LIST OF PAPERS

11.1 T1 - Analytical Modeling and Simulation

ID: 111
Format: CoRe and Theoretical - Completed Research
Crowding of Various Facilities Relevant to Supporting People Who Have Difficulty Returning Home after a Large Earthquake
Toshihiro Osaragi
Tokyo Institute of Technology, Japan

ID: 113
Format: WiPe and Theoretical - Work In Progress
Analytic Decision Gaming – A Tool to Develop Crisis Response and Clinical Reasoning
Graham, Jacob L.; Stephens, Mark B.
The Pennsylvania State University, United States of America

ID: 115
Format: CoRe and Theoretical - Completed Research
Decision Support for the Optimal Coordination of Spontaneous Volunteers in Disaster Relief
Rauchecker, Gerhard; Schryen, Guido
University of Regensburg, Germany

ID: 118
Format: CoRe and Theoretical - Completed Research
Investigating the Use of Visual Analytics to Support Decision-Making in Crisis Management: A Multi-Method Approach
Dusse, Flavio (1); Novais, Renato (2); Mendonça, Manoel (1)
1: UFBA, Brazil; 2: IFBA, Brazil

ID: 137
Format: CoRe and Theoretical - Completed Research
Simulation of The Urban Waterlogging and Emergency Response Strategy at Subway Station's Entry-exit Platform in Heavy Rainstorm
Ni, Xiaoyong (1); Huang, Hong (1); Zhou, Shiwei (1); Su, Boni (2); Zheng, Jianchun (3); Zhu, Wei (3); Liu, Huali (4)
1: Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, China; 2: Electric Power Planning & Engineering Institute, No.65 Ande Road, Xicheng

District, Beijing, China; 3: Beijing Research Center of Urban System Engineering, Beijing, China; 4: Capital University of Economics and Business, Beijing, China

ID: 144
Format: CoRe and Theoretical - Completed Research
Modeling Threats of Mass Incidents Using Scenario-based Bayesian Network Reasoning
Huang, Lida (1,2); Cai, Guoray (2); Yuan, Hongyong (1); Chen, Jianguo (1); Wang, Yan (1,3); Sun, Feng (2)
1: Tsinghua University, China,; 2: Pennsylvania State University, USA; 3: Cornell University, USA

ID: 234
Format: WiPe and Theoretical - Work In Progress
A Multi-Agent System for Studying Cross-Border Disaster Resilience
Klein, Miriam Isabelle (1); Rigaud, Eric (2); Wiens, Marcus (1); Adrot, Anouck (4); Fiedrich, Frank (3); Kanaan, Nour (4); Lotter, Andreas (3); Mahdavian, Farnaz (1); Schulte, Yannic (3); Schultmann, Frank (1)
1: Karlsruhe Institute of Technology (KIT), Germany; 2: MINES ParisTech, PSL - Research University, CRC, Sophia Antipolis, France; 3: University of Wuppertal, Wuppertal, Germany; 4: University Paris-Dauphine PSL, Paris, France

ID: 254
Format: WiPe and Theoretical - Work In Progress
Evaluating Strategies for Intra-Organizational Information Management in Humanitarian Response
Bateman, Lauren; Gralla, Erica
George Washington University, United States of America

11.2 T2 - Command & Control Studies

ID: 128
Format: CoRe and Theoretical - Completed Research
Simulating Spontaneous Volunteers - A Conceptual Model
Lindner, Sebastian; Kühnel, Stephan; Betke, Hans; Sackmann, Stefan
Martin Luther University Halle-Wittenberg, Germany

ID: 129
Format: CoRe and Theoretical - Completed Research
A Practitioners Guide for C2 Evaluations: Quantitative Measurements of Performance and Effectiveness
Baroutsi, Nicoletta (1,2)
1: Swedish Defence University, Sweden; 2: Lund's University

ID: 195
Format: WiPe and Theoretical - Work In Progress
Assessing Interorganizational Crisis Response Capability - Initial Results of a Systematic Literature Review
Granåsen, Magdalena; Olsén, Mari; Oskarsson, Per-Anders
Swedish Defence Research Agency, Sweden

ID: 212
Format: WiPe and Theoretical - Work In Progress
Reflection in Teams for Training of Prehospital Command and Control Teams
Berggren, Peter (1); Herrera Velasquez, Mateo (2); Pettersson, Jenny (1); Henning, Oscar (1); Lidberg, Henrik (1); Johansson, Björn J E (2)
1: Centre for Teaching and Research in Disaster Medicine & Traumatology (KMC), Sweden; 2: Linköping University, Sweden

ID: 231
Format: WiPe and Theoretical - Work In Progress
Towards an Organizational and Socio-Technical Context-Aware Adaptation of Emergency Plans
Barthe-Delanoë, Anne-Marie (1); Truptil, Sébastien (2); Olivier-Maget, Nelly (1); Bénaben, Frédérick (2)
1: Laboratoire de Génie Chimique - Université de Toulouse - CNRS - INPT - UPS - France; 2: Centre Génie Industriel - Université de Toulouse - IMT Mines Albi – France

11.3 T3 - Ethical, Legal and Social Issues

ID: 125
Format: CoRe and Practical - Completed Research
Analysis of Core Social Actors in Nine Types of Mass Incidents Based on Social Network Analysis
Hu, Jun; Shu, Xueming; Tang, Shiyang
Tsinghua University, China, People's Republic of China

ID: 130
Format: CoRe and Theoretical - Completed Research
The Symbiotic Relationship of Crisis Response Professionals and Enthusiasts as Demonstrated by Reddit's User-Interface Over Time
Lalone, Nicolas (1); Kropczynski, Jess (2); Tapia, Andrea (3)
1: Bellevue University, United States of America; 2: University of Cincinnati, United States of America; 3: Pennsylvania State University, United States of America

ID: 230
Format: WiPe and Practical - Work In Progress
Managing inter-organizational breaks in a context of cross-border crisis
Kanaan, Nour; Adrot, Anouck
PARIS DAUPHINE UNIVERSITY, France

ID: 232
Format: WiPe and Practical - Work In Progress
Is-IT-ethical? Responsible Research and Innovation for Disaster Risk Management
Buscher, Monika; Lujan Escalante, Maria Alejandra; Alter, Hayley; Kerasidou, Xaroula
Lancaster University, United Kingdom

ID: 241
Format: WiPe and Theoretical - Work In Progress
Ethical, Legal and Social considerations surrounding the use of social media by citizens during Hurricane Irma in Cuba
Batard, Robin (1,2); Benaben, Frederick (2); Montarnal, Aurélie (2); Prieur, Christophe (1); Rizza, Caroline (1)
1: Institut Mines Telecom - Telecom ParisTech Institut Mines Telecom – Telecom ParisTech. I3 UMR 9217 – CNRS, France; 2: Institut Mines Telecom - Mines Albi – France

11.4 T4 - Logistics and Supply-Chain Management in Crisis Response

ID: 216
Format: WiPe and Practical - Work In Progress
A Sustainability Maturity Assessment Method for the Humanitarian Supply Chain
Laguna Salvadó, Laura (1); Lauras, Matthieu (1); Comes, Tina (2)
1: IMT Mines Albi (France); 2: University of Agder (Norway)

11.5 T5 - Cybersecurity Issues and Innovations for Crisis Response

ID: 217
Format: WiPe and Theoretical - Work In Progress

The determination of critical components of European Rail Traffic Management systems towards cyber-attacks

Gabriel, Alexander (1); Brauner, Florian (2); Lotter, Andreas (3); Fiedrich, Frank (3); Mudimu, Ompe Aimé (1)
1: TH Köln - University of Applied Sciences, Germany; 2: Kölner Verkehrs-Betriebe AG, Emergency and Crisis Management Systems, Germany; 3: University of Wuppertal, Germany

11.6 T6 - Geospatial Technologies and Geographic Information Science for Crisis Management (GIS)

ID: 143
Format: CoRe and Practical - Completed Research
Mapping Mobility to Support Crisis Management
Ciravegna, Fabio (1); Gao, Jerry (1); Ingram, Chris (2); Ireson, Neil (1); Lanfranchi, Vita (1); Simanjuntak, Humasak (1)
1: Sheffield University, United Kingdom; 2: K-Now Ltd, United Kingdom

ID: 185
Format: WiPe and Practical - Work In Progress
Towards Using the Potential of OpenStreetMap History for\\ Disaster Activation Monitoring
Auer, Michael; Eckle, Melanie; Fendrich, Sascha; Griesbaum, Luisa; Kowatsch, Fabian; Marx, Sabrina; Raifer, Martin; Schott, Moritz; Troilo, Rafael; Zipf, Alexander
HeiGIT, GIScience Research Group, Heidelberg University, Germany

ID: 211
Format: WiPe and Theoretical - Work In Progress
Conceptualizing the Role Geographic Information Capacity has on Quantifying Ecosystem Services under the Framework of Ecological Disaster Risk Reduction (EcoDRR)
Sutherby, Zachary Philip; Tomaszewski, Brian
Rochester Institute of Technology, United States of America

ID: 218
Format: WiPe and Practical - Work In Progress
GPS-based solution for tracking and protecting humanitarians in conflict zones
Lanfranchi, Vitaveska (1); Noori, Nadia (2); Sirbu, Tudor (3)
1: University of Sheffield, United Kingdom; 2: University of Agder, Norway; 3: K-Now ltd, United Kingdom

ID: 244
Format: WiPe and Practical - Work In Progress
3-1-1 Calls Hot Spot Analysis During Hurricane Harvey: Preliminary Results
Kotak, Chanvi; Tomaszewski, Brian; Golen, Erik
Rochester Institute of Technology, United States of America

ID: 246
Format: WiPe and Theoretical - Work In Progress

Flood Hazard, Vulnerability, Risk Assessment for Uttarakhand State in India

Hassan Vishwanath, Varsha; Tomaszewski, Brian
Rochester Institute of Technology, United States of America

11.7 T7 - Planning, Foresight and Risk Analysis

ID: 162
Format: WiPe and Theoretical - Work In Progress
Study on the Utility of Emergency Map in Emergency Response
Zhang, Zewei; Yuan, Hongyong; Huang, Lida
Tsinghua University, China

ID: 181
Format: WiPe and Theoretical - Work In Progress
Approaching the criticality of information for emergency response and control center operations
Dombois, Marcus; Bittner, Timo; Rüppel, Uwe
TU Darmstadt, Germany

ID: 192
Format: WiPe and Theoretical - Work In Progress
Accident Analysis Methods and Models - a Systematic Review
Wienen, Hans Christian Augustijn (1); Bukhsh, Faiza Allah (1); Vriezekolk, Eelco (1,2); Wieringa, Roel J. (1)
1: University of Twente, Netherlands, The; 2: Agentschap Telecom, The Netherlands

ID: 200
Format: WiPe and Practical - Work In Progress
A Conceptual Double Scenario Model for Predicting Medical Service Needs in the International Disaster Relief Action
Zhu, Min (1,2); Chen, Ruxue (1); Chen, Shi (1); Zhong, Shaobo (2); Liu, Cheng (2); Lin, Tianye (2,3); Huang, Quanyi (2); Zhai, Xin (1)
1: Navy General Hospital of PLA Beijing, China; 2: Institute of Public Safety Research(IPSR), Tsinghua University. Beijing, China; 3: Department of Engineering Physics, Tsinghua University, Beijing 100084, China

ID: 201
Format: WiPe and Theoretical - Work In Progress
A coordination lattice model for building urban resilience
Ciumasu, Ioan M.
University of Versailles Saint-Quentin-en-Yvelines (UVSQ), France

ID: 203
Format: WiPe and Practical - Work In Progress

Analyzing Cascading Effects among Critical Infrastructures
Schauer, Stefan (1); Rass, Stefan (2); König, Sandra (1); Grafenauer, Thomas (2); Latzenhofer, Martin (1)
1: AIT Austrian Institute of Technology GmbH, Austria; 2: Alpen Adria Universität Klagenfurt, Austria

ID: 215
Format: WiPe and Theoretical - Work In Progress
Towards Disaster e-Health Support Systems
González, José J. (2); Canós-Cerdá, José H. (1); Norris, Tony (3); Abbas, Reem (3)
1: Universitat Politècnica de València, Spain; 2: CIEM, University of Agder, Norway; 3: SCMS, Auckland University of Technology, New Zealand

11.8 T8 - Social Media Studies

ID: 116
Format: CoRe and Theoretical - Completed Research
ISCRAM turns 15: A Trend Analysis of all ISCRAM-Papers 2004-2017
Reuter, Christian (1); Backfried, Gerhard (2); Kaufhold, Marc-André (1); Spahr, Fabian (1)
1: Technische Universität Darmstadt, Germany; 2: Sail Labs Technology AG, Austria

ID: 119
Format: WiPe and Theoretical - Work In Progress
Terror Management and Twitter: The Case of the 2016 Berlin Terrorist Attack
Fischer, Diana; Schwemmer, Carsten; Fischbach, Kai
University of Bamberg, Germany

ID: 122
Format: CoRe and Practical - Completed Research
Communicating Crisis with Persuasion: Examining Official Twitter Messages on Heat Hazards
Li, Yajie; Hughes, Amanda Lee; Howe, Peter D.
Utah State University, United States of America

ID: 132
Format: CoRe and Practical - Completed Research
Evaluation results for a Social Media Analyst Responding Tool
Marbouti, Mahshid (1); Anslow, Craig (2); Maurer, Frank (1)
1: University Of Calgary, Canada; 2: Victoria University of Wellington, New Zealand

ID: 135
Format: CoRe and Theoretical - Completed Research
Sydney Siege, December 2014: A Visualisation of a Semantic Social Media Sentiment Analysis
Wendland, Jan (3); Ehnis, Christian (1); Clarke, Rodney J. (2); Bunker, Deborah (1)
1: The University of Sydney Business School, Australia; 2: University of Wollongong, Australia; 3: University of Muenster, Germany

ID: 141
Format: WiPe and Theoretical - Work In Progress
Bad Weather Coming: Linking social media and weather sensor data
Halse, Shane Errol (1); Montarnal, Aurélie (2); Tapia, Andrea (1); Benaben, Frederick (2)
1: PSU, United States of America; 2: IMT Mines Albi-Carmaux

ID: 142
Format: CoRe and Theoretical - Completed Research
It's what's outside that counts: Finding credibility metrics through non-message related Twitter features
Halse, Shane; Binda, Jomara; Weirman, Samantha
PSU, United States of America

ID: 146
Format: CoRe and Theoretical - Completed Research
Damage Identification in Social Media Posts using Multimodal Deep Learning
Mouzannar, Hussein; Rizk, Yara; Awad, Mariette
American University of Beirut, Lebanon (Lebanese Republic)

ID: 149
Format: CoRe and Theoretical - Completed Research
Harnessing Data to Create an Effective Drought Management System
Musaev, Aibek; Stowers, Kimberly; Kam, Jonghun
The University of Alabama, United States of America

ID: 151
Format: CoRe and Theoretical - Completed Research
A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria
Alam, Firoj; Ofli, Ferda; Imran, Muhammad; Aupetit, Michael
Qatar Computing Research Institute, Qatar

ID: 152
Format: CoRe and Theoretical - Completed Research
Social Media Resources Named after a Crisis Event

Chauhan, Apoorva; Hughes, Amanda Lee
Utah State University, United States of America

ID: 153
Format: CoRe and Practical - Completed Research
Possibility of Using Tweets to Detect Crowd Congestion: A Case Study Using Tweets just before/after the Great East Japan Earthquake
Oki, Takuya
Tokyo Institute of Technology, Japan

ID: 157
Format: CoRe and Theoretical - Completed Research
Crisis Event Extraction Service (CREES) - Automatic Detection and Classification of Crisis-related Content on Social Media
Burel, Grégoire; Alani, Harith
The Open University, United Kingdom

ID: 158
Format: CoRe and Theoretical - Completed Research
Community Coordination: Cooperative Uses of Social Media in Community Emergency Management
Grace, Rob (1); Kropczynski, Jess (2); Tapia, Andrea (1)
1: Pennsylvania State University; 2: University of Cincinnati

ID: 174
Format: WiPe and Practical - Work In Progress
Does Flight Path Context Matter? Impact on Worker Performance in Crowdsourced Aerial Imagery Analysis
Spatharioti, Sofia Eleni; Wylie, Sara; Cooper, Seth
Northeastern University, United States of America

ID: 177
Format: WiPe and Theoretical - Work In Progress
November 2015 Paris Terrorist Attacks and Social Media Use: Preliminary Findings from Authorities, Critical Infrastructure Operators and Journalists
Petersen, Laura (1); Fallou, Laure (1); Havarneanu, Grigore (3); Reilly, Paul (2); Serafinelli, Elisa (2); Bossu, Rémy (4)
1: Euro-Mediterranean Seismological Centre (EMSC); 2: University of Sheffield; 3: International Union of Railways; 4: CEA, DAM, DIF, F-91297 Arpajon, France

ID: 187
Format: WiPe and Theoretical - Work In Progress

Social Media in Citizen-Led Disaster Response: Rescuer Roles, Coordination Challenges, and Untapped Potential
Smith, William R.; Stephens, Keri K.; Robertson, Brett; Li, Jing; Murthy, Dhiraj
The University of Texas at Austin, United States of America

ID: 198
Format: WiPe and Practical - Work In Progress
Helping Crisis Responders Find the Informative Needle in the Tweet Haystack
Derczynski, Leon (1); Meesters, Kenny (2); Bontcheva, Kalina (1); Maynard, Diana (1)
1: University of Sheffield, United Kingdom; 2: TU Delft, Netherlands

ID: 205
Format: WiPe and Practical - Work In Progress
Leveraging Elasticsearch and Botometer to Explore Volunteered Geographic Information
Toepke, Samuel Lee
Private Engineering Firm, United States of America

ID: 210
Format: WiPe and Practical - Work In Progress
Deep Neural Networks versus Naive Bayes Classifiers for Identifying Informative Tweets during Disasters
Neppalli, Venkata Kishore (1); Caragea, Cornelia (2); Caragea, Doina (2)
1: Kaiser Permanente; 2: Kansas State University

ID: 219
Format: WiPe and Theoretical - Work In Progress
Understanding eyewitness reports on Twitter during disasters
Zahra, Kiran (1); Imran, Muhammad (2); Ostermann, Frank O (3)
1: University of Zurich, Switzerland; 2: Qatar Computing Research Institute, Doha Qatar; 3: University of Twente, The Netherlands

ID: 228
Format: WiPe and Theoretical - Work In Progress
The Sound of Silence: Exploring How Decreases in Tweets Contribute to Local Crisis Identification
Samuels, Rachel; Taylor, John Eric; Mohammadi, Neda
Georgia Tech, United States of America

ID: 229
Format: WiPe and Theoretical - Work In Progress
Linguistic Feature Assisted Deep Learning Approach towards Multi-label Classification of Crisis Related Tweets

Aipe, Alan (1); Ekbal, Asif (1); NS, Mukuntha (1); Kurohashi, Sadao (2)
1: Indian Institute of Technology Patna, India; 2: Kyoto University, Japan

ID: 245

Format: WiPe and Practical - Work In Progress

Using Twitter Data to Determine Hurricane Category: An Experiment

Yue, Songhui (1); Kondari, Jyothsna (1); Musaev, Aibek (1); Yue, Songqing (2); Smith, Randy (1)
1: University of Alabama, United States of America; 2: University of Wisconsin - Platteville, United States of America

ID: 248

Format: WiPe and Theoretical - Work In Progress

Classification of Twitter Disaster Data Using a Hybrid Feature-Instance Adaptation Approach

Mazloom, Reza (1); Li, HongMin (1); Caragea, Doina (1); Imran, Muhammad (2); Caragea, Cornelia (1)
1: Kansas State University, United States of America; 2: Qatar Computing Research Institute, HBKU, Doha, Qatar

11.9 T9 - Universal Design of ICT in Emergency Management

ID: 112
Format: CoRe and Theoretical - Completed Research
Situation Detection based on Activity Recognition in Disaster Scenarios
Lieser, Patrick; Alhamoud, Alaa; Nima, Hosam; Richerzhagen, Björn; Huhle, Sanja; Böhnstedt, Doreen; Steinmetz, Ralf
Technical University Darmstadt, Germany

ID: 117
Format: CoRe and Practical - Completed Research
The sensor to decision chain in crisis management
Moßgraber, Jürgen (1); Hilbring, Désirée (1); van der Schaaf, Hylke (1); Hertweck, Philipp (1); Kontopoulos, Efstratios (2); Mitzias, Panagiotis (2); Kompatsiaris, Ioannis (2); Vrochidis, Stefanos (2); Karakostas, Anastasios (2)
1: Fraunhofer IOSB, Germany; 2: Centre for Research and Technology Hellas (CERTH), Greece

ID: 148
Format: CoRe and Theoretical - Completed Research
Information gain in sociotechnical systems
Linot, Béatrice (1); Dinet, Jérôme (1); Charoy, François (1,2); Shalin, Valérie L. (3,4)
1: Lorraine University, France; 2: INRIA, Nancy, France; 3: Wright State University, Dayton OH; 4: KNOESIS Dayton OH

ID: 207
Format: WiPe and Theoretical - Work In Progress
Towards an Operational Emergency Response System for Large Scale Situations: POLARISC
Linda, Elmhadhbi; Mohamed Hedi, Karray; Bernard, Archimède
University of Toulouse, Toulouse, 31013, France

ID: 238
Format: WiPe and Theoretical - Work In Progress
A Volunteer Coordination System Approach for Crisis Committees
Betke, Hans Julius
Martin-Luther Universität Halle-Wittenberg, Germany

11.10 T10 - Case studies and reflections from practice

ID: 110
Format: CoRe and Theoretical - Completed Research
Hurricanes Send Signals for the Future of Emergency Preparedness
Turoff, Murray
NJIT, United States of America

ID: 127
Format: CoRe and Theoretical - Completed Research
Immersion and Presence in Virtual Reality Training for Mass Casualty Incidents
Berndt, Henrik; Wessel, Daniel; Willer, Lennard; Herczeg, Michael; Mentler, Tilo
Institute for Multimedia and Interactive Systems (IMIS), University of Luebeck, Germany

ID: 134
Format: CoRe and Theoretical - Completed Research
Practical Insights into the Design of Future Disaster Response Training Simulations
Alharthi, Sultan A. (1); LaLone, Nick (2); Khalaf, Ahmed S. (1); Torres, Ruth (1); Nacke, Lennart (3); Dolgov, Igor (4); Toups, Zachary O. (1)
1: Department of Computer Science, New Mexico State University, United States of America; 2: School of Information Sciences, University of Illinois at Urbana-Champaign, Champaign, Illinois, United States; 3: HCI Games Group, Department of Drama and Speech Communication, University of Waterloo, Waterloo, Ontario, Canada; 4: Department of Psychology, New Mexico State University, Las Cruces, NM, USA

ID: 136
Format: WiPe and Practical - Work In Progress
Risk Analysis and Management of IT Systems: Practice and Challenges
Sulaman, Sardar; Höst, Martin
Lund University, Sweden

ID: 224
Format: WiPe and Practical - Work In Progress
Information Systems for Disaster Management Training – Establishing User Needs with a Design Science Research Approach
Monika Magnusson, Lars Nyberg, Malin Wik
Karlstad University, Sweden

ID: 242
Format: WiPe and Practical - Work In Progress

Getting Disaster Data Right: A Call for Real-time Research in Disaster Response

Steve Peterson (1), Chris Thompson (2), Cat Graham (3)

1: National Institutes of Health, United States of America; 2: Humanity Road, United States of America; 3: Humanity Road, United States of America

11.11 T11 - Community Engagement & Healthcare Systems

ID: 145

Format: CoRe and Theoretical - Completed Research

Information Requirements for Disaster Victim Identification and Emergency Medical Services:Hajj Crowd Disaster Case Study

Shada A Alsalamah (1,7), Hessah A Alsalamah (1), Jaziar Radianti (2), Sakher Alqahtani (3), Thamer Adnan Nouh (4), Mohamed Abomhara (5), Ibrahim Alyahya (6)

1: College of Computer and Information Sciences, King Saud University; 2: Centre of Emergency Management, University of Agder; 3: College of Dentistry, King Saud University; 4: Trauma and Acute Care Surgery Unit, Department of Surgery, College of Medicine, King Saud University; 5: Department of Information and Communication Technology, University of Agder; 6: Emergency Medical Services,, Saudi Red Crescent Authority; 7: MIT Media Lab, MIT

ID: 170

Format: WiPe and Theoretical - Work In Progress

Detecting & Visualizing Crisis Events in Human Systems: an mHealth Approach with High Risk Veterans

Zeno Franco (1), Katinka Hooyer (1), Tanvir Roushan (2), Casey O'Brien (2), Nadiyah Johnson (2), Bill Watson (3), Nancy Smith-Watson (4), Bryan Semaan (5), Mark Flower (6), Jim Tasse (1), Sheikh Iqbal Ahamed (2)

1: Medical College of Wisconsin, United States of America; 2: Marquette University; 3: University of Wisconsin - Milwaukee; 4: Feast of Crispian; 5: Syracuse University; 6: Dryhootch (fmr)

ID: 183

Format: WiPe and Theoretical - Work In Progress

Inter-Agency Communication and Information Exchange in Disaster Healthcare

Reem Abbas (1), Tony Norris (2)

1: Auckland University of Technology (AUT), Auckland, New Zealand; 2: Auckland University of Technology (AUT), Auckland, New Zealand

ID: 250

Format: WiPe and Theoretical - Work In Progress

Citizens Communicating Health Information: Urging Others in their Community to Seek Help During a Flood

Keri K. Stephens, Jing Li, Brett W. Robertson, William R. Smith, Dhiraj Murthy

The University of Texas at Austin, United States of America

11.12 T12 - Designing for Resilience

ID: 138
Format: CoRe and Theoretical - Completed Research
The lack of preparedness for payment disruptions in local community core businesses
Björn Johan Erik Johansson (1), Amanda Jaber (1), Joeri van Laere (2), Peter Berggren (1)
1: Linköping University; 2: University of Skövde

ID: 178
Format: WiPe and Practical - Work In Progress
Evaluating Team Resilience in Simulator-Based Crisis Management Training
Björn Johan Erik Johansson (1), Joeri van Laere (2), Peter Berggren (1)
1: Linköping University, Sweden; 2: Skövde University

ID: 204
Format: WiPe and Theoretical - Work In Progress
Evaluating Platforms for Community Sense-making: Using the Case of the Kenyan Elections
Vittorio Nespeca, Kenny Meesters, Tina Comes
Delft University of Technology

ID: 208
Format: WiPe and Theoretical - Work In Progress
Crisis Cleanup: Creating a Virtual Command Post to Support Relief Organizations on the Ground
Lise Ann St. Denis (1), Amanda Hughes (2)
1: University of Colorado at Boulder, United States of America; 2: Utah State University, United States of America

ID: 247
Format: WiPe and Practical - Work In Progress
An Episode as a Trace of Resilient Performance in Multi-Agency Incident Management Systems
Changwon Son (1), Jukrin Moon (1), S. Camille Peres (1,2), Farzan Sasangohar (1,2)
1: Industrial and Systems Engineering Department, Texas A&M University, College Station, TX; 2: Environmental and Occupational Health Department, Texas A&M University, College Station, TX

ID: 249
Format: WiPe and Theoretical - Work In Progress

The Digital Crow's Nest: A Framework for Proactive Disaster Informatics & Resilience by Open Source Intelligence

Hemant Purohit (1), Kathleen Moore (2)

1: George Mason University, United States of America; 2: James Madison University, United States of America

11.13 T13- Open Track

ID: 123
Format: CoRe and Theoretical - Completed Research
Co-Designing a Virtual Training Tool for Emergency Management
Jaziar Radianti, Santiago Gil Martinez, Bjørn Erik Munkvold, Morgan Konnestad
University of Agder, Norway

ID: 131
Format: WiPe and Theoretical - Work In Progress
An Architecture for Simulating Drones in Mixed Reality Games to Explore Future Search and Rescue Scenarios
Ahmed S. Khalaf, Poom Pianpak, Sultan A. Alharthi, Zahra NaminiMianji, Ruth Torres, Son Tran, Igor Dolgov, Zachary O. Toups
Department of Computer Science, New Mexico State University, United States of America

ID: 156
Format: WiPe and Practical - Work In Progress
WalkSafe: College Campus Safety App
Saloni JD Vaghela (1), Patrick C. Shih (2)
1: Cummins, United States of America; 2: Indiana University Bloomington

ID: 167
Format: CoRe and Practical - Completed Research
Why IT systems for emergency response get rejected: examining responders' attitude to IT
Erion Elmasllari
Fraunhofer Institute for Applied Information Technology FIT, Germany

ID: 179
Format: WiPe and Theoretical - Work In Progress
A Conceptual Framework for Civil-Military Interaction in Peace Support Operations
Dick Ooms (1,2), Willem-Jan van den Heuvel (3), Bartel Van de Walle (4)
1: Tilburg University, The Netherlands; 2: Netherlands Defence Academy, The Netherlands; 3: Jheronimus Academy of Data Science, The Netherlands; 4: Delft University of Technology, The Netherlands

ID: 180
Format: WiPe and Theoretical - Work In Progress
The Hidden Crisis : Developing Smart Big Data pipelines to address Grand Challenges of Bridge Infrastructure health in the United States

Robin Gandhi (1), Deepak Khazanchi (1), Daniel Linzell (2), Brian Ricks (1), Chungwook Sim (2)
1: University of Nebraska at Omaha, United States of America; 2: University of Nebraska Lincoln, United States of America

ID: 188
Format: WiPe and Theoretical - Work In Progress
Challenges of Modeling Community-Driven Disaster Operations Management in Disaster Recurrent Areas: The Example of Portsmouth, Virginia.
Josey Chacko (1), Christopher Zobel (2), Loren Rees (2)
1: Mount St Mary's University; 2: Virginia Tech

ID: 190
WiPe and Theoretical - Work In Progress
Turning data into action: supporting humanitarian field workers with open data
David Paulus (1), Kenny Meesters (2), Bartel Van de Walle (3)
1: TU Delft, Netherlands, The; 2: TU Delft, Netherlands, The; 3: TU Delft, Netherlands, The

ID: 236
WiPe and Theoretical - Work In Progress
Determining flooded areas using crowd sensing data and weather radar precipitation: a case study in Brazil
Flavio Horita (1,2), Ricardo Vilela (2), Renata Martins (2), Danielle Bressiani (2), Gilca Palma (2), João Porto de Albuquerque (3)
1: Federal University of ABC, CMCC; 2: Brazilian Meteorological Agency, CLIMATEMPO; 3: University of Warwick, CIM

ID: 237
WiPe and Theoretical - Work In Progress
Measuring Innovations in Crisis Management
Adam Widera (1), Chiara Fonio (2), Sandra Lechtenberg (1), Bernd Hellingrath (1)
1: University of Münster, Germany; 2: European Commission, Italy

11.14 W1 - 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)

ID: 166
Format: 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
Ontology-based Representation of Crisis Management Procedures for Climate Events
Efstratios Kontopoulos (1), Panagiotis Mitzias (1), Jürgen Moßgraber (2), Philipp Hertweck (2), Hylke van der Schaaf (2), Désirée Hilbring (2), Francesca Lombardo (3), Daniele Norbiato (3), Michele Ferri (3), Anastasios Karakostas (1), Stefanos Vrochidis (1), Ioannis Kompatsiaris (1)
1: Center for Research and Technology Hellas (CERTH), Greece; 2: Fraunhofer IOSB, Germany; 3: Alto Adriatico Water Authority, Italy

ID: 169
Format: 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
Sentinel-1 Based Near-Real Time Flood Mapping Service
Iftikhar Ali, Vahid Freeman, Senmao Cao, Wolfgang Wagner
Vienna University of Technology, Department of Geodesy and Geoinformation, Vienna, Austria

ID: 189
Format: 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
PERCEIVE: Precipitation Data Characterization by means on Frequent Spatio-Temporal Sequences
Alessandro Farasin (1,2), Paolo Garza (1)
1: Politecnico di Torino, Italy; 2: Istituto Superiore Mario Boella

ID: 191
Format: 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
Calibrating Ensemble Forecasts to Produce More Reliable Probabilistic Extreme Weather Forecasts
Kaisa Riikka Ylinen, Juha Pekka Kilpinen
Finnish Meteorological Institute, Finland

ID: 197
1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)
Online clustering and classification for real-time event detection in Twitter
Federico Angaramo, Claudio Rossi

Istituto Superiore Mario Boella, Italy

ID: 253
Format: 1st International Workshop on Intelligent Crisis Management Technologies for Climate Events (ICMT)

Intelligent Utilization of Dashboards in Emergency Management

Yaniv Mordecai, Boris Kantsepolsky
Motorola Solutions Israel, Israel

11.15 Posters

ID: 159
Format: Poster
Using Metrics of Stability to Identify Points of Failure and Support in Online Information Distribution during a Disaster
Halse, Shane (1); Kropczynski, Jess (2); Tapia, Andrea (1)
1: The Pennsylvania State University, United States of America; 2: University of Cincinnati, United States of America

ID: 173
Format: Poster
Optimal UAV 3D Path Planning in Mountainous Environments for Post-Earthquake Multi-region Search
Deng, Lizheng; Yuan, Hongyong; Huang, Lida
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, China, People's Republic of

ID: 182
Format: Poster
Identifying and Assessing Points of Interest through Crowdsourced Image Analysis
Spatharioti, Sofia Eleni; Wylie, Sara; Cooper, Seth
Northeastern University, United States of America

ID: 186
Format: Poster
Incorporating Digital Volunteers into Exercises: A Case Study on CAUSE V
Peterson, Steve (1); Gusty, Denis (2)
1: National Institutes of Health, United States of America; 2: Department of Homeland Security, United States of America

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Format: Poster
Identifying Semantic Domains in Emergency Scenarios
Quesada Real, Francisco José (1); McNeill, Fiona (2); Bella, Gábor (3); Bundy, Alan (1
1: University of Edinburgh, United Kingdom; 2: Heriot-Watt University, United Kingdom; 3: University of Trento, Italy

ID: 202
Format: Poster

Informing decision makers: facilitating communication and trust for decision makers during crises

McNeill, Fiona Jennet (1); Bental, Diana (1); Bryans, Jeremy (2); Missier, Paolo (3); Steyn, Jannetta (3)
1: Heriot-Watt University, United Kingdom; 2: Coventry University, United Kingdom; 3: University of Newcastle, United Kingdom

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Format: Poster

beAWARE: Enhancing Decision Support and Management Services in Extreme Weather Climate Events

Karakostas, Anastasios (1); Vrochidis, Stefanos (1); Kompatsiaris, Yiannis (1); Kantsepolsky, Boris (2); Moßgraber, Jürgen (3); Dasiopoulou, Stamatia (4); Mandler, Benjamin (5); Karppinen, Ari (6); Ferri, Michele (7); Vourvachis, Iosif (8); Castro, Carmen (9); Lintrup, Kim (10)
1: Centre for Research and Technology Hellas, Greece; 2: Motorola Solutions Israel Ltd; 3: Fraunhofer Institute of Optronics, System, Technologies and Image Exploitation (IOSB); 4: Universitat Pompeu Fabra; 5: IBM Israel - Science and Technology LTD; 6: Finnish Meteorological Institute; 7: Alto Adriatico Water Authority; 8: Hellenic Rescue Team; 9: Àrea de Protecció Ciutadana - Valencia Local Police; 10: Frederiksborg Fire & Rescue Service

ID: 226
Format: Poster

A new approach of monitoring system for Supply Chain management during crisis

Schoen, Quentin (1,2); Truptil, Sebastien (1); Lauras, Matthieu (1); Conges, Aurelie (1); Fontanili, Franck (1) 1: IMT Mines Albi - CGI; 2: Etablissement Français du Sang

ID: 233
Format: Poster

Evaluation of a flying localization system for the rescue of buried victims – A scenario based training approach

Schmitz, Sebastian; Landsberg, Lennart; Brüstle, Tim; Weinem, Johannes; Mudimu, Ompe Aimé
TH Köln - University of Applied Sciences, Germany

ID: 235
Format: Poster

Universal Design of ICT for Emergency Management: A Research Agenda

Gjøsæter, Terje (1); Radianti, Jaziar (2); Chen, Weiqin (1)
1: Oslo Metropolitan University, Norway; 2: University of Agder, Norway

ID: 243
Format: Poster

Geographic Information Capacity (GIC) Across International Scales: Comparing Institutional Structures of Germany to the United States

Ruggero, Tayler; Tomaszewski, Brian
Rochester Institute of Technology, United States of America

ID: 257
Format: Poster
Intelligent Wireless Infrastructure Management for Emergency Communications
Nygate, Yossi; Johnson, William; Indelicato, Mark; Bazdresch, Miguel; Hochgraf, Clark
Rochester Institute of Technology, United States of America

ID: 276
Format: Poster
A Model for Assessing Label Quality in Crowdsourced Crisis Mapping Systems: A Case of 2010 Haiti Earthquake
Valecha, Rohit (1); Oh, Onook (2); Rao, H. Raghav (1)
1: University of Texas at San Antonio; 2: University of Colorado at Denver

12. Full Papers and Posters

Track 1

Analytical Modeling and Simulation

Crowding of Various Facilities Relevant to Supporting People Who Have Difficulty Returning Home after a Large Earthquake

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ABSTRACT

When a large earthquake occurs, many people are presumed to have difficulty in returning home. However, no research has been achieved yet to discuss the congestion of supporting facilities for stranded people in terms of site, the number and spatial distribution. In this study, we construct a simulation model, which describes people's behavior such as returning home or going to other facilities after an earthquake occurs. Using the model, we estimate the congestion of facilities which varies according to day of the week or the time when the event occurs, and demonstrate the effective methods for reducing the congestion, which include offering information for people and cooperation of private institutions.

Keywords

Large earthquake, difficulty in returning home, temporary shelter, support station for people returning home on foot, crowding.

INTRODUCTION

The Great East Japan Earthquake (March 11, 2011) caused little material damage in the Greater Tokyo Area, but transport systems including buses and private cars were paralyzed and a large number of people had difficulty returning home. As a result, the Tokyo Metropolitan Government enacted the Ordinance on Measures for Stranded Persons (which came into effect in April 2013). This ordinance advances measures and preparations by local governments in the Greater Tokyo Area for an imminent earthquake directly beneath the capital city, including designating temporary shelters and support stations to help those trying to return home.

In simulation studies of stranded people, Osaragi (2008, 2012) estimated the spatio-temporal distribution of people in places distant from their own homes using person trip survey data (PT data) focusing on the Greater Tokyo Area, and by simulating the behavior of people returning home on foot, estimated the number of stranded people and the number of people staying in the streets according to the time that the earthquake strikes. Osaragi's study (2008, 2012) was carried out before the Great East Japan Earthquake, but it accurately estimated the chaos in the Greater Tokyo Area, including the time it took for people to return home on foot and the number of stranded people who abandoned the idea of returning home and stayed in their offices, for example. However, it was necessary to update the model by performing the survey for the people who had actually experienced East Japan Earthquake. Also, it was difficult to understand the mechanism of people's decision making of returning home, since the model was a neural network model. Hiroi et al. (2011) carried out a questionnaire survey immediately after the Great East Japan Earthquake and used the obtained trip data on people returning home on foot to carry out a disaggregated analysis and estimate the number of people who stayed and the number of people who returned home on foot according to each municipality. Osaragi (2016a) used the behavioral characteristics of people returning home on foot revealed by this survey to construct a probabilistic model (a nested logit model) for estimating the behavior of people in the city after a disaster according to their attributes, where they are, and the time at which the disaster occurs. Based on the results of estimating the number of people according to behavior type, Osaragi's study also considered the effectiveness of the Ordinance on Measures for Stranded Persons. This probabilistic model will be used to predict people's decision making on returning home behavior in this study.

Okawa et al. (2009) analyzed the number of toilets and the area of rest stops required, focusing on arterial roads from the city center to the outskirts. However, they did not examine the number, size, or positioning of facilities designated by local governments for the Greater Tokyo Area.

In the present study, we first estimate the level of crowding of various facilities (temporary shelters, support stations, and train stations) relevant to supporting people who have difficulty returning home in the Greater Tokyo Area by constructing a model to describe the movement of people and their choice behavior regarding facilities after a large earthquake, and simulating movement on foot assuming an earthquake directly beneath the capital city. Next, we consider measures for reducing crowding of facilities based on the estimation results. Specifically, in terms of soft measures, we consider the effect of reducing crowding by providing information to people returning home on foot; and in terms of hard measures, we consider the effect of opening up facilities belonging to private businesses.

CONSTRUCTION OF WALKING SIMULATION MODEL

People and Facilities Subject to Simulation

Table 1 gives a summary of the people and roads subject to this simulation. The people subject to simulation were extracted from the 2008 Tokyo Metropolitan Person Trip Survey data (hereinafter, PT data), which includes detailed personal attributes, as well as the location and time information of the departure and arrival. Also, purpose of trip, and means of transportation are also included. Specifically, in order to conduct an analysis that focuses on people returning home on foot from the city center to the outskirts of the city and the crowding of facilities in the city center and its vicinity, people passing even just once through the area within a 20 km radius of the city center (Imperial Palace) were extracted from the PT data and taken as subjects of the analysis.

Table 1. Summary of Area, People, and Roads Subject to Simulation

People/ Area/Road	Definition
Area subject to simulation	Every road in Tokyo Metropolitan, Kanagawa Pref., Saitama Pref., Chiba Pref., South part of Ibaraki Pref. (Highway and driveway are excluded).
People subject to simulation	People staying at places outside home at the assumed disaster occurrence time were extracted from the PT data. The shortest route for returning home was analyzed and those passing through the 20 km radius centered on the Imperial Palace were extracted. The PT data of non-business day were estimated by using the method shown in Osaragi (2016b).
Main road	National road, prefectural road, city road (When heading to the destination, it is assumed that main roads are preferentially used as easy-to-navigate routes).
Narrow street	Roads other than the main roads

Figure 1 shows the spatial distribution and Table 2 shows a summary of the various facilities (temporary shelters, support stations, and train stations) subject to simulation. The information about the location and type of facilities were taken from GIS-based database compiled by Tokyo metropolis. In this study, the support facilities for people who have difficulty returning home were defined as shown in Table 2, and the means of accessing the facilities from the roads were modeled according to Figure 2.

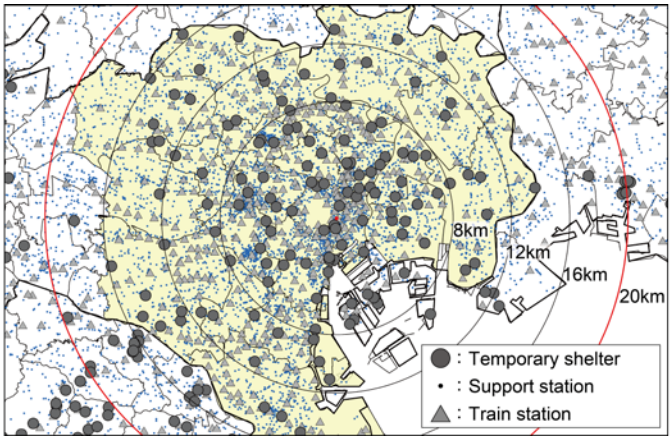


Figure 1. Spatial Distribution of Facilities to be Analyzed

Table 2. Outline of various facilities for people who have difficulty returning home

Type of facility	Classification	Number of facilities	Number of people to be accepted for each facility	Number of toilets for each facility	Behavior of people
Temporary shelter	Facility of Tokyo government	201	350	not specified	Temporary stay (People who visit once stay until the next morning [*1] Defined by the local governments
	Facility of other local governments	271	220 – 650 [*1]		
Support station	Municipal high school	238	400	20	Use of toilet facility (including waiting for toilet use) Taking a rest (10 to 30 minutes)
	Convenience store	13,552	20	1	
	Restaurant	2,545	40	2	
	Gas station	3,085	30	2	
	Car store	304	50	2	
Train station	Station designated for a temporary stay	210	not specified	[*2]	Stay till going to a temporary shelter or stay until the next morning [*2] Estimated from the number of people staying at the station at 8 o'clock on weekdays
	Other station	1,377			

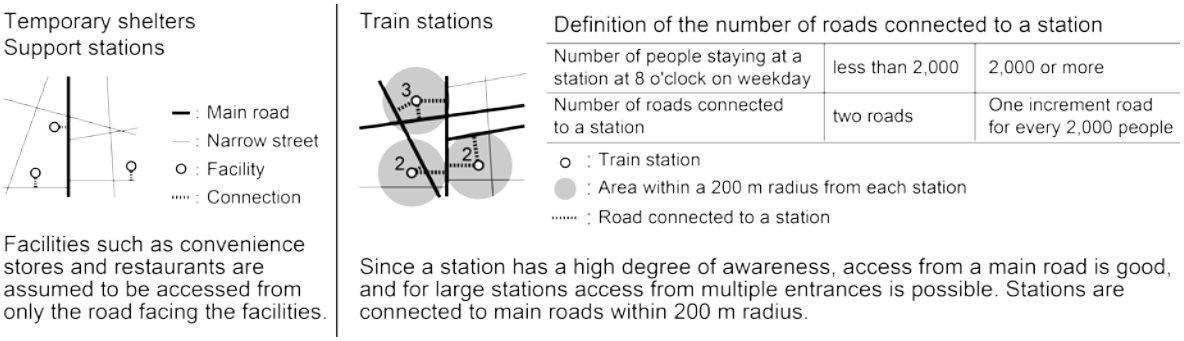


Figure 2. Modeling of Accessing Facilities from Roads

Construction of Walking Model

Table 3 and Figure 3 show a model that describes the travel behavior of people in the city after a large earthquake (walking model). Based on the intention model (Osaragi, 2016a), which describes decision-making and behavior of individuals, people who are at their place of work or school when the earthquake strikes were assumed to either stay where they are or head home. Other people were assumed to head either home, to their place of work/study, or to some another place. Among the people who head toward some other place, those who have location information of shelters were assumed to head toward a temporary shelter, whereas those who do not have location information were assumed to head toward the nearest train station (Table 3). Here, people other than those who stay at their place of work/study were defined as "walkers", and the timing of the start of their action was established based on the results of a survey carried out after the Great East Japan Earthquake (Hiroi et al., 2011). After starting their action, they were considered to walk toward their destination, stopping at support stations and train stations along the way for a rest and to use the toilet. Also, physical limit distances (Cabinet Office, 2008) were set on the basis of sex and age. When walkers approached a place within 2 km from their physical limit distance, they were assumed to give up on going to their original destination and to change their destination to a nearby temporary shelter or train station (people who have given up on walking). Furthermore, walkers who reached their physical limit distance were assumed to stop walking and stay where they were (people staying in the street) (Figure 3).

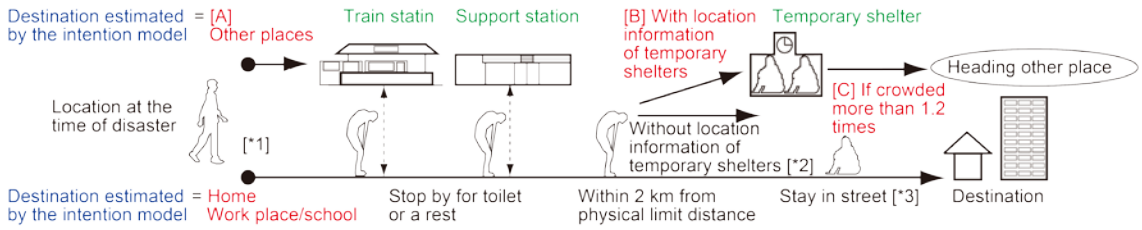
Table 3. Outline of Modeling of Walkers' Destinations

Location at the time of disaster	Destination estimated by the intention model		
	Home	**Work place/school**	**Other places**
At their place of work/study	Heading home	Staying at work place/school (Not treat as target walkers in simulation)	
At station/ in train	Heading home	Heading to work place/school	Heading to temporary shelters [* 1]
At other facility/ outdoor	Heading home	Heading to work place/school	Heading to temporary shelters [* 2] or nearest station [* 3] (After taking a rest, heading to temporary shelters [* 1])

[* 1] Set the facility to be the destination according to the intention model.

[* 2] Heading to temporary shelters, if only walkers who have the location information before the action.

[* 3] Many people visited railway stations just after the East Japan Earthquake (2001) in order to collect the information about the restoration of transportation or the locations of temporary shelters.



[*1] The walking speed is 4 km/h, and it decreases according to the density of walkers.
[*2] Continue directly to the destination and check whether there is temporary shelters within 1km radius for each intersection. If there is a temporary shelter, change the destination to it.
[*3] Reached the physical limit distance, stop moving and stay in street.

[Assumption]
1. When walking on a road connected to a support station or station, a walker will stop by if he/she want to go to toilet or want to take a rest.
2. Waiting time for the use of toilet is assumed to be (the number of people in line / the number of toilets) multiplied 1 min. The rest time was set as a uniform random number from 10 to 30 minutes.
3. The time until a walker wants to go to the toilet is set as a uniform random number from 0 to 192 minutes for the first time of use. For the second time of use, it is set as a random number following the normal distribution with an average of 123 minutes and variance of 34.5 minutes.
4. A walker who has taken a rest more than once takes a rest after walking a distance more than half of the physical strength limit distance.
5. A walker does not stop by if he/she has to wait for more than 15 minutes. Also, he/she does not stop by for a rest if the number of people taking a rest exceeds the capacity of facility.

Figure 3. Outline of Walking Model

Construction of Facility Choice Model

Most people are thought to head toward a temporary shelter or train station after an earthquake strikes (Figure 3, [A],[B],[C]), but their preference regarding the choice of facility will differ depending on their individual situation

and circumstances. Therefore, facility choice behavior was modeled under various situations and circumstances (Figure 4(1)). First, facilities located further than the reachable distance (Figure 4(2)) and severely overcrowded facilities (when information on crowding is available) were considered unlikely to be chosen, and so these facilities were excluded from the destination choices. Then, the model was created by multiplying each facility by a weighting according to each person's situation and circumstances (Nakasone et al. 2014, 2015), and assuming that people head toward the facility with the highest value. Specifically, the model assumes that people in situation [A] in Figure 3 have a relatively large amount of physical strength remaining and so they tend to choose a facility that is uncrowded, whereas people in situation [B] have little strength left and so they tend to choose a nearby facility located in the direction that they have been traveling.

Walkers [A], [B], [C] are shown in Figure 3.

(1) Reliable temporary shelters are limited to whose that satisfy both [a], [b1] or [b2] shown below.
([b1] or [b2] is used only for walkers with information about level of crowding)

[a] Located within reachable distance (see below)
[b1] Level of crowding at the time of acquiring information is 1.2 times or less (for walkers [A], [B])
[b2] Level of crowding is 0.8 times or less than current shelter (for walkers [C])
[c] In case that there is no facility which satisfies the criteria:
- People at station stays in the same station until the next morning, and others head to the nearest station (for walkers [A])
- If there is a station within reachable range, a walker stay there, if not, he/she stay in a road (for walkers [B])
- Stay in current temporary shelter (for walkers [C])

(2) Weighting of facility choice is performed according to the location classification of facilities based on the distance to each facility, the level of crowding, and the direction of destination.
A walker goes to a temporary shelter with the highest value of weighting.

[Definition of reachable distance]
People giving up on going >>> Reachable distance = 2 km - [Distance moved after giving up on going to the original destination]
People staying at a temporary shelter >>> Reachable distance = 2 km
Others >>> Reachable distance = Physical limit distance

[Facility location classification]

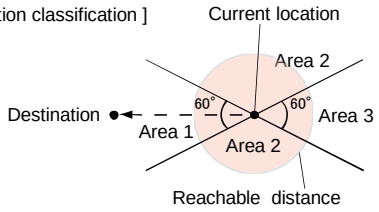


Figure 4. Outline of Facility Choice Model

Simulation Assumptions

In this study, it is assumed that an earthquake occurs directly beneath the capital city and all public transportation in the Greater Tokyo Area becomes paralyzed. However, for simplicity, outbreaks of fire and road blockages were not taken into account, and it was assumed that walkers are able to walk on the roads in an orderly way. The earthquake was assumed to occur at 9:00, 14:00, or 18:00 on either a weekday or a non-business day, and at 8:00 on a weekday only, supposing occurrence during the weekday commuter rush. The simulation period was set at 720 minutes (12 hours) from the time at which the earthquake occurs. In a Monte Carlo simulation, it is generally preferable to perform the simulation many times, but in this study, computation load constraints meant that the simulation was performed only 20 times for each case. Mean values of the simulation results were used in the analysis.

ESTIMATION RESULTS FOR CROWDING

Crowding of Temporary Shelters

The level of crowding of temporary shelters is high when the earthquake occurs at 14:00, a time at which there are many people in the city center. Particularly on non-business days, there are many people in the city center eating, shopping, and other activities, and so the level of crowding of train stations and temporary shelters becomes very high (Figure 5(a)). Crowding decreases as distance from the city center increases. However, approximately 12 to 14 km from the city center, crowding increases because many people give up on walking while returning home and the density of facilities is low (Figure 5(b)). Looking at the spatial distribution of crowding, the highest level of crowding is found in the vicinity of Shinjuku Station on a non-business day. This is followed by the areas around Tokyo Station, Ikebukuro Station, and Ueno Station, which shows that crowding is particularly severe around the main terminals (Figure 5(c)).

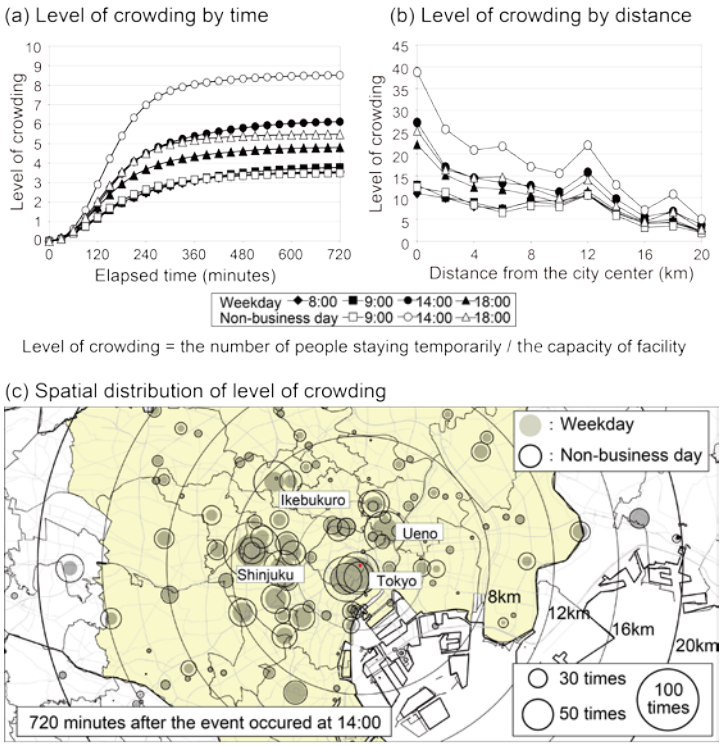


Figure 5. Estimated Level of Crowding of Temporary Shelters

Crowding of Support Stations for People Trying to Return Home

On weekdays, many people return home on foot from their place of work/study in the city center to the outskirts of the city, and so crowding of toilet facilities is found to be greater than on non-business days. In addition, the decrease in crowding is delayed because people at their places of work/study return home in a dispersed manner (Figure 6(a)).

However, because walkers take a rest after walking for a certain distance, the number of people resting reaches a peak approximately 4 hours after the earthquake on non-business days, and approximately 5 to 6 hours after the earthquake on weekdays (Figure 6(b)). Similar to the number of people using toilet facilities, the number of people taking a rest is higher on weekdays than on non-business days, and it is particularly high when the earthquake occurs at 9:00 or 14:00. Looking at the spatial distribution, there is a succession of facilities where the numbers of people taking a rest are extremely high along the main arterial roads such as National Route 6 and the Keiyo Road from the city center toward Chiba, and the Setagaya Avenue and Nakahara Street toward Kanagawa (Figure 6(c)). The numbers are particularly high approximately 8 to 20 km from the city center, and are highest along the Keiyo Road.

Focusing on the facilities along the six main arterial roads heading in various directions from the city center shown in Figure 6(c), when the earthquake occurs at 14:00 on a weekday, it is clear that the level of crowding of toilet facilities is higher than in Figure 6(a), most prominently along the Keiyo Road (Figure 6(d)). The number of people taking a rest shows a similar trend, and many people take a rest along National Route 6 and the Setagaya Avenue (Figure 6(e)).

The above results show a requirement for prioritized measures along the main arterial roads mentioned above (particularly the Keiyo Road).

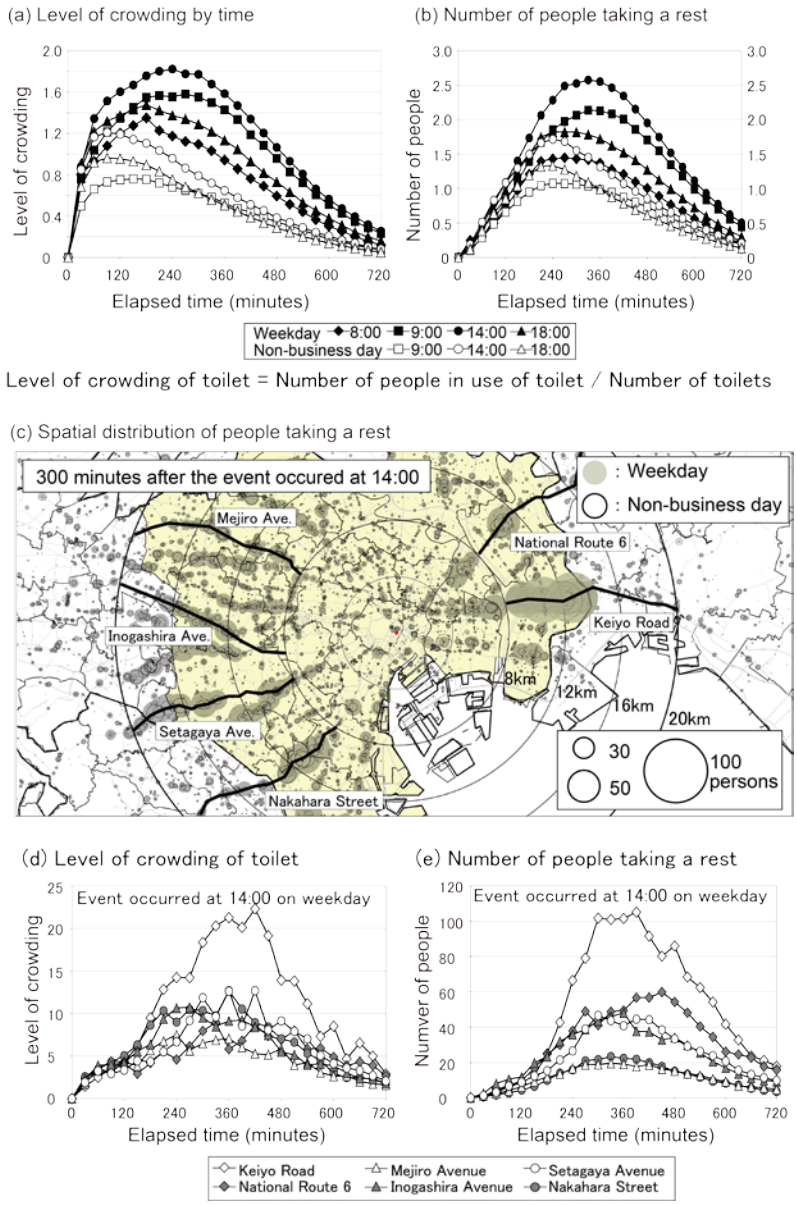


Figure 6. Level of Crowding of Support Stations for People Returning Home on Foot

Crowding of Train Stations

When the earthquake occurs at 8:00 on a weekday, a time at which many people are on their way to work or school, extremely large numbers of people stay inside train stations (Figure 7(a)). Looking at the spatial distribution, a large number of people stay at each station on Yamanote Line, particularly Shinjuku, Shibuya, and Ikebukuro Stations (Figure 7(c)). Focusing on these stations, when the earthquake occurs at 8:00 on a weekday, there are a large number of people staying at the station immediately after the earthquake. In contrast, when the earthquake occurs at 14:00 on a non-business day, people staying in the vicinity of the station gather gradually, and they become most numerous between 1 and 2 hours after the earthquake (Figure 7(b)). For example, when the earthquake occurs at 14:00 on a non-business day, the number of people staying at Maihama Station (the station closest to Tokyo Disneyland) increases to a level comparable to the city center (Figure 7(b)). This shows the importance of measures not only in the city center but also in the neighborhoods of facilities that attract large numbers of visitors.

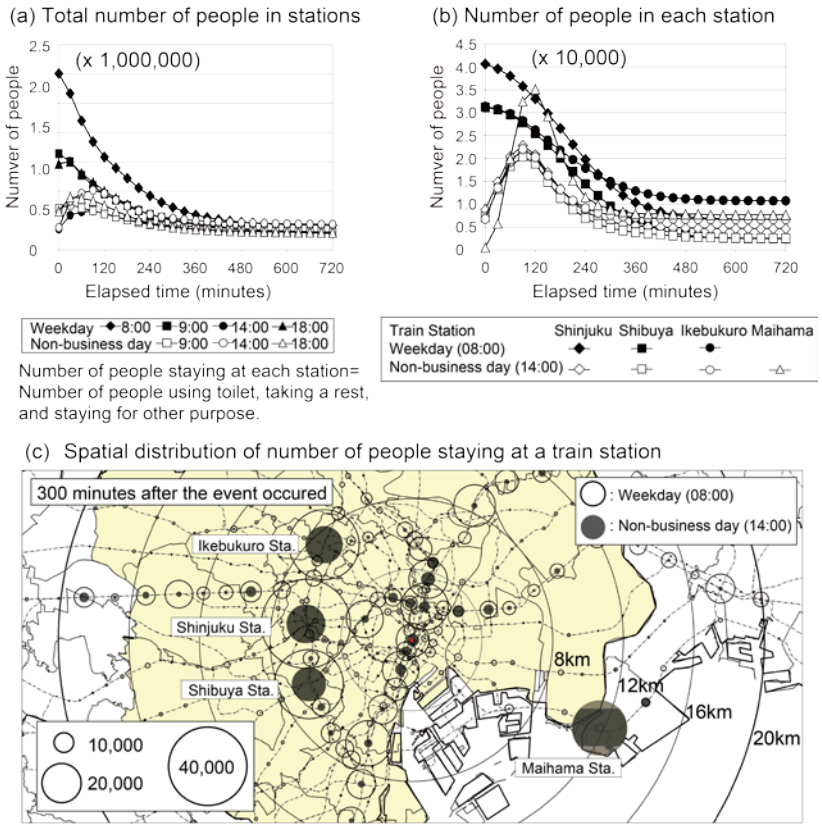


Figure 7. Spatial Distribution of Number of People Staying at Train Stations

Spatial Distribution of People Staying in the Street

The number of people staying in the street (people who have given up on walking to their destination) is highest when the earthquake occurs at 14:00 on a weekday (Figure 8(a)), and by distance, it is highest approximately 16 to 20 km from the city center (Figure 8(b)). Looking at the spatial distribution of linear density of people staying in the street (in terms of 100 m of road) when the earthquake occurs at 14:00 on a weekday, the density is high on the segments beyond 8 km from the city center of the main roads heading in various directions from the city center (Figure 8(c)). In particular, the number of walkers on National Route 6 is high, but because there are relatively few support stations in this far from the city center, they are unable to rest adequately and so end up staying in the street (Figure 8(d)).

The above results show that the existing facilities for people who have difficulty returning home are seriously insufficient for the potential numbers of stranded people, and there will be severe crowding of facilities and a large number of people staying in the street. The following sections propose and evaluate measures for reducing crowding, focusing mainly on temporary shelters as destinations taking in stranded people.

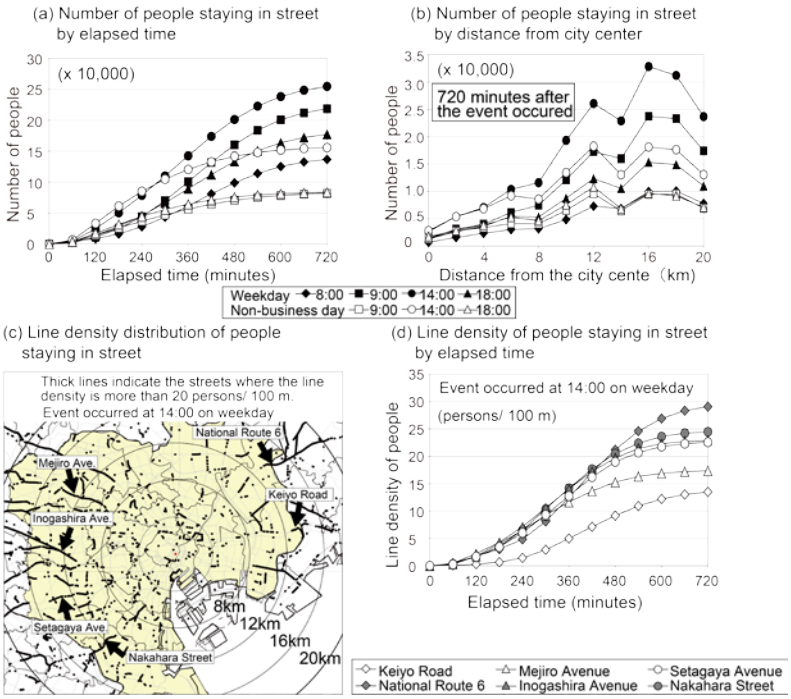


Figure 8. Number of People Staying in Street (People who have given up on walking to their destination)

ANALYSIS OF REDUCTION IN CROWDING AS A RESULT OF INFORMATION PROVISION

Assumptions about Provision of Information

This study considered the effect of providing information to people as a measure to reduce crowding at temporary shelters, specifically shelter location and crowding information (Table 4). The effects of word-of-mouth should not be ignored in a crisis situation. We have investigated it by simulating the evacuation behavior (Tsuchiya et al. 2015). We intend to combine all the related models into one big simulation model in the future. However, we omitted discussion about the effects of word-of-mouth in this paper due to the limitation of number of pages. The simulation was performed for an earthquake occurring at 14:00 on a weekday/non-business day, when crowding of facilities becomes highest, assuming the information provision probabilities shown in Table 5.

Table 4. Assumptions about Provision of Information

Information on locations of temporary shelters	Once a walker gets this information, he/she will know the location of all temporary shelters.
Information on level of crowding	Once a walker gets this information, he/she will know the level of crowding of all temporary shelters, which is updated every time.

Table 5. Assumptions about Probability of Obtaining the Information

Places where a walker is staying at the time of disaster	Probability of providing information at emergency				Probability of providing information when visiting a facility [*2]		
	Indoor			Outdoors	Temporary shelter	Support station	Train station
	Work place /school	Train station [*1]	Other facility				
Information on locations of temporary shelters	100 %	100 %	50 %	0 %	100 %	100 %	100 %
Information on level of crowding	0 %	100 %	0 %	0 %	100 %	50 %	100 %

[* 1] Including those who are riding in the train at the time of disaster.

[* 2] The latest information of level of crowding is provided at the time of departure from the facility.

Effect of Providing Information during an Earthquake Disaster

The effect of providing information at train stations and support stations during an earthquake disaster was analyzed. Simulations were performed under each of three assumptions (Figure 9(a)): Assumption (1), under which the results described in Section 3 were obtained, and Assumptions (2) and (3), under which information is provided.

The trend in the level of crowding at shelters is more crowding under Assumption (2) than under Assumption (1), for both weekdays and non-business days. This is because people who have acquired location information are better able to reach a shelter (Figure 9(b)). However, crowding is lower under Assumption (3), and this is considered to be because convergence of people on crowded shelters is reduced as a result of the acquired crowding information. Looking at the level of crowding by distance zone, the differences between Assumptions (1), (2), and (3) increase as the shelter becomes closer to the city center for both weekdays and non-business days (Figure 9(c)). Looking at the spatial distribution, crowding at the shelters near the main terminals, such as Shinjuku, Ikebukuro, and Tokyo Stations, is particularly low under Assumption (3) compared to Assumption (1) (Figure 9(d)).

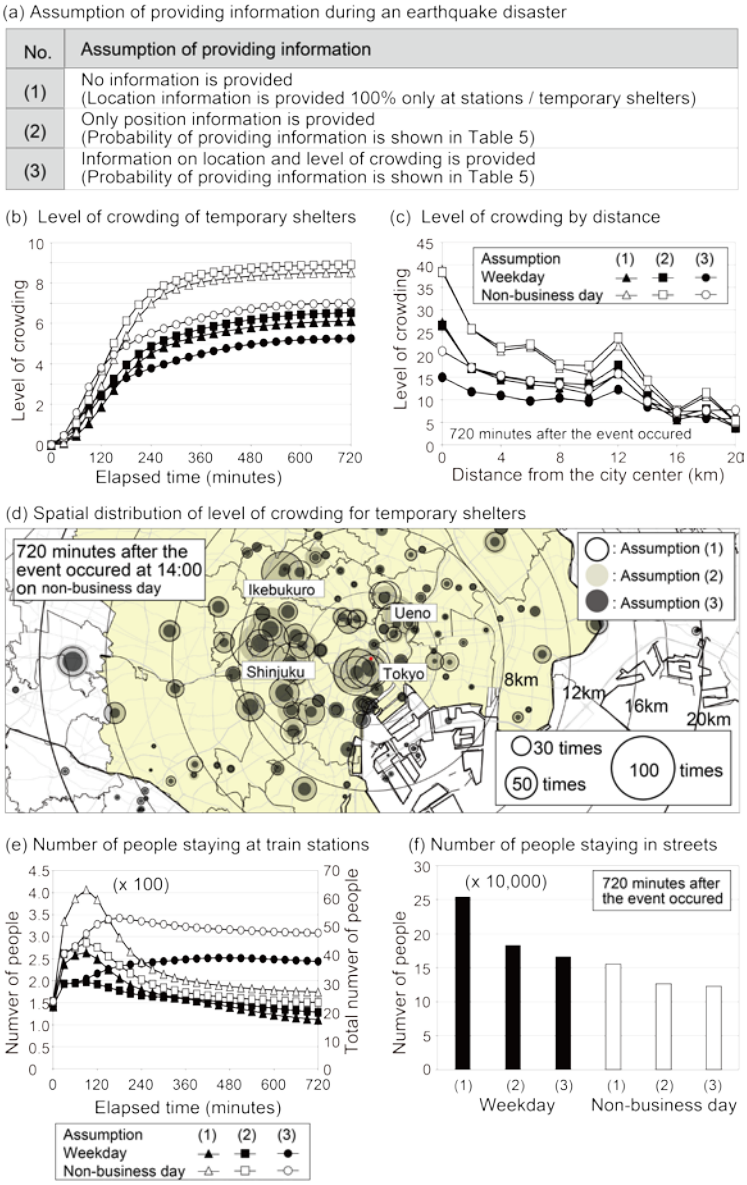


Figure 9. Effect of Providing Information during an Earthquake Disaster

In contrast, the number of people staying at train stations is greatest under Assumption (1) approximately 2 hours after the earthquake occurs in the case of both weekdays and non-business days; however, by the end of the simulation, the number is greatest under Assumption (3) because people who have acquired crowding information gather at the stations (Figure 9(e)). In addition, the number of people staying in the street is greatest in the order (1) > (2) > (3) for both weekdays and non-business days, but the difference is particularly noticeable on weekdays (Figure 9(f)).

The above results show that the provision of information on crowding in addition to location information, as in Assumption (3), could reduce crowding at temporary shelters in the city center and mitigate chaos by reducing indiscriminate travel.

Effect of Regularly Providing Information

The effect of providing information about shelters on a regular basis at places of work/study and via the Internet was analyzed. Simulations were performed separately under Assumptions (4) and (5) shown in Figure 10(a), and the results were compared with those under Assumption (3), in which information is provided only during the earthquake disaster (Figure 9(a)).

Looking at the level of crowding at shelters, crowding is greater under Assumptions (4) and (5) than under Assumption (3) because people who have acquired location information in advance are better able to reach a shelter (Figure 10(b)). Looking at the level of crowding by distance, it is evident that even in the region that shows a locally high value under Assumptions (3) and (4) (approximately 12 km from the city center), crowding is controlled to the same level as the surrounding area under Assumption (5) (Figure 10(c)).

(a) Assumption of providing information during an earthquake disaster

No.	Assumption of regularly providing information [*1]
(4)	Only position information is provided (It is assumed that everyone has information before an earthquake occurs)
(5)	Information on location and level of crowding is provided (Level of crowding after 720 minutes of temporary shelters in Assumption (3))

[*1] Assumption of providing information during the event is the same as Assumption (3)

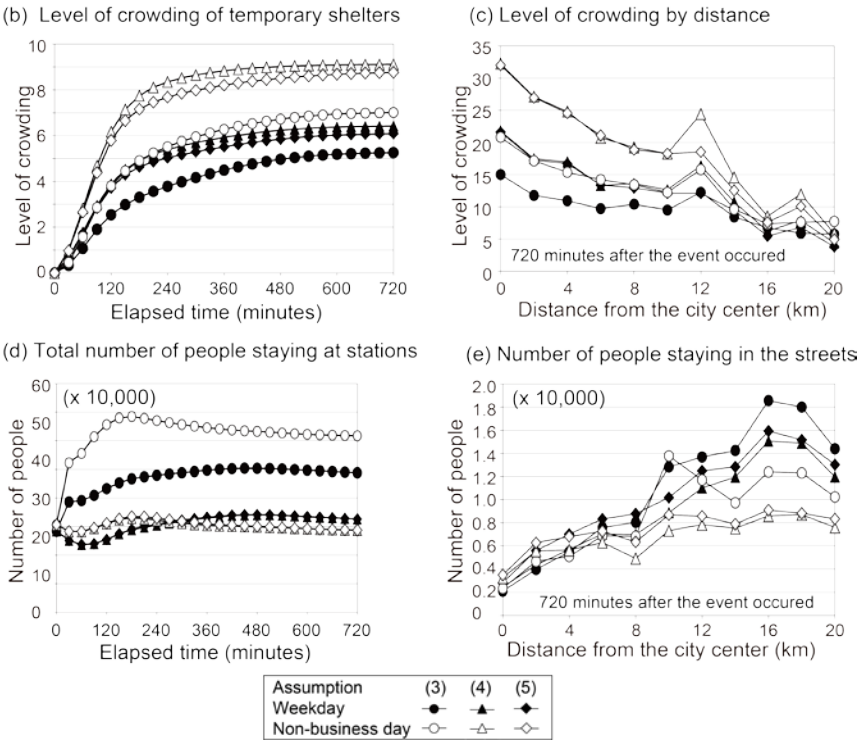


Figure 10. Effect of Regularly Providing Information

In contrast, looking at the number of people staying at train stations, crowding is greatly reduced under Assumptions (4) and (5) compared to Assumption (3) (Figure 10(d)). This is because, under Assumption (3), many people collect information at train stations, but under Assumptions (4) and (5) in which they have acquired location information in advance, people head directly to the shelters. In addition, looking at the number of people staying in the street by distance, the number is lower under Assumptions (4) and (5) compared to Assumption (3) approximately 10 to 20 km from the city center (Figure 10(e)).

The above results show that, although crowding of shelters would increase, providing information on the locations of shelters on a regular basis could reduce the number of people who are forced to stay in unsuitable places, such as in the street or at a train station. In addition, regularly providing information on the predicted level of crowding for each shelter could control imbalances in level of crowding between shelters.

ANALYSIS OF REDUCTION IN CROWDING AS A RESULT OF COLLABORATION WITH PRIVATE-SECTOR FACILITIES

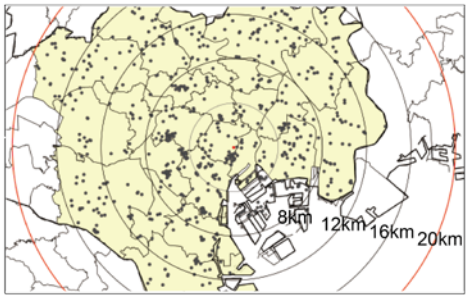
Method of Selecting Private-sector Facilities

During the Great East Japan Earthquake disaster, many private-sector facilities that were not designated as temporary shelters fulfilled the same function. In particular, accommodation facilities, large commercial facilities, and sports facilities took in many stranded people. Therefore, this study considered the effect of collaboration with private-sector facilities as a hard measure for reducing crowding. Specifically, the effect of private-sector facilities (20–100 facilities) within the 23 wards of the Tokyo Metropolis shown in Figure 11(a) taking in stranded people was examined. Three methods of selecting facilities were different in the following options: (i) arbitrary (regardless of crowding estimated by the simulation, facilities are chosen randomly from private-sector facilities whose building area is greater than 1,500 m^2), (ii) batch priority (facilities are all chosen at the same time with priority given to shelters with severe crowding estimated by the simulation), (iii) sequential priority (facilities are chosen in sequential order from shelters with severe crowding estimated by the simulation) (Figure 11(b)). The simulation was performed 10 times for each case, with 20 private-sector facilities added at a time. The earthquake was assumed to strike at 14:00 on a non-business day, which causes the most crowding of shelters, and information provision was taken to be as in Assumption (3) shown Figure 9(a).

(a) Outline of private-sector facilities and their spatial distribution

Facility Type	Number of facilities
Accommodation	109
Large commercial	433
Sports	146

- Building area of private-sector facility is greater than 1,500 m2
- 5 people can stay for 100 m2 of building area of each facility



(b) Method of Selecting Private-sector Facilities

(i)	Arbitrary (facilities are chosen randomly regardless of crowding)
(ii)	Batch priority (facilities are chosen at the same time according to severe crowding)
(iii)	Sequential priority (facilities are chosen in sequential order from shelters with severe crowding)

Figure 11. Outline of Private-sector Facilities

Comparison of Selection Method

Looking at the level of crowding of shelters according to number of private-sector facilities and the selection method, the difference according to the selection method is small, but crowding is lowest using Method (ii) (batch priority) (Figure 12(a)). Looking at the level of crowding of shelters by distance, crowding is lowest using Method (ii) (batch priority) until approximately 6 km from the city center, and beyond that, the difference according to

the selection method is small (Figure 12(b)). Looking at the spatial distribution, compared to no private-sector facilities, both Method (ii) (batch priority) and Method (iii) (sequential priority) reduce the levels of crowding of shelters in the city center (Figure 12(c)).

However, the mean level of crowding of collaborating private-sector facilities increases in the order (i) < (ii) < (iii) (Figure 13(a)). Looking at the level of crowding by distance zone, crowding in the city center is lowest using Method (i) (arbitrary) and Method (ii) (batch priority) (Figure 13(b)), but looking at the spatial distribution, it is evident that there are facilities with extremely high levels of crowding on the outskirts of the city (Figure 13(c)). In contrast, using Method (iii) (sequential priority), there are few private-sector facilities with markedly high levels of crowding.

The above results show that the method of selection of private-sector facilities that is effective in reducing crowding of shelters may differ depending on the location. Specifically, Method (ii) (batch priority) is capable of effectively reducing levels of crowding of shelters in the city center, whereas while Method (iii) (sequential priority) is capable of stably reducing levels of crowding of shelters on the outskirts and therefore less likely to cause severe crowding of private-sector facilities. This implies that it could be more effective to select and request the collaboration of private-sector facilities using Methods (ii) and (iii) separately for the city center and the outskirts, respectively.

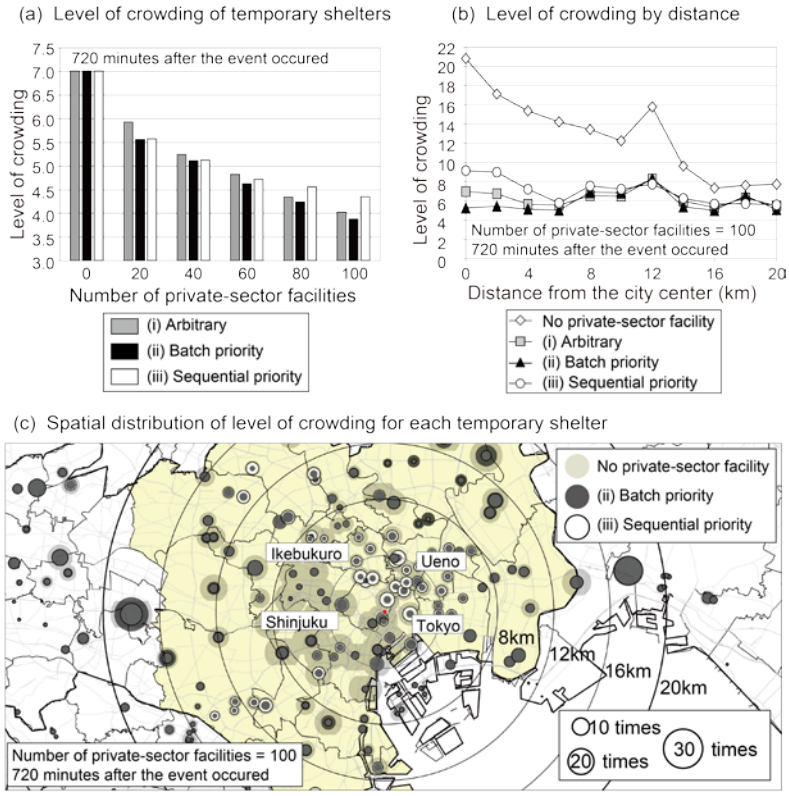


Figure 12. Cooperative Effect of Private-sector Facilities

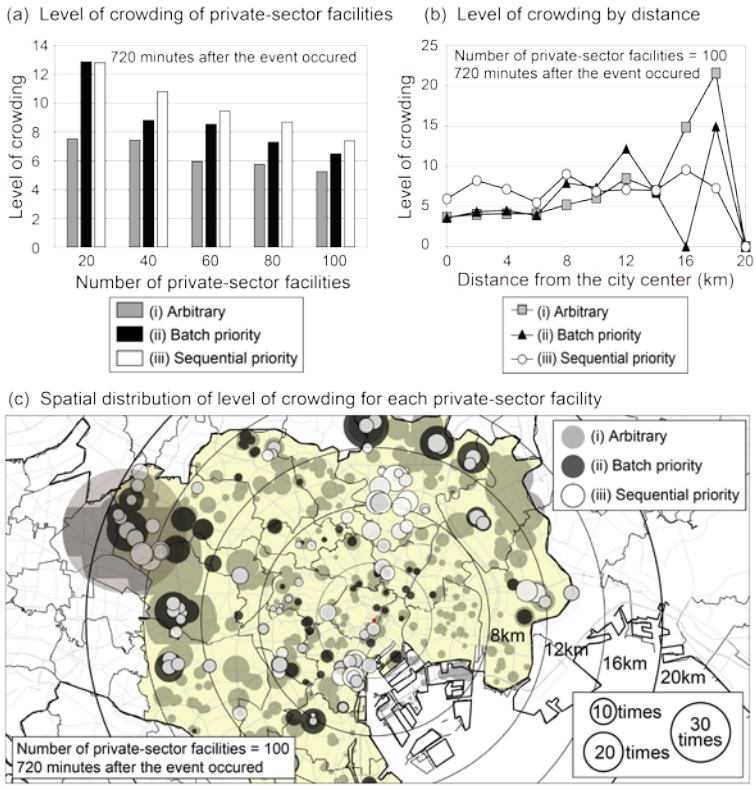


Figure 13. Level of Crowding by Cooperating Private-sector Facilities

SUMMARY AND CONCLUSIONS

In this study, the travel behavior of people in Tokyo after a large earthquake was modeled, and the levels of crowding of facilities for people who have difficulty returning home were estimated by performing simulations of people traveling on foot. The results showed that temporary shelters become most crowded when the earthquake strikes at 14:00 on a non-business day, a time at which there are many people (eating and shopping) in the city center with nowhere to shelter after the quake. The results also showed that support stations for people trying to return home become crowded when the earthquake occurs at 14:00 on a weekday, an occurrence time that generates a large numbers of walkers. The number of people staying at train stations is highest when the earthquake occurs at 8:00 on a weekday, a time at which many people are commuting to work or school. It was also found that, when the earthquake occurs at 14:00 on a weekday, many people stay in the street on the arterial roads leading in various directions from the city center (segments beyond 8 km from the city center).

Next, the effect of reducing crowding by providing people with information was analyzed. Shelters are likely to become more crowded as a result of providing people with information on the location of the shelters, whether the information is provided at the time of the earthquake or on a regular basis. On the other hand, the number of people having to spend a night at a train station or in the street is likely to be reduced. In addition, if information on crowding can be provided in real time after the earthquake, it may be possible to control rises in crowding at shelters. Further, by regularly providing information on predicted level of crowding, it may be possible to control imbalances in level of crowding between shelters.

Finally, the study analyzed the effect of reducing crowding through collaboration with private-sector facilities (opening up of facilities). The results of examining methods of selecting private-sector facilities for collaboration showed that, in the city center, it is effective to select private-sector facilities in the vicinity of shelters that are predicted to become crowded. However, on the outskirts of the city center, it is possible that private-sector facilities will become extremely crowded, and so it is preferable to perform multiple selections while checking crowding at private-sector facilities using sequential simulations.

The simulation models developed in this research can provide detailed information about the facilities to be congested and where people are most likely to strand. The civil protection authorities can use this information for increasing the capacity of the critical facilities or setting-up emergency check-points or mobile assistance.

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Analytic Decision Gaming – A Tool to Develop Crisis Response and Clinical Reasoning

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ABSTRACT

Emerging threats provide motivation to develop new methods for preparing the next generation of crisis responders. Bayesian theory shifts reasoning toward a probabilistic, epistemic paradigm, giving rise to Evans' revised heuristic-analytic theory. Researchers at The Pennsylvania State University use scenario-based training and the analytic decision game (ADG) to blend and implement these processes as foundational pedagogy for engaging, educating and training medical students as crisis responders and critical thinkers. The ADG scenarios vary by content and level of expertise, lending themselves readily adaptable to both crisis response preparation and the development of clinical reasoning. The ADG creates a virtual crisis requiring participants to engage in scenario management as role-players. For the past two years, students from the Penn State College of Medicine, in their first year of training, have participated in the ADG Lights Out scenario, testing community preparation and resilience after a wide-spread and months-long power outage.

Keywords

Clinical reasoning, crisis response, medical school, scenario-based training, analytic decision game.

INTRODUCTION

Early studies on human reasoning describe decision-making processes based on past experiences and how those experiences were used to shape actions and outcomes. These previously held beliefs in the study of human reasoning have been challenged at multiple levels (Manktelow et al., 2011). Classical definitions focus on how people "should reason" in order to conform to norms of rationality and utility (Kneale and Kneale, 1962). Bayesian theory shifts this notion away from dichotomous, binary reasoning toward a more probabilistic and epistemic paradigm, eventually giving rise to Evans' revised heuristic-analytic theory of reasoning (Evans, 2006). In the context of applying decision-making to crisis response, the National Incident Management System (NIMS) was developed as a framework for crisis incident response for both natural and man-made disasters. The cornerstone of NIMS is the Incident Command System (ICS), which promotes procedural interoperability across all levels of incident response (Annelli, 2006). Despite this, nuanced emergency situations inevitably dictate that not all exigencies can be adequately addressed. Emergency responders often find themselves developing and deploying improvised, moment-to-moment methodologies to address complex and multidimensional crisis situations (Mendonca et al., 2003). Recent studies evaluating hospital preparedness and adherence to NIMS principles, suggest that medical facilities lack a gold standard for measuring and evaluating readiness. This is particularly true for command, communications and information management (Jenkins et al., 2009). Steady increases in emerging threats provide ample motivation to develop new methods of preparing the next generation of crisis responders (Hall et al., 2015).

Researchers at The Pennsylvania State University have made extensive use of scenario-based training to meet this goal and to extend the use of the analytic decision game (ADG) as pedagogy for engaging, educating and

training medical students as critical thinkers. The ADG is an adapted tactical (war) game. ADG scenarios vary by subject and audience and are readily adaptable to a wide variety of crisis responses. The ADG creates a virtual crisis requiring participants to engage in scenario management as role-players. For the past two years, students from the Penn State College of Medicine have participated in the ADG Lights Out scenario, testing community preparation and resilience after a wide-spread and months-long power outage. The Lights Out scenario was specifically selected to introduce Penn State medical students to the resource infrastructure of the local community as part of their orientation activities. The scenario has a rural setting that is similar to the area surrounding the medical school campus. Recognizing the modern reliance on digital technology and electricity, the exercise commences with a complete failure of the regional power grid following a coronal mass ejection (CME) event. All unshielded digital electronics are inoperable and it is unknown what remains of existing government infrastructure. During the facilitated exercise, participants collaborate to address an ever-expanding set of community, security and health-related issues that force students to engage in decision making processes in the context of crisis response. This process is analogous to clinical reasoning skills students will develop and employ as physicians (Trowbridge & Rencic, 2015). Events arising within the Lights Out scenario are highly modifiable and can be tailored to meet specific learning and engagement objectives, including adaptive reasoning and problem-solving.

CRITICAL THINKING—CRISIS RESPONSE MEETS CLINICAL REASONING

Tversky and Kahneman, (1974) made a distinction between intuitive reasoning and extensional reasoning, citing the former as unstructured and informal (utilizing heuristic-enabled processes) and the latter as structured and controlled. Extensional reasoning was viewed as a measure of control for intuitive reasoning. Evans (1984) developed the heuristic-analytic theory to reconcile demonstrated mismatches in competency across reasoning tasks due to the presence of cognitive bias. Heuristic-analytic theory proposes that two sequential cognitive processes are at work for any given reasoning task. These cognitive processes include: 1) *heuristic* processes, which draw from prior experience and expectations to aid in the formulation of representative models, and 2) *analytic* processes, which draw on sense-making techniques to form judgments on these models. Some theorists view dual-process theory as a pairing of separate cognitive functions, that turn on and off according to the task at hand; however, this notion has not found universal agreement. Heuristic-analytic theory was extended (Evans 2003) to account for the inclusion of hypothetical thinking as a means to broaden the range of possible considerations beyond those represented by known facts. Previously held distinctions between analytic and intuitive reasoning have been challenged suggesting the utility of a single-system framework offering dynamic graded continuum or DGC framework (Osman, 2004), as an alternative approach to consider dual-process theory. The DGC framework proposes that representative reasoning could be viewed as a continuum, where *representative quality* leads to a corresponding progression in learning types – from implicit to explicit and on to automatic, recognizing that each learning type "has a different functional role."

The intent of this paper is not to challenge the tenets of dual-process or any other human reasoning theory. Rather, we propose a practical view in recognizing the benefits of hypothetical reasoning as a tool for teaching clinical reasoning skills in medical education and for dealing with crisis situations. The asymmetric nature of crises demand such attention. Asymmetric threat is loosely defined as an unusual threat to our political, strategic or military culture. Most literature addressing the notion of an asymmetric threat is dedicated to the study of political-military affairs. Doctrinal debates on the use of the term arose almost simultaneously with a rise in popular use, coinciding with the rise of counter-insurgency and counter-terrorist operations and the introduction of asymmetric warfare doctrine. Our paper takes a different slightly different approach to asymmetric threat. We offer the argument that asymmetric threats can be both man-made and natural. Evidence of the unusual (asymmetric) nature of natural disasters are aptly illustrated by events such as, Super-Storm Sandy, Hurricane Katrina, and more recently, Hurricane Irma, the most destructive Atlantic hurricane since Wilma in 2005. The proceedings of the eighth symposium of Asymmetric Threats to National Security, held in October, 2014 in McLean, Virginia, opened with the following question, "What if the United States were suddenly deprived of electricity, water, money, fuel and access to cyberspace?" As of this writing and as a result of Hurricane Irma, which crossed Puerto Rico on 6 September 2017, the U.S. island territory still experiences most all of the deprivations described above. The hurricane season of 2017 is a prime example of an ongoing asymmetric threat. To address such threats requires thought processes that are dynamic, adaptable and tailorable to a wide range of possibilities, much like that found in hypothetical reasoning. In this same vein, clinical reasoning processes in complex medical cases (Custers, 2013) can be viewed as a series of asymmetric threats.

PENN STATE COLLEGE OF MEDICINE: THE PROCESS OF INQUIRY AT A NEW REGIONAL CAMPUS

The Penn State College of Medicine has a long-standing scientifically and clinically rigorous educational tradition with deep foundations in scholarship and humanistic care. Penn State has recently built on this experience to open a regional campus in University Park, PA. This innovative program uses trans-disciplinary educational strategies to create a flexible and integrated program of study. Students learn in an environment that fosters interprofessional team skills, curiosity, and a commitment to the calling of Medicine. The curriculum of the Penn State College of Medicine prepares students for the ongoing practice of evidence-based medicine in the rapidly changing healthcare environment of the 21st century. A number of guiding principles form the basis of this collaborative curriculum. Students are engaged from the first day of medical school to contribute in meaningful ways to the health of patients and populations and to improving the health system. Students are required to address the needs of the local community as a scaffold for transferring cognitive and clinical skills to a national and global context. To support the design and implementation of the new medical program, the curriculum design leadership team agreed upon the following key features:

1. Community Engagement;
2. Inter-professional, team-based care;
3. Advocacy and leadership to promote health of patients and populations;
4. Experientially-driven learning in biomedical science, clinical science and health systems science;
5. Longitudinal learning relationships;
6. Flexible assessment and progression; and
7. A culture of respect and humanistic care.

Educational experiences are designed to emphasize interprofessional collaboration, critical thinking and systems thinking. To do this, the curriculum uses experiential learning and clinical immersion for students to integrate four core educational pillars: biomedical sciences, clinical sciences, health systems sciences, and health humanities. The design of the curriculum is based on best evidence in the science of learning and anchored in a culture of continuous critical reflection, rigorous evaluation, adaptability and innovation. This thoughtful educational design embraces opportunities for interprofessional collaboration with other Penn State educators, a process that gave rise to translating the Analytic Decision Game: *Lights Out* to medical education.

As part of the curriculum design process, specific foundational teaching and learning processes have been incorporated as cultural norms. As one example, training in observation and field notes is used to support critical reflection on workplace experiences. Education in the science of learning includes mentored development of higher order questioning to develop specific learning objectives based on student experiences in their clinical spaces. These immersive patient and system-based experiences provide the triggers for inquiry and discovery in medical, clinical, and systems sciences and also promote personal and professional growth as humanistic caregivers. Following these immersive patient-based experiences, student learning incorporates principles of inquiry, critical thinking, and systems thinking to discuss targeted learning objectives mapped to the School of Medicine requirements. Finally, students are developing a multi-layered geographic and public health "map" of the local area to facilitate patient-centered care, health systems science learning, and community engagement. It is this last objective that further facilitated the collaboration with the Red Cell Analytics Lab at Penn State and the partnership of crisis response and clinical reasoning.

TRAINING MEDICAL STUDENTS FOR CRISIS RESPONSE AS A WINDOW TO CLINICAL REASONING

Clinical reasoning is the process by which health care providers solicit and collect cues, process information, assess available data to arrive at a diagnosis, plan and implement strategies to overcome the problem, evaluate the results in terms of patient outcomes and reflect on their action to learn from the process to better inform future practice. In this context, there is keen interest in how people make decisions under high-stakes, time-constrained, dynamic conditions. Recognition Primed Decision (RPD) and naturalistic decision making (NDM) are two lanes of research that describe how experience enables practitioners to solve complex problems. Klein (2008) cites NDM as valuable for understanding "how people didn't make decisions." NDM research revealed that decision-makers failed to adequately develop and compare alternate options or conduct probability estimates against alternative courses of action. In contrast to laboratory-based experiments, RPD and NDM researchers took to the field to better understand how real decisions are made. RPD recognizes the value of intuition-enabled analysis in decision making, especially when applied by seasoned practitioners - doctors, military personnel, and emergency responders who often operate in high-stakes situations. Whereas intuition, gained through experience, can help recognize patterns and construct potential response strategies, research also

indicates that **intuition-based strategies** are often appropriate to a specific situation. This begets the question, however, "How do we train future practitioners, who currently lack experience, to construct intuitive strategies?" One such method is through gaming and simulation.

RED TEAM ANALYTICS

The ongoing discourse on the role of hypothetical thinking is expandable well beyond the bounds of academic writings on human reasoning theory. Problem solving techniques such as: alternate futures analysis, devil's advocacy, inside-outside thinking and hypothesis mapping, among others, each include some form of hypothetical reasoning and have gained prominence across the analytic community. The use of hypothetical thinking in problem solving is not new – *Red Team Analysis*, a form of alternative analysis - has been in use by military planners since the Cold War (Zenko, 2015). In the 1960s, early military red teamers utilized game-theory techniques to evaluate strategic decisions, including those governing the use of nuclear weapons. Red team analytics models the behavior of individuals or groups by emulating their thought processes in order to anticipate probable (adversary) actions. Military red teams, acting as the counter-force, perform operational and feasibility checks on military plans and related strategic policies. The Red Cell Analytics Lab (RCAL), a group of aspiring analysts, on the campus of The Pennsylvania State University, has combined the tenets of red teaming with the ADG to prepare the next generation analyst. RCAL members have taken on a wide variety of security problems, including the research of tomorrow's disruptive technologies and the ever-expanding social media phenomena. Utilizing red cell techniques, RCAL members seek to uncover potential threats and aid in the development of mitigating strategies. Whether emulating an adversary, or adopting the persona of an emergency manager, the benefit of using a red cell analytics approach to problem solving is in the generation of alternative solutions, hypotheses, courses of action or engagement strategies. Red cell teaming develops new strategies, exposes biases emerging from group think; identifies gaps and vulnerabilities that are overlooked because of over familiarity with the operation and/or security environment, highlights areas for improved inter-organizational cooperation in preparedness, response, and mitigation; and provides recommendations for insuring unchecked assumptions do not become threats. Kretz, et al., (2012) used the SYNCOIN (Synthetic Counter-Insurgency) ADG to test for analytic bias in investigators of improvised explosive device (IED) incidents. Leveraging the inherent capabilities of the digital native - those, who have come of age during the proliferation of open source information, the Internet, mobile technologies and social media, further enhances the red cell process. This emerging group of analysts is comfortable with technology; they are masters of "the search engine," and possess the analytic skills required to envision the future threat. They are comfortable accessing "the hive mind" for collaborative analysis.

THE ANALYTIC DECISION GAME (ADG)

The Analytic Decision Game was developed as pedagogy to bridge theory to practice in the college classroom and to promote and teach the application of structured and unstructured analytic techniques to solve problems of security and risk, including natural and mad-made crises. (Graham, 2012). Adapted from the tactical (war) game, the ADG has been integral to the study of Security and Risk Analysis (SRA), in the College of Information Sciences and Technology (IST) at The Pennsylvania State University, for the past ten years. The SRA curriculum was expressly developed around problem-based learning (PBL) and experiential learning strategies. The ADG combines the tenets of PBL and experiential learning with analytic techniques, thus allowing students to witness the relevance of academic content while simultaneously developing skills in problem-solving, critical thinking, communication, collaboration, and creativity.

To date, some eight different ADGs have been developed for such use. ADG scenarios vary by subject and audience and are readily adaptable across a wide area of interest, from intelligence analysis to crisis response. In the case of the virtual crisis, participants are thrust into crisis management as role-players and decision-makers. The military has long understood the value of testing and evaluation of operational concepts. More recently, large sectors of the public safety community have come to adopt reality or decision-based models for training and the evaluation of contingency plans, command and control procedures and incident management strategies. Properly designed, simulations can also expose bias emerging from group-think, or the over-reliance on outdated, but ingrained procedures. When used in combination with standing operating procedures, simulations can expose procedural gaps and intra-organizational planning and logistical shortfalls. Similarly, simulations such as the ADG that emulates realistic command and control procedures may reveal interoperability issues and cross-sector communication conflicts. While any well-oiled simulation benefits from the participation of subject matter expertise, innovations often emerge from novice participants who are not blinded by preconceived notions or embedded bias.

Lights Out in Weaver County--IMPLEMENTATION

Over the past several years, we have used the Lights Out ADG to implement the blend of crisis response and clinical reasoning in a small cohort of students at the regional campus of the Penn State College of Medicine. Lights Out is notionally set in idyllic Weaver County; a fictionalized grouping of communities molded to emulate the topography and ethnography of Central Pennsylvania. Various synthetic products were created to provide a comprehensive description of its terrain, people, traditions and histories to form the backdrop of Weaver County. These products include a complete set of topographical county and community maps, a by-community demographic study, a countywide Strengths-Weaknesses-Opportunities-Threat (SWOT) analysis and a 200-year oral history. The polymorphic nature of Weaver County makes it suitable for employing various types of disasters - both natural and man-made. To date, Weaver County has been seen multiple crises including: power failure, pandemic, and an industrial disaster. Each crisis is tailored to meet specific learning objectives and drive specific individual and team-based cognitive and decision-making processes.

The Weaver County backdrop was originally created to support the Capstone course for Security and Risk Analysis students in the Penn State College of Information Sciences and Technology. The exercise causes students to consider life in a post-cyber society. In this iteration, the scenario is played out over nine weeks of the 15-week semester, in three parts: Part-1: *Taking Stock*, begins as soon as the lights go out. In this initial phase, community leaders identify immediate threats, conduct risk assessments and identify high-risk populations. Part-2: *Governance*, begins 30 days after lights out. In this phase community leaders have resolved that they must prepare for life in a post-cyber society. Issues such as governance and the identification of public and private property are at the forefront. Part-3: *Circle the Wagons*, is set some 6 months after lights-out. In this last phase community leaders must decide on one of three courses of action: 1) Cooperate, 2) Declare Independence, or 3) Conquer.

A truncated version of Lights Out was adopted for the medical school use and is conducted over four days. The attending scenario for both iterations includes a complete failure of the U.S. power grid; followed by a series of localized emergencies and compounding countywide failures. Teams are formed by community, with exercise participants taking on leadership roles to guide their respective neighbors through the ever-devolving crisis. As the scenario progresses (for both versions), it becomes obvious that identified issues cannot be fully resolved during the span of the exercise (a situation often found in the context of clinical decision making in real-life patient care). There are some notable differences in the execution of the two versions. For the longer (Capstone) version, participants have the luxury of time to contemplate many of the deontological issues that might arise over the span of such a crisis and to integrate these notions into problem solving and course of action development strategies. The time-constrained nature of the medical school version fosters a sense of priority and focus, which better emulates conditions under stress as may be found in a real crisis event. The differences between versions have exposed potential weaknesses in both cases; and have set the stage for the development of strategies to ensure future iterations include both long-range (contemplative) and time-constrained (crisis-focused) problems.

Even the best laid plans--LESSONS LEARNED

True to the red-team process, a comprehensive after-action (AA) review was conducted at conclusion of the medical school offering of the Lights Out ADG. The AA review was held in open discourse with all participants, facilitation and support staff present. All were encouraged to share their thoughts, insights, individual and team strategies and to ask unfiltered questions. Overall, the exercise was deemed a success, but not without issues. Several notable findings for process improvement were identified. One of the most important findings was the central role of participant personality. Throughout the exercise, it was clear that personality drives team goals and strategies. This can be for the good of the team and the exercise. It can also detract from learning and teamwork. Second, for medical students early in their training, policy issues seemed to be a distraction from their perceived primary focus—to learn medicine. As a result, there was a consistent plea to focus more on medical issues. This led to the next concern, which was a need to better define overall exercise purpose and goals in the context of both crisis response and how this relates to clinical reasoning and medical decision-making.

Finally, there was an identified need to address how best to induce and maintain a healthy level of stress and competition in the context of ethical decision making around medical issues. Without a sharp focus on the medical elements of the exercise, participants noted that they had difficulty embracing the exercise emotionally.

Ways forward

The beauty of the ADG is that it is highly adaptable. In order to maximize the ADG as an instrument to help train future medical students in crisis response and to augment their experience in developing clinical reasoning skills, the following discussion & recommendations are offered:

1) *"Personality drives team (community) goals and strategies."*
    a. Discussion: Teams tended to adopt the problem-solving style of the most prominent (or vocal) member(s). Two dominant models emerged in our scenario—a rules-based, equity model and a fairness-based model. Clausewitz describes the role personality plays in making command decisions. Personality has less influence on decisions by a commander implementing collective actions than in those cases where the commander is the chief decision-maker (Ferris 2005).
    b. Recommendation: Designate specific role-players/personalities for specific tasks. Doing so may encourage students to act out/think through problems that conflict with or run counter to their natural tendencies.
2) *"Some exercise elements detracted from primary mission focus."*
    a. Discussion: Issues of governance may be better addressed as part of the scenario, rather than as "items for resolution" by medical students whose (perceived) primary focus is to identify and resolve medical needs/requirements. Given the complexity of crisis situations, there will always arise those situations where there is no designated subject matter expert at hand, yet the issue must be dealt with.
    b. Recommendation: Add enough variety in the individual exercise injects to challenge participants to conduct problem solving, while not losing focus of the overall exercise objectives. Many of these issues, once contemplated, can addressed by down-range policy/course of action add-ons to the exercise.
3) *"Focus more on medical issues."*
    a. Discussion: The exercise includes many issues that are best addressed through a body of community policy-makers. This requires some simple but easily achieved redesign. Instead of having medical students act as overall community leaders, assigning them to medical advisory roles would free them up to address pressing medical issues. Community-wide policy decisions could be accounted for as exercise injects as the scenario roles out. The adaptive nature of the ADG allows for rapid changes to address this concern.
    b. Recommendation: Maintain the current Weaver County backdrop, and redesign the exercise scene setter and supporting exercise injects to focus on a specific medical crisis or associated medical aspects within a given crisis. The redesign of the exercise elements should be conducted in concert with the medical school faculty to identify specific learning outcomes, strategies and objectives.
4) *"Need to better define overall exercise purpose and goals."*
    a. Discussion: Many of the underlying purposes/goals are implied but go unstated over the course of the exercise. Some of this is intentional to allow participants to determine team priorities and goals; but much is due to the nature of the exercise design, where the shortened ramp-up time to the exercise causes medical student participants to concentrate on the information elements of the scenario; where their SRA counterparts have a 6-week lead-time to understand exercise purpose and goals.
    b. Recommendation: This concern can be addressed along with number 3 above.
5) *Need to induce and maintain stress & competition throughout."*
    a. Discussion: Several factors contributed to this concern, including the fact that the exercise was conducted in medical school classroom, interrupted by a weekend break, and the overall scenario focused mostly on long-term objectives, vice intermediate short-duration problems. On competition: earlier iterations of the exercise were dominated by game-theory prompted

competition, whereas the most recent iteration tended toward less overall competition and higher degrees of cooperation.

b. Recommendation: This concern can be addressed along with number 3 above.

6) *"Ethical discussions around medical issues are an important aspect of the exercise."*

a. Discussion: Many of the decisions/strategies adopted by the teams were made along demonological lines; but in retrospect, may not have aligned with the greater community needs.

b. Recommendation: This concern can be addressed along with number 3 above, with sufficient time set aside for larger group discussion, and should consider including medical faculty and outside experts in the mix.

7) *"Participants didn't/couldn't embrace the exercise emotionally."*

a. Discussion: The phenomena can be traced back to two primary factors: 1) Inability to associate with the scenario; and 2) The lack of vested interest. In the former, participants simply could not relate, either because they felt the problem was unrealistic or they simply, "fought the scenario." In the latter, absent a formal assessment component to the exercise, the participants considered the scenario as "fun to do activity," and not a component of medical school learning.

b. Recommendation: Along with item 3 above, formally integrate the ADG into the curriculum, with similar expectations borne of other medical school requirements, including scheduling, assessments and expectations.

6) *"There was a general lack of knowledge transfer from one exercise part to the next."*

a. Discussion: Students tended to approach the exercise as a series of sequential problems rather than a set of contiguous, related issues.

b. Recommendation: This concern can be addressed along with number 3 above. Construct a set of "bridging injects" between exercise parts to induce the notion of the crisis continuum such that they cause participants to consider the impact of past decisions/outcomes on future courses of action/outcomes.

7) *"Need for more analytic rigor."*

a. Discussion: Much of the focus was too "in-close," offering localized (based on individual cases) rather than more strategic (community-based) solutions.

b. Recommendation: This concern can be addressed along with number 3 above. During the design review process, identify the desired "analytic touchpoints" throughout the exercise where specific items are addressed and emphasis placed on the exercise as a corollary to the clinical reasoning process.

8) *"Failure to acknowledge people-to-people or community-to-community conflict not a realistic approach."*

a. Discussion: Some exercise participants chose to not address conflict-related issues such as, crime, lawlessness, corruption, etc., introduced across the scenario as they felt these concerns detracted from their ability to concentrate on more pressing medical issues. Conflict is a natural component of crisis and should be considered part and parcel to the pathology of most all disaster scenarios. Harris, et al (2013) address the convergence of natural disaster and conflict-affected states and the difficulty that exists in managing risk across this space. The role of conflict in the Lights Out scenario, or any other ADG for that matter, is meant to highlight the connectedness of the human dilemma with the crisis environment. It is not intended to be the overarching theme or principal analytic focus; but the issues surrounding conflict are worthy of consideration – how much attention need to paid across the scenario can be controlled through design.

b. Recommendation: During the design review process, identify the "conflict touchpoints" appearing throughout the exercise and the attention that should be placed on each.

CONCLUSION

The asymmetric nature of crisis, whether by mother nature or man-made, requires thought processes and analytic strategies that are dynamic, adaptable and tailorable to a wide range of possibilities. The analytic decision game is an effective pedagogical strategy to promote critical thinking in the context of developing clinical reasoning skills. The Penn State College of Medicine has developed a new and innovative approach to medical school education at its new regional campus. By employing trans-disciplinary educational strategies to create a flexible and integrated program of study, the program fosters the development of interprofessional team skills, curiosity, and commitment to the calling of Medicine. The new curriculum prepares students for the ongoing practice of evidence-based medicine in the rapidly changing healthcare environment of the 21st century.

The use of the Weaver County ADG is the perfect backdrop for medical students to develop the clinical reasoning skills required to address the needs of the local community and build a foundation for transferring these skills to a national and global context. Further adaptation of the ADG with a focus on long/intermediate objectives to build problems that focus on healthcare issues will likely strengthen the program and serve to augment current experiential learning and clinical immersion methodologies. The modular nature of the ADG also lends to transportability to other learning environments and situations.

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Decision Support for the Optimal Coordination of Spontaneous Volunteers in Disaster Relief

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ABSTRACT

When responding to natural disasters, professional relief units are often supported by many volunteers which are not affiliated to humanitarian organizations. The effective coordination of these volunteers is crucial to leverage their capabilities and to avoid conflicts with professional relief units. In this paper, we empirically identify key requirements that professional relief units pose on this coordination. Based on these requirements, we suggest a decision model. We computationally solve a real-world instance of the model and empirically validate the computed solution in interviews with practitioners. Our results show that the suggested model allows for solving volunteer coordination tasks of realistic size near-optimally within short time, with the determined solution being well accepted by practitioners. We also describe in this article how the suggested decision support model is integrated in the volunteer coordination system which we develop in joint cooperation with a disaster management authority and a software development company.

Keywords

Coordination of spontaneous volunteers, volunteer coordination system, decision support, scheduling optimization model, linear programming

INTRODUCTION

In the light of climate change, urbanization, and global conflicts, natural and man-made disasters have increasingly severe consequences on humans and their environment (Schryen et al. 2015). This leads to a rising importance of an effective disaster relief. In the wake of a disaster, professional relief units are usually supported by volunteers affiliated with humanitarian organizations, e.g., the International Federation of Red Cross and Red Crescent Societies (IFRC 2015). In addition to these affiliated volunteers, cooperativeness of citizens results in large amounts of spontaneous (i.e., not affiliated to any humanitarian organization) volunteers offering their help. As many as two million citizens assisted others in the aftermath of the 1985 earthquake in Mexico City (Dynes et al. 1990) and after 9/11, more than 15,000 people gathered at Ground Zero offering their services (Lowe and Fothergill 2003). The effective usage of these additional capabilities provides an invaluable resource that must not be neglected. However, spontaneous volunteers are present on disaster sites regardless of a request for their assistance and their mass movements (also known as *convergence*) are highly unpredictable (Fernandez et al. 2006; Lodree and Davis 2016). This makes their coordination a complicated task and often a burden. In summary, the coordination of spontaneous volunteers is a challenging yet very important part of disaster relief (FEMA 2013; Mayorga et al. 2017).

The unpredictable behavior of spontaneous volunteers results in an ad-hoc on-site coordination when it comes to real-world disasters. However, this distracts professional responders from their primary duties (Fernandez et al. 2006). This serious issue calls for the deployment of volunteer coordination systems that enable an off-site coordination of spontaneous volunteers, i.e., before they arrive at the disaster site. Such a system must enable a live interaction between professional responders and off-site volunteers during the disaster situation via modern information and communication technology. Furthermore, appropriate mathematical models and algorithms for solving problem instances are key to supporting decisions on how to exploit the capabilities of volunteers. The literature on quantitative approaches for volunteer coordination is discussed in the following section. However, we

found out that all approaches miss at least one key requirement for coordinating spontaneous volunteers that we have identified in interviews with professionals at the Disaster Management Authority in Halle (Saale), Germany, which is referred to as *DMA Halle (Saale)* in the remainder of the paper). This issue leads to the following research question that we address in our paper: *How can the problem of coordinating spontaneous volunteers be mathematically modeled and solved in order to improve the coordination of spontaneous volunteers and to relieve professional responders in real-world disasters?*

This research question is addressed in our paper by developing and testing a novel approach that automatizes the coordination of spontaneous volunteers. Based on key requirements for coordinating spontaneous volunteers, which we have identified in interviews with professionals at the DMA Halle (Saale), we present an optimization model that can be solved by off-the-shelf-solvers. We computationally solved a real-world instance of the suggested model and empirically validated the determined solution of the coordination task. Our results show that a problem instance of realistic size can be solved near-optimally within short time with the determined solution being well accepted by practitioners. Professionals at the DMA Halle (Saale) confirmed that such complex coordination decisions can hardly be provided manually by professional responders in comparable quality - especially when they are under severe time pressure. Working closely together with the DMA Halle (Saale) and the software development company *esri Germany*, our optimization model is integrated in a holistic volunteer coordination system called *KUBAS*, which guarantees the practical applicability of our approach (see KUBAS (2018) for further information). Thus, our contributions can be used in practice to improve the coordination of spontaneous volunteers and to relieve professional responders at the same time.

The remainder of the paper is structured as follows: In the following section, we discuss relevant literature. Then, we provide a detailed overview on the KUBAS system. After that, we give a description of our volunteer scheduling problem as well as a mathematical formulation as a linear optimization model. Subsequently, we use an off-the-shelf solver to solve case study instances that represent a real-world flood scenario. Finally, we discuss our results and present our conclusions.

RELATED WORK

Volunteerism in general and volunteer management in particular are vitally discussed in the field of disaster and emergency management, see reviews by Alexander (2010) and Whittaker et al. (2015) for an overview. In this regard, especially the use of information systems has gained increasing attention in recent years, see Auferbauer et al. (2016), Van Gorp (2014), Havlik et al. (2016), Horita and De Albuquerque (2013), Lindner et al. (2018), and Siemen et al. (2017), for example. In our paper, we focus on the coordination of spontaneous volunteers in disaster relief. As unfolded in the introduction, this demands for automatized decision support and therefore quantitative approaches. In the following, we discuss relevant literature.

Mayorga et al. (2017) present a queuing system to model the uncertain arrival and departure of spontaneous volunteers. They present four heuristics to assign volunteers to queues. This is the only article that explicitly deals with coordinating spontaneous volunteers. Liu and Wang (2013) develop an integer linear program (ILP) to coordinate entire volunteer teams and minimize their travel costs. Pielorz and Lampert (2015) also present an ILP to coordinate the volunteer organization *Team Austria*. They seek an assignment that requires a minimal amount of volunteers to meet all task demands. The approaches in both articles assume that task demand can always be fulfilled, i.e., that there is no shortage of volunteers in any task.

Falasca, Zobel, and Fetter (2009) and Falasca and Zobel (2012) formulate volunteer scheduling as a bi-objective optimization model. They minimize the number of unmet task demands as well as the number of volunteer assignments to undesired tasks or time slots. Furthermore, Falasca, Zobel, and Ragsdale (2011) introduce a spreadsheet modeling approach and apply it to a South American development organization. They use a single objective function representing a weighted sum of the percentage of undesired assignments, the percentage of unmet task demands, and the percentage of budget used. Lassiter, Alwahishie, et al. (2014) and Lassiter, Khademi, et al. (2015) optimize volunteer scheduling on a semi-professional level involving long-term training. They seek to minimize several costs associated with the volunteer coordination. Another approach was presented by Aman et al. (2012) who use a goal programming model to schedule volunteer organizations after a volcano eruption. Their objective is to minimize deviations from task demands as well as from the desired number of shifts expressed by each volunteer.

Two earlier works on volunteer coordination have been developed in application areas different from disaster management. Sampson (2006) presents a goal programming model minimizing deviations in both task demands and volunteer preferences. They apply their model to reviewer assignment for a scientific conference. In addition, they elaborate crucial differences between volunteer assignment and traditional labor assignment; the most important of

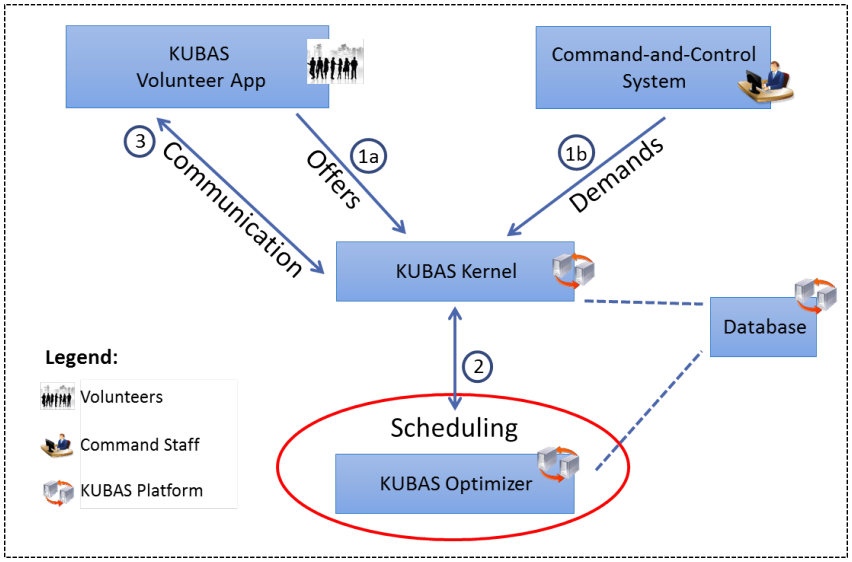

Figure 1. Volunteer coordination system KUBAS

which are that the variable costs of labor are usually trivial for volunteers and that there is a possibility that task demands cannot be fully covered. This prevents using algorithms from the vitally studied field of traditional labor assignment (see Van den Bergh et al. (2013) for an overview) to the volunteers setting. Gordon and Erkut (2004) present an optimization model to automatize the volunteer shift assignment process for the Edmonton Folk Festival. They assume that enough volunteers are available and maximize volunteers' shift preferences subject to covering all shifts.

With the exception of the work of Mayorga et al. (2017), who suggest an approach for on-site coordination, all other approaches address off-site coordination, which is the focus of our work. However, none of the latter approaches considers a key requirement that we identified in interviews with professionals at the DMA Halle (Saale): When there is volunteer shortage (which may occur, for example, at night or when there is bad weather), unmet task demands should be kept to a minimum while the unmet demands should be distributed among tasks in a balanced way. For example, when there are two tasks that both demand for ten volunteers of the same capability and there are only ten eligible volunteers available, then it is better to assign five volunteers to each task than to assign ten volunteers to one task and no volunteer to the other task. In order to develop a decision support approach for off-site coordination of spontaneous volunteers that accounts for requirements occurring in real-word scenarios, including the previously mentioned one, we (1) conducted interviews with professionals at the DMA Halle (Saale) to identify those requirements and (2) propose and (computationally and empirically) validate an optimization model that considers the identified requirements. A full list of requirements is presented in the *Problem Description* section.

VOLUNTEER COORDINATION SYSTEM KUBAS

In this section, we explain the volunteer coordination system KUBAS for which the optimization model presented in this article is the key decision support methodology. The KUBAS system is developed in close cooperation with the DMA Halle (Saale) and esri Germany. As demanded by the former, it is designed to enable an optimal coordination of spontaneous volunteers *before* they arrive at the disaster site in an uncontrolled way. To achieve this, the KUBAS system takes advantage of both mathematical methods, which are developed in our paper, and modern information and communication technology. A graphical overview of the KUBAS system is given in Figure 1, which is explained in the following. Using the term *volunteer*, we refer to a spontaneous volunteer in the remainder of the paper.

Volunteers can register at any time via smartphones using the *KUBAS volunteer app* and submit offers for their help to an administrative component called *KUBAS kernel*. The command staff is connected to the KUBAS kernel via an interface to their command-and-control system, which allows them to submit and prioritize demands for volunteers. The submission of offers and demands is labeled as steps 1a and 1b, respectively, in the figure. After collecting this information, the KUBAS kernel calls the *KUBAS optimizer*, which uses an optimization model to coordinate the registered volunteers. The KUBAS optimizer matches offers and demands to schedule volunteers in a way that satisfies preferences of both the command staff and the volunteers. This is marked as step 2 and is the focus of this paper. Finally, relevant information about the scheduling decision is communicated to the individual

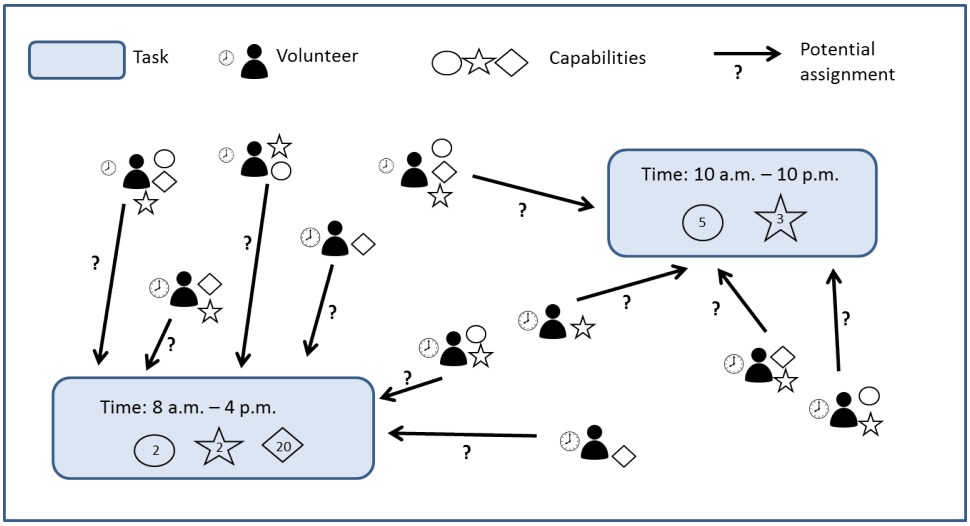

Figure 2. Sample situation for VSP with two tasks and ten volunteers

volunteers, which are prompted to confirm their assignments (step 3). We stress that our interview partners at the DMA Halle (Saale) pointed out that due to time pressure, it is more convenient for the command staff to not confirm or adjust the schedules calculated by the KUBAS optimizer. Therefore, the scheduling decisions are immediately broadcast to the volunteers. Note that it may be convenient to also communicate the scheduling decision to the command-and-control system for visualization purposes. However, this it not essential for the workflow presented in Figure 1. A description of a basic implementation of the KUBAS system – including a graphical user interface as proxy for the command-and-control system – can be obtained from Betke (2018).

The ad-hoc nature of volunteers implies that they may register in any number at any time. In addition, the command staff may submit new demands or reset their priorities at any time due to the unpredictability of changes in disaster relief situations. The KUBAS system explicitly takes into account this dynamic setting. The KUBAS kernel starts the KUBAS optimizer whenever the situation has changed substantially, e.g., when new demands occur, when priorities change, or when a number of new volunteers register. Each time when the KUBAS optimizer is started, it schedules the registered volunteers based on current information, i.e., a sequence of scheduling problem instances is solved over time to reflect the dynamic setting. Technically spoken, steps 2 and 3 are repeated automatically as soon as new submissions in steps 1a and 1b change the situation substantially.

PROBLEM DESCRIPTION AND DECISION SUPPORT MODEL

Problem Description

In the following, we describe the problem which is solved by the KUBAS optimizer. To construct a realistic setting, we have developed the problem in close cooperation with the DMA Halle (Saale). It is important that volunteers can be coordinated with high flexibility. Our interview partners therefore prefer a *scheduling* problem type instead of a pure assignment problem. [1] Consequently, we refer to our problem as *volunteer scheduling problem* (VSP). We present and explain VSP using a fictitious sample situation, which is illustrated in Figure 2.

Each VSP instance consists of a set of volunteers who offer their help. Each volunteer expresses his/her preferences in terms of available times and personal capabilities. For example, a volunteer may be available from 8 a.m. to 1 p.m. and again from 6 p.m. to 10 p.m. offering the capabilities *physical labor* and *writing*.

Furthermore, there is a set of *tasks* which volunteers are required to work on. Each task has a fixed location and a specified time when it takes place. Each task consists of several activities, each of which is characterized by demanding a certain number of volunteers with a specific capability. An example for a task during a flood would be *working at the sandbag supply station* taking place from 8 a.m. to 4 p.m. and consisting of the following activities: *filling sandbags* with a demand for 10 volunteers capable of physical labor; *carrying sandbags* with a demand for 10 volunteers capable of physical labor; *disposing meals* with a demand for 2 volunteers capable of light physical labor; and *documenting* with a demand for 2 volunteers capable of writing. These activities require in total 20

[1] Note that a scheduling problem type is possible because we coordinate off-site volunteers. On-site volunteers do not allow for this flexibility since they cannot be sent back home (to be assigned at a later time) without negative consequences on their motivation.

volunteers with the capability *physical labor*, 2 volunteers with capability to perform *light physical labor*, and 2 volunteers with *writing* capabilities.

Finally, each VSP instance addresses a discrete planning horizon with a positive number of equal-length time slots. The aim of solving the VSP is to schedule the volunteers to process all *task activities* (e.g., activity *filling sandbags* of task *working at the sandbag supply station*) during the entire planning horizon such that real-world requirements are fulfilled in an optimal way. We have identified those requirements in personal interviews with professionals at the DMA Halle (Saale) and present them in the following:

(i) The crucial metric for all task activities at any time is the ratio of assigned to requested volunteers. These ratios are called *workloads* and become especially important when there is a shortage of volunteers. The overall goal is to maximize the aggregated workload over all task activities and all time slots under the restriction that workloads must not exceed 100%; i.e., there must not be assigned more volunteers than requested to any task activity in any time slot.

(ii) There are several priority levels for tasks. Unmet demands for volunteers are more severe for activities of a higher-prioritized task than for activities of a lower-prioritized task. When there is volunteer shortage, workloads (i.e., assignment ratios) should be higher in activities of higher-priority tasks.

(iii) Unmet demands for volunteers are more severe in earlier time slots than in later time slots, since unmet demands in early time slots are more likely to be lost for good than demands in later time slots (which might be fulfilled when new volunteers register).

(iv) Workloads of task activities that have the same priority levels and require the same capability should be identical within each time slot.

(v) When task activities with different priorities demand for volunteers with the same capability at the same time, there must be a compensation between these task activities; i.e., activities of lower-priority tasks may be filled to a certain level even if activities of higher-priority tasks cannot be filled to 100%. [2]

(vi) A volunteer cannot work on more than one task activity at the same time.

(vii) A volunteer can only be scheduled to process a task activity at a certain time slot when s/he has the appropriate capability and availability.

(viii) When a volunteer is assigned to a task activity, there must be a lower bound on the time s/he works consecutively on this task activity because short work blocks would lead to chaotic situations.

(ix) There must be an upper bound on the total working hours during the entire planning horizon that must not be exceeded by any volunteer.

(x) Volunteers require a break (setup time) when switching from one task activity to another. Factors contributing to setup times are, for example, traveling between locations of activities, changing wet clothes, consuming food, or getting briefed about the next activity.

While requirements (i)-(vi) mainly ensure that a VSP solution is regarded as optimal by the command staff, requirements (vii)-(x) aim at achieving a high level of volunteer satisfaction, which is important to maintain volunteer motivation – in the current disaster as well as future disaster situations.

As outlined in the previous section, the KUBAS optimizer is started automatically whenever the situation changes substantially. Then, a new VSP instance is generated and solved based on current information, which includes the scheduling decisions from the solution of the previous VSP instance. Since scheduling decisions are broadcast to volunteers immediately after solving a VSP instance (see step 3 in Figure 1), the following requirement aims at avoiding confusion among volunteers:

(xi) When a volunteer has assignments from the solution of the previous VSP instance, these assignments must not be changed by the solution of the current VSP instance.

This requirement implies that the feasible solutions of a VSP instance are also affected by the optimal solution of the previously solved VSP instance, the scheduling decisions of which must not be changed. Note that all presented requirements hold for arbitrary off-site volunteers, not only for spontaneous volunteers. Although the intention of the KUBAS system is to coordinate (otherwise hardly controllable) spontaneous volunteers, it can be used to coordinate any off-site volunteers – as long as they register via the KUBAS volunteer app.

[2]Note that assigning volunteers to activities of a lower-priority task leads to smaller workloads in activities of higher-priority tasks.

Table 1. Notation for optimization model

Notation	Description
$t = 0, \ldots, T$	Time slots (planning horizon)
$i = 1, \ldots, V$	Volunteers
$c = 1, \ldots, C$	Capabilities
$j = 1, \ldots, A$	Task activities
$p = 1, \ldots, P$	Priorities
$\mathcal{A}_{pct}$	Set of task activities that have priority p and demand for volunteers with capability c at time t
X_{ijt}	Binary decision variable (volunteer i is assigned to task activity j at time t or not)
L_{pct}	Continuous variable (minimum workload among all task activities $j \in \mathcal{A}_{pct}$)
pr_j	Priority of task activity j (depends only on the underlying task)
r_{jt}	Binary indicator showing whether time slot t is within the time frame of task activity j or not (depends only on the underlying task)
req_{jc}	Binary indicator (task activity j requires capability c or not)
n_j	Number of volunteers requested by task activity j
w_{pt}	Weight parameter which indicates the severity of unmet demands for volunteers in time slot t at task activities with priority p
d_{pt}	Scaling parameter which represents the fraction of demands of the task activities with priority p and demands of all task activities at time t
$\sigma_{p-1,p}$	Compensation factor which indicates the relative importance of adjacent priorities $p-1$ and p
o_{ijt}	Binary indicator (volunteer i has an assignment to task activity j in time slot t from the solution of the previous VSP instance or not)
a_{it}	Binary indicator (volunteer i is available in time slot t or not)
cap_{ic}	Binary indicator (volunteer i offers capability c or not)
τ_1	Number of slots that a volunteer must work consecutively on the same task activity
τ_2	Number of slots that each volunteer is allowed to work in total during the planning horizon
τ_3	Number of slots for setup time between working on different task activities

Decision Support Model

Based on the problem description, we present a linear optimization model for the VSP. All notation that we use and introduce in this subsection is summarized in Table 1. The table lists all relevant indices, sets, variables, and parameters – in this order and separated by horizontal lines. A problem instance comprises a discrete planning horizon of equal-length time slots $t = 0, \ldots, T$ in which volunteers $i = 1, \ldots, V$ with certain capabilities $c = 1, \ldots, C$ are scheduled to work on task activities $j = 1, \ldots, A$ which have task-specific priorities $p = 1, \ldots, P$.

Each task activity (e.g., activity *filling sandbags* of task *working at the sandbag supply station*) comes with a priority pr_j (where higher numbers represent a higher priority) and a time frame (indicated by binary parameters r_{jt}) in which volunteer help is needed. Priority and time frame of a task activity depend only on the underlying task, i.e., they are the same among all activities of the same task. A task activity j is further characterized by a single capability that the underlying task requires (indicated by binary parameters req_{jc}) and the corresponding number n_j of requested volunteers.

We use binary decision variables X_{ijt} to indicate whether volunteer i is assigned to work on task activity j in time slot t ($X_{ijt} = 1$) or not ($X_{ijt} = 0$). Furthermore, we define

$$\mathcal{A}_{pct} := \{j = 1, \ldots, A | pr_j = p \text{ and } r_{jt} \cdot req_{jc} = 1\}$$

as the set of task activities that have priority p and request for volunteers with capability c in time slot t. This allows us to introduce variables

$$L_{pct} = \min_{j \in \mathcal{A}_{pct}} \frac{1}{n_j} \sum_{i=1}^{V} X_{ijt},$$

which represent the minimum workload (i.e., assignment ratio) among all task activities $j \in \mathcal{A}_{pct}$. Note that these minimum workloads are to be maximized in the objective function to take into account requirements (i) and (iv). To show how the variables L_{pct} help to balance workloads and therefore to fulfill requirement (iv), we present a small example. Consider a scenario where we have two task activities, both with task priority $p = 2$. Each task activity demands for 40 volunteers with capability $c = 4$. We fix a time slot $t = 6$ and assume that there are exactly 40 eligible volunteers. Now, we compare L_{246} for three different possible solutions in Figure 3. In the first solution,

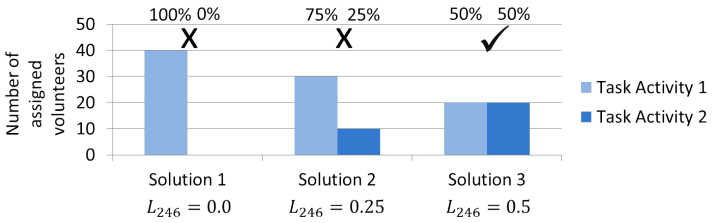

Figure 3. Comparison of L_{246} for three different feasible solutions

the workload of task activity 1 is 100% while the workload of task activity 2 is 0%. L_{246} is the minimum of both workloads and hence $L_{246} = 0.0$. The values of $L_{246} = 0.25$ in solution 2 and $L_{246} = 0.5$ in solution 3 can be calculated analogously. In summary, solution 3 has the highest minimum workload L_{246} among the presented solutions.

According to requirements (ii) and (iii), we introduce weights $w_{pt} > 0$, which indicate the severity of unmet demands for volunteers in time slot t at task activities with priority p. However, maximizing (a sum of) weighted workloads $w_{pt} \cdot L_{pct}$ is not sufficient to fulfill all requirements (i)-(iv) as we illustrate again in a small example. We fix a time slot t and assume $w_{1t} = 1$ and $w_{2t} = 5$. In particular, priority $p = 2$ is more important than priority $p = 1$. Consider an example where two task activities demand for the same capability c. Task activity 1 has priority $p = 1$ and demands for 5 volunteers. Task activity 2 has priority $p = 2$ and demands for 50 volunteers. Further assume that there are exactly 5 eligible volunteers. Now, the maximum value for $w_{1t} \cdot L_{1ct} + w_{2t} \cdot L_{2ct}$ is achieved by assigning all volunteers to task activity 1 resulting in $1 \cdot 1 + 5 \cdot 0 = 1$. However, assigning all volunteers to the task activity with the lower priority and no volunteer to the task activity with the higher priority contradicts requirement (ii). To address this issue, we define for all priorities p and time slots t a scaling parameter

$$d_{pt} = \frac{\sum_{c=1}^{C} \sum_{j \in \mathcal{A}_{pct}} n_j}{\sum_{j=1}^{A} r_{jt} \cdot n_j}$$

which represents the fraction of the demands of task activities j with priority $pr_j = p$ at time t and the demands of all task activities at time t. In the example, we have $d_{1t} = \frac{1}{11}$ and $d_{2t} = \frac{10}{11}$. Evaluating $w_{1t} \cdot d_{1t} \cdot L_{1ct} + w_{2t} \cdot d_{2t} \cdot L_{2ct}$ we see that the sum now achieves its maximum when all five volunteers are assigned to the higher-priority task activity. Using the introduced notation, we formulate the following optimization model:

$$\max \quad \sum_{p=1}^{P} \sum_{c=1}^{C} \sum_{t=1}^{T} w_{pt} \cdot d_{pt} \cdot L_{pct} \qquad \text{(Max-WL)}$$

$$L_{pct} \leq \frac{1}{n_j} \cdot \sum_{i=1}^{V} X_{ijt} \qquad \forall p = 1, \ldots, P; c = 1, \ldots, C; t = 1, \ldots, T; j \in \mathcal{A}_{pct} \qquad (1)$$

$$\sum_{i=1}^{V} X_{ijt} \leq n_j \cdot r_{jt} \qquad \forall j = 1, \ldots, A; t = 1, \ldots, T \qquad (2)$$

$$0 \leq L_{pct} \qquad \forall p = 1, \ldots, P; c = 1, \ldots, C; t = 1, \ldots, T \qquad (3)$$

$$X_{ijt} \in \{0, 1\} \qquad \forall i = 1, \ldots, V; j = 1, \ldots, A; t = 1, \ldots, T \qquad (4)$$

A mapping of requirements from the previous subsection and their equivalents in the model is provided in Table 2. The objective function (Max-WL) maximizes a weighted (by parameter w_{pt}) and scaled (by parameters d_{pt}) sum of workload variables L_{pct}, which are specified by constraint (1). Constraint (2) ensures that the number of assigned volunteers does not exceed the number of requested volunteers at any task activity in any time slot. The workload variables L_{pct} also balance workloads among all task activities $j \in \mathcal{A}_{pct}$ as presented in Figure 3. Constraints (3) and (4) define the domain of definition of the variables L_{pct} and X_{ijt}. [3] To sum up, the objective function (Max-WL) and constraints (1)-(4) ensure requirements (i)-(iv).

[3]Note that constraint (2) also implies $L_{pct} \leq 1$ for all priorities p, capabilities c, and time slots t.

Table 2. Mapping of requirements vs. constraints

Requirements	Constraints
(i), (ii), (iii), (iv)	(Max-WL), (1), (2), (3),(4)
(v)	(5)
(vi)	(6)
(vii)	(7)
(viii)	(8), (9)
(ix)	(10)
(x)	(11)
(xi)	(12)

In order to fulfill the compensatory requirement (v) for task activities of different priorities, we introduce a compensation factor $\sigma_{p-1,p} \in [0, 1)$ for all priorities $p = 2, \ldots, P$ which indicates the relative importance of priority $p - 1$ in comparison to p in all time slots and formulate the following constraint: [4]

$$L_{(p-1)ct} \geq \sigma_{p-1,p} \cdot L_{pct} \quad \forall p = 2, \ldots, P; c = 1, \ldots, C; t = 1, \ldots, T \tag{5}$$

This constraint ensures that for any priority $p \geq 2$, any capability c, and any time slot t, the workload $L_{(p-1)ct}$ must be at least as high as the workload L_{pct} multiplied by the compensation factor (e.g., 30% which corresponds to $\sigma_{p-1,p} = 0.3$). When $\sigma_{p-1,p} = 0$, we do not have any compensation between the priorities $p - 1$ and p. Thereby, constraint (5) takes into account requirement (v).

In the following, we introduce additional constraints that are necessary to fulfill requirements (vi)-(xi). A binary parameter a_{it} indicates availabilities and equals 1 if and only if volunteer i is available in time slot t. Another binary parameter cap_{ic} is 1 if and only if volunteer i has capability c. Furthermore, let the binary parameter o_{ijt} be 1 if and only if volunteer i has an assignment to task activity j in time slot t from the solution of the previous VSP instance. [5] Let τ_1 be the minimum number of time slots that a volunteer must work consecutively on the same task activity. Let τ_2 be the maximum number of time slots that a volunteer is allowed to work in total during the entire planning horizon. Finally, let τ_3 be the number of time slots that represents the setup time between working on two different task activities. [6] This notation allows for formulating the following constraints:

$$\sum_{j=1}^{A} X_{ijt} \leq 1 \qquad \forall i = 1, \ldots, V; t = 1, \ldots, T \tag{6}$$

$$X_{ijt} \leq a_{it} \cdot \sum_{c=1}^{C} cap_{ic} \cdot req_{jc} \qquad \forall i = 1, \ldots, V; j = 1, \ldots, A; t = 1, \ldots, T \tag{7}$$

$$X_{ij0} = o_{ij0} \qquad \forall i = 1, \ldots, V; j = 1, \ldots, A \tag{8}$$

$$\sum_{t'=1}^{\min\{\tau_1, T-t+1\}} X_{ij(t+t'-1)} + \tau_1 \cdot \left(X_{ij(t-1)} - X_{ijt} + 1\right) \geq \tau_1 \quad \forall i = 1, \ldots, V; j = 1, \ldots, A; t = 1, \ldots, T \tag{9}$$

$$\sum_{j=1}^{A} \sum_{t=1}^{T} X_{ijt} \leq \tau_2 \qquad \forall i = 1, \ldots, V \tag{10}$$

$$\sum_{j \neq j'=1}^{A} \sum_{t'=1}^{\min\{\tau_3, T-t\}} X_{ij'(t+t')} \leq \tau_3 \cdot (1 - X_{ijt}) \qquad \forall i = 1, \ldots, V; j = 1, \ldots, A; t = 1, \ldots, T \tag{11}$$

$$X_{ijt} \geq o_{ijt} \qquad \forall i = 1, \ldots, V; j = 1, \ldots, A; t = 1, \ldots, T \tag{12}$$

[4] We assume that priority levels are ordered such that priority $p = 1$ represents the lowest priority level and $p = P$ represents the highest priority level.

[5] Note that we solve a sequence of dependent VSP instances over time as explained at the end of the previous subsection.

[6] We assume a constant setup time of τ_3 time slots since it is impossible to exactly predict sequence- and volunteer-dependent setup times in the chaotic setting of disaster relief. Nevertheless, the concept of setup times is an important feature of real-world scheduling and consequently is included in the model.

Constraint (6) assures that a volunteer is not assigned to multiple task activities simultaneously, see requirement (vi). Constraint (7) ensures that a volunteer is only assigned to task activities where s/he has the matching capability and in time slots where s/he is available, see requirement (vii). Constraint (8) includes the assignments that volunteers have at time of decision making $t = 0$. [7] We have $X_{ij0} = o_{ij0} = 1$ if and only if volunteer i works on task activity j at time of decision making due to an assignment from the solution of the previous VSP instance. This is important for constraint (9) where the index $t - 1$ can be 0. In constraint (9), we have $X_{ij(t-1)} - X_{ijt} + 1 = 0$ if and only if $X_{ijt} = 1$ and $X_{ij(t-1)} = 0$, i.e., when volunteer i begins working on task activity j at the beginning of time slot t. [8] In this case, constraint (9) assures that volunteer i keeps working on task activity j for at least τ_1 time slots. The combination of constraints (8) and (9) therefore ensures requirement (viii). Constraint (10) assures that each volunteer does not work more than τ_2 time slots in total during the entire planning horizon, see requirement (ix). In constraint (11), we have $1 - X_{ijt} = 0$ if and only if $X_{ijt} = 1$. In this case, it is assured that volunteer i has no assignment to any task activity different from j during the τ_3 time slots after t. [9] Therefore, constraint (11) accounts for the setup times from requirement (x). Constraint (12) guarantees that if a volunteer i has an assignment to task activity j in time slot t from the solution of the previous VSP instance (i.e., $o_{ijt} = 1$) then X_{ijt} must be 1. Consequently, requirement (xi) is fulfilled. Finally, all features of VSP as introduced in the previous subsection are incorporated in the presented model with objective function (Max-WL) and constraints (1)-(12).

CASE STUDY: 2013 SAALE FLOODING

We evaluate the presented model using tasks from the Saale flooding, which was part of the major floods across Central Europe in early summer 2013. This flooding was characterized by the highest Saale water level ever recorded and a high number of uncoordinated volunteers according to interviews with practitioners. We begin with a description of our case study instances before we explain our parameter setting for solving the corresponding optimization models. Finally, we present and discuss our computational results. All information and data in this section is conducted from an internal flood report of the DMA Halle (Saale) and personal interviews with professionals at the agency.

Case Study Instances

In our case study, we distinguish four capabilities, namely *hard physical labor* ($c = 1$), *medium physical labor* ($c = 2$), *light physical labor* ($c = 3$), and *writing* ($c = 4$). Furthermore, we distinguish three different priorities, namely *low* ($p = 1$), *medium* ($p = 2$), and *high* ($p = 3$) priority. We demonstrate the applicability of our model in a dynamic setting by considering a sequence of two dependent VSP instances that represent real instances during the Saale flooding 2013:

Instance 1 *The initial instance consists of the four tasks flood control 1, flood control 2, flood control 3, and sandbag supply. Flood control tasks consist of the three activities carrying sandbags, disposing meals, and documentation which require the capabilities hard physical labor, light physical labor, and writing, respectively. A sandbag supply task consists of the three mentioned activities plus the activity filling sandbags which requires the capability medium physical labor. This leads to a total of 13 task activities. The demands and priorities of all tasks are presented in Figure 4. All four tasks demand for volunteers during the entire planning horizon. We further assume that there are 400 volunteers registered in the KUBAS system.*

Instance 2 *Two hours later, a new task occurs and we assume that 300 new volunteers have registered. The new instance consists of the five tasks flood control 1, flood control 2, flood control 3, flood control 4, and sandbag supply. Priorities and demands of all tasks can again be obtained from Figure 4. All five tasks demand for volunteers during the entire planning horizon. The 300 newly registered volunteers - in addition to the 400 volunteers from instance 1 - give us an instance with 700 volunteers and 16 task activities.*

Since there is no empirical data about volunteer behavior in the 2013 Saale flooding, we have to generate volunteer availabilities and capabilities randomly. We investigate a 24-hour planning horizon and divide it into six four-hour segments. For each of the segments, the probability for each volunteer to be available in the segment is set to $\frac{1}{3}$. This allows for multi-hour consecutive volunteer availabilities and leads to an average volunteer available time

[7] Note that $t = 0$ is an auxiliary time slot that represents the time of decision making where no new assignments are made. In particular, X_{ij0} is fully determined by o_{ij0}.

[8] In all other cases, we have $X_{ij(t-1)} - X_{ijt} + 1 \geq 1$ and therefore, constraint (9) is trivially fulfilled.

[9] Note that the left hand side in constraint (11) is always $\leq \tau_3$ because of constraint (6). Therefore, constraint (11) is trivially fulfilled in the other case where $X_{ijt} = 0$.

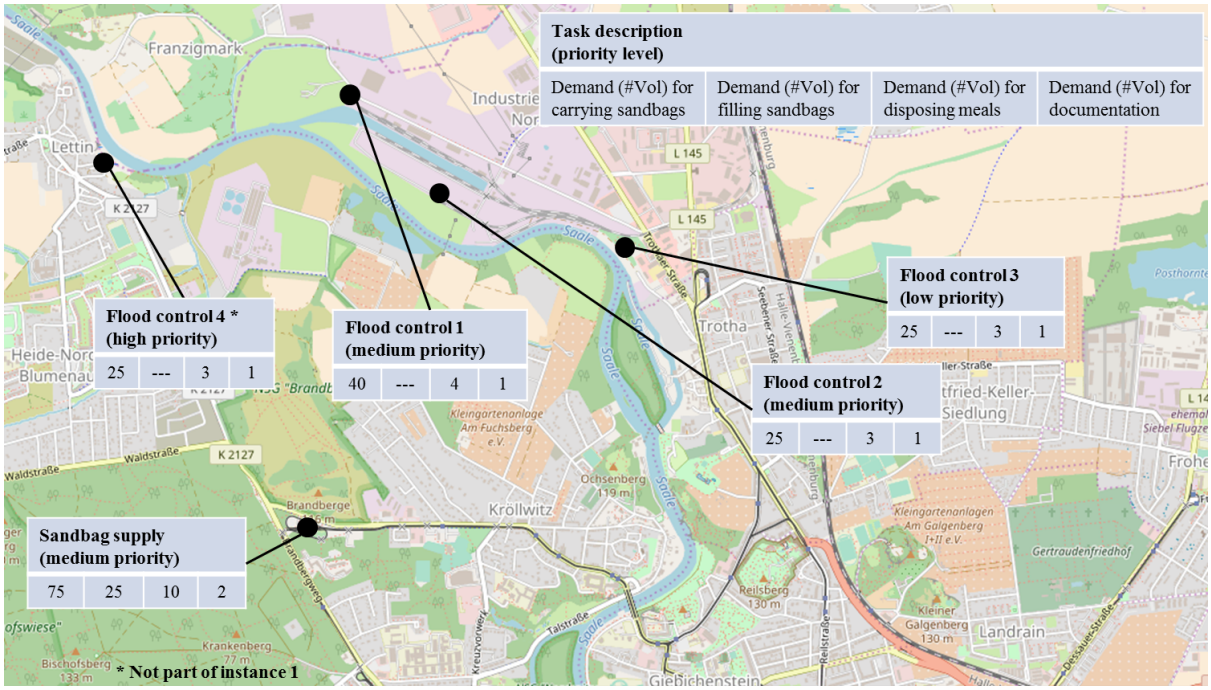

Figure 4. Task details for case study instances

Table 3. Setting of instance-independent parameters

Description	Value/Range/Distribution
Number of time slots ...	
... in entire planning horizon	$T = 24$ (representing 24 hours)
... that a volunteer must work consecutively on a task activity	$\tau_1 = 2$
... that a volunteer is allowed to work during planning horizon	$\tau_2 = 8$
... for setup/travel	$\tau_3 = 1$
Weight parameters which indicate the severity of unmet task demands	w_{pt} defined in equation (13)
Compensation factor which indicates the relative importance ...	
... between priorities *low* ($p = 1$) and *medium* ($p = 2$)	$\sigma_{12} = \frac{1}{3}$
... between priorities *medium* ($p = 2$) and *high* ($p = 3$)	$\sigma_{23} = 0$

of eight hours, which corresponds to a standard work day. We finally set the probability for a volunteer to offer capability *hard physical labor*, *medium physical labor*, *light physical labor*, and *writing* to 0.5, 0.7, 0.9, and 0.95, respectively. Note that these settings lead to an expected number of approximately 67 (for instance 1) and 117 (for instance 2) volunteers with capability *hard physical labor* in each four-hour segment. This implies a shortage of volunteers for the carrying sandbag activities, which have a cumulated demand for 165 (instance 1) and 190 (instance 2) volunteers.

Parameter Setting

In order to solve the presented instances using our optimization model, we specify all instance-independent parameters from Table 1 in this subsection. A summary is given in Table 3. The 24-hour planning horizon is represented by 24 one-hour time slots, i.e., $T = 24$. We set the minimum number of time slots that a volunteer must work consecutively on the same task activity to $\tau_1 = 2$. Furthermore, we set the maximum number of time slots that a volunteer is allowed to work in total during the entire planning horizon to $\tau_2 = 8$. Finally, we set the number of time slots that represent the setup/travel time between working on two different task activities to $\tau_3 = 1$.

Next, we set the weight factors w_{pt} that indicate the severity of unmet demands for volunteers in time slot t at task activities with priority p. According to requirement (ii), we have $w_{1t} < w_{2t} < w_{3t}$ for all time slots $t = 1, \ldots, 24$. Requirement (iii) implies $w_{pt} > w_{p,t+1}$ for all priorities $p = 1, 2, 3$ and time slots $t = 1, \ldots, 23$. Furthermore, high workloads in activities of low-priority tasks in earlier time slots are more important than high workloads in activities of medium-priority tasks in later time slots. We quantify this by setting $w_{1t} = w_{2,t+4}$ for all time slots $t = 1, \ldots, 20$.

[10] In addition, high workloads of activities of high-priority tasks are more important (even in the last time slot $t = 24$) than high workloads in any other task activities in any time slot $t = 1, \ldots, 24$. This means that $w_{3t} > w_{2t'}$ for all time slots $t, t' = 1, \ldots, 24$. The presented relations can be guaranteed by setting

$$w_{3t} = 25 \cdot \left(1 - \frac{t-1}{24}\right), \quad w_{2t} = 1 \cdot \left(1 - \frac{t-1}{24}\right), \quad w_{1t} = \frac{20}{24} \cdot \left(1 - \frac{t-1}{24}\right) \tag{13}$$

for all time slots $t = 1, \ldots, 24$.

Finally, we specify the compensation factors $\sigma_{p-1,p}$, which indicate the relative importance between adjacent priorities $p-1$ and p. The compensation factor between the priorities *low* and *medium* is $\sigma_{12} = \frac{1}{3}$. This means that in each time slot t and for each capability c, the workload L_{1ct} of activities at low-priority tasks must be at least one-third of the workload L_{2ct} of activities at medium-priority tasks. Furthermore, there is no such lower bound on the workloads L_{2ct} of activities of medium-priority tasks. In particular, there is no compensation between the priorities *medium* and *high*, i.e., $\sigma_{23} = 0$. This – in combination with the weight setting from equation (13) – implies that in each time slot, high-priority activities have to be filled with volunteers as good as possible before volunteers can be assigned to any other activities.

Computational Results and Discussion

Having outlined our parameter setting in the previous subsection, we solve both presented case study instances by calculating a near-optimal solution of their corresponding model instances. To achieve this, we use the off-the-shelf solver GUROBI 7.5 on a laptop with an Intel Core i5-3340M CPU @2.70GHz and 4 GiB RAM. The results are presented and discussed in the following.

We abort calculations for the first instance after 30 minutes where the provable gap (returned by the GUROBI solver) between the objective function value of the obtained solution and the optimal objective value was at most 0.08%. The best known solution was found after approximately 13 minutes, which is sufficient in practical disasters according to our interviews with the DMA Halle (Saale). The activities filling sandbags, disposing meals, and documentation are filled to 100% during the entire planning horizon $t = 1, \ldots, 24$. The reason is that they demand for a relatively low numbers of volunteers. The bottleneck in all tasks is the activity of carrying sandbags (capability $c = 1$). Therefore, we present only the workloads L_{p1t} for capability $c = 1$ in the upper half of Figure 5 and discuss them in the following. Workloads L_{31t} equal 0 in all time slots since there is no task with priority *high* ($p = 3$) in the first instance. All other workloads during the entire planning horizon $t = 1, \ldots, 24$ of the first instance are non-zero. However, they are all clearly below 1 because there are not enough volunteers to meet the entire demand in any time slot. One important trend is that the workloads are decreasing with increasing t. [11] The reason is that volunteer shortages in early time slots are more severe than in later time slots and consequently, our model prefers feasible schedules in which volunteers work on activities as early as possible. Since volunteers are not allowed to work for more than eight hours within the entire planning horizon, this leads to higher volunteer shortages in later time slots. Finally, the workloads of the sandbag filling activities of medium-priority tasks are at most three times higher than the workload of the corresponding activity of the low-priority task. This effect mirrors the compensation factor $\sigma_{12} = \frac{1}{3}$.

Two hours later, when the new task *flood control 4* occurs, we solve the second instance. Again, we abort calculation after 30 minutes where the provable gap (returned by the GUROBI solver) between the objective function value of the obtained solution and the optimal objective value was at most 0.01%. The best known solution was again found after approximately 13 minutes. As for the first instance, the only activities where there is a shortage of volunteers are carrying sandbags activities (capability $c = 1$) and consequently, the lower half of Figure 5 presents only the workloads L_{p1t} for capability $c = 1$. [12] We see that the activity of the high-priority task ($p = 3$) is filled to 100% during the entire planning horizon $t = 3, \ldots, 26$. This is forced by high weights w_{3t} for all time slots t and a zero compensation factor $\sigma_{23} = 0$ between the priorities *medium* and *high*. Note that assignments from the solution of the first instance are not changed due to constraint (12). Consequently, only volunteers that have registered after the solution of the first instance can work on the new activity in time slots $t = 3, \ldots, 24$. Furthermore, the activities of the medium- and low-priority tasks have higher workloads than in the solution of the first instance since not all newly registered volunteers are necessary to fill the high-priority activity to 100%. Again, workloads decrease with

[10] The skip from t to $t + 4$ is used because the volunteer availabilities are generated using four-hour segments.

[11] There are some exceptions, e.g. in $t = 17$, because the number of available volunteers is not constant over time due to the random generation of volunteer availabilities.

[12] Since the second instance is solved two time slots after the first instance, time of decision making $t = 0$ in the second instance is equal to $t = 2$ in the first instance. For the sake of presentation, however, we set the time of decision making in the second instance to $t = 2$ which leads to a 24-hour planning horizon of $t = 3, \ldots, 26$.

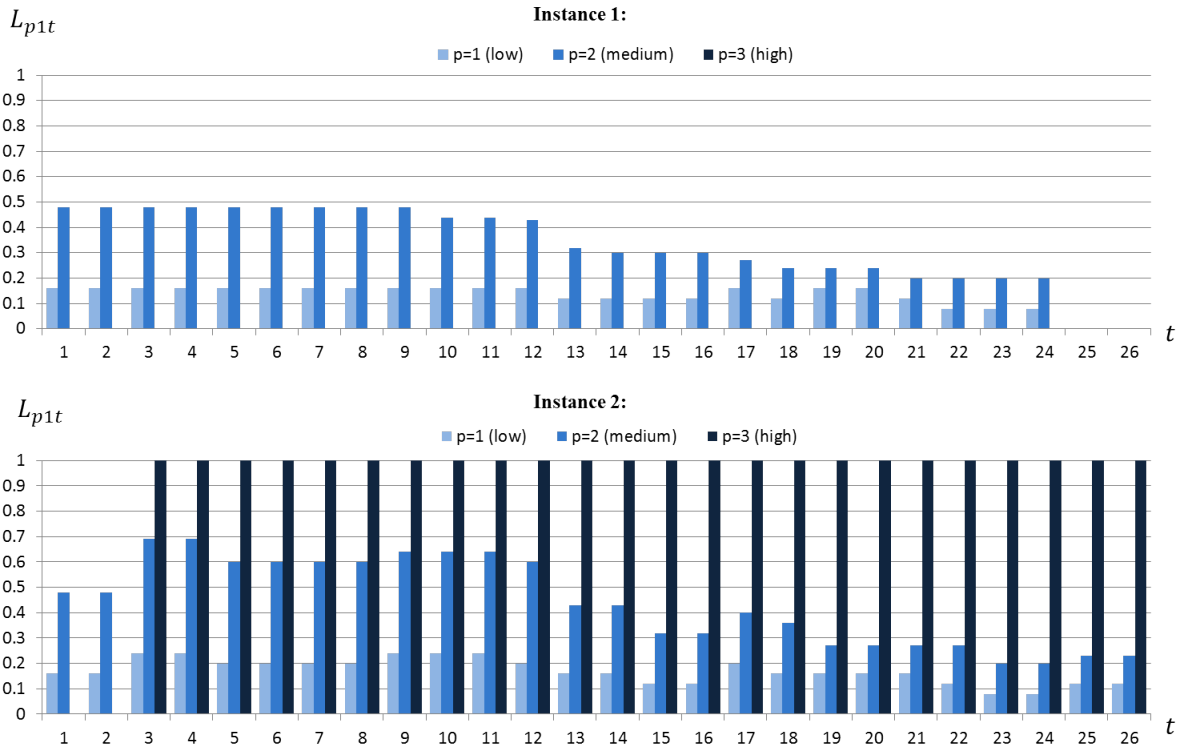

Figure 5. Workloads L_{pct} for all priorities p, capability $c = 1$, and time slots t for both instances

increasing t (with some exceptions, e.g. in $t = 17$) during the entire planning horizon $t = 3, \ldots, 26$ for the same reason as explained above for instance 1.

To sum up, our model can be used to obtain near-optimal solutions in a big real world case study scenario with 16 task activities and 700 volunteers within a few minutes. Beyond the computational evaluation in this section, we presented the solution of both instances to practitioners at the DMA Halle (Saale) for an empirical ex-post validation. They confirmed that our solutions meet their expectations on an effective coordination of volunteers and that it is hardly possible for professional responders to find better solutions manually - especially under severe time pressure during a disaster situation.

CONCLUSIONS

In this section, we present our conclusions. We sum up the findings and contributions of our paper before we provide several avenues for further research.

Summary

In disaster situations, there is often a large number of spontaneous (i.e., not affiliated to any humanitarian organization) volunteers that offer their help. These volunteers represent a precious resource that must not be neglected but their coordination is often a burden that distracts professional responders from their primary duties. In our paper, we develop and test a novel approach that uses an optimization model to automatize the coordination of spontaneous volunteers. We conducted interviews with professionals at the DMA Halle (Saale) to identify key requirements for coordinating spontaneous volunteers in real-world disasters. Based on these requirements, we develop a linear optimization model that can be used by off-the-shelf solvers to solve problem instances of realistic size near-optimal within short time. We confirm this in a case study where we use the model in combination with the GUROBI solver to calculate coordination decisions for problem instances that represent a real-world flood scenario. In addition to this computational evaluation, we presented the solutions of our case study instances to the DMA Halle (Saale) for an empirical ex-post evaluation in which our solutions were well accepted by practitioners. Our interview partners confirmed in particular that such complex coordination decisions can hardly be provided manually by professional responders in comparable quality under the severe time pressure of a disaster situation. Our optimization model is integrated in a holistic volunteer coordination system called *KUBAS*, which we develop in close cooperation with the DMA Halle (Saale) and esri Germany. This guarantees that our approach can be used to improve the coordination of spontaneous volunteers and to relieve professional responders during real disasters.

Future Work

There are several directions for future work. First, it would be interesting to analyze how our model works on larger scenarios, e.g. the 1985 earthquake in Mexico City where up to two million volunteers offered their help (Dynes et al. 1990). Second, further case studies may also be used to measure the robustness of our optimization model against parameter changes. Third, it may be convenient to develop heuristic solution algorithms to obtain good suboptimal solutions instead of using an off-the-shelf solver to obtain optimal solutions for computationally hard scheduling instances. Fourth, we aim at further developing the presented requirements and the model itself. For example, it may be convenient to balance work among volunteers, i.e., that total working hours of volunteers do not differ more than necessary. Real GPS-based (instead of constant) setup times could also be integrated into the model. Fifth, the performance of the entire KUBAS system – and of our scheduling approach in particular – should be evaluated when applied in live disaster situations.

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Investigating the Use of Visual Analytics to Support Decision-Making in Crisis Management: A Multi-Method Approach

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ABSTRACT

People working in a crisis are generally under stress while having to make the right decisions at the right time. They have to process large amount of data as well as assimilate the received information in an intuitive way. Like Crisis Management (CM) itself, Visual Analytics (VA) is a multi-disciplinary research area and is potentially useful to analyze and understand the huge amount of multidimensional data produced in a crisis. Our work investigates how researchers and practitioners are using VA in decision-making in CM. We aim to develop a computational reference model based on VA. For that, we carried out a multi-method approach to collect and analyze CM data. This paper presents our multi-method investigation on the use of VA in CM context. It firstly reports on a systematic mapping study to analyze the available information visualization tools and their applications in CM. To complement this information, we report on questionnaires and ethnographic studies applied during the large events held in Brazil in recent years. Then, we analyze existing tools for visualizing crisis information. Lastly, we analyze the data gathered from interviews with six professional crisis managers. The compiled results show that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We consider that further research into the application of VA is required to improve decision-making processes in CM.

Keywords

Crisis Management, Decision-Making, Visual Analytics, Data Collection Methods.

INTRODUCTION

Crises have very complex and dynamic contexts where the response process should suit unforeseen situations without causing social harm or jeopardizing people's lives (ESRI, 2009). Examples of crises that greatly stimulated research interest in this area were the attacks of September 11, 2001 (Schmemann, 2001) and Hurricane Katrina in 2005 (Waugh and Streib, 2006), both in the United States. More recently, the Hurricanes Harvey, Irma and Maria (CNN, 2017) and a sequence of terrorist attacks in European cities (Bloomberg, 2017), mass shootings in U.S. (CNN, 2018) among others have reinforced this. Crisis management (CM) refers to the ability to deal with crisis tasks in all their phases and iterations. In general, this is done by multiple government agencies which do not work together routinely. These agencies usually use the doctrine of Command and Control (C2) to help in the coordination of activities (Turoff et al., 2004).

CM varies because the context, events and information are never the same from one crisis to another. Each

management task requires many different types of information about the incident from several sources (Turoff et al., 2004), such as information systems, external proprietary databases, resources in the field, Internet of Things sensors, social media and other open source media. Nowadays, C2s are equipped with breakthrough technologies, especially visual systems, such as the latest generation mobiles, tabletops, e-caves and video walls (Duse et al., 2004). This union of data sources and novel technologies provides C2 with a huge amount and of information of great heterogeneity.

Decision making during a crisis requires having the right information, provided in the right way, to the right people, at the right time. While crisis managers working in a crisis are generally under stress, they have to make effective decisions with agility. Having reliable and up to date information is essential in order to help in making decisions (Yates and Paquette, 2011). Crisis managers need to assimilate the received information in an intuitive way and the information needs to be adaptable in the context of the current crisis. In addition, if the information is not presented in effective ways, it can be hard to analyze it, or in the worst cases, it can be misinterpreted. Literature shows that suitable information visualization techniques improve the understanding of crisis information (Dusse et al., 2016).

Recently, researchers have been using Visual Analytics (VA) to support understanding in this subject (Andrienko et al., 2007; Tomaszewski and MacEachren, 2012; Chae et al., 2014;). VA is potentially useful for analyzing and understanding the huge amount of multidimensional information produced in a crisis (Keim et al., 2008). The benefits brought by VA to the analysis of crisis information also come along with certain challenges. These include: (1) how to map VA concepts with the countless variables of a crisis to support the managers in quickly identifying reliable information to make decisions; (2) whether researchers and practitioners are using VA techniques and tools effectively to tackle challenge 1; and, (3) how to enhance VA applications with minimal impact on current CM activities. This paper reports our initial steps to address these challenges.

The objective of this paper is to investigate the use of VA in CM context using a multi-method approach carried out in long-term studies. We collected and analyzed data from the literature through a systematic mapping study and *in-vivo* studies such as two ethnographies, questionnaires and a survey (interview) protocol. These investigations are the initial part of a broader work that aims to define a computational reference model. The main objective of this model is to use VA to enhance decision-making in CM. The research question of the broader work is “What aspects of Visual Analytics are under-exploited in supporting decision-making in Crisis Management?” The data collection and analysis reported in this paper are geared to answer this question.

We found that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We expect that extending research and the application of VA techniques and tools in CM will have a positive effect on the area.

The rest of the paper is presented as follows. In the following section, we provide a theoretical background followed by a brief discussion of our research approach. We then present our data collection and analyze our findings. In closing, we suggest future research directions to enhance VA to support decision-making for CM.

BACKGROUND AND RELATED WORKS

Crisis policymakers recommend the use of local-based information (e.g. demographic density, building materials, city structures); the use of social technologies (e.g. social media, crowdsourcing); and hazard-monitoring systems (e.g. satellite remote sensing, climate sensors, suspected terrorists) for crisis risk reduction (Horita et al., 2013; Turoff et al., 2004). These, in turn, increase the volume and heterogeneity of the available information, causing problems in the completeness and timely analysis of this information. We identified some works in the literature that address these problems by using VA in their approaches (Andrienko et al., 2007; Tomaszewski and MacEachren, 2012; Chae et al., 2014).

VA is more than just information visualization. It is the science of analytical reasoning facilitated by highly interactive visual interfaces. It can be seen rather as an integral approach to decision-making, combining visualization, human behaviors and data management (Keim et al., 2008). Recently, Keim et al., (2008) adjusted Shneiderman’s mantra[1] to VA context: “Analyze first, Show the Important, Zoom, Filter and Analyze further, Details on demand”. In other words, this extended mantra is calling for an astute combination of analyticals

[1] "Overview first, Filter and Zoom, Details on demand" (Shneiderman, 1996)

approaches together with advanced visualization techniques (Keim et al., 2008). In Andrienko et al., 2007, the authors designed a suite of tools to support transportation-planning tasks such as crisis evacuation. The transportation schedule is a complex construct involving heterogeneous objects with states and positions varying in time. The tools used genetic algorithm with VA techniques such as interactive visual interfaces. In Tomaszewski and MacEachren (2012), the authors present visual interfaces to construct and represent geographical and historical context in CM and humanitarian relief. They implemented geovisual analytics tools that supports document foraging and sense making to construct the geo-historical context. In Chae et al. (2014), the authors analyze social media data, with an interactive spatiotemporal VA and spatial decision support environment to assist in evacuation planning. They demonstrated how to improve investigation by analyzing the extracted public behavior responses from social media before, during and after natural crisis. Their approach focuses on identifying the whereabouts and movements of people in order to understand mass behavior.

Analyzing the state-of-the-art, we concluded that the current works lack context-sensitive approaches. Moreover, the visualizations fail to use multiple data sources and, in general, the visualizations are used for a specific activity, e.g. evacuation plan, humanitarian relief. Given the research gap, our goal at the moment is to collect data from the literature and the CM environment to understand and to propose solutions in the visualization and analysis of crisis information.

Some works gave us insights on how to collect data in this research area. Horita et al. (2013) and Mirbabaie et al. (2016) carried out systematic literature reviews, both about volunteered geographic information and crowdsourcing in CM. The former work focuses on which crisis phases and crisis types the primary studies use voluntary information. The latter addresses quality assessment elements that are used in the studies, as well as the methods that are employed to measure these elements. In Gralla et al. (2015), the authors held a workshop with experienced specialists to understand the information requirements of humanitarian responders to sudden onset crises. Simões et al. (2015) were in the Rescuer Project (Villela et al., 2014), which develops a solution to support command centers in quickly managing crisis based on crowdsourcing information focusing on incidents in industrial areas and at large-scale events; the authors held workshops with specialists in crisis response and their intentions were twofold: to validate the preliminary visualizations and to improve them based on the received feedback. Horita et al. (2016) conducted participatory observations and interviews with practitioners from a C2 that monitors imminent natural crisis, mainly floods; the authors collected data so as to understand the activities required in the decision-making process of early warning systems.

It is clear from the literature that most works are highly context-specific, e.g. industrial areas, large events or floods. The state-of-the-art may derive general principles of information requirements, but the literature provides a limited basis for doing so at this point. As a result, in order to drive the development of visualization tools, researchers are analyzing the information needs within a limited scope and in specific CM contexts. However, the C2 practitioner's routine requires a multi-context visualization approach because they deal with crises regardless of cause, size, location, or complexity.

Very little work of this type has focused on a given CM. A critical step is to ask those who manage crisis what information they actually use, how visualizations are presented to guide their decisions and how system developers can improve this. Hence, we collect and analyze data from the literature and *in-vivo* studies through a multi-method approach. The present study takes initial steps to fill this gap by linking VA for the decision-making needs of crisis managers.

METHODS

Our multi-method approach followed three stages: the planning of the scope of work (Stage I), the data collection itself (Stage II) and the data analysis in depth (Stage III). Figure 1 shows the research approach that we detail in this Section.

This paper is **part** of a bigger research work. We are carrying out an *in-vivo* study, immersing ourselves in the day-to-day of CM activities in the Intelligence and Operation Center (COI) (SSP-BA, 2016), which is a branch of the Public Security Secretary of the state of Bahia. COI was created in 2016, taking the place of the Regional Command and Control Integrating Center of the state of Bahia (CICCR-BA). Previously in 2011, the Federal Government of Brazil created the Extraordinary Secretary of Security for Large Events (SESGE), which is a branch of the Brazilian Ministry of Justice. The main purpose of SESGE is to coordinate the activities of the agencies involved in public security and civil defense during the large events that have taken place in Brazil in

recent years (SESGE, 2012). In 2013, SESGE se up C2s, in headquarters cities of large events. The old CICCR-BA was one of these. In these centers, multi-agencies work together in coordination and sharing resources.

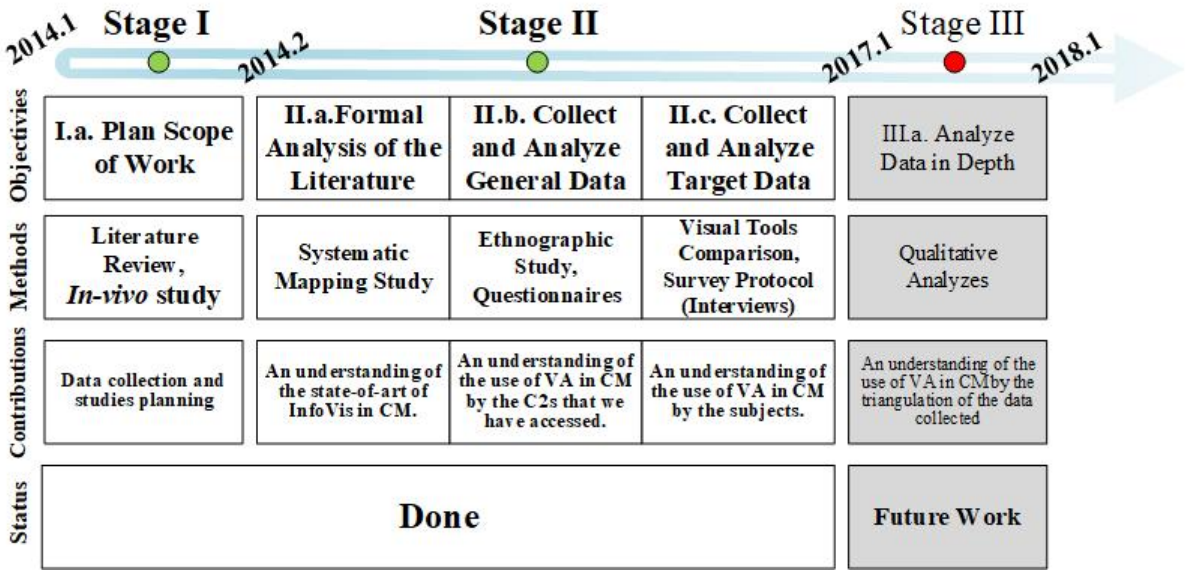

Figure 1: Multi-Method Approach

We also visited others Brazilian C2s and one in Europe. During Stage II, we visited the Regional Command and Control Integrating Center of the state of Rio de Janeiro (CICCR-RJ), the National Command and Control Integrating Center of Brazil (CICCN-DF), Command Integration Center of the City of Porto Alegre (CEIC), Defense Zone of the Paris Police Prefecture (DZPPP), among others. Visiting other C2s was very useful to compare and map similarities and inconsistencies among them.

Although COI has its own resources, the center works in collaboration with several institutions such as other CICCRs, the Federal Police, Military Forces and even with foreign police services, e.g. Interpol. Among COI's activities, the following tasks play a crucial role in supporting CM in Bahia: (1) risk assessment that can support prevention and response actions; (2) the development, implementation and operation of monitoring systems for crisis (natural or man-made); (3) the development of crisis response plans; (4) simulations and trainings to evaluate the effectiveness of these plans; (5) crisis response actions; and (6) support in post-crisis reconstruction. All these six activities, and many others, produced a huge amount of information. Without tools and techniques, it is almost impossible to analyze this information to produce knowledge effectively.

Concerning the planning (Stage I), we decided to carry out a literature review and to run an *in-vivo* study involving a C2. We collected data over 30 months starting in the second semester of 2014 and finishing in the first semester of 2017 (Stage II). We will carry out a **deep** qualitative data analysis in the future (Stage III).

We collected data from several sources such as literature and direct from C2s, such as their environment, official documents, tools and practitioners' knowledge. We divide this stage in three substages: a) Formal Analysis of the Literature; b) Collect and Analyze General Data; and c) Collect and Analyze Target Data. In the following sections, we detail the data and how we collected it in each substage.

FORMAL ANALYSIS OF THE LITERATURE (Substage II.a)

The purpose of this collection was to provide research data to understand how the state-of-the-art on information visualization applied in EM is structured. We wanted to know common practices in existing studies, to identify research gaps and possible trends in the area. Thus, we performed literature reviews to understand the challenges and find out what researchers are publishing in the area. The focus was on diagnosing the problems and finding some academic solutions to them.

In this substage II.a, this data collection involved a systematic mapping study method, following the rules of Kitchenham et al. (2007) and Peterson et al. (2008).

Systematic Mapping Study in a Nutshell

The systematic mapping study is used to provide a structure for the research and its results (Petersen et al., 2008). The results may highlight gaps and trends in the research area.

First of all, we carried out a systematic mapping study to understand the use of visualization tools and their application in the CM area. We examined the most common visualization techniques applied to CM, as well as the environments and phases in which they were applied following a strict protocol to search and extract data. The papers were randomly divided among three researchers in such a way that two of them read each paper. If there was a disagreement in the paper data extraction, the third researcher gave his/her opinion to reach a consensus.

We designed our mapping defining the research questions, search string, inclusion and exclusion criteria, digital libraries and the classification scheme (categories and facets). We defined the period. We searched primary studies from Jan 01, 2001 to May 31, 2015. We decided to begin with the year of 2001 because Sept 11, 2001 is a milestone in Crisis Domain (Schmemann, 2001). We used the search string defined in Table 1. One relevant facet that we extracted was based on the Information Visualization Paradigm and Visual Attributes. For more details, see Dusse et al., (2016).

Table 1: Defined Search String.

(“Crisis Management” OR “Disaster Management” OR “Emergency Management”) **AND** (Visualization OR Visual OR Visualisation)

The first search found 5083 papers, from which 132 remained after passing through a set of filters. After the analysis of the first 132 primary studies, we used the snowballing technique to search in the references of each of them to find more studies. This led us to 49 more papers. We applied the same technique again to these 49 studies, and selected 15 more papers. We repeated the same process again and did not find any new primary studies, which finally gave us a total of **196 primary studies** to analyze. Figure 2 details the selection process.

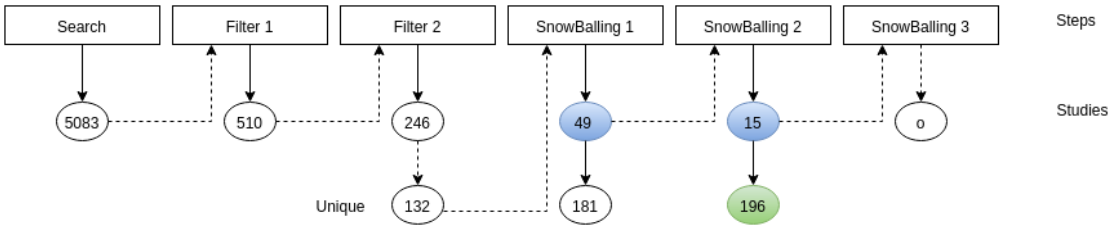

Figure 2: Primary Studies Selection Process (Adapted from Dusse et al., (2016)).

According to the results, the number of published studies that apply visualizations to CM is growing, demonstrating that the relevance and level of interest in the subject is progressing. Considering the distribution per year, we observed that the number of papers grew in 2007 and 2008. In 2014, it reached a peak (41 primary studies) with almost twice as many compared to 2013. When we did the search (May 31, 2015), we found 13 primary studies in 2015. We did not check the total number of studies in 2015. Our expectation is that it reached closer to 2014, as well as the number of works published in 2016 in this research area.

Figure 3 shows that most researchers use similar visual paradigms and attributes focusing on icons, colors, spatial position and shapes plotted on maps (*Geo-spatial 2D and 3D*) to visualize crisis information in a big picture, e.g. affected area and type of crisis. Crisis managers usually have to filter and search the available overview information to detail it on demand (Shneiderman, 1996) for the situation at hand.

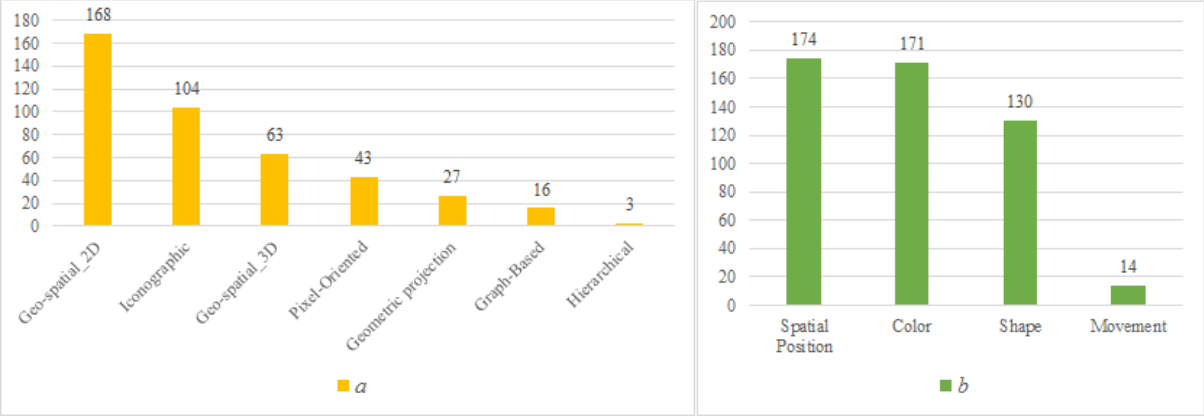

Figure 3: Publications per: a) Visualization Paradigm; b) Visual Attributes (Adapted from Dusse et al., (2016)).

The results from CM point of view show that researchers apply most tools in the response phase of a crisis. This demonstrates the need that crisis managers have for updated information about the situation in the location of the incident to support decision-making. Most works cover a specific type of crisis (e.g. earthquake, hurricane, flood, fire) but we also found some works that address crises in general. We classified 94% of the works as outdoor scenarios and only 11% as indoor. There are very few works in both scenarios (5%).

We also identified gaps and trends in the subject. One of these trends is the use of VA (Andrienko et al., 2007; Chae et al., 2014; Tomaszewski and MacEachren, 2012). We analyzed works that address VA in crises, which generated excellent results according to the authors. However, we consider these studies still incipient. They partially use the concepts of VA described in Keim et al. (2008) and the visualizations address a specific tasks and contexts (e.g. humanitarian aid and evacuation plan).

COLLECT AND ANALYZE GENERAL DATA (Substage II.b)

The purpose of this data collection was **broadly** to understand the overall dynamics of processes and activities, comprising the main aspects of how crisis managers analyze information for decision-making. Thus, we did a general data collection to know the key factors and to understand the challenges in the area. This substage focused on diagnosing the problems.

We had access to practitioners and to materials from Brazilian and French C2s. This data collection involved two methods: questionnaires and ethnographic studies following the rules of Crang and Cook (2007) and Robson (2011).

Questionnaires

During the Olympics and Paralympics, we ran an online questionnaire in which 49 officials from various agencies from different C2s participated (Table 2). The questionnaire is available online (in Portuguese)[2].

Table 2: Number of Respondents of the Questionnaire.

C2	COI	CICC-RJ	CICCN-DF	CEIC	TOTAL
Olympics	37	1	5	1	44
Paralympics	4	1	0	0	5

[2] https://drive.google.com/file/d/1Fr_5p7flrac2ksW-3-D8qLiWbd-duiwv/view?usp=sharing

We divided the questionnaire into 3 parts: (1) qualification of the practitioners, to know their competences and experience; (2) identification of the problems, to confirm if the problem that we are addressing is relevant; (3) suggestions for solutions, to listen to the insights from the practitioners pointing out solutions or workarounds to the problems. We had good feedback from the questionnaires. See Figure 4.

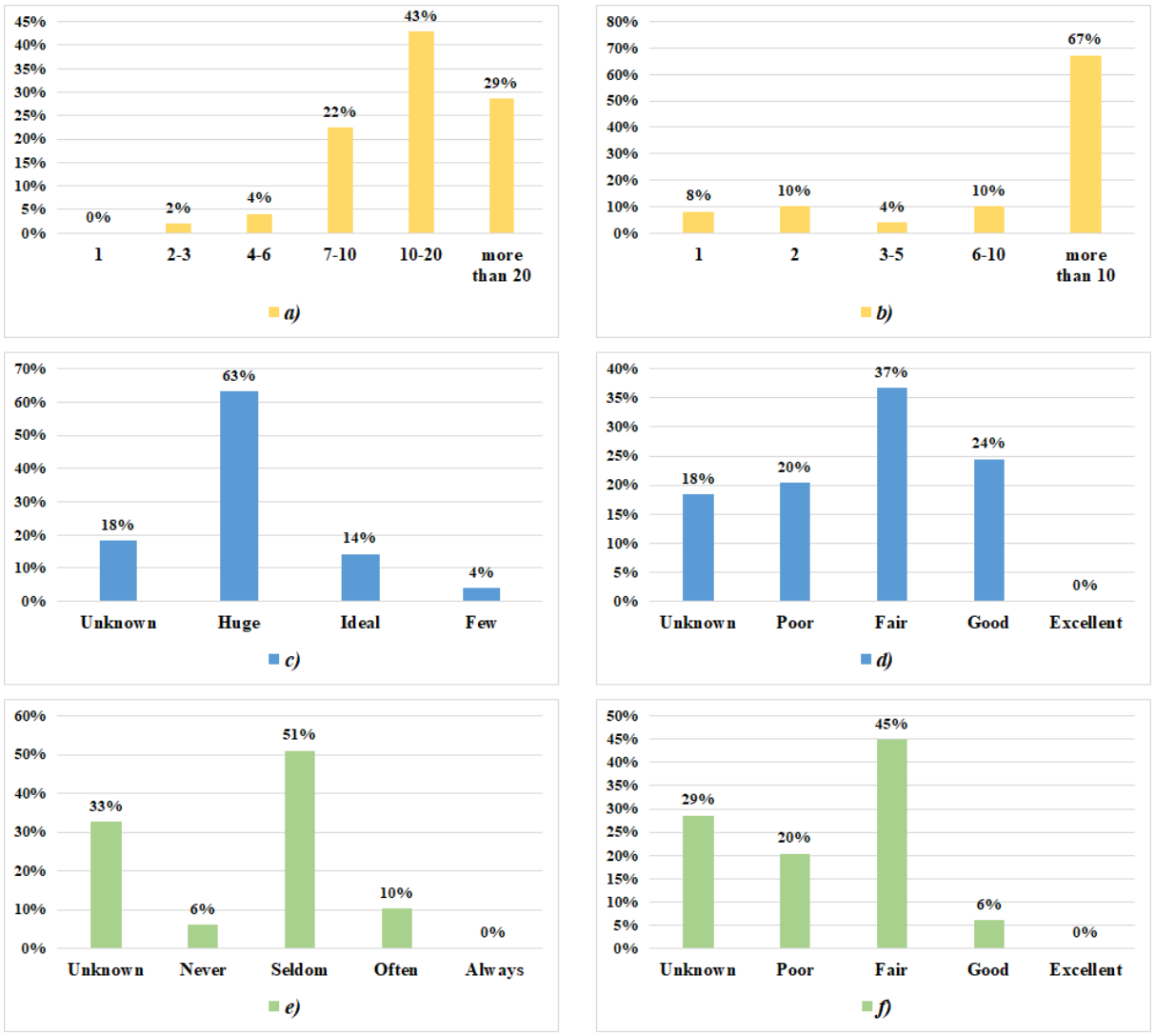

Figure 4: Summary of the questionnaires: *a*) work experience; *b*) work experience in C2; *c*) information quantity versus your analysis capacity; *d*) information quality; *e*) available tools to analyze information for decision-making; *f*) how visual tools represent the information.

First, we found that the majority of the participants are experienced, 72% had more than 10 years' work experience and 67% had more than 10 years of C2 experience (Figure 4*a* and 4*b*). Second, most agree that the quantity of information is huge (63%) and the quality is not good, 57% answered poor or fair (Figure 4*c* and 4*d*). Other relevant findings were: 57% ('*Never*' + '*Seldom*') said that there is lack of tools and 65% ('*Poor*' + '*Fair*') disagree that the existing tools provide effective information for decision-making (Figure 4*e* and 4*f*). None of the 49 practitioners answered '*Always*' for question of Figure 4*e* nor '*Excellent*' for the questions of 4*d* and 4*f*. The last item in the questionnaire was an open question for the practitioner to comment on anything about the survey. About 10 practitioners said that visualizations should improve their knowledge of the crisis operation supporting their activities. The compilation of the questionnaire data shows that there is much to contribute in the area.

Ethnographic Study

To complement our study, we carried out two ethnographic studies during the 2014 World Cup and 2016 Summer Olympics in Brazil. Ethnographic research methods have played a substantial role in sociological research during the last half-century and researchers are now using them in many disciplines, especially those that involve social and human factors (Crang and Cook, 2007). Ethnography is about immersing into the culture of a group for a period in order to participate in social relations, seeking to understand actions, how people act and make sense of their environment.

We adapted our ethnography with a limited degree of interaction. This was particularly helpful in enabling us to gather real, rich and detailed information about staff profiles, processes and technologies used for CM in COI.

We did our first ethnographic study in a partnership with the Brazilian Fraunhofer Project Center (FPC-UFBA) in the context of the Rescuer Project. The focus of this study was crowdsourcing, more specifically, we wanted to investigate C2 theory and practices to understand how crowdsourcing can improve CM decision-making.

The COI prepared itself for possible crises that might happen during the 2014 Brazil FIFA World Cup. The managers called this preparedness '*World Cup Operation'*. We identified some general requirements, such as the main agencies working in this operation, their main activities and the main resources that they used for analyzing information and communicating with each other. We did not witness any impactful crisis, so we did not learn much about crisis responses. However, we could observe that despite having tools with some kind of visualization, they were not exploited much for information analysis for decision-making.

The authors did a second ethnographic study. Unlike the first one, the focus was C2 visualization, more linked to the objectives of this paper. We wanted to understand how visualization could support decision-making. We studied from the collection of crisis raw data to the decisions themselves, going through all the steps of the transformation of the raw data into information including how to visualize the information produced.

The COI prepared itself for possible crises that might happen during the 2016 Rio de Janeiro Olympic Games. The managers called this preparedness '*Olympics Operation'*. We found and confirmed the same requirements as the previous ethnographic study, however, this time, we focused on how the practitioners visualize the information. Again, we did not witness any impactful crises, so we could not observe effective crisis responses. We confirmed what we observed two years before in the '*World Cup Operation*'. The crisis managers have visual tools but they are underused in the information analysis for decision-making.

Besides these two stricter studies, we also observed the day-to-day activities, not necessarily large operations, for example simulated exercises. On two opportunities, the crisis managers of the state of Bahia simulated terrorist attacks during a football match in the Fonte Nova Arena[3], the football stadium where the World Cup and Olympics football matches took place in state of Bahia. The Bahia managers carried out another exercise on the Subway system simulating bombs, kidnappings and shootings in an area of mass transport. Many agencies participated in these exercises, training their operational forces for possible crises.

We found that the agencies in COI uses a common tool in real operations and in the simulated ones too. This tool is *Risk Manager* and it was developed by SESGE and provided for Brazilian C2s. In our observations, we noted that *Risk Manager* is underused and almost all agencies use their own tools to collect and analyze only relevant information for their agency and their attributions. This impacts data integration. We found that decision makers hardly ever used the information visualized by these tools to make decision. We also found that the information analyzed in these tools is compiled with other isolated information[4] in a printed report. If there is a need, the political authorities make strategic decisions based on these reports.

In all of these observed scenarios, we consider it is possible to go further in the use of visual tools and VA has potential to help in this area.

COLLECT AND ANALYZE TARGET DATA (Substage II.c)

[3] http://www.itaipavaarenafontenova.com.br/

[4] Isolated information is the type of information that is added to a report that was not collected using a rigorous process, e.g. information from informal communications or tacit knowledge from the crisis manager.

The purpose of this data collection was to understand **deeply** the overall dynamics of processes and activities, comprising the main aspects of how managers analyzes crisis information for decision-making and **primarily** if we can improve it by using **visualization techniques**.

Two methods were used. The first, we carried out a comparison of visualization tools available in the C2s that we accessed. The second, we conducted an empirical survey (Wohlin et al., 2000) based on semi-structured interviews (Seaman, 1999), following a strict protocol to collect more target data. In this substage, we focused on possible solutions.

Comparison of Visualization Tools

We planned to compare visualization tools developed for CM to which we had access. We aimed to know and understand if the tools implement VA. Our aim was not the tool itself, but the visualizations that the tools provided.

We analyzed seven visualization tools in total from four C2s (COI, CICC-RJ, CEIC and DZPPP), the Ushahidi tool[5] and two versions of the research project Rescuer[6] tool. In general, C2s use proprietary tools purchased from suppliers or developed internally. Ushahidi is an open source platform that has been used in several crises such as the Haiti earthquake. Rescuer tools are deliverables from an international research project with European-Brazilian partnership. The choice of these tools proved very useful. We could compare C2 tools in production against open source tools and against research project tools.

To compare the tools, we used the same facets as Dusse et al., (2016). We divided the facets in two classes: VA facets and CM facets. In the former, we extracted the visual paradigm, visual attributes, interaction mechanisms, context-sensitive and user-centered. In the latter, we extracted phases, types, environments, platforms and data sources. The complete extraction is available online[7].

All the tools provide a combination of icons and shapes plotted on maps. This visual paradigm presents an overview of the crisis field. The details of what is happening there are not present in the views. Crisis managers need interactions mechanisms (e.g. zoom, filter, sort, aggregate, among others) to see the details. All the tools make use of the same paradigm, maps, icons, shapes, colors and so on to all respective users. In general, the visualizations of each tool are the same for all types of crises. Figures 5 to 12 show print screens, or pictures taken, of visual examples of the tools analyzed.

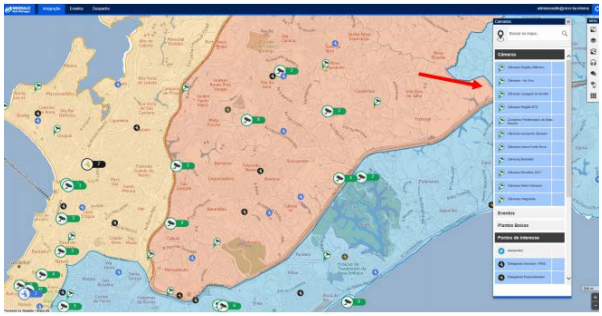

Figure 5: COI (*Risk Manager* 1)

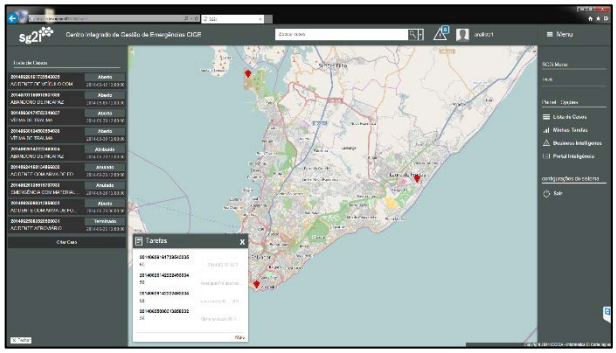

Figure 6: COI (*Risk Manager* 2)

[5] https://www.ushahidi.com

[6] http://www.rescuer-project.org/?lang=en

[7] https://drive.google.com/file/d/1_SNgU0TqgGF7VwSKd8_Z3y70LhvgEU6o/view?usp=sharing

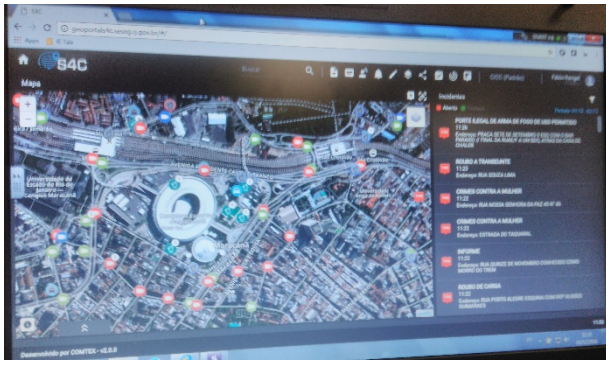

Figure 7: CICCRJ

Figure 8: CEIC

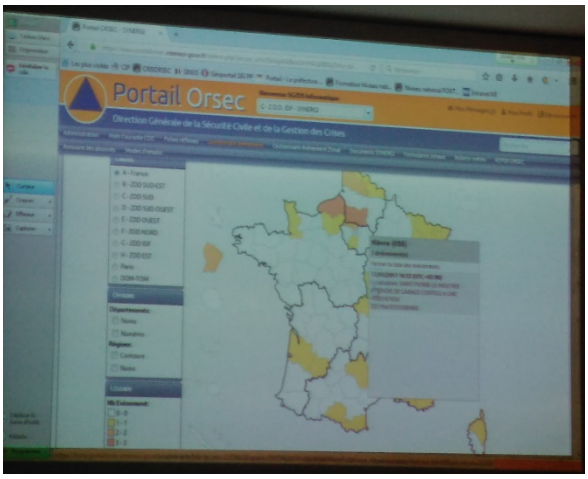

Figure 9: DZPPP

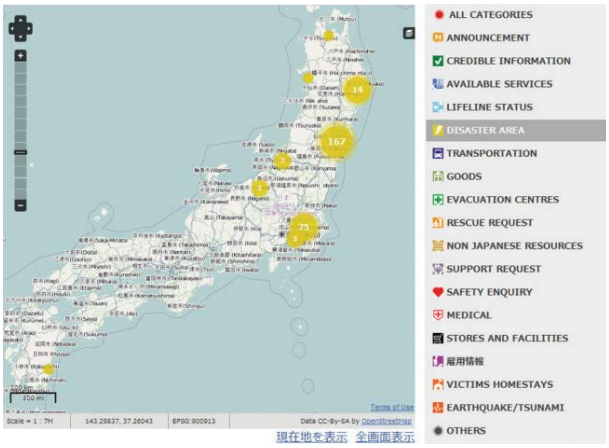

Figure 10: Ushahidi

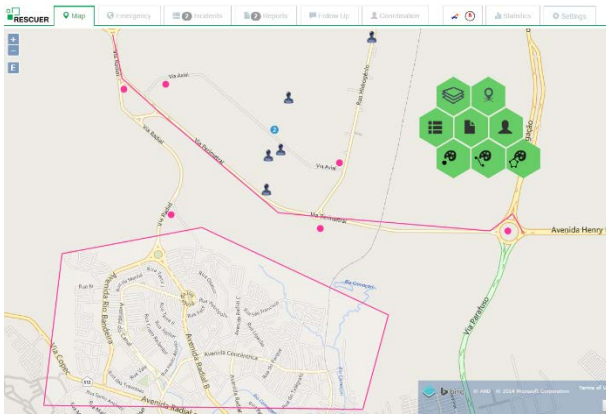

Figure 11: Rescuer v1

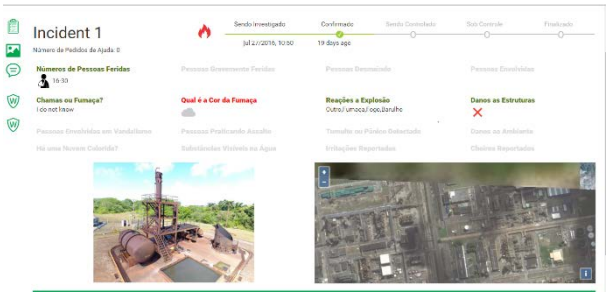

Figure 12: Rescuer v2

They do not take into account the particularities of the agencies. For example, one icon plotted the letter ‘H’ on crisis map which could represent a Hospital for one agency, while it could represent a Hydrant for another. Other examples are temperature and time zone. An agency could use degrees Celsius to measure temperature while another agency could use Fahrenheit, similarly one could use the local time zone while another GMT.

In addition, we found that all the tools are used in response phase, outdoor environments and they use web platforms; except for Ushahidi, which has a mobile version.

In all of these analyzed tools, we think that it is possible to go further in the use of VA in visual tools. As the state-of-the-art, we identified that the state-of-the-practice is neglecting some relevant dimensions, e.g. being

context-sensitive and user-centered. We expect that research and development in VA in the crisis context can improve current tools and, consequently, improve decision-making in CM.

Survey Protocol (Interviews)

During the substage II.c, we used a second method to collect target data. We conducted semi-structured interviews with six crisis managers (domain specialists) from different places and even countries: five Brazilians and one French, from four different C2s, three specialists from COI, one specialist from CICC-RJ, one specialist from CEIC and the last one from DZPPP. Since the interviewees had strict time constraints, the interviews took no more than 30 minutes on average.

We formalized the interviews in a Survey Protocol which defines the method for data collection based on the rules in Ciolkowski et al., (2003). The survey process consisted of six steps:

Step 1. **Survey Definition:**

We determined the goal of the survey to investigate what the factors are and how they influence CM decision-making and how we can treat these factors using VA.

Step 2. **Survey Design:**

We designed the survey (next steps 3 to 6) defining subjects, materials, tasks, criteria, attributes, among others. We chose the methods to collect and analyze the data.

As regards collecting, we decided to conduct semi-structured interviews, with at least three subjects (domain specialists). We chose a semi-structured interview because it is open-ended, more dynamic, and allows improvisation on the part of the interviewer and scope for a fuller exploration of the studied objects (Runeson and Host, 2008).

Based on the data already collected, we defined **three preliminary key factors** to guide the data collection and analysis. Table 3 describes these factors.

We formulated the questions and decided to do a pilot interview (Ciolkowski et al., 2003). The pilot was important to make sure that the protocol was reliable and robust. Then we chose the three first subjects and asked them to recommend other potential subjects. The design or protocol of the survey is available online (in Portuguese)[8].

Table 3: Preliminary Key Factors.

Id	Key factors	Description
1	Raw Data	This key factor refers to a set of values of variables collected from a source, with no handling, with which one can obtain information to support key factor 2.
2	Information Visualization	This key factor defines the area that we are investigating to support key factor 3.
3	Decision-making	This key factor defines the main process that our study aims to support in the CM area.

Step 3. **Survey Implementation:**

We prepared the material necessary for the interview (subject invitation, room, audio recorder, paper, pen, etc.). In this step, we also did a pilot study to refine the Survey Protocol, however, we

[8] https://drive.google.com/file/d/1XXU6IbMwtFV59hhJuQsPESmq4hslNfVi/view?usp=sharing

did not use the pilot data in our analysis. We used it for the sole purpose of evaluating the effectiveness of the Protocol.

Step 4. **Survey Execution:**

We carried out the interviews themselves. As mentioned, we carried ou six interviews with practitioners, from four different C2s and two different countries. We recorded all the interviews.

Step 5. **Survey Analysis:**

Between the interviews and the analysis, we transcribed the interviews verbatim by listening and re-listening to the recording and transcribing them. We carried out all the interviews in Portuguese, apart from one in English. Concerning this specific interview, after the transcription, we translated it to Portuguese. The transcripts of the six interviews produced 116 pages of text.

We discarded one interview, the one with the specialist from CEIC, because the subject's answers were too superficial and, despite our attempts, he was not able to make the link between the preliminary key factors. We concluded that this subject did not have adequate knowledge to meet our goals defined in Step 1.

After the transcription of all the interviews, we sent emails to the subjects, attaching the transcribed text and the audio of their interview. In general, in an interview, people do not have much time to think about their answer. The purpose of the emails was to give them the opportunity to review their answers in their own time. As the interviewees work with strict time constraints, few returned our emails. Those who replied to our emails did not make relevant comments.

We also interacted with the subjects, days after the interviews, mainly with the ones that worked in COI. Whenever doubts arose regarding what some subject meant at some point in the interview, we looked for them and tried to clarify the doubts. These informal conversations with the specialists took no more than 2 minutes on average and they were repeated countless times. Even though these informal conversations do not constitute the same scientific evidence as the Survey Protocol, for example, we did not plan nor record them, the data collected in these conversations were important for our study, mainly to mitigate some threats of validity.

In our preliminary analysis, we found that according to the subject's answers managing a crisis is very hard and complex. Many factors can influence the whole process, from the planning and data collection to the decision-making and the action execution. In general, we found that the subjects cited some factors frequently: C2 doctrine, lack of resources, the type of the crisis, political issues, vanity between agencies, staff motivation and the profile of the information analyst. About the visual tools themselves, they outlined that tools are not valued as they should be. They added that they need investment and research in this area. We conclude that in a multidisciplinary domain, such as CM, it is very hard to prioritize the factors that influence decision-making and it largely depends on the context. You cannot neglect any factor, otherwise the response can be disastrous.

Step 6. **Survey Packaging:**

The objective of the packaging step is to report the survey and results so that external parties can understand the results and their contexts. We considered this text part of the packaging.

The interviews and the other collection methods were complementary. In some situations, we identified an issue in the interview and were able to focus on this issue using other methods and, at another time, we obtained data through literature, observations or questionnaires and had the opportunity to go deeper while interviewing. We compared, crosschecked and triangulated the gathered data.

Among all methods used here to collect data, listening to the domain specialists was the most relevant and scientific-based data collection in our study. The strict protocol used in the collection and the relevance of the data collected demonstrate this. It is important to cast light on the respondents' experiences. Their narrated experiences are very hard to gather from documents or ethnographic studies. The data collected in the interviews was huge and requires **further** analysis. We plan to do this.

RESEARCH FINDINGS

We summarized the main research findings in Table 5.

Table 5: Main Research Findings of Data Collection.

SUBSTAGE	METHOD	MAIN RESEARCH FINDINGS
II.a) LITERATURE REVIEW	**Systematic Mapping Study**	A1. Number of published studies that apply visualizations to CM is growing; A2. Most of the research uses similar techniques such as icons and shapes plotted on maps; A3. The studies in *Response* phase prevail; A4. The studies in *Outdoor* scenarios prevail, A5. The studies of a specific crisis type prevail; A6. VA is a trend in the area but its full potential is not being applied in the state-of-the-art
II.b) COLLECT AND ANALYZE GENERAL DATA	**Questionnaires**	B7. The quantity of information to analyze is huge; B8. The quality of information to analyze is not so good; B9. There is a lack of tools; B10. The practitioners disagree that existing tools provide effective information;
	Ethnographic Studies	B11. Understand the operation coordination of a C2, focusing on the use of visual tools in the decision-making process; B12. Lack of integrated visualization tools; B13. The agencies use their own visualization tools for their specific activities; B14. The common tool is underused; B15. The tools are used mainly in the *Response* phase; B16. The tools are not effective for *Indoor* scenarios; B17. The common tool is not context-sensitive nor user-centered; B18. Lack of use of visualizations in decision-making;
II.c) COLLECT AND ANALYZE TARGET DATA	**Comparison of Visualization Tools**	C19. All tools use similar techniques such as icons and shapes plotted on maps; C20. The paradigms of visualization of each tool are the same for all types of crises; C21. They do not take into account the particularities of the agencies; C22. The tools are used in *Response* phase; C23. The tools are used in *Outdoor* scenarios; C24. The platforms of the tools is practically 100% web;
	Survey Protocol (Interviews)	C25. Understand the use of visualization tools in the decision-making process, what factors can impact it; C26. They do not take into account the particularities of the agencies; C27. They do not take into account the profile of the analysts; C28. The tools are used in *Response* phase; C29. The tools are used in *Outdoor* scenarios; C30. It is hard to prioritize the factors that influence decision-making and it largely depends on the context C31. Lack of use of visualizations in decision-making;

By crosschecking the findings presented in Table 5, it is clear that some methods come to the same results. For example: *i*) A2 and C19; *ii*) A3, B15, C22 and C28; *iii*) A4, B16, C23 and C29; *iv*) A5 and B13; *v*) A6 and C31; *vi*) B17 and C30; *vii*) C21, C26 and C27.

Our investigation presented findings from a multi-method approach that demonstrate that further researches in the application of VA can tackle the challenges of information visualization to support decision-making in CM.

TREATS TO THE VALIDITY

There are some threats to the validity of this study (Wohlin et al., 2000). We present them below with the strategies for their mitigation.

Concerning the Systematic Mapping Study, the threats to the validity can be found in Dusse et al., (2016).

Concerning the interviews that we carried out, as threats to the construct validity, poor survey design based on a poor theoretical basis could figure. To mitigate this, we did a pilot interview to evaluate our survey protocol.

Regarding conclusion validity, CM is complex and dynamic therefore; data collection for scientific research in this area is also complex. The dataset collected could be incomplete or inconsistent. We mitigated this threat by collecting data from different sources and using different approaches; i.e. literature, documents, software tools, observations, questionnaires, interviews. In addition, we compared, crosschecked and triangulated all the collected data. In order to mitigate this threat, we interacted repeatedly with the subjects by email or informal conversations to validate our work.

As threats to internal validity, the researchers responsible for data collection and classification came from the same organization. This may have led to bias in the interpretation of the concepts analyzed. We could not mitigate this threat.

As threats to external validity, we believe that the data collected is representative of CM worldwide. We attempted to mitigate this threat because we collected data from more than one C2. In fact, we are conducting an exploratory study in COI but we studied three other mature C2s too. In addition, the qualifications and work experience of the specialists minimized the impact of this threat.

Moreover, a final threat is that all the subjects are domain specialists and not VA specialists. While they use visual tools in their work routine, they do not have deep knowledge in the area of visualization. We did not mitigate this threat, but we intend to assess it in our future work with visualization specialists.

CONCLUSION

This paper presents an investigation of the use of VA in the CM context by a multi-method approach. We did a formal literature review through a systematic mapping study and collecting local knowledge and data from C2s in Brazil and France through *in-vivo* studies such as questionnaires, ethnographic studies and a survey (interview) protocol. Researchers and practitioners can use the data collected in this work to identify research directions or to evaluate new visualization tools.

Although the use of massive visualizations for sense and decision-making is a reality found in literature and among practitioners, our findings revealed that it is still not clear what information is required in decision-making in a given crisis context. Moreover, the amount and the heterogeneity of crisis information are real-world problems that need investigation to identify gaps.

We conclude that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We identified a lack of suitable visualizations and a research gap in this area. We expect that by extending the research and applying VA techniques and tools, using effective and flexible visualizations will contribute to the crisis domain.

As said before, this paper reports the preliminary work of a broader study that we are carrying out. Our final objective is to support CM decision-making with a computational reference model based on VA. To finish this model, we will carry out a deep qualitative data analysis (Stage III of Figure 1). We assume that to produce scientifically acceptable findings to answer the research question, a high level of rigor in the analysis of the data collected **is required**.

Finally, we plan to carry out further interviews to assess the data collected and to refine it. We also need to assess the data with visualization specialists.

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Simulation of The Urban Waterlogging and Emergency Response Strategy at Subway Station's Entry-exit Platform in Heavy Rainstorm

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ABSTRACT

Underground space like subway stations is prone to be flooded which can lead to severe and unpredictable damage and even threaten human lives. In this paper, four groups of contrastive simulation of urban waterlogging at two subway stations' entry-exit platforms in heavy rainstorm are conducted, and emergency response strategies are suggested. A waterlogging simulation method named UPFLOOD based on shallow water equations is proposed considering complex topography. It has been found that the waterlogging at subway station's entry-exit platforms is easily influenced by several factors and the site selection of the subway stations is very important. A disaster process construction method based on PN model is proposed and it has been found that the response strategies including plugging, drainage and evacuation are important for disaster mitigation. This study helps decision makers to response quickly to meet the emergency of the waterlogging disaster at subway stations caused by heavy rainstorm.

Keywords
Simulation, urban waterlogging, subway stations, emergency response strategy.

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INTRODUCTION

With fast population growth and rapid urbanization, urban storm waterlogging has been a common problem in most countries and regions around the world, including the USA, Canada, Japan, and China (Li, 2012). Urban waterlogging is usually induced by multiple causes, such as extreme weather, land use structure, limited capacity of drainage system and lack of response enforcement (Son et al., 2016; Li et al., 2017). Underground space like subway stations is prone to be flooded when urban waterlogging happens in heavy rainstorm, which may lead to severe and unpredictable damage to underground facilities and even threaten human lives. For example, 11 people died in the underground flood disaster in Seoul and Anyang, South Korea in July, 2001 (Shao, 2010). To avoid the serious consequences of the urban waterlogging at subway stations, reliable analysis methods and emergency response strategies are important.

Traditionally, there are mostly three categories of the analysis methods in the view of the problem of urban waterlogging at subway stations: (1) experimental method, (2) simulation method, (3) data analysis method. With experimental method, the urban flood scenario can be reappeared in different conditions set by the researchers. Response strategies to urban flood can be experimented in flexible and controllable conditions (Fenicia et al., 2012; Guidopetrucci et al., 2012; Dottori et al., 2013; Fraga et al., 2013; Matthew et al., 2017). With simulation method, researchers can utilize computers to simulate the regional waterlogging depth by hydrologic calculating of runoff generation and runoff concentration (Ahn et al., 2014; Rotiroti et al., 2015; Fernández et al., 2016; Haltas et al., 2016; Xue et al., 2016; Bazin et al., 2017). With data analysis method, the waterlogging data measured by specific devices can be combined with related modeling technology and it can be used to analyze the features and regularity of the waterlogging (Morelli et al., 2014; Arnous et al., 2015; Kim et al., 2015; Meesuk et al., 2015; Ebrahimian et al., 2016; Morgan et al., 2016; Tanguy et al., 2017). As to the study of urban waterlogging at subway station's entry-exit platform, simulation method is the most suitable method. In comparison, the cost of building an experimental scene in 1:1 dimension as the actual scene of a subway station is very high. Data analysis method is not suitable because the catastrophic disasters of rainfall and waterlogging are rare and the data of which is hard to be recorded.

Emergency response strategy has been paid much attention to in recent years. It is an important concept and a lot of meaningful research has been carried out. There are mostly two categories of emergency response strategy from different points of view: (1) the emergency response strategy based on spatio-temporal analysis, (2) the emergency response strategy based on logistic analysis. As to the response strategy based on spatio-temporal analysis, emergency response strategy to emergency events can be studied using risk factors and sensitivity analysis together with stochastic simulation (Chen et al., 2016). Emergency response strategy and tactics of a mapping and tracking method are also effective based on a tactics-oriented radar-based observatory (Hajo et al., 2011). As to the response strategy based on logistic analysis, some methods like events classification, process control, Petri Net (PN) model, Markov Chain (MC) model are widely used (Zhong, et al., 2010; Karmakar et al., 2011; Zhou, 2013). As to the study of urban waterlogging at subway station's entry-exit platform, both spatio-temporal analysis and logistic analysis are significant, because the point of time in the whole process of waterlogging and the strategic decision of the managers or people are very important in short time before the subway station is flooded.

In this paper, we further study the simulation of the urban waterlogging and emergency response strategy at subway station's entry-exit platform in heavy rainstorm. A waterlogging simulation method named UPFLOOD based on shallow water equations is proposed considering complex topography. Four groups of contrastive waterlogging simulation are conducted to study the inner laws and influencing factors of waterlogging. The emergency response strategy is discussed considering the disaster process construction based on PN model. The emergency response strategies, including plugging, drainage and evacuation, are evaluated qualitatively and quantitatively. This study can help meet the emergency of the waterlogging disaster at subway stations caused by heavy rainstorm.

METHODOLOGY

Overview

In this paper, simulations of the urban waterlogging at subway station's entry-exit platforms in heavy rainstorm are conducted, and emergency response strategies are suggested. A waterlogging simulation method named UPFLOOD based on shallow water equations is proposed considering complex topography. Four groups of contrastive waterlogging simulation at two subway stations' entry-exit platforms are conducted based on this model. The basic data of the study contains two parts: Digital Elevation Model (hereinafter referred to as DEM) data of large block area covering the subway stations in 10m×10m precision and DEM data of small block

area around the subway stations in 1m×1m precision. The influence of several factors including the duration of rainfall, the sewerage system, the intensity of rainfall and the site selection on the waterlogging at subway stations' entry-exit platforms is also studied in this paper. Moreover, a disaster process construction method based on PN model is proposed. The emergency response strategies including plugging, drainage and evacuation are evaluated. It has been found that the timely response strategies are very important for the mitigation of the waterlogging disaster at the subway stations' entry-exit platforms.

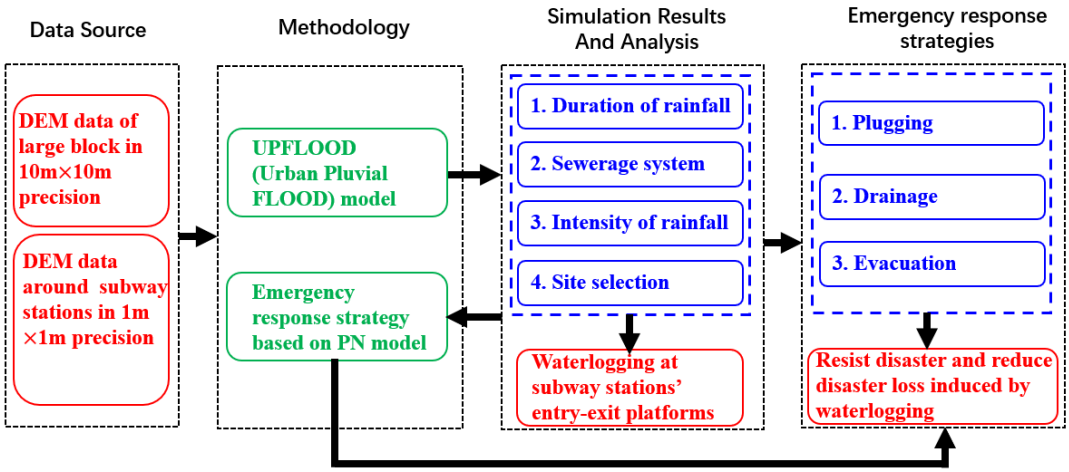


Figure 1. Overview structure of this paper

The fundamental principle of UPFLOOD

The terrain of the cities is usually complex, and the terrain near the subway station is much more complex. The simulation results of 2-D shallow water equations will be easily influenced by the terrain, which asks for a precise numerical simulation model. In this paper, the simulation work is conducted based on a numerical simulation model of urban rainfall accumulation-UPFLOOD (Urban Pluvial FLOOD) proposed by our research team (Su Boni et al., 2015, 2016, 2017).

The 2-D shallow water equations are presented below.

$$\frac{\partial d}{\partial t} + \nabla \cdot \vec{q} = 0 \tag{1}$$

$$\nabla h + \overrightarrow{S_{\mathrm{f}}} = 0 \tag{2}$$

d means the depth of the water (m). t means time (s). q means the flow rate of per unit width (m^2/s). h means the elevations of water surface (m). S_f means the friction slope vector (dimensionless). The value of S_f can be calculated in some different ways, in which the Manning Equation and Darcy-Weisbach Equation are regularly used.

$$S_f = \frac{n^2 V^2}{k^2 d^{\frac{4}{3}}} \ (\text{Manning Equation}) \tag{3}$$

$$S_f = \frac{fV^2}{8gd} \ (\text{Darcy} - \text{Weisbach Equation}) \tag{4}$$

In equation (3) and equation (4), n means the Manning coefficient (dimensionless), V means the depth-averaged velocity of the flow ($\mathrm{m/s}$), k is the unit-conversion coefficient ($= 1\mathrm{m}^{1/3}\mathrm{s}^{-1}$), f means the Darcy coefficient (dimensionless), g is the gravity acceleration ($= 9.8\mathrm{m/s}^2$).

The most important variable is the depth-averaged velocity V. The numerical value of V, marked as $|\vec{V}|$, can be calculated based on equation (1) - (4). If Manning Equation is used, $|\vec{V}|$ can be calculated through equation (5).

$$|\bar{V}| = \frac{k|\nabla h|^{1/2} d^{2/3}}{n} \tag{5}$$

$|\vec{V}|$ can also be calculated when Darcy-Weisbach equation is used to calculate S_f. The simplified formulas of

Darcy coefficient f are shown in equation (6), in which Re means Reynolds number (dimensionless), ϵ means absolute roughness of the surface material (m). ϵ usually can be got by the charting method, or the estimation of the surface roughness. K_1, K_2, K_3 is the constants that can be got by experiments (dimensionless). If Darcy-Weisbach Equation is used, $|\vec{V}|$ can be calculated through equation (7).

$$\begin{cases} f = \dfrac{24}{\mathrm{Re}} & (\mathrm{Re} < 500) \\ \dfrac{1}{\sqrt{f}} = -K_1 \lg\left(\dfrac{\epsilon}{K_2 d} + \dfrac{K_3}{4Re\sqrt{f}}\right) & (\mathrm{Re} > 500) \end{cases} \tag{6}$$

$$|\vec{V}| = \begin{cases} \dfrac{gd^2|\nabla h|}{3v} & (\mathrm{Re} < 500) \\ -K_1\sqrt{8gd|\nabla h|} \cdot \lg\left(\dfrac{\epsilon}{K_2 d} + \dfrac{K_3 v}{\sqrt{128gd^3|\nabla h|}}\right) & (\mathrm{Re} > 500) \end{cases} \tag{7}$$

Apparently, the vector $\vec{V}$ has the different direction to the vector ∇h, and equation (8) can be easily got based on this cognition. Then the flow rate of per unit width q can be got.

$$\vec{V} = -|\vec{V}| \cdot \frac{\nabla h}{|\nabla h|} \tag{8}$$

$\frac{\partial d}{\partial t}$ can be got based on the equation (1). One step of the simulation is completed through equation (1) to equation (8).

The fundamental principle of Petri net model

The Petri net (PN) model was proposed by Petri in 1962 when the information flow model for computer operation system was developed (David et al., 1994). In recent study, the PN model is widely used to describe and analyze the information flow and control flow in a system, especially those with asynchronous and concurrency activities. The formal definition and basic terminology are shown below (Rozenburg et al.,1998; Zhong, et al., 2010; Zhou, 2013).

(1) A net is a triple $N = (P, T, F)$ where:

1. P and T are disjoint finite sets of places and transitions.
2. $F \subset (P \times T) \cup (T \times P)$ is a set of arcs or flow relations.

(2) Given a net $N = (P, T, F)$, a configuration is a set C so that $C \subseteq P$.

(3) An elementary net is a net of the form $EN = (N, C)$ where:

1. $N = (P, T, F)$ is a net.
2. C is such that $C \subseteq P$ is a configuration.

(4) A *Petri net* is a net of the form $\mathrm{P}N = (N, M, W)$, which extends the elementary net so that:

1. $N = (P, T, F)$ is a net.
2. M: P → Z is a place multiset, where Z is a countable set. M extends the concept of configuration and is commonly described with reference to Petri net diagrams as a marking.
3. W: F → Z is an arc multiset, so that the count or weight for each arc is a measure of the arc multiplicity.

Petri net graph is an intuitionistic representation of Petri net model. The circle represents the position (place), and if the circle has the token, it represents that the condition is satisfied. A line segment (bar) represents a transition. A diagrammatic sketch of Petri net graph is shown in the Figure 2.

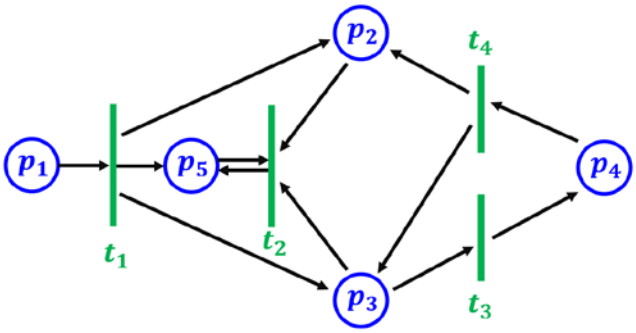


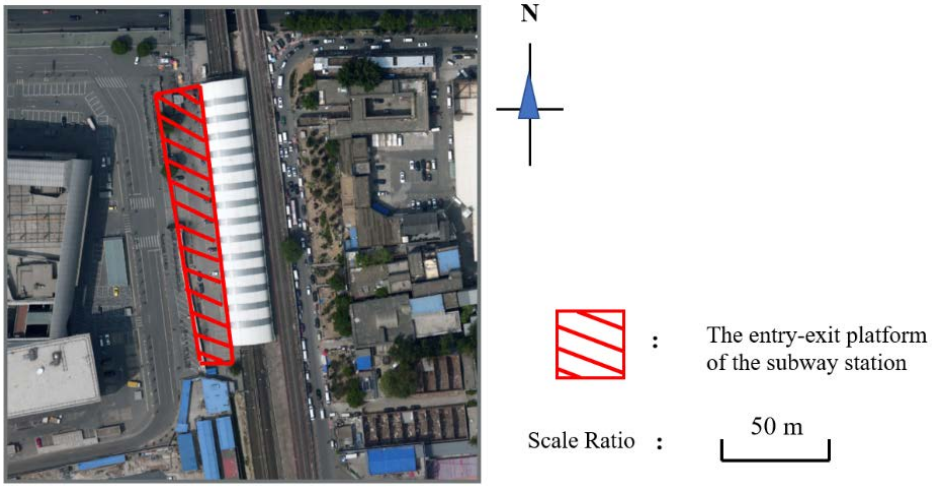
Figure 2. A diagrammatic sketch of Petri net graph

The Petri network is a directed graph. The nodes in the Petri network can be divided into two sets: place and transition. Each arc is from a set of elements to another set of elements, so the Petri network is a directed bipartite graph.

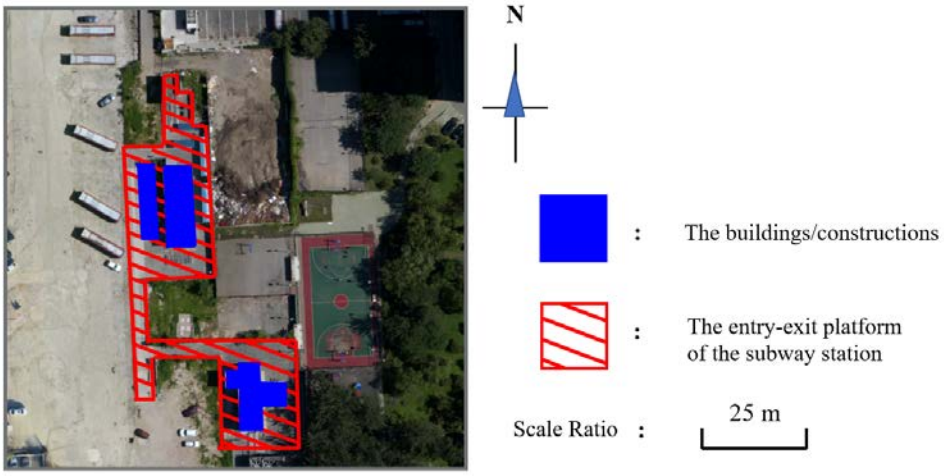
STUDY AREAS AND DATA

Study areas

Dazhongsi subway station and Keyilu subway station (in Beijing, China) are chosen to be the demonstrations in this paper. Dazhongsi subway station was constructed in 2002 and Keyilu subway station was constructed in 2011. There are two common features of these two stations. (1) The elevations of the entry-exit platforms of the stations are smaller than the elevations around the platforms, which makes the entry-exit platforms of the stations be the low-lying areas. The entry-exit platforms are easily flooded in huge rainstorm disasters. (2) There are drains and sewers on the surface of the platforms and there are both draining pumps connected to them. In rainstorm weather, the draining pumps will help reduce the waterlogging problem to a certain extent.



(a) Vertical view of the entry-exit platform of Dazhongsi subway station



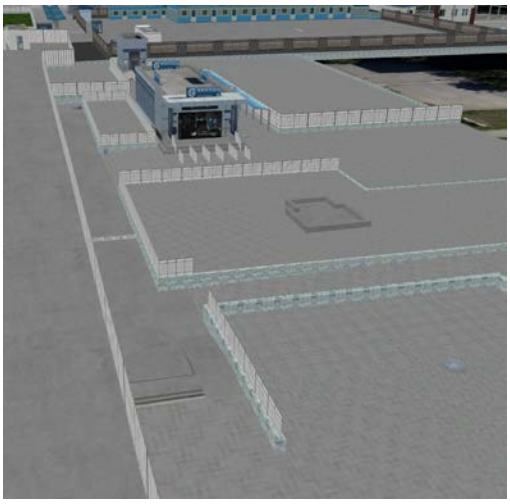
(b) Vertical view of the entry-exit C of Keyilu subway station

Figure 3. Vertical view of the study areas

To get more detailed information, the high definition visualized simulation diagrams in oblique view are shown in Figure 4. From the figures in vertical view and oblique view we can see that the two entry-exit platforms of the stations have different features. The gathering ground of the entry-exit platform out of Dazhongsi subway station looks like a piece of sunken flat ground, which can be seen in Figure 4 (a) and Figure 4 (b). The main ways of the catchment of water include the influent water falling into the gathering ground from the relatively tall fence and the influent water flowing into the gathering ground from the rampways and the steps. The surface of the gathering ground is very smooth and undivided, without any buildings or constructions. The gathering ground of the entry-exit platform out of Keyilu subway station is an irregularly shaped area, with some low buildings and civil constructions above ground, which can be seen in Figure 4 (c). In addition to the two ways of the catchment of water mentioned above, the influent water falling into the gathering ground from the roof of the buildings and civil constructions must be considered as a source item of waterlogging.

(a) Oblique view 1 of the entry-exit platform of Dazhongsi subway station

(b) Oblique view 2 of the entry-exit platform of Dazhongsi subway station



(c) Oblique view of the entry-exit C of Keyilu subway station

Figure 4. Oblique view of the study areas

Data

The most important data in numerical simulation of waterlogging is the elevations data. DEM data is widely used in waterlogging simulation. In this study, the DEM file is got from a data provider and its range is from 39°00' N to 40°00' N, 116°00'E to 117°00'E. The study areas are covered in this latitude and longitude range. 10m×10m-precision DEM files and TXT files of the elevations data, which cover the study areas are got after a series of operation based on Arcmap software: projection, calibration, clipping, floating, resampling and turning grid into ASCII. The 10m × 10m-precision DEM data is useful for the simulation in large blocks. However, the precision is not enough to do fine simulation in the entry-exit platforms if we want to accurately simulate the waterlogging scenes, so 1m×1m-precision DEM data in and around the entry-exit platforms of two subway stations are got for study.

SIMULATION RESULTS AND ANALYSIS

The intensity of rainfall is the fundamental and the most important condition in waterlogging simulation. If the intensity is chosen too small, it is difficult to cause the waterlogging problem because the depth of water may increase slowly. The waterlogging may stay a thin water layer especially when the drainage system is working in the condition of small intensity of rainfall. The quantity of rainfall of different duration-reappearance period has been studied and the results are shown in Table 1 (Ma et al, 2012).

Table 1. Quantity of rainfall (unit: mm) of different duration-reappearance period

reappearance period /a / duration /min	2	3	5	10	20	50	100
5	9.519	9.985	10.805	11.958	13.584	17.394	23.002
10	15.253	16.893	18.809	21.465	24.533	30.210	37.216
15	19.520	21.551	23.902	27.105	30.697	37.053	44.568
20	22.784	25.448	28.392	32.340	36.648	42.929	67.137
30	33.678	38.674	44.426	52.129	60.567	74.901	91.146
45	34.583	40.710	47.800	57.456	72.278	87.404	109.991
60	38.968	44.773	52.239	63.363	71.156	111.244	133.803
90	44.409	52.822	62.636	76.211	91.834	120.585	155.890
120	47.521	55.713	64.457	79.443	96.500	130.519	175.274

The choice of the intensity of rainfall needs to consider the local actual conditions and the simulation requirements. In the study area in Beijing, there are few rainy weather. The greatest threat to the city and the subway stations is the heavy rainstorm. Moreover, we want to reappear the exceptionally severe waterlogging in heavy rainstorm in this paper to study and make emergency response strategies for the worst situation in advance. 71.156 mm/h, 111.244 mm/h and 133.803 mm/h are chosen to be the intensity of rainfall in the simulations with the reappearance period equals 20 years, 50 years, 100 years and the duration equals 60 minutes.

Several contrastive simulations are conducted in this paper, which is shown in Table 2.

Table 2. Contrastive simulations conducted in this paper

Group	Duration of rainfall (min)	Sewerage system	Intensity of rainfall (mm/h)	Station
1	**10-90**	No	111.244	Keyilu
2	90	**Yes/No**	111.244	Keyilu
3	120	Yes	**71.156/111.244/133.803**	Keyilu
4	90	No	111.244	**Keyilu/Dazhongsi**

Simulation group 1: the influence of the duration of rainfall on the waterlogging

In this part of study, 111.244mm/h is chosen as the intensity of rainfall and Keyilu subway station is chosen as the study object. Simulations that last for different duration are conducted to study the influence of the duration of rainfall on the waterlogging. First, four observation points are set at the study area, which is shown in Figure 5. The main component elements include observation points, a drainage ditch, low buildings, civil constructions overland, rampways, steps, regions of the main source of runoff overland and the inaccessible region.

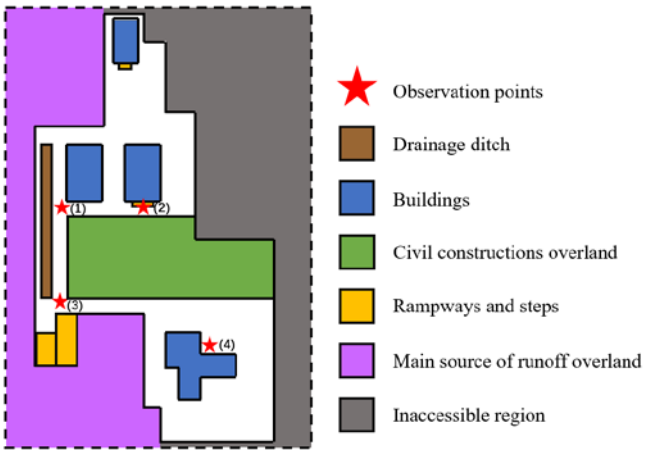


Figure 5. Simplified schematic diagram of the entry-exit C of Keyilu subway station

The results of the simulation group 1 are mainly indicated by the depth of water accumulation. The results are

shown in Figure 6.

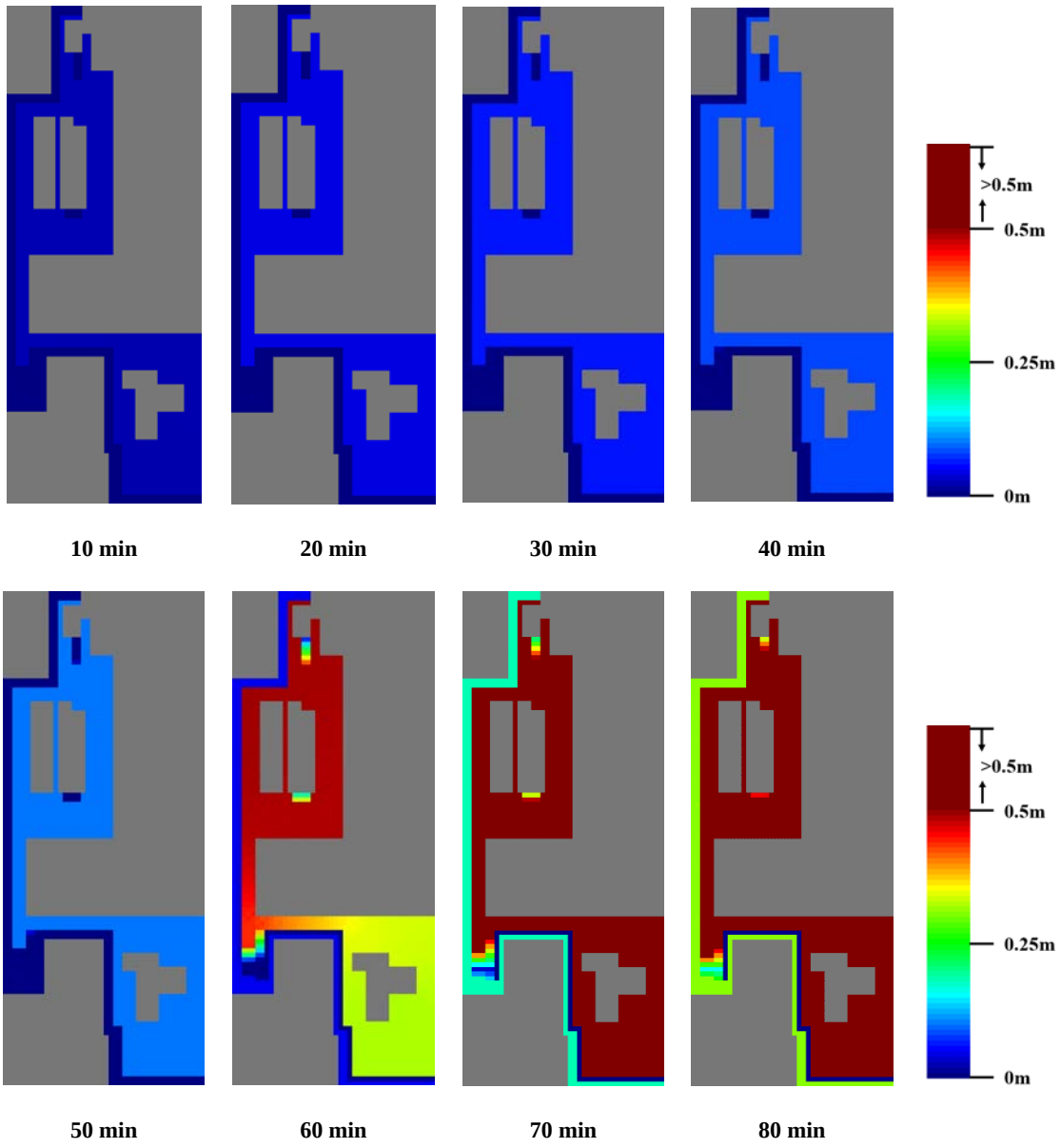


Figure 6. Results of the simulation group 1

It is apparently that 111.244mm/h is a huge intensity of rainfall. It is not common in practice. If the city is totally a flat ground, the depth of water can be easily calculated by intensity of rainfall × duration of rainfall. According to historical study (Ishigaki, 2005), it is hard to evacuate when the depth of water exceeds 70cm. It needs about 6.3 hours to reach to the limited depth for evacuation in the specifically given intensity of rainfall on the ground. It seems like people have enough time to response and react to the disaster. However, the fact is much worse than the assumption above. Because the elevations of the city are wavy and the gap between the higher limit and the lower limit is usually big, the runoff overland will contribute a lot to the urban waterlogging. If the elevations of some areas are relatively small in a city, it will be flooded rapidly because of the runoff. People and constructions in the areas will face huge risk. In this paper, there are two stages of waterlogging: the block where the study area is located not flooded and the block flooded. The difference between the two stages is also studied.

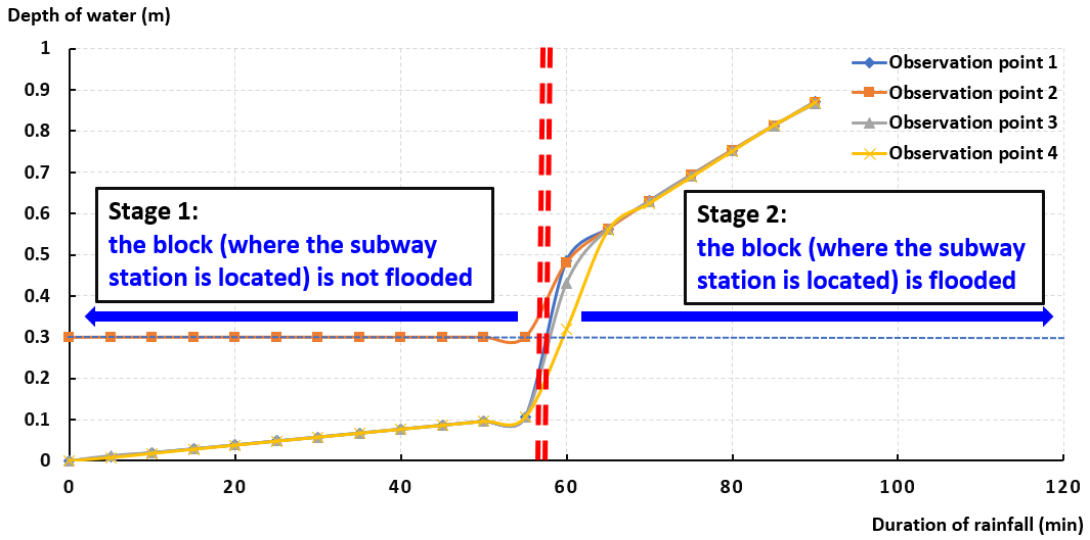


Figure 7. Simulation results of the simulation group 1 when the block is/is not flooded

From the simulation results, we can see that the process of the waterlogging has an obvious step phenomenon at about 55 minutes and the progress can be divided into two stages. In the first stage, when the block is not flooded, the depth of water increases slowly. Despite that the catchment of water includes not only the water from rainfall directly but also the influent water from the main sources of runoff overland, the water from rainfall contributes more to the waterlogging. In the second stage, when the block is flooded, the depth of water increases suddenly and then increases in a much bigger and stable velocity. In this stage, the location covering the entry-exit platform C of Keyilu subway station is flooded. Influent water from the areas with relatively bigger elevations flows into the low-lying lands. In this stage, the influent water contributes more to the waterlogging.

The step phenomenon happens mainly because the elevations of the subway station are not the lowest in the city, but sub low in the city. At the beginning of the simulation, the influent water from the main sources of runoff overland tends to flow into a lower point in the large block instead of the location of the subway station. Along with the progress, the subway station suddenly becomes the target of the runoff at the time of the step point after the quantity of the rainfall exceeds the water holding capacity of the lowest point. The step phenomenon of the waterlogging is very dangerous and must be taken into consideration when the emergency response strategy is proposed.

Simulation group 2: the influence of the sewerage system on the waterlogging

In this part of study, 111.244mm/h is chosen as the intensity of rainfall and Keyilu subway station is chosen as the study object. Simulations with a sewerage system and without a sewerage system are conducted to study the influence of the sewerage system on the waterlogging. According to the practical situation, the water displacement of the pumping machine is set as $145m^3/h$. The contrastive simulation results are shown in Figure 8.

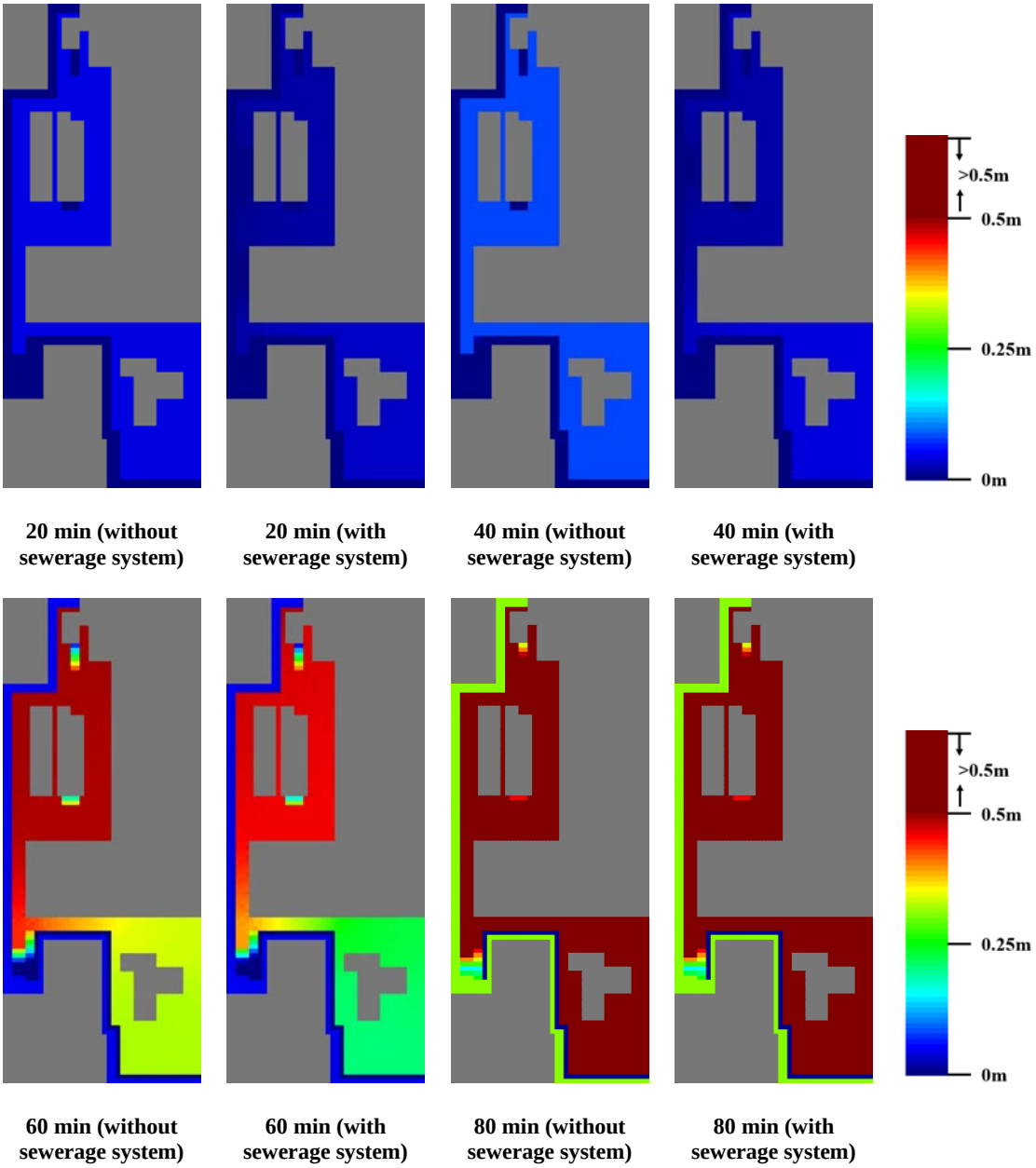


Figure 8. Results of the simulation group 1

It is apparently that the depth of water when a sewerage system is in service is smaller than the depth of water when a sewerage system is closed at 20 minutes, 40 minutes, 60 minutes. However, the depth of water seems the same at 80 minutes regardless of the sewerage system. It can be speculated that when the block where the subway station is located is not flooded, the sewerage system can effectively help reduce the waterlogging. However, when the subway station's block is flooded, the effect of the sewerage system is relatively inconspicuous. The progress is further studied, and the results are shown in Figure 9.

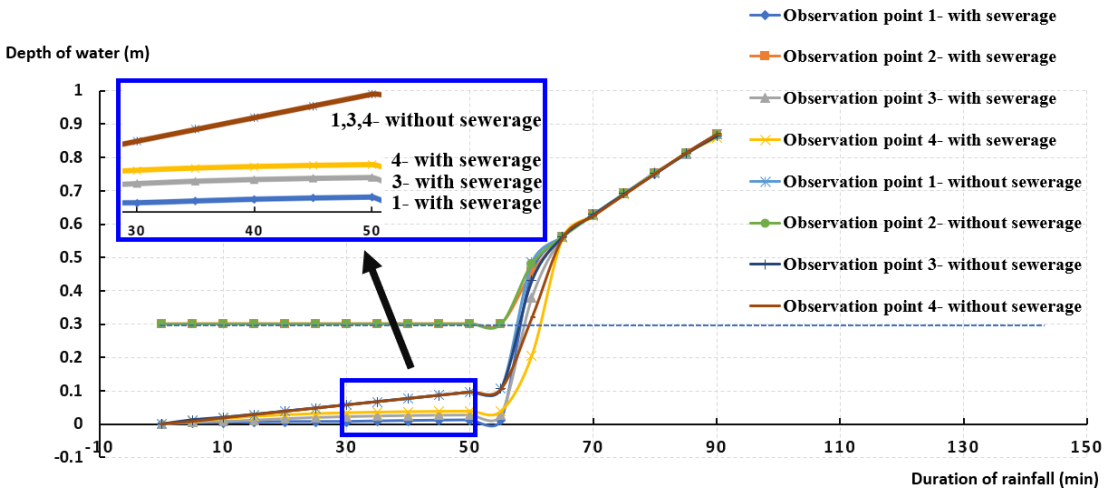
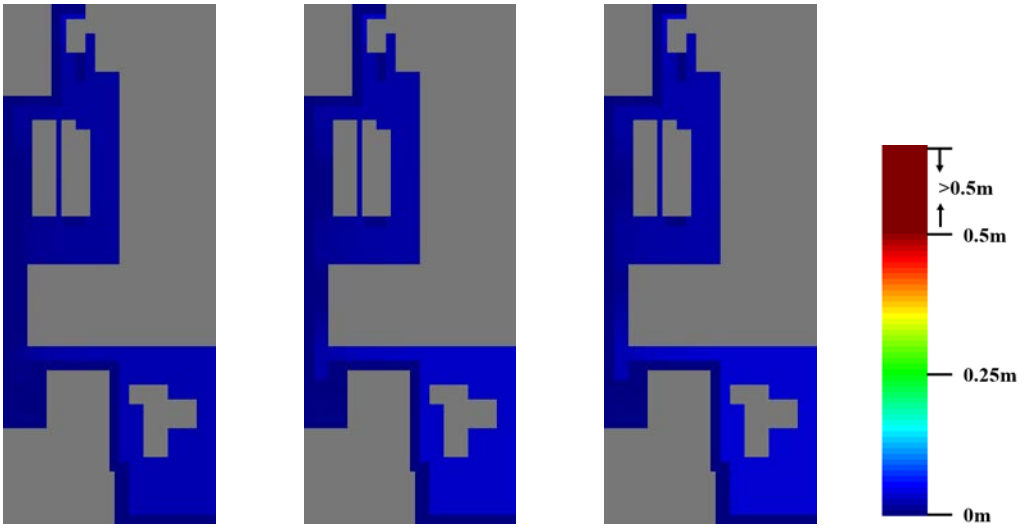


Figure 9. Simulation results of the simulation group 2 at the observation points 1, 3, 4 with/without a sewerage system

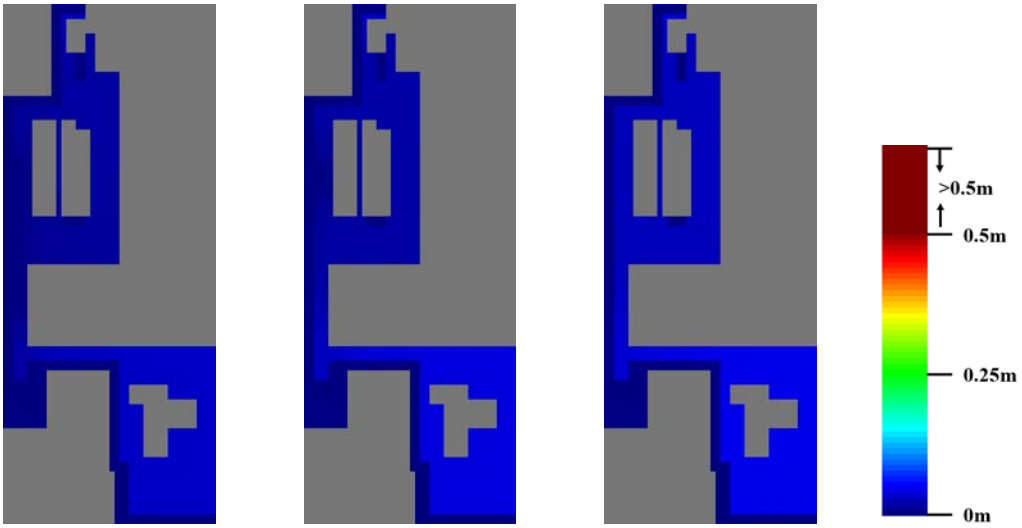
From the results we can see that when the block is not flooded, the sewerage system can help effectively slow down the catchment of water. Moreover, when the observation points are closer to the drainage system, the depth of water accumulation will be smaller, which can be seen from the Comparison of the observation points 1, 3 and the observation point 4. When the observation points are closer to more components of the drainage system, the depth of water accumulation will be smaller, which can be seen from the comparison of the observation point 1 and the observation point 3. As mentioned above, the function of the sewerage system can be ignored once the subway station is flooded.

Simulation group 3: the influence of the intensity of rainfall on the waterlogging

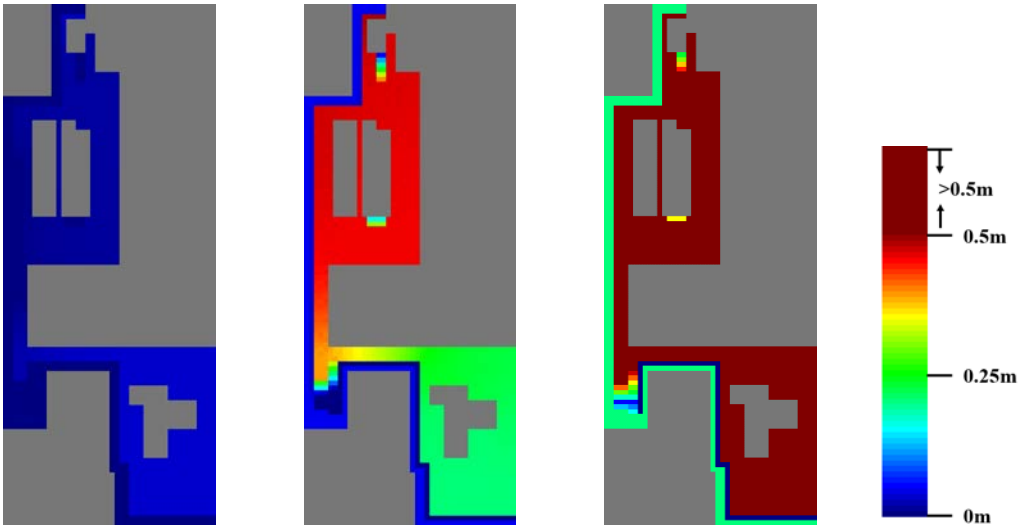
As discussed above, the intensity of rainfall is the fundamental and most important factor that determines the formation of the waterlogging in the rainstorm. Despite the intensity of rainfall is relatively small in daily life in Beijing, China, a sudden heavy rain may destroy the infrastructure and lifeline system of the city if people are not prepared or act no emergency response to the disaster. For example, an extraordinary waterlogging occurred in Beijing, China on July 21, 2012 after continuous heavy rainfall. This disaster resulted in 79 deaths and a direct economic loss of 11.64 billion RMB (Su Y, Zhao F and Tan L, 2015). In summary, the waterlogging problem in heavy rainfall deserves much more attention. In this paper, the performance of waterlogging in the conditions of different intensity of rainfall (71.156mm/h, 111.244 mm/h, 133.803mm/h) is studied.



20 min (intensity of rainfall=71.156 mm/h) **20 min (intensity of rainfall=111.244 mm/h)** **20 min (intensity of rainfall=133.803 mm/h)**



40 min (intensity of rainfall=71.156 mm/h) **40 min (intensity of rainfall=111.244 mm/h)** **40 min (intensity of rainfall=133.803 mm/h)**



60 min (intensity of rainfall=71.156 mm/h) **60 min (intensity of rainfall=111.244 mm/h)** **60 min (intensity of rainfall=133.803 mm/h)**

Figure 10. Results of the simulation group 3

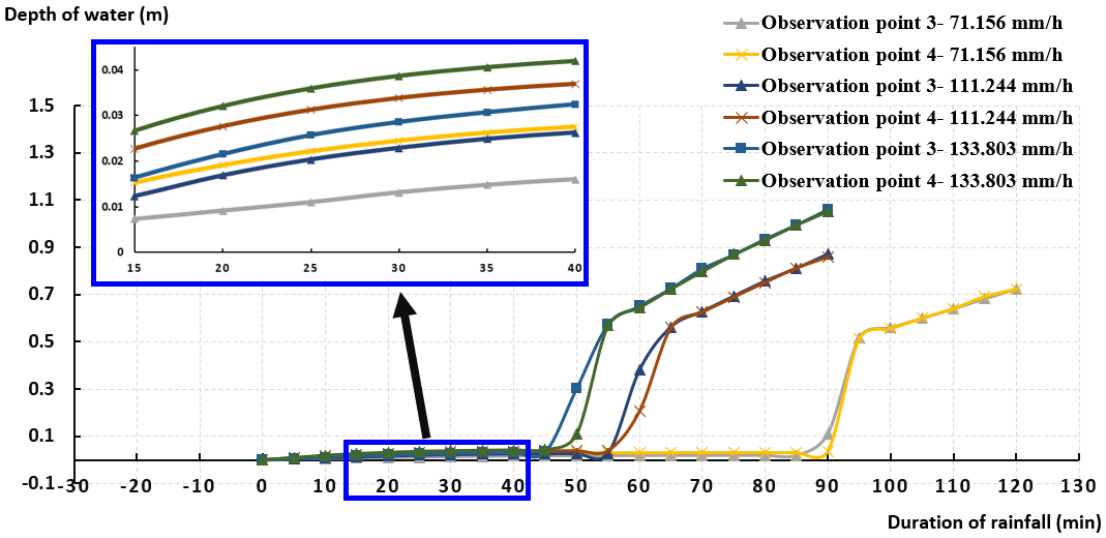


Figure 11. Simulation results of the simulation group 3 at the observation points 3, 4 in different intensity of rainfall

It can be found that the rising speed of the depth of water becomes larger along with the intensity of rainfall becomes larger. The inundation time when the block of the subway station is flooded becomes shorter as the intensity of rainfall becomes larger. The results remind the decision makers and the emergency response department to take different measures facing the rainstorm disaster with different rainfall intensity.

Simulation group 4: the influence of the site selection on the waterlogging

It is very difficult to form the urban waterlogging problem only based on the rainfall even if in the condition of heavy rainstorms. The most important reason for the occurrence of the urban waterlogging is the runoff phenomenon. Water tends to form confluence in low-lying areas, which makes the effect of the runoff overland the fundamental cause of serious urban waterlogging. The location of the subway stations is very important based on this cognition. The subway station will bear the full brunt of the waterlogging if it is built in a low-lying area. It can be seen from the study above that if the location of the subway stations is totally flooded, there are few countermeasures. Traditional response measures such as sewerage systems will lose effectiveness rapidly in extremely bad situation. To study the influence of the site selection of the subway stations on the waterlogging, four observation points are set at the entry-exit platform of Dazhongsi subway station as shown in Figure 12. The contrastive simulations of the waterlogging at Keyilu subway station and Dazhongsi subway station are conducted and the results are shown in Figure 13.

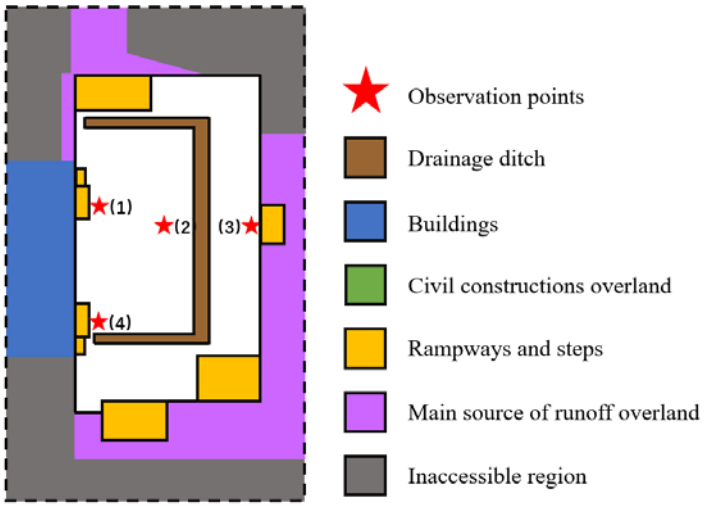


Figure 12. Simplified schematic diagram of the entry-exit platform of Dazhongsi subway station

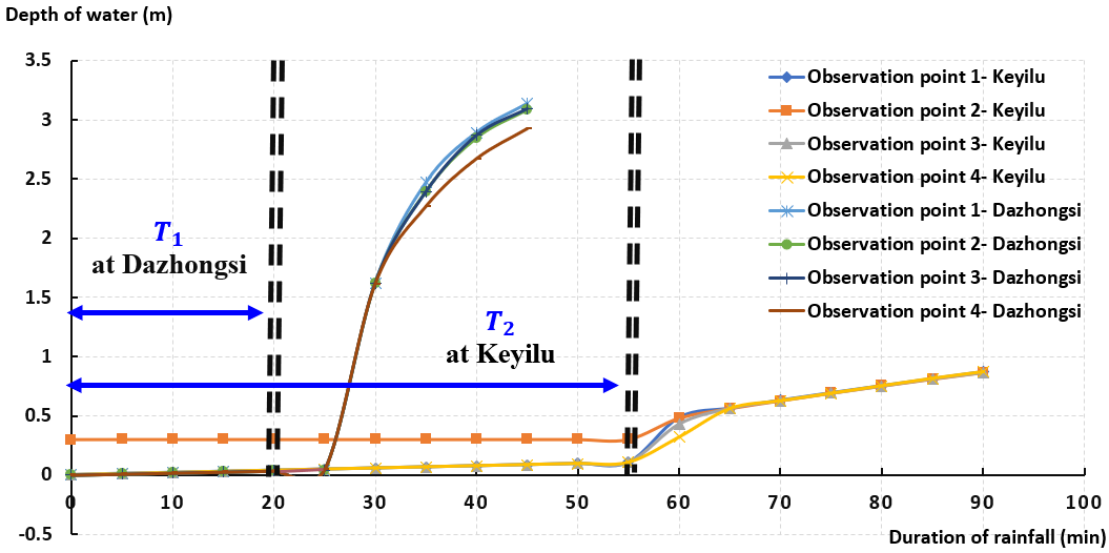


Figure 13. Simulation results of the simulation group 4 at entry-exit platforms of different subway stations

It can be seen that in the same condition, Dazhongsi subway station is more easily to be flooded than Keyilu subway station. In Figure 13, the duration of the stage 1 that the block of Dazhongsi subway station is not flooded (T_1) is much smaller than that of Keyilu subway station (T_2). The result is in accordance with the truth that in practice, Dazhongsi subway station is more likely to be flooded than Keyilu subway station. This study can be popularized to the application at other subway stations. The results should be an important reference item in the site selection of subway stations.

EMERGENCY RESPONSE STRATEGY

Process construction based on PN model

The emergency response strategy needs to be proposed based on the process of the disaster. Considering humans as the main bearers of the disaster, the process construction based on PN model is completed, which is shown in Figure 14. The meanings of p_i $(i = 1,2,\dots,10)$ and t_i $(i = 1,2,\dots,8)$ are shown in Table 3.

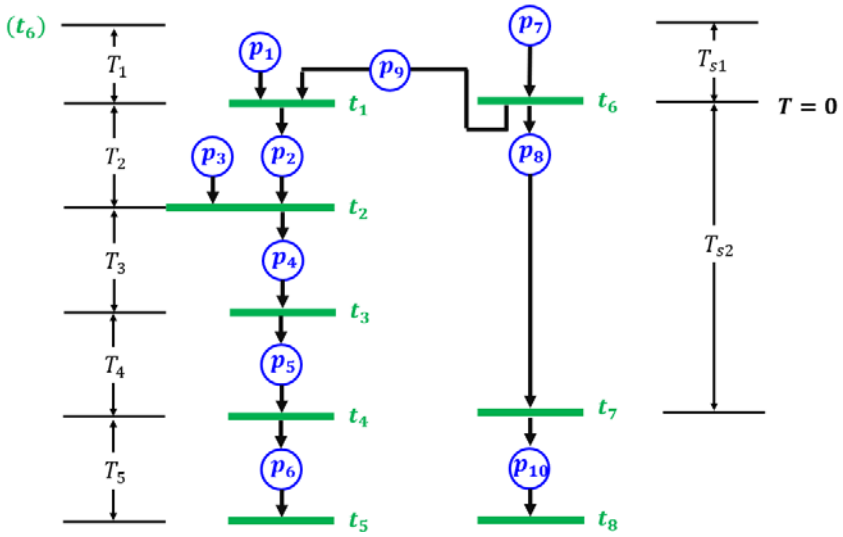


Figure 14. Process construction based on PN model

Table 3. The meaning of the sets of places and transitions

The node symbol p_i	Meaning	The node symbol t_i	Meaning
p_1	Subway station keeps notice on the alarm signal	t_1	Alarm signal is received for the first time
p_2	The alarm signal is spreading underground	t_2	People notice the alarm signal
p_3	People keeps notice on the alarm signal	t_3	People arrive near the entrance of the stairs
p_4	Evacuation progress underground	t_4	People reach the entrance of the stairs
p_5	Advancing towards the entrance of the stairs	t_5	People reach the surface of the ground safely
p_6	Evacuation progress on the stairs	t_6	Depth of water on the ground reaches to the critical point of warning
p_7	It is raining	t_7	Depth of water underground reaches to the critical point of water level allowing evacuation
p_8	The alarm signal appears	t_8	Victims are dead
p_9	The alarm signal is spreading to the subway station		
p_{10}	Victims are trapped in the subway station		

The duration time of the progress of the people's evacuation contains the following main parts (Mo, 2010): (1) T_1, from the time point that depth of water on the ground increases to the critical point, to the time point that alarm signal is received for the first time; (2) T_2, from the time point that the alarm signal is received for the first time, to the time point that people notice the alarm signal; (3) T_3, from the time point that people notice the alarm signal, to the time point that people arrive near the entrance of the stairs; (4) T_4, from the time point that people arrive near the entrance of the stairs, to the time point that people reach the entrance of the stairs; (5) T_5, from the time point that people reach the entrance of the stairs, to the time point that people reach the surface of the ground. T_1-T_5 and the time for people to evacuate safely from the underground space to the ground T_{total} can be calculated by equation (9) - (14).

$$T_1 = \min(t_A, t_B, t_C) \tag{9}$$

t_A refers to the time that the depth of water reached to 10cm overland. t_B refers to the time that the depth of water reached to 10cm in the underground space. t_C refers to the time that the depth of water reached to 3cm in the underground space if the water sensor equipment is installed.

$$T_2 = \frac{\sqrt{A}}{30} + 3 \tag{10}$$

A (m^2) refers to dimension of the underground space.

$$T_3 = \frac{l}{\alpha v_1} \tag{11}$$

Because when people decide to evacuate, the water level has reached to a certain depth. The retardation effect needs to be considered, so discount velocity is recommended here. l means the walking distance (m). v_1 means the walking speed in the crowded condition (m/min). α is the discount parameter which can be calculated by $\alpha = 1 - h_{ug}/(70\mathrm{cm})$ in which h_{ug} means the depth of the water underground (cm).

$$T_4 = \sum_{i=1}^{n} \frac{PA}{NB_i} \tag{12}$$

The flow rate of people and the width of the stairs are key influence factors when calculating T_4. P is the population density ($1/\mathrm{m}^2$). N is the effective flow coefficient (=90 according to the reference) ($1/(\mathrm{m} \cdot \mathrm{min})$). B_i is the effective width of the stair i in the evacuation route (m).

$$T_5 = \frac{\lambda}{\beta v_2} \tag{13}$$

It is difficult for people to pass the stairs if the water flows in an opposite direction. λ is the length of the stairs (m). v_2 is the normal walking speed on the stairs (m/min). β is the discount parameter which can be calculated by $\beta = 1 - h_s/(30\text{cm})$ in which h_s means the depth of the water on the stairs (cm).

In summary, the time for people to evacuate safely from the underground space to the ground T_{total} can be presented by equation (14).

$$T_{total} = \sum_{i=1}^{5} T_i = T_1 + \frac{\sqrt{A}}{30} + 3 + \frac{l}{\alpha v_1} + \sum_{j=1}^{n} \frac{PA}{NB_j} + \frac{\lambda}{\beta v_2} \text{ (min)} \tag{14}$$

The duration time of the waterlogging turning into disaster contains two parts. (1) One part is the duration time (T_{s1}) that the depth of water on the ground increases to the critical point that the water on the entry-exit platforms pours over the highest step at the entry-exit. In this study, the height of highest step at the entry-exit equals 30 cm. Once the water pours over the highest step, it will flow into the underground space through the stairs, which may cause serious consequences. (2) The other part is the duration time (T_{s2}) that the depth of water in underground space increases to the critical point when it is difficult for the victims to walk and evacuate, after the water flows into the underground space. According to the existing study (Mo, 2010), the critical point of the depth of water in underground space should be set as 70 cm.

T_{s1} can be got through equation (15).

$$\int_0^{T_{s1}} u_1 \, dt = h_{c1} \tag{15}$$

h_{c1} means the critical point of the depth of water on the ground (m). h_{c1} equals 0.3 m in this paper. u_1 means the rising speed of the water level. The relationship between the quantity per unit width of the water that invades into the underground space q ($m^3/m/s$) and the depth of the water accumulation at the entrance h_g (m) is shown in equation (16).

$$q = \begin{cases} 0, & h_g \le h_{c1} \\ 1.98 \cdot \left(h_g - h_{c1}\right)^{1.621}, & h_g > h_{c1} \end{cases} \tag{16}$$

The rising speed of the water underground u_2 can be calculated by equation (17). h_{ug} means the depth of water underground (m).

$$u_2 = h'_{ug}(t) = \frac{Q'(t)}{A} = \frac{\left(\int_0^t q \cdot B dt\right)'}{A} = \frac{1.98B\left(h_g - h_{c1}\right)^{1.621}}{A} \tag{17}$$

T_{s2} can be got through equation (18). h_{c2} equals 0.7 m in this paper.

$$\int_{T_{s1}}^{T_{s2}} u_2 \, dt = h_{c2} \tag{18}$$

Emergency response strategies-plugging and drainage

From the Results and analysis above, some traditional response methods to urban rainstorms and urban waterlogging are effective in the stage that the block of the subway stations is not flooded. Take the simulation 2 for an example, detailed analysis is conducted. The relationship of the depth h_g of the water and the duration of the rainfall t ($t \le 50$ min) in the condition of intensity of rainfall equals to 111.244 mm/h, the water displacement of the pumping machine is set as $0 m^3/h$ and $145 m^3/h$ is shown in equation (19) and (20).

$$h_g = -2 \times 10^{-7} t^2 + 0.0019t \text{ (min)} \ (without\ sewerage), \qquad R^2 = 0.999 \tag{19}$$

$$h_g = -1 \times 10^{-5} t^2 + 0.001t \text{ (min)} \ (with\ sewerage), \qquad R^2 = 0.998 \tag{20}$$

Stage 1 refers to the condition that block of Keyilu subway station is not flooded. The simulation results in stage 1 are shown in Figure 15.

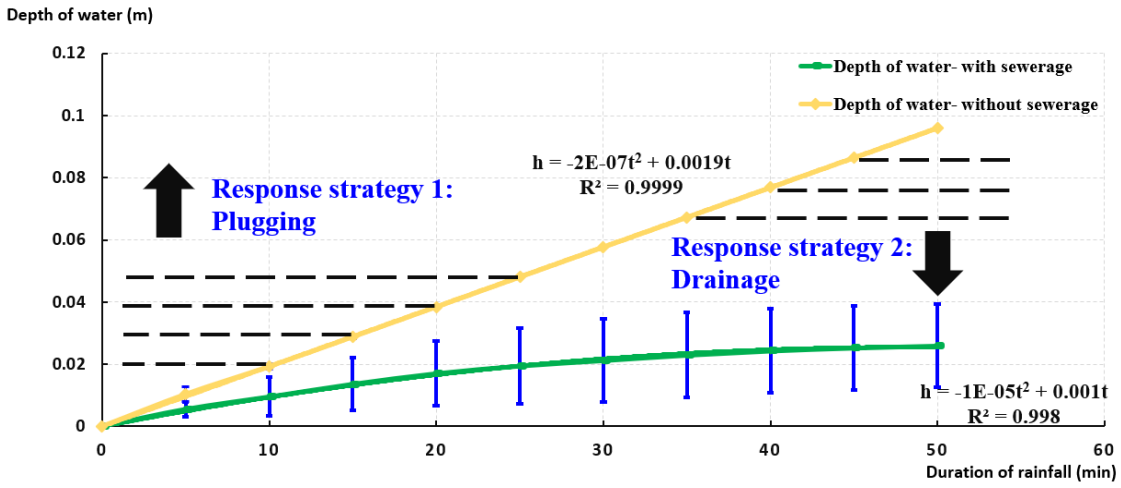


Figure 15. Response strategy: plugging and drainage

From the results we can see that the traditional response methods are well-founded. Normally, the time that the top steps of the entrance of the subway station is flooded is seen as a critical point. If the steps of the entrance of the subway station is flooded, the intrusion of water into the underground space will bring unexpected consequences. One kind of response strategy is plugging, which means blocking the entrance of the subway station with blockage like sandbags. This strategy can make the height of the entrance h_{c1} bigger. The time that the entrance is overflowed will be delayed because h_g equals to h_{c1} at the critical point. The other kind of response strategy is drainage, which means pumping water out of the specific area. It can be seen from the results that drainage is also effective because it reduces the rising speed of the water level to a great extent.

Emergency response strategies-evacuation

In the case of extremely huge rainstorm disasters, the problem is not only the waterlogging at the subway stations' entry-exit platforms but also the invasion of the water into the underground space. The reaction time between the formation of the flood and the implementation of the evacuation plan is very short in an extreme rainstorm disaster. It is very dangerous if the prewarning and evacuation is not timely because there are usually enormous people underground in the subway stations, especially during the rush hours. The emergency response and evacuation in extreme rainstorm disasters are also studied in this section. It is not difficult for people to evacuate on the ground because it is an open space. However, it is much more difficult for people underground to evacuate up to the ground surface in disasters.

In the case study in this paper, the relationships among T_{total} and the factors are studied. The factors include the dimension of the underground space, A; the population density, P; the effective width of the stairs in the evacuation route, B; the length of the stairs, λ. The constant conditions are set as $l = 100\text{m}$, $v_1 = v_2 = 60\text{m/min}$, $\beta = 2/3$. In this paper, $T_1 = 0$ min because the depth of water has reached to 30cm (the critical point of warning) overland before alarm signal is received for the first time.

According to the previous study in simulation group 2, T_{s1} and h_{ug} can be calculated in the condition of intensity of rainfall equals to 111.244 mm/h at Keyilu subway station. When the depth of water underground reaches the critical point ($h_{c2} = 0.7$ m), $T_{s1} + T_{s2}$ and T_{s2} can be got by equation (22) and (23). T_{s2} means the time left for people to safely evacuate up to the ground.

$$T_{s1} = 55 \text{ (min)} \tag{21}$$

$$h_{ug} = 0.122t - 0.232 \text{ (m)} \tag{22}$$

$$T_{s2} = \frac{0.7(the\ value\ of\ h_{c2}) + 0.232}{0.122} - 55 = 21.23 \text{ (min)} \tag{23}$$

In the case study in this paper, the conditions that people can safely evacuate from the subway station have been studied. We compare the evacuation time T_{total} and T_{s2} in several conditions.

$$\begin{cases} It\ is\ in\ safe\ condition, & T_{total} \le T_{s2} \\ It\ is\ in\ dangerous\ condition, & T_{total} > T_{s2} \end{cases} \quad (24)$$

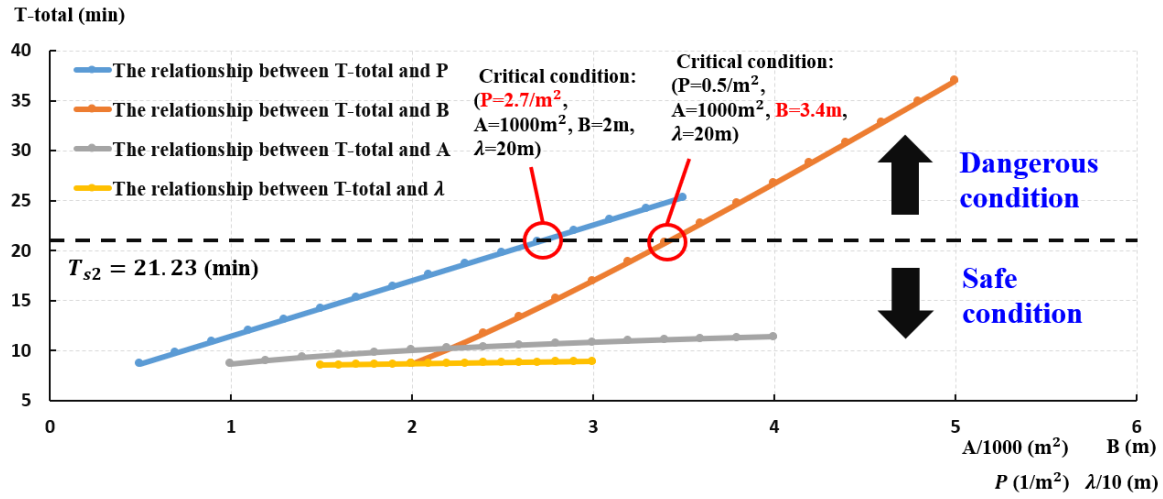


Figure 16. The relationships among the left safe evacuation time and the factors

From the result, it can be seen that the population density, P and the effective width of the stairs in the evacuation route, B are most important for people to safely evacuate up to the ground. In the condition of ($A = 1000\text{m}^2$, $B = 2\text{m}$, $\lambda = 20\text{m}$), the critical value population density P is 2.7 persons/m^2, which means if the underground space is too crowded, the safe evacuation time will be insufficient. In the condition of ($P = 0.5\ \text{persons/m}^2$, $A = 1000\text{m}^2$, $\lambda = 20\text{m}$), the critical value population density B is 3.4 m, which means if the width of the stairs is too narrow, the safe evacuation time will be insufficient.

CONCLUSION

In conclusion, simulations of the urban waterlogging at subway station's entry-exit platforms in heavy rainstorm are conducted, and emergency response strategies are suggested in this paper.

In simulation part, it has been found that the waterlogging at subway stations' entry-exit platforms in rainstorm disasters is easily influenced by the duration of rainfall, the sewerage system, the intensity of rainfall, the site selection of the subway stations. In brief, the waterlogging problem will become more severe when the duration of the rainfall becomes bigger, the sewerage system is closed and the intensity of rainfall becomes bigger. It reminds the decision makers to pay more attention to huge rainstorm and the waterlogging caused by it. Moreover, a prepared drainage system is important at the subway stations' entry-exit platforms.

It has also been found in this paper that the site selection for the subway stations is very important. There exists a critical time point and a step feature of waterlogging at the subway stations' entry-exit platforms. It means that the flooded time will be very short if the subway stations is located at a low-lying area. It is important to do waterlogging risk evaluation before the site selection of the subway stations. The methods proposed in this paper can effectively help do waterlogging simulation and waterlogging risk evaluation before the site selection.

Finally, a disaster process construction method based on PN model is proposed in this paper. It has been found that the emergency response strategies including plugging, drainage and evacuation are important for disaster mitigation at the subway stations' entry-exit platforms. First, plugging and drainage help in disaster mitigation to an extend because these emergency response strategies delay the critical time point when water enters the underground space (depth of water on the ground = the height of the highest stair step). Second, the evacuation time is tense considering the water has entered the underground space. When the depth of water underground reaches the critical point (=70 cm), it is hard for people to evacuate. It has been found that the population density and the effective width of the stairs in the evacuation route are most important factors, which determine whether people can safely evacuate up to the ground.

There are still some aspects remaining to be further studied. The precision of DEM data is very important for the performance and accuracy of waterlogging simulation. In this paper, we got 1m×1m-precision DEM data around the subway stations. It is expected that the results can be improved if full-scale high precision DEM data is used

in the simulation, despite it will cost much more computing time. Moreover, matching real-size rainfall, waterlogging and evacuation experiments in the future are valuable for the modelling verification and modification.

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Modeling Threats of Mass Incidents Using Scenario-based Bayesian Network Reasoning

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ABSTRACT

Mass incidents represent a global problem, putting potential threats to public safety. Due to the complexity and uncertainties of mass incidents, law enforcement agencies lack analytical models and structured processes for anticipating potential threats. To address such challenge, this paper presents a threat analysis framework combining the scenario analysis method and Bayesian network (BN) reasoning. Based on a case library of mass incidents in China, a BN capturing the interaction of twelve key factors in mass incidents is developed, where the network structure is determined by data and expert knowledge. The model is compared with two base-line BN models (use only expert knowledge or data) and a logistic regression model, proving to be the most robust. Using sensitivity analysis, we further identify a more critical subset of those threat-predicting factors. Finally, we present a case study to demonstrate how to apply the proposed framework to assessing the threat of ongoing mass incidents.

Keywords

Bayesian Network, mass incidents, threat assessment, scenario analysis, interpretive structural modeling.

INTRODUCTION

Mass incidents refer to a group of people coming together for a common purpose of requesting actions from authorities (Shao, 2016). Examples are demonstrations, protests, strikes, or petitions for government actions.

Depending on the degree of social harm, a mass incident can be categorized as *unusual major*, *major*, *large* or *general*. Conflicts of economic, social, and political interests are the main reasons triggering mass incidents (Wei et al., 2014). Although the majority of the mass protests are peaceful gatherings at their initiation, some of them may evolve into advocating criminal activities (such as riots) and create significant public security threats (Wood, 2014). The transition from peaceful gatherings to violent states is hardly predictable and contingent upon many known and unknown factors. Traditional police responses were typically based on experiences and passive reactions to threatening events, and they were not effective for mass protest events. The threat-minded policy strategies tend to lead to militarized police action and pre-emptive policing, which have been observed in the US (Starr, Fernandez and Scholl, 2011), Canada (Rafail, 2010), and China (Tong and Lei, 2010). Recently, law enforcement officials have developed many innovations and strategies for preventing disruptive and violent protests. One of them is Intelligence-Led Policing (Ratcliffe, 2008), which emphasizes the use of information and intelligence operation on threat and risk assessments and aids law enforcement agencies in identifying threats and developing responses to prevent or reduce those threats.

Effective threat assessment provides decision-makers with a picture of the situation including the nature, extent, and trends of the problems, allowing them to create response plans with priorities and resource commitments (De Lint and Hall, 2009). Preparing for contingencies in mass incidents requires a good understanding of the patterns and evolutions of those incidents and what factors influence the processes. Wood, *et al* (2014) found that (1) top three of the threat-predicting variables are the most significant: *protest size*, *the use of confrontational tactics*, and *advocating radical goals*; (2) events that include confrontational tactics are seven times more likely to result in violence; and (3) if the size of the protest increases by one standard deviation, the level of police presence needs to be 54 percent greater. Similarly, events that include radical goals are almost twice as likely to result in violent behaviors. Although these findings are insightful for typical crime scenarios, mass incidents have much more complexity and we are still far from being able to characterize the process of evolution of mass incidents.

Assessing threats for mass incidents is inherently challenging for several reasons. First, there exist great uncertainty and complexity of group behaviors that we have limited methods to model and predict. Second, mass incidents involve risk factors (like the number of participants and the extent of violence) that are unforeseeable at the incident preparedness stage. This leads to great difficulty in anticipating the evolution of an incident. Typically, a threat evaluation involves two tasks (Vellani, 2014): (1) an analysis of past performance, and (2) an analysis of ongoing organizing. Both of these tasks are difficult for mass incidents. While it is relatively easy to evaluate police records for individuals, mass incidents are usually organized by networks of individuals and small groups, as well as large formal organizations from various towns and cities. This creates difficulties in deciding whose past records and performance are to be evaluated. It is even more difficult to analyze ongoing organizing, because a mass incident tends to have multiple events and sites that are impossible to observe and monitor. Although studies from sociology and social psychology have revealed some of the important factors that contribute to threat of mass protests (Tong and Lei, 2010; Qiu *et al.*, 2015; Huang *et al.*, 2017; Xiao, 2014; Wei *et al.*, 2014; Lee and Zhang, 2013; Shao, 2016), their methods are primarily based on survey and regression analysis. For example, Earl *et al*. (2003) used multinomial logistic regression analysis to explain policy actions in 1905 events happened in New York. Such methods can be useful for explaining incidents of the past, but they are not feasible for assessing the threats of ongoing incidents. An alternative paradigm for modeling threat of mass incidents is to use past cases as a rich knowledge source that informs the reasoning of threats in the current incident based on the anticipation of possible future scenarios. Combining an analysis of "past activity" records of incidents with intelligence gathering or current organizing, threat assessment does not have to go with "one size fits all" approach (Wood, 2014). This is the direction that our work is designed to explore.

This paper constructs a *Bayesian Network for Scenario Generation* (BNSG) framework to assess the threat of an ongoing event. The framework can generate possible scenarios of a mass incident given partial knowledge of what has happened. An important resource for our study is the availability of a digitally curated library of 3394 mass incidents in China from 1998 to 2016 collected from news sources (Huang *et al.*, 2017). To configure and train a reliable Bayesian Network based on the K2 algorithm (Cooper and Herskovits, 1992), we applied a structure learning method that combines domain knowledge and observations from a case library. The domain knowledge is determined by interviewing public safety experts using the interpretive structural modeling (ISM) method (Warfield, 1974). We evaluate our K2-ISM-BN model using a test set of mass incident cases and compare the results with three other models (including the logistic regression (LR), a BN learned only by domain knowledge (BN-ISM), and a BN learned only by training data (BN-TAN)). The result shows that K2-ISM-BN is the most robust one. Using sensitivity analysis and critical node analysis on our BN, we further identify a subset of those threat-predicting factors as more critical than others. Finally, we present a case study to demonstrate how our model can be used to generate future scenarios as the basis for assessing the threat of an ongoing mass incident.

PROBLEM FORMULATION

We take the perspective that a protest is a process that tends to develop over social space and time from a small-scale, peaceful demonstration into a larger crowd of participants and further into possible disturbance and riots behavior (Wood, 2014). An example is the large-scale mass incident in Dongzhou village, Shanwei County of Guangdong Province, China (Tong and Lei, 2010).

> The electricity plant built in 2002 occupied a large land area in Dongzhou village. The villagers believed that they were not properly compensated and protested. After receiving no satisfactory response, they started to build sheds outside the factory and attempted to stop the construction. The arrest of three villagers in the effort to demolish the sheds escalated the protest and the rank of protestors soared to several thousand. Armed police were dispatched. Tear gas was used to dispel the crowd and the riot became violent in December 2006. There were explosions and the major part of the plant was blown away.

This incident shows that the development of the mass incident may cause a 'chain reaction', which will probably trigger the incident to develop into a more serious crisis (Wei et al., 2014). We define threat analysis on mass incidents as the problem of generating future scenarios that simulate the possible development of an ongoing incident from its current state to sometime in the future (Tucker, 1999).

Suppose that each mass incident $\emptyset$ can be characterized by a set of attributes $\{A_j\}$ where j=1, 2, …, n. At any moment *t*, we assume that we have a library of cases as records of past incidents $\Psi_t = \{\emptyset_i\}$, where i=1, 2, …, m. In the meantime, we suppose that there is an ongoing incident ϕ, that was started at a time before *t* and is still developing. We use $\phi_t = \{A_j\}_t$ to represent the current state of the incident. Then, a threat analysis is to predict ϕ_{t1}, the state of the indent ϕ at a future time t_1, based on what we know at time *t*, thus, Ψ_t and ϕ_t.

METHODOLOGY

We follow a scenario-based approach (Punjabi, 2005) to develop a framework for assessing the threat of mass incidents. Scenarios are plausible, consistent and coherent descriptions of the different possible future development of situation (Comes and Hiete, 2009). This approach fits especially the situations where the prediction of the future state of an event faces a great amount of uncertainty.

Typically, a scenario-based approach involves three main steps (Punjabi, 2005): (1) identify the driving forces that affect the system; (2) divide the driving forces into possible trends and uncertain elements; (3) develop scenarios based on uncertain elements and their possible consequences. We extend this approach by the use of Bayesian Network (BN) for knowledge representation and reasoning. BN is a probabilistic graphical model (PGM) that is able to reason under uncertainty and has the unique capacity to represent knowledge of causal relationships among a set of variables. The result is a structured framework specialized for threat assessment. We refer to this framework as BNSG (*Bayesian Network for Scenario Generation*). The general idea of this framework is to use a multi-layered Bayesian network to capture the identified driving forces (or key elements) of mass incidents as the input variables, configure the topological structure of the BN to represent the causal relationships among those key elements through training the BN with expert knowledge and data, and finally use the BN to reason about the future states of an ongoing mass incident.

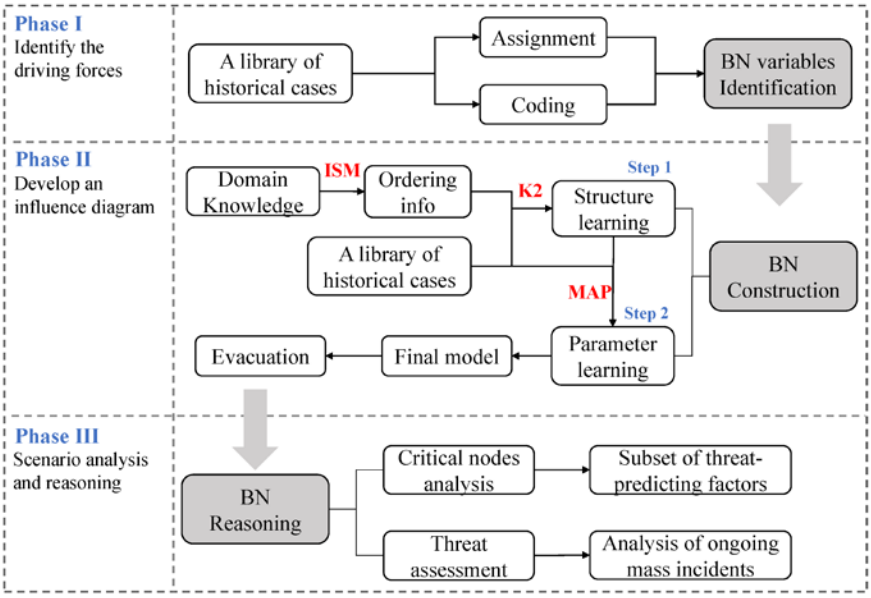


Figure 1: The Process Flow of Scenario-based BN Reasoning

Using the BNSG framework for threat assessment involves three phases of activities (as illustrated in Figure 1): In Phase I, we use a BN to capture the identified driving forces of mass incidents as the input variables and assign the input variables with different states. In Phase II, in order to identify interactions among different variables, we construct the BN model, where the structure is learned with the K2 algorithm combining the domain knowledge and historical cases, and parameters are obtained using the MAP algorithm. In Phase III, based on BN reasoning, we get the subset of threat-predicting factors and assess the threats of ongoing mass incidents. The specific methods to implement this process will be described in detail below.

[Phase I] *Identify the driving forces that influence the development of mass incidents, and represent them as Bayesian Network variables.*

This is accomplished by a deep analysis of the domain of mass incidents to understand the key social, organizational, environmental, economic, and psychological factors that play roles in the evolution of mass incidents. The literature on mass incidents research recognizes four types of factors: background factors, organization factors, process factors and result factors. Background factors describe the formation environment of mass incidents, including *the class of trigger events* (Shao, 2016), *the location*, and *the object of protest* (Xiao, 2014). Organization factors refer to the organizational elements of people in the fermentation period of mass incidents, including *the scene* (Chen, Hong and Zhang, 2015), *relationship* (Pruitt, Kim and Rubine, 2004), and *organization* (Yu, 2006). Process factors mean the scale and violence extent of people and police disposal measures during the development period, including *the participant number*, *violence extent of group behavior*s, *the police number*, and *the police strategy* (Martin, McCarthy and McPhail, 2009)(Skolnick, 2010)(Wood, 2014). Result factors mean the duration and casualties of mass incidents, including *the duration* and *casualties*. Although literature can suggest what key factors should be included in our BN model, we must also find out what values can be assigned to each variable. We answer the BN variable value assignment question by manually coding records of historical incidents. This process involves interpretive analysis of all possible states of those BN variables to discover a reasonable coding scheme to tag observations in the data. This process is guided by the Grounded Theory (Glaser, 1978).

[Phase II] *Develop an influence diagram that captures the knowledge of how those key factors interact and represent such knowledge as a probabilistic directed graph of BN variables.*

Bayesian networks have two main inference processes, *structure learning*, and *parameter learning*.

Step 1: Structure learning

In order to learn the BN structure from data, we adopt the K2 algorithm (Cooper and Herskovits, 1992) which is the most impactful algorithm that can heuristically search for the most probable belief-network structure given a database of cases. Without any other knowledge, a search algorithm has to do an exhaustive search on all possible links of a complete graph structure, which turns out to be computationally intractable (Amirkhani and Rahmati, 2015). To reduce the computational complexity, the K2 algorithm adds two auxiliary messages to limit its search space, *the ordering information* and *the maximum number of parent nodes*. The ordering information is applied by choosing the parents of the node only form those nodes that precede in the input order. The information about *the maximum number of parent nodes* is used to restrict the maximum number of incoming connections to a node.

The K2 algorithm is highly sensitive to the input order. To obtain a rational ordering of BN variables, we use the interpretive structural modeling (ISM) method (Warfield, 1974) to transform unclear mental models of a system into visible hierarchal models. ISM is a process that turns knowledge about a series of one-to-one relationships among all elements into a hierarchal model. Specifically, in our study, ISM can help to decompose the complex relationships among BN variables into *the ordering information* and *the max number of parent nodes* in the network. In order to confirm that BN-K2-ISM model is a better choice over other alternatives, we compare the results with three other models, the logistic regression (LR), a BN learned only by domain knowledge from ISM model (BN-ISM), and a BN learned only by training data using TAN algorithm (BN-TAN).

Step 2: Parameter learning

BN parameters are the set of probability distributions associated with each variable. For discrete variables, the probability distribution is described by a conditional probability table (CPT) that contains the probability of each value of the variable given each instantiation of its parent values. We use the MAP (maximum a posteriori) (Zhou, Fenton and Zhu, 2016) to determine these parameters using the Maximum Likelihood Estimate (MLE).

[Phase III] *Scenarios analysis and reasoning to anticipate possible consequences of policing strategies.*

This involves evaluating the effects of different process parameters on the results and generating possible future

scenarios for an ongoing mass incident. In our study, BN reasoning is used to answer two questions:

(1) *What variables are more important to mass incidents threats*? we use sensitivity analysis to identify the highly sensitive parameters that affect the reasoning results more significantly.

(2) *How can we assess the threat of an ongoing mass incident and provide advice to the government*? We set some variables that are already certain in an ongoing mass incidents as evidence, and generate the posterior probability distributions of other uncertain variables, based on which we can assess the threat of consequence. Over the course of the development of a mass incident, new observations or evidence appears and the posterior probability distributions of the BN representation is updated accordingly. This allows us to ask "what-if" questions on the potential effects of alternative policing strategies and help police make the best decision under the current situation.

MODELING THREATS OF MASS INCIDENTS IN CHINA

In this section, we will apply the BNSG framework to construct a BN network model of mass incidents using historical records of 3394 mass incidents in China from 1998 to 2016 (Huang *et al.*, 2017).

Phase I: Identify BN variables

We analyzed the literature of mass incidents in both English and Chinese journals and conferences and identified 12 factors that that play critical roles in the evolution process of mass incidents. These factors are captured as 12 BN variables (the second column in Table 1). In the previous study, we organized 3394 mass incidents in China from 1998 to 2016 (Huang *et al.*, 2017). Then we need to code this case library with the 12 BN variables and their discrete states, which is guided by the Grounded Theory (Glaser, 1978). The Grounded Theory is an inductive methodology for discovering themes or categories through qualitative analysis. We recruited 20 coders, who are graduate students with some understanding of emergency management. The 20 coders randomly selected 10 cases of our data and independently labeled each one. Then, the coders discussed the states of variables they generated and agreed on an assignment rule. This rule is used by all the coders in labeling the remaining 3194 cases. Finally, another independent coder sampled and reviewed the coding. At last, all 3394 cases were coded. The 12 variables and their states are briefly shown in Table 1.

Table 1. States of BN variables Set

Type	BN variables	States of variables
Background factors	Class of trigger events(C_1)	s1 Land dispute; s2 Project dispute; s3 Chenguan (city management officials); s4 Law-enforcement dispute (expect for those caused by Chengguan); s5 Accident; s6 Business issue; s7 Property dispute; s8 Local governance; s9 Labor dispute; s10 Industrial action (like taxi strikes and veterans' appeals); s11 Pollution; s12 Sport/party; s13 Flight delay; s14 Disaster; s15 Ethnic and religious conflict; s16 Looting
	Location (L)	s1 Village; s2 Town; s3 City
	Object of protest (O_1)	s1 Government sector; s2 Law-enforcement officer; s3 Public institution (like schools and hospitals); s4 Company; s5 Group (like football fans and gangs); s6 Person
Organization factors	Scene (S)	s1 in front of the government; s2 Street; s3 Open place; s4 Un-open place
	Relationship (R)	s1 Geo; s2 Families & friends; s3 Colleagues; s4 Spontaneous; s5 Group; s6 Student; s7 Comrades-in-arms
	Organization (O_2)	s1 Unorganized; s2 Organized
Process factor	Participant number (N)	s1 <10; s2 10-100; s3 100-1000; s4 1000-10000; s5 >10000
	Violence extent of group behaviors (V)	s1 Non-violent (like sitting quietly, putting out banners, and strikes); s2 Low-violent (like blocking roads, and disorderly conducts); s3 High-violent (like beating, smashing, looting, and burning)
	Police number (P_1)	s1 0; s2 1-10; s3 10-100; s4 100-1000; s5 >1000
	Police strategy (P_2)	s1 No police or no control measure; s2 Communicate; s3 Physical force; s4 Weapon; s5 Arrest
Result factors	Duration (D)	s1 1-2h; s2 2h-1d; s3 2-7d; s4 >7d
	Casualties (C_2)	s1 None; s2 <10 injured; s3 >=10 injured or >0 dead

Phase II: Construction of Bayesian Network Model

We randomly select 2545 cases in our case library as training data to learn the BN structure and parameters, and the other 849 cases are reserved for testing the effectiveness of the BN model. The ratio of training data to testing data is about 3:1.

Step 1: Structure Learning

To learn the BN structure with the K2 algorithm, *the ordering information* and *the maximum number of parent nodes* are needed. As mentioned before, we adopt ISM to obtain these messages. The specific procedures are as follows:

(1) Establish the influential relationship between any two BN variables from domain knowledge, which represents whether one variable leads to another. Figure 2 shows the interactions among various variables. There are 79 pairs of relationships needing to be evaluated.

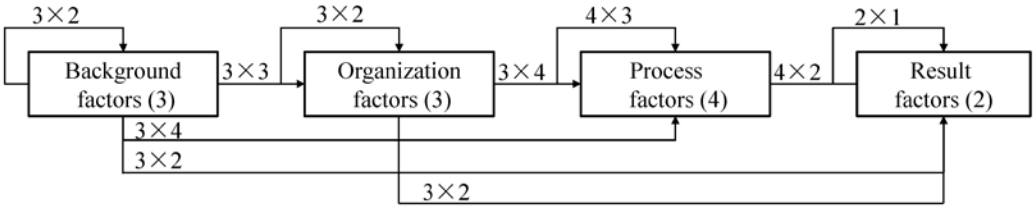


Figure 2. The Interactions among Various variables

The initial relationships are obtained from the findings in published literature. For examples, the location (L), relationships of participants (R), and organization (O_2) would influence the violence extent (V) (Xiao, 2014); the scenes (S) would affect the participant number (N) (Chen, Hong and Zhang, 2015). For those relationships that can be not found in the published studies, they are determined by consulting an expert in the public security system. For examples, given that the relationship between the police number (P_1) and the police strategy (P_2) is not clear, to make it sure, we ask the expert whether there is a relationship between P_1 and P_2; if yes, P_1 influences P_2 or P_2 influences P_1.

(2) Based on the influential relationships derived from step (1), we establish the adjacency matrix $\mathbf{A} = [a_{ij}]_{n \times n}$, which denotes the direct relationship between two elements.

$$\mathbf{A} = \begin{array}{c} \\ C_1 \\ L \\ O_1 \\ S \\ R \\ O_2 \\ N \\ V_1 \\ P_1 \\ P_2 \\ D \\ C_2 \end{array} \begin{array}{c} \begin{array}{cccccccccccc} C_1 & L & O_1 & S & R & O_2 & N & V & P_1 & P_2 & D & C_2 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

where

$$a_{ij} = \begin{cases} 1 & s_i \text{ is related to } s_j \\ 0 & \text{no relationship between } s_i \text{ and } s_j \end{cases}$$

Dimensions of this matrix, {C_1, L, O_1, S, R, O2, N, V, P_1, P_2, D, C_2}, correspond to those defined in Table 1.

(3) Calculate the reachability matrix $\mathbf{M}$, which denotes whether there is a connected path between any two

elements. $\mathbf{M}$ can be obtained by $\mathbf{M} = (\mathbf{A}+\mathbf{I})^{n+1} = (\mathbf{A}+\mathbf{I})^{n} \neq \mathrm{L} \neq (\mathbf{A}+\mathbf{I})^{2} \neq (\mathbf{A}+I)$.

(4) Partition $\mathbf{M}$ into different levels, which in our research is seven levels.

(5) Draw the direct links and derive the directed acyclic graph, shown in Figure 3.

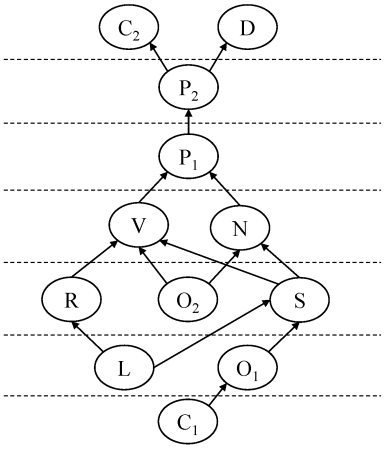


Figure 3. ISM model of Mass Incidents

The ISM model in Figure 3 has seven levels, from which we can infer the following information:

- The order of the nodes is *the class of trigger events* (C_1), *location* (L), *the object of protest* (O_1), *relationship* (R), *organization* (O_2), *scene* (S), *violence extent of group behaviors* (V), *the number of participants* (N), *police number* (P_1), *police strategy* (P_2), *the duration* (D) and *casualties* (C_2).
- Some nodes are not related to other nodes in the same levels, including L and O_1, R, O_2 and S, V and N, and C_2 and D.
- The max number of parent nodes is 10 (which equals the max parents number of D and C_2).

All this information is used as input to the K2 algorithm. Then we construct a BN structure through learning the 2545 training data cases. The result of the K2 structural learning is shown in Figure 4.

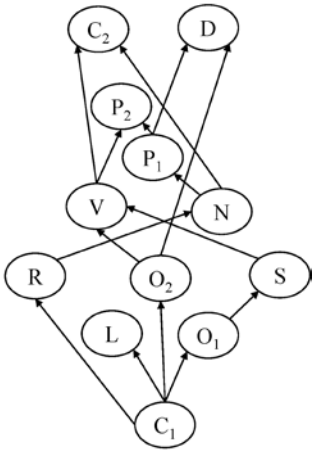


Figure 4. BN structure of Mass Incidents

Comparing Figure 4 with Figure 3, it can be seen that some connections disappear (e.g., the connection between the scene and participants number), while some new connections emerge (e.g., the connections between *organization* and *duration*), which indicates the discrepancy between expert cognition and the real cases.

Step 2: Parameter Learning

Based on the BN structure and the 2545 training data, we use the MAP (mximum a posteriori) algorithm with GeNIe 2.2 software (BayesFusion, 2017) to learn conditional probability table. The final Bayesian Network model is shown in Figure 5.

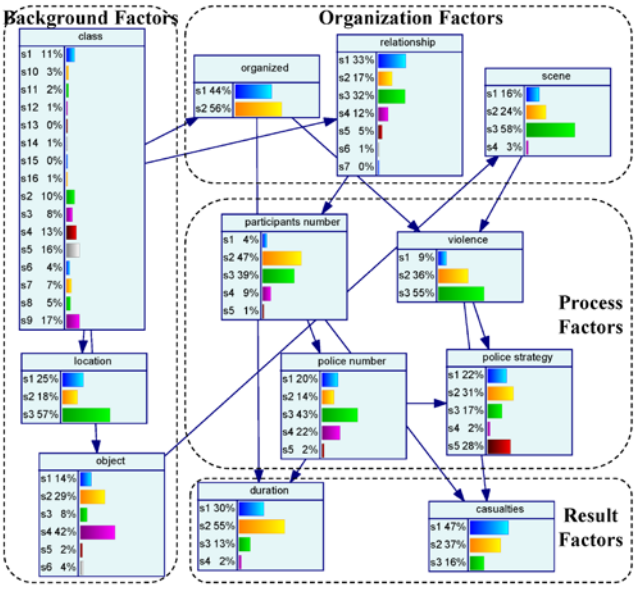
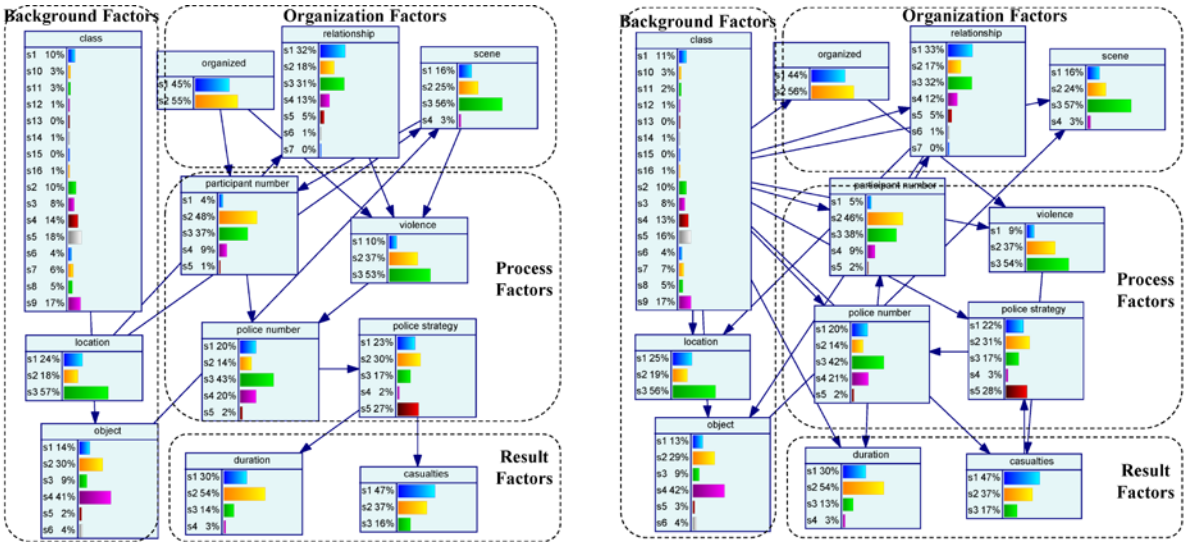


Figure 5. BN model of Mass Incidents (BN-ISM-K2)

Confirming the Choice of BN-ISM-K2 model

We would like to show that there is some benefit of choosing BN-ISM-K2 algorithm for learning the BN structure. For this purpose, we compare our BN-ISM-K2 model with two other models, including the logistic regression (LR), the BN constructed only by domain knowledge, and the BN constructed only by data learning with the Tree Augmented Naïve (TAN) algorithm (Friedman, Geiger and Goldszmidt, 1997). For convenience, we use BN-ISM to represent the BN learned only by domain knowledge from ISM model, BN-TAN to represent the BN learned only by data using TAN algorithm, and BN-ISM-K2 to represent the BN learned by our approach. Figure 6 shows the two base-line BNs where conditional probabilities tables are computed by GeNIe 2.2 software. The figure shows that BN-ISM and BN-ISM-K2 have similar topology structure, while BN-TAN is quite different.



(a) BN-ISM (b) BN-TAN

Figure 6. Base-line BNs of Mass Incidents

We also provided a comparison of the training performance and prediction performance of LR model and all these three BN models, as shown in Table 2 and Table 3. Performance is measured by *the level of casualty* of a

crime event since it is significant for characterizing mass incidents. We use predicted casualty to compare the performance of different models. The performance measures are overall accuracy (OA) of all casualties states, recall, precision, F_1 score and area under the curve of receiver operating matrix (AUC) (Hu, Tang and Qiu, 2015). OA is the proportion of correctly predicted instances among all of the data. Recall is the same as the true positive rate, which means the proportion of relevant instances that have been retrieved over the total number of relevant instances. Precision is the proportion of relevant instances among the retrieved instances. The F_1 score is the harmonic mean of the values of recall and precision. AUC equals to the probability that a randomly chosen positive instance is ranked higher than a randomly chosen negative one (assuming positive ranks higher than negative) (Fawcett, 2006).

Table 2. Training Performance of 2545 Cases

Model	OA	s1: none				s2: <10 injured				s3: >10 injured or >0 death			
		Recall	Precision	F_1 score	AUC	Recall	Precision	F_1 score	AUC	Recall	Precision	F_1 score	AUC
LR	0.68	0.79	0.78	0.78	0.80	0.74	0.60	0.66	0.73	0.24	0.54	0.33	0.60
BN-ISM	0.56	0.72	0.64	0.68	0.73	0.57	0.47	0.52	0.64	0.06	0.46	0.11	0.69
BN-TAN	**0.73**	**0.82**	**0.81**	**0.82**	**0.89**	0.76	**0.62**	**0.69**	**0.82**	**0.27**	0.57	**0.37**	**0.82**
BN-ISM-K2	0.68	0.77	0.80	0.78	0.83	**0.79**	0.59	0.67	0.78	0.20	**0.59**	0.30	0.79

Table 3. Prediction Performance of 849 Cases

Model	OA	s1: none				s2: <10 injured				s3: >10 injured or >0 death			
		Recall	Precision	F_1 score	AUC	Recall	Precision	F_1 score	AUC	Recall	Precision	F_1 score	AUC
LR	**0.72**	**0.80**	0.81	**0.80**	0.80	0.77	**0.64**	**0.70**	0.76	**0.28**	0.57	**0.37**	0.62
BN-ISM	0.58	0.73	0.65	0.69	0.72	0.60	0.49	0.52	0.66	0.05	0.35	0.09	0.66
BN-TAN	0.70	0.79	0.82	**0.80**	**0.87**	0.75	0.60	0.67	**0.81**	0.19	0.43	0.27	0.77
BN-ISM-K2	0.71	0.77	**0.83**	**0.80**	0.83	**0.81**	0.61	**0.70**	0.80	0.21	**0.59**	0.31	**0.78**

Comparing Table 2 and Table 3, firstly, it is obvious that BN-ISM performs worst in both training and predicting, which infers we cannot get a reliable assessment by relying only on expert knowledge. Besides, we can find that BN-TAN has the best training performance. However, for the prediction performance, it seems that BN-ISM-K2 and LR work better than BN-TAN. That is because when learning only from data, BN-TAN is easy to over-fit for the goal of a better fitting result.

In Table 3, it can be seen that for all test data, LR has the highest value of OA, followed by BN-ISM-K2, and BN-ISM has the lowest value. For events without casualties, BN-TAN has the highest value of AUC, and the followings are BN-ISM-K2 and LR. For events with less than 10 injured, BN-ISM-K2 has the best predictive performance, followed by BN-TAN, LR, and BN-ISM. For events with more than 10 injured or some deaths, BN-ISM-K2 with the obviously highest AUC and precision is the best mode. In general, BN-ISM-K2 performs best in predicting, especially for the mass incidents with heavy casualties. That is to say, in the early stage of mass incidents, BN-ISM-K2 can accurately determine the events that may lead to severe threats, which is important to emergency preparedness and response.

Phase III: Scenario Analysis and Threat Assessment

Critical Nodes Analysis

Identifying highly sensitive parameters allows for a directed allocation of effort to get accurate results of a BN model. In our research, we use sensitivity analysis to investigate the effect of small changes in prior probabilities on the posterior probabilities. Findings from such analysis can help law enforcement agencies to identify the critical nodes of severe consequences and make a advanced preparation for mass incidents.

GeNIe software provides sensitivity analysis based on an algorithm proposed by Kjaerulff (Kjaerulff and van der Gaag, 2000). In a nutshell, given a set of target nodes, the algorithm derives a complete set of derivatives of the posterior probability distributions for each node of the BN. If the derivative is large for a node P, then a small deviation in P will lead to a large difference in the posteriors of the targets. Otherwise, even large deviation in a node with a small derivative makes little difference in the posterior.

Figure 7. Results of Sensitivity Analysis about Casualties (The blue node means the target, the red nodes mean the most sensitive parameters, the light red ones mean less sensitive, and the grey one mean insensitive)

Figure 7 shows the results of sensitivity analysis about casualties. Nodes colored in red are the sensitive parameters. The most sensitive variable is the *violence extent*, followed by the *participant number* and the *class of trigger event*s. It can also be inferred that *violence extent* is sensitive to the *scene* and *organization*. These findings are consistent with the literature (Xiao, 2014).

In addition, if we want to identify the most likely situations of severe mass incidents, BN can help us with the *most probable explanation* (MPE). As shown in Figure 8, for a high-violent mass incident involving more than 10,000 participants with severe casualties, the MPE is that the class of trigger event is s3 (city management officials) or s5 (accidents), the location is s3 (city), the object of protest is s2 (law-enforcement officer), the scene is s3 (open place), the relationship is s4 (spontaneous), the organization is s1 (unorganized), the police number is s5 (more than 1000 police officer), the police strategy is s5 (arresting leaders), and the duration is s2 (2h-1d). In other words, for all mass incidents, the disputes caused by city management officials or accidents happened in the open places of a city, participated by unorganized spontaneous people are most probable to have severe consequences, and it is most likely to involve more than 1,000 police officers, with the strategy of arresting the protest leaders; the duration of these mass incidents is probably 2h-1d. These scenarios call for more attention.

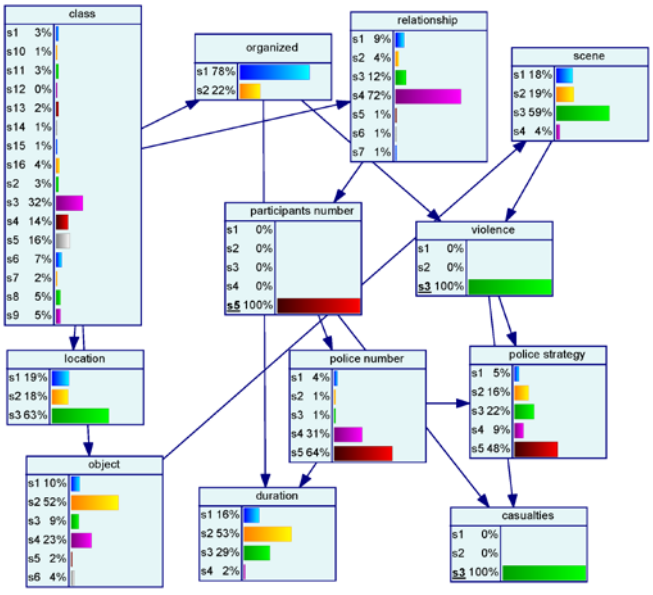


Figure 8. The Most Likely Situations of Severe Mass Incidents

THREAT ASSESSMENT

In this section, we will develop an example scenario to show how the BN-ISM-K2 model can be used to assess threats of mass incidents.

Suppose that there was a serious traffic accident in a town a while ago. The victim died on the spot, however, the perpetrator was very insolent and rude. A crowd of people block and blame the perpetrator. As shown in Figure 9, at the time t_1, police receive the alarm, and they only know that the trigger of the incident is an accident, the location is a town, the protest object is a person, and the scene is on the street. All these evidences are circumscribed with black strokes. At this time, the authorities want to know how many police officers should be dispatched. Suppose they have two choices, 5 or 20, which are circumscribed with orange strokes. Then we generate scenario S1-1 and S1-2 and calculate their corresponding posterior probability distributions. It can be seen that in scenario S1-1 (where police number is 5), the event is most likely to rest within 2 hours, however, in scenario S1-2 (where police number is 20), it offers a relatively high probability to last more than 2 hours. That is to say, at time t_1, the better decision is dispatching 1-10 police officers to the scene.

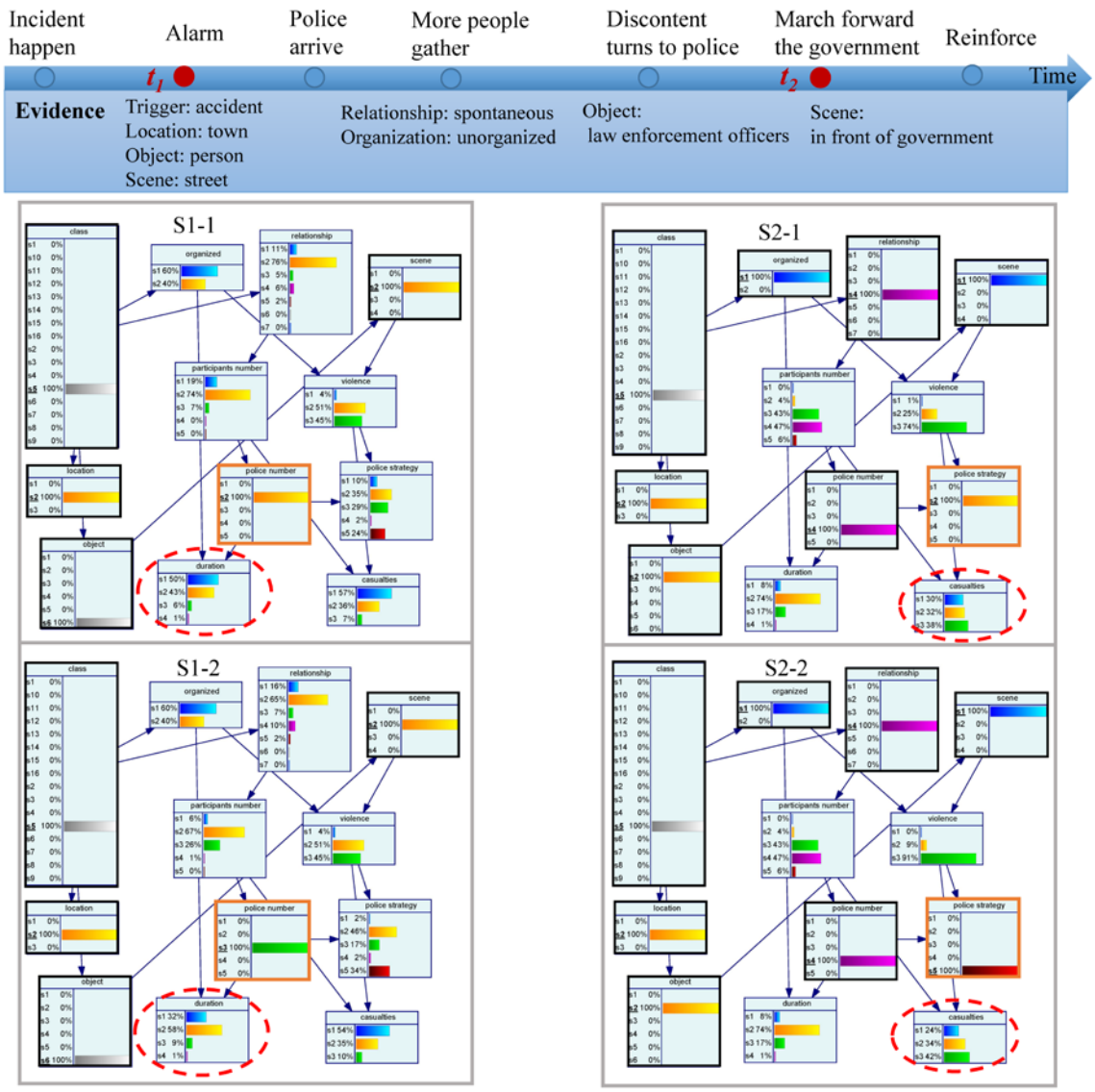


Figure 9. Scenario Inference of a Mass Incident Caused by an Accident (We use a black stroke to circumscribe the evidence, and an orange stroke to circumscribe the alternative policing. The different results are circled by the red dotted line.)

Then, as time goes by, more and more people gather spontaneously, and the five police officers could not

control the situation. The growing discontent of the crowd towards the law enforcement officers was gradually transformed into an intent to march toward the government. At the time t_2, the protest object becomes law enforcement officers, people are spontaneously unorganized, and the scene is in front of the government. Suppose that we would like to assess the consequence if the strategy is to dispatch 100 police officers to the scene. We generate S2-1 and S2-2 to compare two police strategies, communication (s2) and arresting protesters (s5). From Figure 9 it can be seen that S2-2 has higher probabilities to result in heavier casualties. That is to say, at time t_2, it is better for police to communicate and negotiate with the protesters rather than to arrest them.

Through above hypothetical scenario, we showed that our model can be used to assess potential threats of an ongoing mass incident. Law enforcement officers can update the BN model based on real-time evidences, generate possible future scenarios, and assess the nature and degree of threats given the choices of intervention strategies. Our BNSG framework has the potential to be implemented as part of a decision support tool that can provide support for their possible policing strategies.

CONCLUSION

Mass protests and similar incidents require careful design of response plans informed by threat assessment. Due to the complexity and uncertainty of modeling many interacting factors in the process of mass incidents evolution, formal approaches for threat analysis have been less successful. This paper extended the scenario-based method by a Bayesian Network knowledge representation and reasoning to propose a principled and scalable framework for analyzing threats of mass incidents. This BNSG framework features three aspects innovations: (1) we identified twelve driving factors of mass incidents evolution and represented them as 12 variable with different state values; (2) we constructed a Bayesian Network model for mass incidents scenario generation using domain knowledge (elicited from experts using ISM) and supervised learning from historical data; (3) among the twelve variables of our BN model, we found that "violence extent" and "class of trigger events" are the most critical nodes in the causal chain that led to casualties. The utility of our model is demonstrated through a case study on the threats of China mass incidents, where a BN model was trained using historical data and used to generate future scenarios as the basis for assessing the threat of an ongoing mass incident.

Our BNSG framework is flexible and effective in dealing with the complicated situation in the crisis preparing stage. Given some evidences of mass incidents, law-enforcement officers can implement it to generate possible scenarios, assess potential threats, explore the what-if analysis and compare different alternative intervention strategies. Besides, the BN model proposed in this paper is easy to can be updated with new cases extend with new BN variables, which means it has good expansibility and high availability.

Our approach still needs to be further refined before it can be applied in practice. First, the case library is compiled from contents of publicly available online news. Such data sources only provide partial descriptions of the stories in each case. We plan to enrich the descriptions of historical cases by incorporating other data sources in the future. Second, due to the limited time, the domain knowledge in the ISM construction is obtained from the literature and one expert, which may be influenced by the subjectivity of the expert. In subsequent work, we will consult more experts and integrate their opinions. Finally, we plan to build an interactive decision-support system that is enabled by our BNSG model and can be used by law enforcement agencies to conduct scenario-based planning.

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A Multi-Agent System for Studying Cross-Border Disaster Resilience

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ABSTRACT

Resilience to disasters depends on measures taken before, during and after the occurrence of adverse events. These measures require interactions between people belonging to different organizations (public, private, non-profit) and citizens in normal and stressful situations. The efficiency of resilience measures results from the collective interaction of individuals, groups of individuals, and organizations, as well as the situational characteristics of the decision environment. The aim of the French-German research project INCA is to develop a decision support framework for improving cross-border area resilience to disasters. This project comprises the design and the implementation of a multi-agent system with the objective to study the behavioral and organizational implications of cross-border cooperation for crisis management and disaster resilience. The analyzed measures focus on citizens who require medical support and the integration of volunteers into the crisis management procedure. This paper outlines the potentials of the multi-agent system and provides first implementation insights.

Keywords

Multi-agent system, disaster resilience, coordination procedures, cross-border cooperation, volunteer management

INTRODUCTION

In spite of the trend towards urbanization, there is an increasing susceptibility of cities to crisis events due to their dependency on critical infrastructures as well as an increased exposure to natural disasters. However, crisis events such as epidemics or local natural disasters do not stop at national, geographic, political or cultural borders. It is therefore extremely important to develop cross-border concepts for resilience and crisis management. Since March 2017, a consortium of French and German researchers is focusing on the issue of cross-border resilience in the context of the research project INCA. The objective of the INCA-project is to develop a decision-support framework for improving cross-border risk and crisis management operations for the context of a long-lasting power blackout. A special focus of the research agenda is on the issue of cross-border cooperation facing the challenges of intercultural communication and inter-organizational coordination. The improved crisis management procedures should comprise the integration of volunteer helpers on both sides of

the border to achieve a better and faster treatment of medical dependent people ("disaster victims"). Considering the individual and collective behavior of involved actors on an individual, organizational and country level constitutes an intricate challenge. From an analytical point of view, this task is accomplished by a multi-agent system, which makes it possible to depict, simulate and analyze the collective interaction of various actors in dynamic crisis. Multi-agent systems are powerful tools when it comes to the analysis of the collective and dynamic behavior of a large number of distinct "types" of decision-makers. The emerging patterns of behavior are difficult to capture. In most cases, they are even intractable for standard decision-making approaches or game-theoretic models. The aim of this paper is, thus, to give an insight into the basic structure of the multi-agent system of the INCA-project, to present some preliminary simulation results and to discuss further steps and prospects. The remainder of the paper is organized as follows: In the next section, we give a brief account on the concepts of cross-border resilience and culture and provide a short introduction on multi-agent systems. After that, we introduce the INCA simulation framework, describe the basic structure of the multi-agent system for disaster resilience, and we present first simulation results. In the last section, we briefly discuss the preliminary insights and the prospective potentials of the model.

CROSS-BORDER RESILIENCE, CULTURE AND MULTI-AGENT SYSTEMS – A BRIEF ACCOUNT

Cross-border resilience, culture and communication

Resilience is an integrative concept, which became prominent in science and on the political agenda. It encompasses two main ideas: a response to stressful events and the sustainability of systems when coping with stressful events (Reich et al. 2010). At a geographical level, the United Nations define resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR 2009).

The capacity of a region to withstand disasters depends on five factors (Boin et al. 2011): disaster risk assessment, disaster risk mitigation, disaster preparedness, disaster response, and disaster recovery. Risk assessment refers to the identification, analysis, and evaluation of potential disaster risks and vulnerabilities. Risk mitigation and prevention refer to actions that reduce the vulnerability to disasters. This includes measures that reduce causalities, disruptions, and exposure to damages as well as measures that provide passive protection. Disaster preparedness refers to measures that bolster emergency response capabilities, including warning systems, evacuation routes, supply chains and communication procedures (decision-makers must implement these measures before a disaster occurs). Disaster response refers to measures taken immediately before, during, and after a disaster to save lives, to eliminate or at least to minimize damages. Disaster recovery includes short-term activities, that restore vital support systems as well as long-term activities to rebuild physical, social, and economic infrastructures.

Regional disaster resilience relies on the interaction of public, private, and non-profit organizations among themselves and on the interaction between these organizations and the community. These interactions face a significant amount of obstacles - especially in cross-border regions. Therefore, it is mandatory to assess the specific characteristics of borders. In general, geographic borders are "line[s] on a map" (Agnew 2008). They not only separate geographic areas, but also political systems, economic systems, cultures, values and norms. Geographic borders are not always tangible: they can be natural structures (mountains, rivers, seas, etc.), artificial structures (walls, meridians, etc.), or mental borders between different cultures (Guo 2015). Although cross-border regions have been empowered in the past, their vulnerabilities to disasters remain. Especially, in times of increasing natural and man-made disasters, it becomes ever more important to improve disaster resilience across borders (Adrot et al. 2018).

Cultural differences may have an impact on people's collective behavior and thus on the disaster resilience in cross-border regions. In 1871, Tylor, a social anthropologist, defined culture as the "complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of a society" (Tylor 1871). In 1953, Jacques, a sociologist, proposed one of the first definitions of organizational culture. According to Jacques (1952), organizational culture is the "customary and traditional way of thinking and doing of things, which is shared to a greater or lesser degree by all its members, and which new members must learn, and at least partially accept, in order to be accepted into service in the firm". Since then, scholars identified different cultural factors of variability. This includes, inter alia, uncertainty avoidance, long-term versus short-term orientation, individualism versus communitarianism, achievement versus ascription, sequential time versus synchronous time, degree of the importance of the context in communication, task based versus relationship based trust building, or different forms of time management (e.g., Hofstede et al. 2010, Trompenaars & Hampden-Turner 2012, Meyer 2015).

A classical definition of *communication* is: "the definition of a *message* by a *sender* with some *intentions* transmitted to *receivers* by the mean of a communication *channel* where *noise* can affect negatively the performance of the communication process" (Shannon & Weaver 1949). With the concept of *feedback* (Wiener 1948) the role of sender and receiver can be interchanged and positive or negative feedbacks amplify or attenuate the communication process. Sender and receiver shared a *context* and a *code* for generating and understanding *messages* (Jakobson 1965). Hymes (1974) extends the model by considering various attributes as the *setting and the scene* (when and where the communication process takes place), the *ends* (referring to purpose, goals and outcomes of the process) the *act sequence* (corresponding to the form and the order of the process), the *keys* (describing tone, manner or spirit of the exchange of messages), or the *norms* (related to social rules governing the communication process). Newcomb (1953) associates communication with social relationships and derives the hypothesis that communication process supports the equilibrium between the sender, the receiver, and a topic. In the context of cross-border communication, it is necessary to extend these models by dimensions as language or culture for the sender and the receiver.

Multi-agent systems

Multi-agent systems are computational models, developed for the simulation of actions and interactions of autonomous agents in order to assess their behavioral impact on a particular system. The concept of an agent is central to this approach. An agent is an encapsulated computerized entity that is situated in an artificial environment. It is capable of carrying out flexible, autonomous actions in that environment in order to meet its design objectives (Jennings 1999). Agents represent heterogeneous groups of discrete individuals, which are autonomous, self-directed, and able to interact. Furthermore, agents can store resource attributes, they are adaptive to their environment, and they have goals that drive their behavior (Macal 2009). The program code itself represents the processes that the modeler thinks how they exist in the real world (Macy & Willer 2002). Multi-agent systems provide concepts, methodologies and tools for specifying, designing, and engineering software for autonomous and/or distributed acting entities. This allows the simulation of complex individual and social behavior.

Various decision frameworks for disaster management, such as the decision support system VESTA, developed by Kamissoko et al. (2014), already exist. They take into consideration that decision making in the case of an emergency is more complex than under "normal" circumstances while focusing on vulnerability calculations. Multi-agent systems are suitable for disaster management analysis because they allow decision-makers to analyze complex dynamic situations without global information by simulating different types of agents with various characteristics. In the following, we outline some existing agent-based models for a disaster context: Joo et al. (2013) compare various evacuation strategies for warehouses in the event of a fire. Aldewereld et al. (2011) analyze efficiency differences between individually operating and hierarchical organized emergency management teams. Fikar et al. (2017) simulate the impact of transport disruptions. Moreover, Crooks & Wise (2013) analyzed the Haiti earthquake of January 2010 by using crowdsourced GIS data. The authors explored how people react to the distribution of aid as well as how rumors relating to aid availability propagate through the population. In their model, agents are equipped with an energy level, which allows them to move only predefined distances without refilling their energy. These energy levels represent the health of an agent and therefore simulate human needs, such as food, water, and rest. Cross-border coordination problems and the potential of the integration of spontaneous volunteers were not analyzed in the literature yet.

THE SIMULATION FRAMEWORK

We developed a basic simulation framework based on a multi-agent system in order to study characteristics of cross-border disaster resilience. This framework consists of four components:

- A methodological *guideline*: This component provides support functionalities to users as defining the context of their simulation, defining the required data set for their simulation, defining their simulation sessions, and visualizing as well as analyzing their simulation results.
- Simulation *editor*: This component provides editing and visualization functionalities to users for the definition of input parameters for the simulations. Parameter sets describe cross-border characteristics, disaster scenarios and resilient management use cases (e.g. search and rescue).
- *Simulator*: This component provides functionalities for conducting simulation sessions of use cases. By modifying key variables, individual and collective behavior is generated and visualized as well as consequences of agents' decisions-making processes and tasks.
- Results *visualization* and *analysis support system*: This component provides functionalities for the visualization and interpretation of simulation results and for generating simulation reports.

The model is implemented using the multi-agent system toolkit *Repast Simphony*. This toolkit is written in the *Java* programming language and belongs to the *Repast Suite*, a family of free and open-source agent-based modeling and simulation toolkits (North et al. 2013). The definition of the multi-agent system is based on the *Gaia* methodology for agent-oriented analysis and design (Wooldridge et al. 2000). *Gaia* is a conceptual framework, which allows specifying and designing models and software using the multi-agent system paradigm.

Aims of the multi-agent system

The multi-agent system aims to support the simulation of individual, collective, and organizational behavior in the context of disaster resilience management. It considers effects of the presence of a border, such as cultural biases, communication problems and regulatory issues. Furthermore, the presence of the border can affect technical skills of emergency operations (such as search and rescue or evacuation) and non-technical skills (such as decision-making processes, tasks planning and realization, communication and coordination processes, conflict management, stress and fatigue management, or situation awareness). The simulation illustrates a borderland territory with two countries separated by a physical border - a river - with only one passage – a bridge - as a connection between the two countries. This passage can be opened and closed to control the exchanges of health infrastructures or the mobilization of volunteers. Furthermore, the model considers variation in the health status of the victims. Depending on this status, the victims' diagnostic, transport and care will require specific competences and technological requirements. A set of performance indicators related to the efficiency of tasks and to the quality of the management of victims is implemented to study impacts of the variability of borderland resilience and the performance of cross-border crisis management operations. Additionally, effective coordination of spontaneous volunteers in the cross-border setting will be analyzed.

Multi-agent system design

The model considers three types of agents: *passive agents* that have properties but do not behave autonomously, *reactive agents* that perform roles when receiving signals from other agents or from the environment and *self-finalization agents* that behave autonomously and intentionally according to their objectives and to events occurring in the environment. Passive agents are characterized by a set of attributes, which can be modified by the actions of reactive and self-finalizing agents. Reactive agents are characterized by a set of attributes and a set of roles triggered by signals coming from the environment of other agents. The consequences of the execution of specific roles depend on the agent's attributes, on the attributes of the environment, and on other agents' reactions. Self-finalizing agents have belief attributes (related to their environment or other agents) and cultural attributes (related to individual, collective, organizational, and national specificities influencing their behavior). They dispose of knowledge and the ability to perform tasks. A specific set of roles can be performed under conditions associated to their identity or organizations they belong to. The following classes of agents are realized:

Victims are instances of passive agents. A variable describes their health and state of injury representing three levels: extremely injured, slightly injured, or not injured. This state variable is initialized by a uniform distribution over an interval corresponding uniquely to the level of injury. It constantly decreases over time except that compensating measures are taken, such as getting food or receiving a specific medical treatment. If the value is equal to zero, the agent dies (see Crooks & Wise 2013). Depending on their health status, agents can move or have to be transported to a hospital. Furthermore, dynamics in the decrease of energy levels are subject to the agents' attributes. For example, the health status of special needs and elderly persons decreases faster than the health status of young adults.

Volunteers are instances of self-finalizing agents. They adapt their behavior according to their energy status and motivation (on an "altruism"-spectrum starting with "no specific motivation to help" via "search and rescue of relatives and acquaintances" up to "search and rescue of unknown citizens"). So far, two kinds of volunteers are specified: Those who engage in terms of neighborhood help ("volunteers") and those without any motivation to help ("no volunteers"). The effectiveness of their engagement depends on external events occurring in the environment, on their abilities, and on the interference with other agents.

Ambulances are instances of reactive agents. They receive the instruction to search, diagnose, transport, or eventually treat victims. They are characterized by a status of occupation, a target, transport capacities (restricted by both - a maximum number of victims and a maximum distance), and a technical status (traditional versus advanced health management capacities).

Hospitals are self-finalizing agents. Hospitals have a fixed location and a set of capacities including available competencies, medicine, specialized material, and bed capacities. The latter variable varies depending on the number of victims arriving at one hospital. Subject to the evolution of these variables, the hospital can decide to cooperate with other hospitals.

Search and rescue coordinators are self-finalizing agents. Their target is to allocate ambulances and volunteers in the most efficient way to search and rescue victims and to transport them to hospitals. The feasibility of the solution results from the consideration of dynamics in the environment (e.g. opening of the border, increase of the number of victims, availability of hospitals). However, hospitals' reaction time can increase (e.g. due to a delay of available information updates or due to stress), which can result in difficulties of the emergency coordination.

Multi-agent system roles and protocol

The list of roles and protocols of the multi-agent system was established in accordance with the *Gaia* methodological framework. An initial list of roles has been identified related to the management of victims, the management of volunteers, and with respect to cooperation between health organizations:

- Roles associated to victims' management are: coordinate search and rescue, search of victims, diagnose victims' health status, transport victims, and treat victims. These roles include organized search strategies initiated by a coordination center, professionals and volunteers with medical or logistical competences, and equipment for transport and care. This also includes spontaneous volunteers searching, providing first aid, and transporting victims to hospitals.
- Roles associated to the management of volunteers are: register volunteers, assign tasks to volunteers, coordinate with professionals, and monitor volunteer activities.
- One role is associated to cooperation between health organizations that reach their maximum capacity: transfer victims from one organization to another.

Associated to these roles, a set of protocols are implemented which define exchanges between individual agents and between individual agents and organizations:

- The purpose of the "search for victim"-protocol is to structure the organized search and rescue process of a group of victims. This protocol is initiated when rescue agents receive a message related to a set of victims in a given area, which is subject to coordinated search and rescue procedures. Agents in charge of victim search, transport, and treatment are part of this protocol. Input of the scenario is a group of victims with diverse levels of affectedness (injuries or illness) in a given area. Output is the same group with a final level of affectedness. During the course of actions, there is communication between agents about the identification of victims, about the results of their health and injuries diagnostic, and about the used or available transportation modes.
- The purpose of the "volunteer management"-protocol is to organize the realization of a set of tasks by a group of professionals and volunteers. The protocol is initiated when search and rescue tasks require volunteer support and volunteers are available. Participants are professionals-agents and volunteer-agents which all follow the standard rescue procedure (search, diagnose, transport, care). The input is a group of tasks to perform. The output is the same group of tasks assigned to agents (professional or volunteers). The course of actions is composed of requesting availabilities for personal and volunteer agents, assigning suitable tasks to them by considering their competences and preferences and taking decisions to achieve a final schedule of tasks. These decisions include the possibility to assign tasks to a group consisting completely of professionals, to a group consisting completely of volunteers or to a group mixing professionals and volunteers together. Additionally, a precise schedule of tasks within the groups has to be communicated.

PRELIMINARY SIMULATIONS

The multi-agent system is designed to study the behavioral and organizational implications of cross-border cooperation for crisis management and disaster resilience in response to a long-lasting power blackout. Due to this objective, the simulation has a high level of abstraction and the root cause of the disaster - the long-lasting power-blackout - is modelled indirectly. Focusing the health dimension of the model, we are primarily interested in the number of victims specified by their degree of injuries and by the time required to guarantee an adequate treatment. Since these states are not predictable, we apply scenarios to achieve a robust treatment strategy. Hence, the simulation captures the degree of injuries by the mentioned energy levels and the time period within which a person turns to a victim, differentiating between short-term victims and victims who are affected over a longer time period. In the real world setting, short-term victims are for example persons trapped in an elevator or persons having an accident due to traffic light failures. Over time, the number of victims will grow for example due to the lack of water and food supply. These specific triggers are not explicitly represented in the simulation due to the level of abstraction. The number of short-term victims is difficult to forecast from the point of view of civil protection agencies whereas vulnerable groups of society (e.g. special needs or elderly people) represent a more stable group of potentially affected victims.

The multi-agent system is implemented using the *Repast Simphony* toolkit. So far, a cross-border region with two bordering countries is modelled. The countries are separated by a physical border: a river with only one bridge across. Three cities are located in the modelled territory, two on one side and one on the other side of the border. Each city has one hospital and there are five ambulances available at each hospital. We assume a uniform distributed population for the rural area. Additionally, a uniform distributed population with a higher population density is given for each city. It is assumed that a disaster occurs, which randomly affects the population equally on both sides of the border. The simulation starts by the exogenous event of a power-blackout but technical details leading to the failure are not within the scope of the model. Hence, the system is initialized (T0) and agents take one out of three possible states of injury: extremely injured (red colored agents in *Figure 1*), slightly injured (violet colored agents in *Figure 1*), or not injured (white colored agents in *Figure 1*), which is uniquely indicated by the actualization of the energy variable. Thereby short-term victims are modelled. With each discrete time step, the time-dependent variables of agents and environment are updated. Decreasing levels of energy thereby model an increasing number of victims over time. Agents who are not injured can decide to volunteer. Depending on their motivation, they either bring neighboring persons in need to a hospital (if they do so, they get a yellow color in the picture of *Figure 1*) or they do not volunteer (then their color remains white). The white arrows in *Figure I* illustrate the correspondence of a victim with an ambulance or voluntary helper. In a first set of simulations, two states of the border are implemented: the border can either be closed (with no access from one side to another) or opened (allowing volunteers and ambulance to cross the border). *Figure 1* illustrates the dynamics of the model. The picture on the left shows a situation of search and rescue with suppressed cross-border activities. Ambulances on each side of the border collect victims in star-shaped routes around the hospitals. Here, the movement range of agents is concentrated on a limited areal. The picture on the right shows the same model with the only modification that cross-border collaboration is allowed. Agents can pass the border at one fixed point (a bridge over the border river) so that the cross-border activities concentrate around this point. The access to the neighboring areal increases the overall variation of distances and directions.

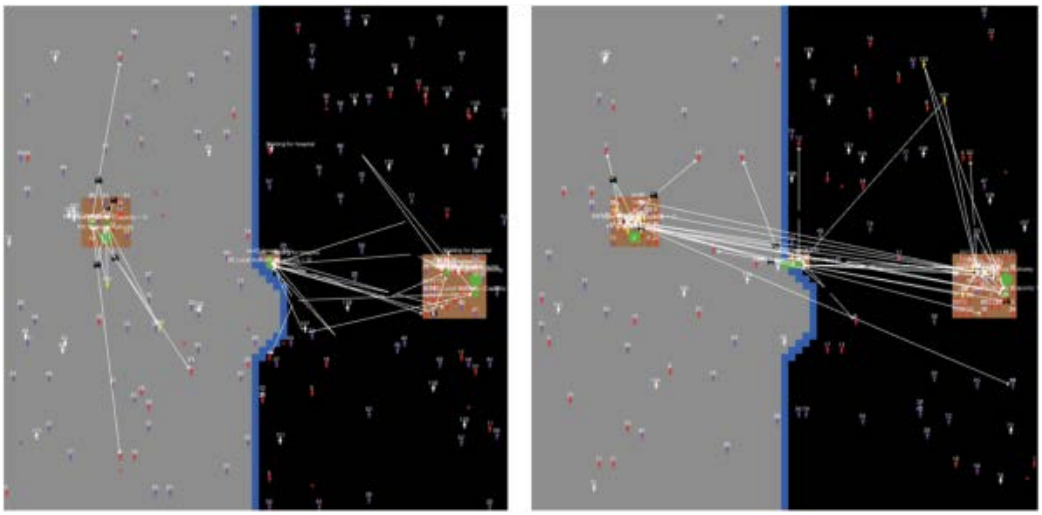

Figure 1. Illustration of the dynamics comparing cross-border cooperation disabled and enabled

The variation in the health status variable of the victim-agents is registered through the variable tracking functionalities provided by *Repast Simphony*. *Figure 2* presents the increasing number of dead agents (due to limited capacities in health facilities) as well as a decreasing number of volunteers (due to fatigue and decreasing resources) over time. The number of extremely injured people decreases in the first period due to the activities of health facilities, but increases later since minor injuries that are not treated increase to extreme injuries (due to limited capacities, health facilities have to prioritize). The red curve indicates the number of slightly injured agents. It increases at time T30 since agents fall into this category after they were released from the hospital. The subsequent decrease is caused by minor injuries which are not treated and therefore extend to extreme injuries.

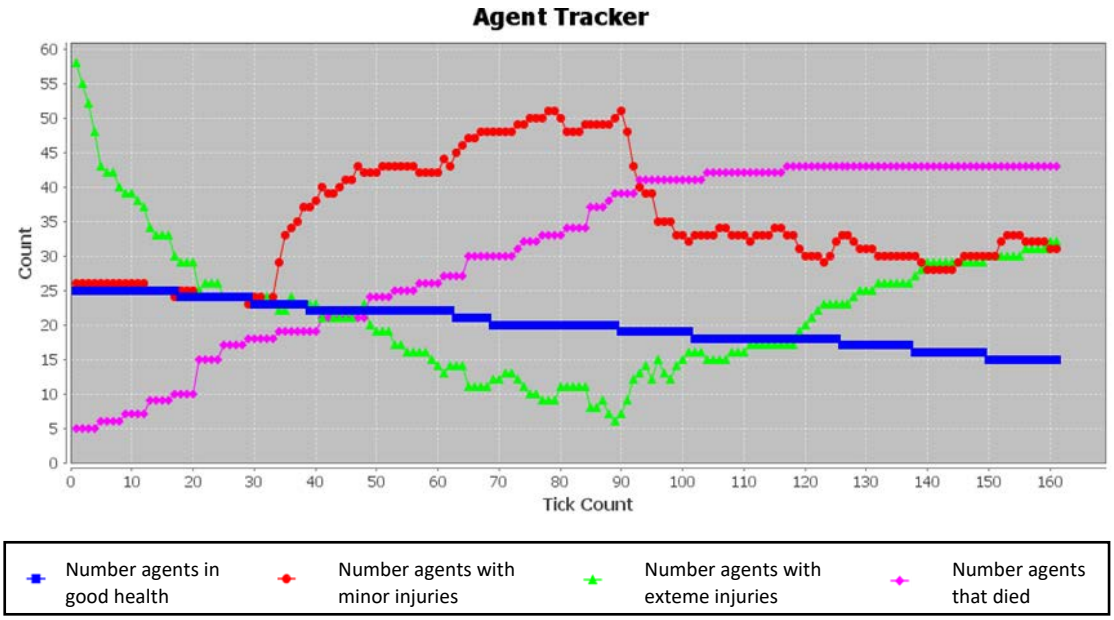

Figure 2. Illustration of the dynamics of the agents' status

This first round of simulations demonstrates the potential of the basic model to describe and analyze collective and partly coordinated rescue activities in a cross-border region. The first realizations are characterized by strong assumptions, such as perfect information flows and optimized actions. Ambulances and volunteers know the available capacities of the closest hospital and can bring victims on the shortest path to the best suitable hospital. In case of an open border, the perfect information flows and optimized actions spread to the whole area without facing any difficulties in terms of language, culture or law. In a more realistic scenario of a power-blackout, long-distance communication via telephone or mobile phone is strictly limited which will complicate the coordination procedures. Hence, we address different scenarios in the agent-based model in order to derive suitable procedures. The external validity of these assumptions will be checked, too.

FURTHER STEPS

Considering culture in the communication process

The ongoing process aims at the implementation of inter-agent's communication strategies. To describe the nature of communication, we use a set of key concepts deducted from a literature review as indicated in the corresponding section. These key concepts offer a structure to the model of communication, which will be extended for our considered cross-border studies by personal traits of the sender and the receiver. Bowles & Gintis (2004) analyzed trust and exclusion in ethnic networks, analyzed communication difficulties between individuals of various trait types, and derived a trust equilibrium. In order to transfer these ideas, a network will be implemented such that each agent is represented by a node. Two nodes are connected by an edge, if the two agents corresponding to these nodes know each other. The relationship of two agents can be indicated via weights on the connecting edge between these agents. Additionally, the model yields the possibility to equip each agent with a personal vector representing the "character" of the agent. In our context traits as ethnicity, language and cultural characteristics are of special interest since these characteristics will either complicate or simplify communication. Differences in the personal vector of the sender and the receiver can result in delayed information via misunderstandings and even lead to complete failure of communication. The more similar these personal vectors of the sender and the receiver are, the easier and more reliable communication will be. Hence, the expected probability of successful communication increases. The case of perfect communication - which is already implemented - corresponds to identical trait variables in the personal vector. In order to quantify a "degree of similarity" in this context, the authors will apply the concept of *expected communication difficulty* defined by Bowles & Gintis (2004). It is planned to study the impact on communication for various trait types. Another challenge is the assessment of the communication efficiency. The concepts of good and bad communication need to be investigated and a qualitative scale has to be developed that allows the visualization of communication performance.

Increasing degree of realism and complexity of the model

With an increasing degree of realism - and thus complexity - of the model it is important to up-scale the technical capacities of the model simultaneously. For that purpose, a set of refinements and extensions needs to be defined.

The first set of refinements and extensions relates to the model itself:

- The geographical model can be more realistic. Spatial, topological, and demographic dimensions could be enhanced as well as critical infrastructures interdependencies. However, this requires the selection of an example region in a first step.
- Furthermore, the diversity and complexity of the border can be increased with respect to several aspects. Different typologies of borders have to be considered by the model as well as – which is one of the main upcoming tasks - the sociological dimension of the cross-border region.
- It is possible to give a more detailed description of the disaster itself. For example, the dynamic features of the model provide the opportunity to considerate complex disaster scenarios that comprise phases like propagation and escalation.

A second set of extensions relates to the software:

- A far-reaching but highly interesting extension is the definition of interfaces with cross-border regions, disasters and simulations editors. For this objective, the software should be able to integrate editors, that provide relevant input models. Furthermore, the software has to be able to import models with a standardized language.
- A specific interface to monitor simulations can be defined. The simulation above includes a very basic set of target values and key performance variables which can be extended to more sophisticated performance indicators such as vulnerability measures or resilience indices. With an increasing number of variables, it becomes more practical to develop an associated simulation interface that allows these variables to be modified.
- A specific interface could be developed for the visualization of the results as well as an interface presenting the tracked variables.

SUMMARY AND OUTLOOK

Enhancing the understanding of disaster resilience of a cross-border region is a challenging task. In this paper, we gave an overview of the multi-faceted concept of cross-border resilience and presented a preliminary draft of a multi-agent system which is designed to depict and analyze the behavioral dynamics of key actors during a crisis situation. The model has been designed and implemented using the *Repast Simphony* toolkit. The outlined simulation focused on rescue operations carried out by volunteers and professional rescue units. First insights with respect to the evolution of different types of victims, their degree of affectedness and the motivation of volunteers – both with and without a separating border – were discussed.

It is quite clear that this basic version is still based on a very high a degree of simplification which is unavoidable for a first set-up. In principle, it is a good practice to follow the “from simplicity to complexity”-rule for modeling tasks in order to keep track of the model’s mechanisms from the very beginning. However, it is an ongoing work and the model will be refined and continuously approached to the relevant properties of the behavioral characteristics of agents as well as the driving factors of the “real” environment. In this respect, a number of refinements, extensions and technical requirements were listed. As mentioned above, the dimension of culture (e.g. on an organizational and country level) as well as the specific characteristics of crisis communication in all interesting directions (within and between organizations, among volunteering helpers and between organizations and volunteers) will play a key role in the future.

While focusing on culture, the authors of this contribution also seek to shed light on an issue which is often overlooked when analyzing cross-border phenomena: In cross-border regions, the borders do not just have a separating function creating an obstacle for cooperation. Cross-border regions are not just separated by culture but they also created their own culture and “cross-border identity”, which is sometimes even rooted more deeply than the respective “national cultures” (Adrot et al. 2018). Therefore, the multi-agent system has to be complemented on an empirical ground, which has to be accomplished by both intense social research and data acquisition. In this regard, the research agenda of the INCA-project also comprises surveys, interviews, and experiments.

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Evaluating Strategies for Intra-Organizational Information Management in Humanitarian Response

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ABSTRACT

Information management is critical in humanitarian response, yet intra-organizational information management practices have not been well-studied. This paper evaluates several strategies for intra-organizational information management. An agent-based model represents the dynamics of information-gathering and -sharing, in order to examine the impact of each strategy on (1) the time required to acquire adequate information for decision-making and (2) the amount of excess information acquired in the process. The results show that holding regular information-sharing meetings significantly reduces the time to acquire adequate information, but does not reduce information overload; however, deploying an information management specialist reduces both time required and information overload. Other strategies enable smaller improvements. The results support recommendations for humanitarian organizations deciding how to improve their internal information management approaches. As the role and importance of humanitarian information management is expanding and changing rapidly, our results are a timely contribution to both inspire further research on intra-organizational information management and to support practice decisions as organizations design their own information management strategies.

Keywords

information management, agent-based model, intra-organizational, humanitarian

INTRODUCTION

In the first days following a disaster or emergency declaration, humanitarian organizations scramble to understand the size, scope, and impact of the event, in order to support critical decisions about how to respond. In these contexts, information is scarce and rapidly changing, due to infrastructure damage and fast-moving events. Organizations spend significant time and resources to understand what the needs are following the event so as to shape their response efforts. (Gralla et al. 2013; Digital Humanitarian Network, Decision Makers Needs Community and UN OCHA 2013. The problem of how organizations decide to manage their information is highly relevant, not just for the strategic resource deployment that hinges on this decision, but also because the operational decisions that are made using situational information- such as the appropriate locations for medical clinics- are critical to the effectiveness of the subsequent response and recovery.

Information management is both critical and challenging in humanitarian response (Schryen et al. 2015; Comfort 2007; Altay and Labonte 2014). Information must be diffused as quickly as possible to enable time-sensitive

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decisions, but practitioners also bemoan the "fire hose" effect when they must handle vast amounts of information, overwhelming their capacities to determine what is useful information and what is superfluous to their specific tasks but important for the overall response (Altay and Labonte 2014; Bui et al. 2000).

In practice and in research, humanitarian information management is receiving increased attention, especially information-sharing across organizations. The Office for the Coordination of Humanitarian Affairs (OCHA) typically coordinates information and response efforts (IASC Working Group 2008), and studies have examined barriers to and strategies for effective inter-organizational information management and coordination (Altay and Pal 2014; Faraj and Xiao 2006; IASC 2010, e.g.,).

However, humanitarian organizations are increasingly standing up their own information management (IM) teams to assist in funneling useful information to their field teams to assist in planning, situational awareness, and decision-making (Surge Information Management Support 2014; NetHope Inc. 2017; Pham 2016). This relatively new organizational function in humanitarian organizations, and the various strategies used to accomplish this work, has not yet been explored in the literature, despite work that looks at inter-organizational information management strategies.

This paper uses an agent-based model to analyze various strategies for intra-organizational information management, in order to identify how each of these strategies contributes to humanitarian team members' faster task accomplishment. We consider six strategies that are either employed in practice or recommended by other studies: (1) increasing willingness to share information with other agencies; (2) holding meetings to share information; (3) deploying an IM specialist; (4) deploying an IM specialist with a remote team of IM support specialists; (5) improving the quality of the IM specialists' work; and (6) varying the frequency of information-sharing meetings. Our agent-based model builds on Altay and Pal's framework and updates the scenario to reflect the recent focus on intra-organizational information management.

BACKGROUND AND RELATED LITERATURE

Information management (IM) is acknowledged as an important part of humanitarian response (Christopher and Tatham 2014; Tomasini and Van Wassenhove 2009).Organizations understand that information can improve the efficacy of humanitarian operations (Schryen et al. 2015; Comfort 2007). However, historically, individual organizations have not had a specific IM function on their teams. The cluster system has provided information management support to the response community for a number of years, serving as an information hub for the overall response as well as for individual sectors such as water and sanitation or nutrition (UN OCHA 2017).

To support the humanitarian community's focus on coordination through information-sharing, studies have investigated the benefits of various strategies for information management. In particular, Altay and Pal evaluate the value of two strategies in speeding up information diffusion in a response: employing an information hub (which represents the information management function of the clusters) and improving inter-organizational trust. Their findings support the assertion that clusters can help diffuse information more quickly, but they found that the willingness to share information between organizations was the greater determinant of rapid information spread.

In addition to inter-organizational IM, information management happens within organizations as well. While OCHA leads on the coordination of information between actors, much of the information they coordinate originates from individual operational organizations (Verity et al. 2014). Some of the most important coordination information consists of which organizations are doing what in which parts of the affected area. These commitments can only be shared for wider distribution among partners *after* individual organizations have made those decisions internally, based on their own process of evaluating information and determining where their organization will work and in what capacity.

Internal IM is therefore critical to the success of each organization's response and to the coordination of the response overall. Theory supports the importance of improving internal information management: Faraj and Xiao argue that an organization working in fast-paced, high-stakes environments must practice knowledge coordination in order to manage and effectively apply distributed expertise. It is not clear whether the internal barriers to information management are similar to the barriers to inter-organizational information management.

Low willingness to share was identified as a key barrier for inter-organizational information sharing (Altay and Pal 2014), but is less likely to inhibit internal IM, except when information originates outside the organization. Other barriers, such as "information overload", when huge amounts of information start becoming available (Bharosa et al. 2009), are likely to be equally challenging for internal and inter-organizational information management. Internal information management requires investment and attention to information-sharing and -management

practices within the organization, which is difficult for reasons ranging from a lack of understanding the benefits of information coordination to a lack of available resources.

IM functions are now being stood up within operational organizations in some contexts (Surge Information Management Support 2014; NetHope Inc. 2017; Pham 2016). For example, the Surge Information Management Support project at the International Federation of Red Cross and Red Crescent Societies (IFRC), and various National Societies, supports response information management with either remote or deployed information managers (Surge Information Management Support 2014). However, since many of these IM roles have been introduced recently, their effectiveness and structure have not been evaluated in depth.

To support the deployment of more effective internal IM functions, it is important to understand what IM strategies work well. Altay and Pal have evaluated practical strategies for inter-organizational information management; this paper builds on their framework to explore a gap in the existing literature- strategies for *internal* information management- and makes recommendations that we hope will enable improvements to organizational IM in practice.

METHODS

To examine the advantages and disadvantages of various strategies for internal information management, we use an agent-based model that represents key dynamics of information-seeking and -sharing in humanitarian response. Our model builds on the framework developed by Altay and Pal. Agent-based models are useful for this purpose because they explore how the interactions among responders collectively contribute to organization- and system-wide outcomes. Specifically, this model examines the influence of individual information-sharing interactions on the diffusion of information within the humanitarian response ecosystem, measured by the time it takes individual responders to find the information they need in order to make decisions and plan operations. It also represents the "cost" of improving information-sharing by computing the information overload – information that is irrelevant for a particular task, acquired by each responder.

While the model represents information diffusion across the entire response, we are particularly interested in how an individual organization, which we label the "focal" organization, chooses to manage its own information. Several internal IM strategies are modeled and evaluated. We first analyze a baseline situation with no active strategy for managing and sharing information, then examine the following strategies to understand their relative effectiveness in improving speed of information diffusion and reducing information overload:

- Increasing willingness to exchange information with other organizations
- Implementing regular team meetings to exchange information
- Deploying an IM specialist (with regular IM tag-ups)
- Deploying an IM specialist with a remote support team
- Varying the frequency of exchange meetings or IM tag-ups

The model uses simple rules to represent the essential elements of seeking and exchanging information in humanitarian response. By focusing only on the key dynamics, the model makes clear how different organizational strategies for managing information compare with each other, and provides some indication of which strategy might be most useful in different response scenarios. The paragraphs below provide a summary of the model environment and performance measures; then, the following sections explain in more detail the types of agents and the types of interactions among agents, and finally the way the model represents the six strategies for information management.

Model Environment The model simulates the basic interactions that may result in an exchange of information during the response – interactions with other responders and with information sources. Borrowing from Altay and Pal's conceptualization of the response environment, agents move around a physical space, and when they randomly encounter other agents, they seek to exchange information with them. They may or may not gain some information from each interaction (the details of each interaction and its success are discussed in Section). When responders have sufficient information, they stop seeking information and exit the environment (move to a "camp"). Figure 1 illustrates the model environment. The physical space of the model represents the geographic area affected by the disaster and, in particular, the space within which agents must move to find their information. The "camp" represents the ability to make a decision – when agents have enough information, they can work on their tasks (move to the camp) and stop seeking information. The random movement models the need for physical movement in the response area and the lack of knowledge of where to find people or who must be found.

The model also represents the various elements of information – both relevant and irrelevant – that may be acquired by actors, and the diverse information needs of actors with different roles. There are a finite number of 'pieces' of information available in the scenario - represented by a complete 10-item array. As agents learn a new piece of information, their personal array of information gets updated. If the agent already has that piece of information, then their body of knowledge remains the same. To represent the different specializations of each responder and the ensuing differences in their information needs, each agent is randomly assigned a 'task'- represented by a portion of the complete array of information in the model, from 1-10 items, depending on the complexity of their task- at the start of the simulation which dictates which specific pieces of information are required for them to complete their information-seeking. For example, if an agent's task requires them to have 4 specific pieces of information, then there are 6 pieces of irrelevant information in the model, and 4 pieces that are relevant. To avoid information overload, responders want to reach their destinations with little to no irrelevant information. Irrelevant information is information that does not help the agent make the decision about their assigned task. Information that is relevant to their task is not considered part of the information overload.

This model environment abstracts away many features of the real response environment in order to focus only on the key dynamics: the need for interactions with other actors in order to acquire information, the time required to identify and meet those actors, the need for particular information, and the factors that enable or constrain information exchange in these actor interactions. One important dynamic that is not represented is the time required to process and format information; this is left to future research. Collectively, this model environment enables investigation of the relative effectiveness of various simple strategies for information management – such as filtering information for relevance before passing it to responders, or increasing inter-organizational willingness to exchange.

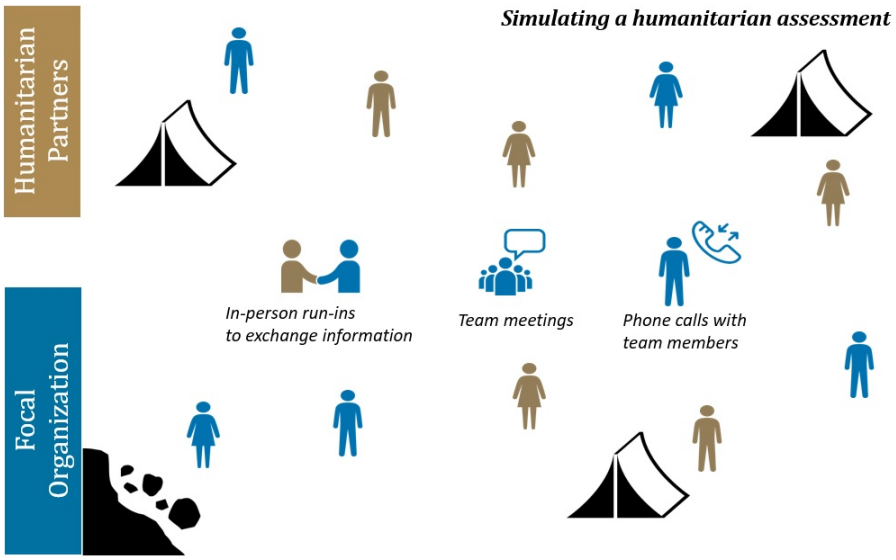

Figure 1. Model Environment: Agents move through the response space, interacting with other agents to find information needed for decision-making and planning

Measures of Performance In this study, the performance of various organizational IM strategies is evaluated based on two performance measures: (1) how quickly the focal organization's responders are able to find the information they need in order to make their response decisions, and (2) the amount of irrelevant information these responders acquire in the process.

Time to task accomplishment is measured by the median number of 'turns' required before all of the focal organization's responders finish their information seeking and arrive at their camps (the number of 'turns' is a rough measure of time, since a turn involves one movement each by all agents in the model).

Information overload is captured by the number of excess, unneeded pieces of information that a responder holds when they finish their information-seeking. In this model, as in reality, responders hope to focus on just the information that is most relevant for them and avoid acquiring and processing excess information.

Types of Agents

Humanitarian response organizations typically deploy an initial team to assess the situation, plan their organizational response, and start the aid delivery process. In addition to specialists in program management or relevant sectors

such as health, nutrition, or logistics, humanitarian organizations have also begun deploying information managers to assist with information seeking, analysis, and distribution.

We model six types of agents, each of which are described in more detail below. They include 'implementers' (responders) from our focal organization, implementers from other organizations, a deployed IM specialist, remote IM specialists, and injectors.

'Focal' Implementers & Other Implementers Implementers agents represent the response team members who, in actual response contexts, perform assessments, coordinate with other agencies, and plan organizational responses. Implementers are split into two categories: those who work for our focal organization, and those who work for other organizations. Implementers move around the model's physical space, looking to exchange information with the other agents that they encounter. When they are done looking for information, they move to one of the four camps.

Deployed IM specialist The focal organization can choose to deploy an IM agent to support the deployed implementers. This agent will also move around, looking for information. The deployed IM role hopes to facilitate the search for information that the implementers are undergoing, by filtering and sharing relevant information with team members quickly. The information management role does not have programmatic decisions to make, so it does not go to a camp, but rather continues to seek information until all its colleagues have reached their camps.

Remote IM support team Remote IM specialists support the focal organization from afar, and can only interact with injectors (representing online information sources) and the deployed IM agent. Like the deployed information management role, the remote roles also do not end up at a camp because they do not make programmatic decisions.

Injectors The injectors represent other actors in the affected area who might have or acquire information about the situation. This includes community-based organizations, government offices, news outlets, and the affected population. Injectors are the agents that hold the most information at the start of the simulation, and (in our model) are always willing to exchange information with other agents.

Agent Interactions

Much of the information exchanged in actual responses occurs through direct interactions between individuals. Responders meet each other at meetings, during meals, and in transit, and exchange information during these encounters.

To represent these dynamics in the model, we assume information must be gathered from other agents. Implementers may interact with any other agents, including implementers from their own or other organizations, injectors, and the information management function within their organization. Agents can exchange information in two different ways. First, they may exchange information through in-person interactions, when they are in the same physical space as another agent. Second, they may exchange information through remote communications; these are restricted to members of the same organization. The random movements required to encounter other agents and try to exchange information with them represent the greater difficulty of tracking down and meeting with actors external to the organization. Both kinds of interaction are described below.

In-person interactions Agents move randomly throughout the model environment seeking information from other agents. When an agent encounters another agent by chance, they go through a series of negotiations that determine whether or not they will get any information from this exchange (see Figure 2, below).

As Figure 2 shows, when an agent starts its turn, it checks to see if there is an agent in its immediate vicinity. If there is, the agent checks to see if the second agent has information. If the second agent does have information, the agents decide whether they are willing to exchange information with each other (determination of willingness to exchange is described in more detail below). If the agents decide that they are willing to exchange information with each other, they then decide for themselves whether the information they are receiving is of high quality (determination of information quality is also described in more detail below). If the information is not of high quality, the agent does not take the information; otherwise, the agent receives the information, whether it is relevant to their task or not. If the information is deemed to be of high quality, the information is exchanged. If, at any point during this interaction, the answer to any of these questions is "no", then the information is not exchanged, and each agent continues to seek information elsewhere. At the end of the turn, each agent checks to see if the information they

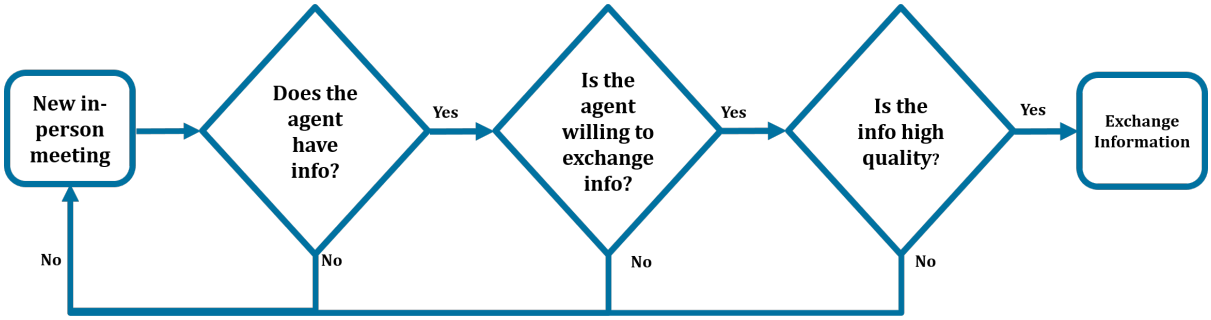

Figure 2. Model Rules

have received gives them sufficient information to proceed to the camp. If so, they move to the camp location and remain there for all remaining turns (because they have finished their information seeking).

Willingness to exchange information In reality, organizations make decisions about what information is share-able with their operational partners and which needs to be communicated only to its own staff (Chan et al. 2016; Karunakara 2013). As in Altay and Pal, the concept of willingness to exchange information is represented as the probability that a particular interaction will involve two agents who are both willing to exchange information with each other. As mentioned earlier, agents are always willing to share with their own organizations, and we also assume injectors are always willing to share their information, to represent the behavior of information sources in a response.

Quality of information The quality of information represents the real-life operational scenario of whether implementers can readily use the information they receive. Information may be in various formats, such as PDF reports, excel spreadsheets, maps, and other forms of processed data, and not all such formats may be usable to implementers (Day et al. 2009; Altay and Labonte 2014). Each implementer is assumed to judge for themselves the usability of any information. Information quality is represented in the model as a probability that the information obtained can be used by the implementer (as in Altay and Pal); if the information is deemed to be of low quality, the information is useless to the agent and thus is not exchanged or "gained" by the agent who are offered it. We do not assume that information received from one's own organization, including from the IM support, is always high-quality.

Remote Interactions When no IM specialist is present, implementers from the focal organization may hold regular coordination and information exchange meetings in which all the information held by any implementer is shared with all other implementers. Information filtering does not happen in meetings, because each team member is exposed to each piece of information. When an IM specialist is present, on the other hand, the IM specialist holds individual meetings with each implementer in order to share the specific information that the implementer needs. In this manner, the IM specialist acts as a filter, so that these regular "tag-up" meetings provide only the relevant information to each implementer (see Figure 3, below). As a result, the IM specialist provides less unneeded information because their job function is to seek and filter information. Importantly, the IM specialist is the only strategy that explicitly works to reduce information overload through information filtering during an information exchange.

Evaluating strategies for managing information

The agent-based model is used to evaluate how different strategies for information management impact the time to acquire information and information overload. The paragraphs below describe each of the evaluated strategies and how it is represented in the model, and Table 1 shows the parameters for each scenario.

Baseline In the baseline scenario, there is no IM specialist, and the willingness to share with other organizations is assumed to be a 50% chance that any given agent interaction will result in willingness to share. Similarly, the chance of receiving information that is of high quality is also 50%. No regular meetings or calls are held. This represents the lack of an active strategy for information management.

Increase willingness to exchange information with other agencies In Scenario 2, we vary all agents' willingness to share information with other agencies, in order to see how much this strategy influences performance. We

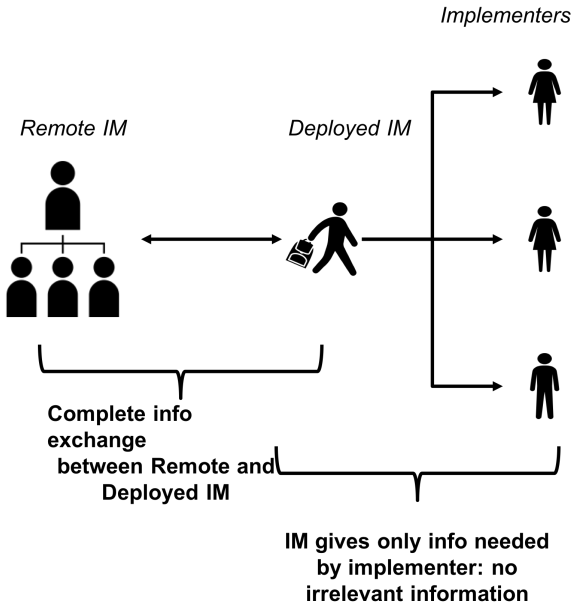

Figure 3. Exchanging Information during Communications with IM Support

Scenario	Team composition	IM team quality	Willingness to share with other orgs.	Meeting/call frequency
1. Baseline	No IM support	N/A	0.5	None
2. Increase willingness to exchange information with other agencies	No IM support	N/A	Varied among: 0.25, 0.5, 0.75	None
3. Hold meetings to share information	No IM support	N/A	0.5	Every 10 turns
4. Change frequency of meetings/calls	No IM Support / Deployed IM	0.5	0.5	Varied among: 10, 40, 100, 300, 450, 600, 1000 turns
5. Deployed IM	Deployed IM	0.5	0.5	Every 40 turns
6. Deployed + Remote IM	Deployed + Remote IM	0.5	0.5	Every 40 turns
7. Improve quality of IM support	Deployed IM	Varied among: 0.25, 0.5, 0.75, 1.0	0.5	Every 40 turns

Table 1. Scenarios for investigating strategies for information management

modeled various levels of openness to sharing: no organization will be 100% willing to share all information with others, so organizations were assigned levels that represented mostly willing to share (75%), neutral to sharing (50%, the baseline), and hesitant to share (25%).

Hold regular internal team meetings to share information A simple strategy for improving information management is to hold a regular information-sharing meeting within the organization. We represent meetings in Scenario 3 by enabling team-wide remote exchanges of information at regular intervals. When no deployed IM specialist is present, the response team exchanges all information with one another.

Deploy an information management specialist An alternative strategy that an organization might employ to manage information in a response is to deploy an information manager as part of the response team to seek out and filter information. This strategy is represented in Scenario 4 by adding an additional agent to the organization, which does not seek a camp, dedicated to information-seeking. In addition, the IM specialist holds regular "tag-up" calls with each of the implementers to exchange only information that is relevant for each implementer at regular intervals.

Activate remote information management support Scenario 5 includes both remote and deployed IM specialists. The addition of remote IM agents adds five more information-seeking agents to the team. While they move around the same physical space in the model, these agents represent remote agents, and they can only gather information from injectors, and can only share information with the deployed IM agent. The remote IM agents share all their information with the deployed IM agent just before the IM tag-up calls, so the implementers benefit from their information-gathering activities.

Improve quality of information management support If the focal organization has decided to use dedicated IM support, a further strategy for facilitating the management of information is to improve the skill level of the IM support, which increases the probability that the information they offer to others is of high quality. To evaluate this strategy, Scenario 6 includes variations with various levels of skill for both the deployed IM support agent, and is operationalized as probabilities that the agent offers information that is usable by the recipient, as described above. Varying the quality of the IM support demonstrates the extent to which the quality of the support influences performance.

Note that the quality of IM support does not refer to the specialist's ability to *seek out* information, but rather to their ability to process it into a useful product.

Change the frequency of meetings or tag-up calls Scenario 7 runs the model with several different meeting frequencies in order to examine whether there is an optimum cadence to these information-sharing meetings. The meeting frequency is set to occur every 10 turns, every 40 turns, and every 100 turns. A 'turn' is roughly a measure of time, but is better thought of as a response's clockspeed (Fine 1998), tied to the speed at which decisions are being made. Therefore, Scenario 7 investigates how often meetings should occur relative to the response clockspeed.

Implementation

The model was developed using NetLogo 6.0 (Northwestern University, Evanston, IL). The independent variables were varied as shown in Table 1, and the impact on the dependent variables – time to task accomplishment and information overload – was examined. Each variation of each strategy was run 1,000 times, and the average values are reported. (Convergence was tested by running some strategies 10,000 times and ensuring that the average values were the same). The baseline scenario includes 10 implementers from the focal organization, 10 other implementers, 10 injectors, and optionally 1 deployed IM specialist and five remote IM support specialists for the focal organization.

RESULTS

The results are summarized in Figures 4 and 5 and Table 2. Figure 4 shows the impact of each strategy on the time to task accomplishment, and Figure 5 shows its impact on information overload. The speed of information diffusion is the number of turns until all tasks within the organization's response team are completed, averaged across the 1,000 runs for each strategy and normalized against the baseline scenario, as well as the median turns to complete

task, i.e., the number of turns until half of the team completed its tasks (normalized against the baseline scenario). We added the median time to avoid the "long tail" of the last implementer seeking the last piece of information. The information load is reported as the average excess information that any given individual carries, across all runs. These results allow us to identify the organizational strategies for information management that may reduce the time that response teams spend on seeking information and reduce the amount of information overload that they experience. The paragraphs below discuss the results for each of the strategies evaluated.

Figure 4. Impact of Organizational Strategies on Time to Completion Overload

Improving all agents' willingness to exchange information did not make much of an impact on time to task accomplishment, and had a non-linear effect as organizations went from 25% willing to exchange to 50 and then to 75. There was a larger effect on time to task completion when organizations moved from 25% willing to exchange to 50%, as compared to moving from 50% to 75%. Even if there are diminishing returns as organizations become more willing to exchange information, being more willing to share helps reduce the time that organizations spend looking for information. There is no impact on information overload when willingness to share is varied.

This result is surprising in light of the findings of Altay and Pal. They found that willingness to exchange information achieved significant time savings. Their focus, however, was on inter-organizational information diffusion, whereas our analysis focuses on internal information management. Willingness to share makes little difference in our model because many of the actors are working for the same organization and therefore are always willing to exchange information with one another.

Information sharing meetings without IM support result in significant improvements in time to task accomplishment, by 50% over the baseline, but do not result in decreases in information overload, as there is no filtering during meetings. The time to task accomplishment is faster because responders share all their information with one another regularly without waiting to "bump into" each other in physical space.

Deploying an information management specialist of medium skill (with a 50% probability of offering high quality information to others) results in a decrease in time to task completion by 24% compared to the baseline, and a reduction in average information overload by 8% compared to the baseline. The time to task accomplishment is faster for several reasons. First, there is one additional agent seeking information, and that agent never leaves to work on a task, enabling more information-gathering interactions. Second, the presence of the deployed IM agent enables regular, team-wide communication, so information is spread without waiting to encounter responders in

Figure 5. Impact of Organizational Strategies on Information Overload

Strategy	Speed of Average Team Task Completion: % Change from Baseline	Speed of Median Individual Task Completion: % Change from Baseline	Information Overload : Percent Change from Baseline
1. Baseline	Baseline	Baseline	Baseline
2. Increase willingness to exchange info	-4%	-1.3%	0%
3. Regular meetings to share information (40 turns)	+1%	-23%	+3%
7. Change frequency of meetings/calls (100 turns)	-15%	-37%	+5%
4. Deploy IM support	-23.5%	-24%	-7.2%
5. Deploy IM support with Remote IM support	-25%	-24%	-7%
6. Improve quality of IM support	-30%	-34%	-12.6%

Table 2. Comparison of Organizational Strategies

physical space. Third, the deployed IM agent replaces the information-sharing meeting with a targeted interaction to each responder, sharing only relevant information, which results in the decrease in information overload.

Activating a remote information management team to support the deployed IM specialist has almost no impact on reducing time to task accomplishment or on information overload. The remote IM team does not add much value because they can only gather information from the limited sources, and do not provide any additional information-sharing functions.

Improving the quality of the information management support can further improve the time to task accomplishment and information overload. Figures **??** and **??** show results for a deployed IM specialist who can produce high-quality information 25% of the time, 50% of the time, and 75% of the time. Improving the quality can reduce the time to task accomplishment more than a remote IM team. The results are similar for information overload.

Varying the frequency of meetings or tag-up calls can also affect the time to task accomplishment. We compared different meeting frequencies; Figures **??** and **??** show results for meetings every 10 turns (baseline), every 40 turns, and every 100 turns. Comparing different meeting frequencies suggests that there is an organizational decision to make regarding meeting frequency- time to task accomplishment can drop dramatically more when meetings are held at an appropriate frequency, but information overload actually increases when meetings are less frequent, likely because the team members have more information on hand when they meet with their team to exchange information. When meetings are held too frequently, team members have not had enough time to gather new information, and so the meeting passes without significant information exchanged; essentially, the time is wasted in a meeting when the team members should be seeking information. Additional preliminary results that are not shown here suggest that there is an optimal frequency to hold meetings. These results need to be explored further to draw conclusions about what this means for operational teams. This model only takes into consideration how meetings contribute to information sharing, and does not take into consideration other benefits of meetings, such as coordination, setting priorities, etc.

While previous work has identified successful strategies for information sharing across organizations in humanitarian response, these findings start to identify the successful strategies that individual organizations can use for their own internal operations.

DISCUSSION

The results suggest that, among several strategies for information management, holding regular meetings or deploying an IM specialist make the largest difference in the time it takes to collect sufficient information for decision-making. Of these two strategies, only the IM specialist also reduces information overload. Both increasing willingness to share and improving the quality of the IM team can improve time to task accomplishment, but not as significantly. Activating remote support for the deployed IM team has limited value for information seeking, especially when weighed against the significant resources required.

These conclusions are based on a simple model, but they nonetheless provide insights that may be relevant and valuable in practice. Organizations must make decisions about how to approach the task of information management, and the strategies evaluated here are some of the options that they may use. While the model does not reflect all aspects of reality, it models the fundamental information-seeking and -sharing dynamics that govern the acquisition and spreading of information. Future work could test and validate these conclusions empirically.

The strategies explored in this paper require very different resources from organizations. Some strategies involve policy changes, such as an organization's willingness to exchange information with other actors. Other strategies involve staffing decisions that impact the composition and structure of response teams. Organizations are faced with very real political, security, and resource constraints that may make one or more of these strategies unrealistic for a given organization and/or response. The "cost" and resource commitment required to deploy each strategy will differ across organizations and responses. However, by understanding the relative benefits of each option, organizations may be able to make more informed decisions that address their own goals and priorities.

The findings suggest some recommendations for when each strategy would be appropriate. When resources are limited and speed of information acquisition is critical, regular information-sharing meetings are a useful strategy. They are simple to implement and highly effective at improving the speed of information diffusion, although they will not result in a reduction in information overload. Information-sharing meetings are recommended for any response, as long as they are not held overly frequently.

When the speed of information acquisition is important and information overload is also a concern and/or there are available resources, deploying an IM specialist is the best choice. In addition to speeding up the acquisition of information by adding dedicated information-gathering capacity and holding regular information tag-ups to provide

targeted information to responders, in reality an IM specialist adds additional value. The IM support specialist is dedicated to the tasks associated with information management, ensuring that they are completed rather than slipping further down the to-do list of a responder who is also dealing with programmatic, logistical, or financial aspects of the response (represented in our model by leaving the information-gathering arena to do work at a camp).

Surprisingly, willingness to share information does not, in this model, make a significant impact on information acquisition in the focal organization. However, this model focuses primarily on a single organization, rather than the humanitarian system as a whole in a response. Both in practice and in research (**AltayLabonte2014b**; Altay and Pal 2014; Bharosa et al. 2009; Faraj and Xiao 2006; IASC Working Group 2008; UN OCHA 2017), information sharing is emphasized for the impact it can have across organizations, when every actor in the system opts to increase their willingness to share. The results from this model should not be taken as justification for refusing to share information in a response. Instead, the results simply show that increasing willingness to share does not increase a single organization's own information-seeking capabilities in the environment we modeled.

The remote information management support did not, in this model, have much added value beyond the value of the deployed information manager whom they support. This may be due to their remote status, which limits the sources of information they have access to. Their main value may instead lie in assuming the work of processing information, such as making maps or cleaning data sets, so that the deployed team can focus on the tasks that require direct participation in the response. This model does not account directly for information processing, but future iterations could include it. Further research is needed to understand in which contexts remote IM teams are most helpful and why, so organizations can make informed decisions about activating remote staff.

We see some improvements in time to task accomplishment when the quality of the IM team improves, suggesting benefits of investing resources in training and human resource development for personnel to fill this role. Conversely, if skilled IM support personnel are not available, our results suggest that unskilled personnel should not be deployed; instead, team-wide information sharing meetings result in almost the same time savings as deploying someone who is ill-equipped to manage information in these settings, and do not require the resources of a dedicated deployment for a role that does not benefit the team.

These recommendations all come at some amount of cost to an organization, which is not explored here - the contribution of this paper is to explore how each of the information management strategies impact the speed of finding information for decision-making and on the amount of information overload that teams might experience.

CONCLUSIONS

These findings are initial explorations of how various strategies for managing information might assist a humanitarian organization's response – and in particular, how each strategy affects the speed and efficiency of information acquisition. The results should support humanitarian organizations in deciding how to invest resources in information management, both in the short term, for a given response, and in the long term, for human resource development and internal policies. Further research on the specific structure and function of information management teams, as well as how internal information management processes link to inter-organizational coordination, would provide more specific guidance on IM processes and structures, and help to link the existing understanding of inter-organizational coordination to information management at the organizational level. Successful internal information management is a necessary precondition for successful information-sharing and coordination at the inter-organizational level, since much information about a response originates within individual organizations. Therefore, our focus on internal information management is an important complement to existing theory on inter-organizational coordination.

As the role and importance of information management is expanding and changing rapidly, this is a timely contribution to both inspire further research on intra-organizational information management and to support practice decisions as humanitarian organizations design their internal information management strategies.

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Track 2

Command & Control Studies

Simulating Spontaneous Volunteers – A Conceptual Model

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ABSTRACT

Recent disasters have revealed growing numbers of citizens who participate in responses to disasters. These so-called spontaneous unaffiliated on-site volunteers (SUVs) have become valuable resources for mitigating disaster scales. However, their self-coordination has also led to harm or putting themselves in danger. The necessity to coordinate SUVs has encouraged researchers to develop coordination approaches, yet testing, evaluating, and validating these approaches has been challenging, as doing so requires either real disasters or field tests. In practice, this is usually expensive, elaborate, and/or impossible, in part, to conduct. Simulating SUVs' behaviors using agent-based simulations seems promising to address this challenge. Therefore, this contribution presents a conceptual model that provides the basis for implementing SUV agents in simulation software to perform suitable simulations and to forecast citizens' behaviors under a given set of circumstances. To achieve adequate simulations, the conceptual model is based on the identification of 25 behavior-affecting attributes.

Keywords

spontaneous volunteers, disaster management, agent-based simulation, conceptual model, citizen behavior

INTRODUCTION

Disasters during the last decade have revealed a growing number of untrained citizens participating in disaster responses. Along with the increasing number of natural and man-made disasters worldwide, the relevance of these so-called spontaneous unaffiliated on-site volunteers (SUVs) has increased dramatically. Disaster managers and practitioners have reported that several disasters would have been far more lethal and on a more dramatic scale without the help of SUVs (Detjen et al., 2015; Geißler, 2014). Beyond these undoubtedly positive aspects of their help, however, SUVs have also caused unintentional harm or put themselves in dangerous situations.

Utilizing SUVs as a valuable resource in disaster response requires proper coordination by disaster managers (Betke, 2018; Betke et al., 2017; Rauchecker and Schryen, 2018) and has led to a growing field of research for IT-supported disaster management. In Germany, e.g., the government has focused on this issue specifically by funding several projects such as KUBAS and REBEKA in order to effectively assign SUVs in disaster management (BMBF, 2017). This contribution is part of the research project KUBAS that aims at (a) an IT-based solution for coordinating SUVs, (b) a general evaluation method to measure the effectiveness/efficiency of approaches/methods/tools and drills aiming at the integration and coordination of SUVs during disaster response and (c) predicting volunteer participation in various disaster scenarios.

The main challenge of all these research efforts lies in testing, validating, and evaluating new approaches as well as proofing the concept, e.g., in practitioners' drills. New approaches are usually evaluated through field experiments, yet field experiments with many SUVs require massive numbers of participants, may have durations of many days, and can take place at several locations simultaneously. Such experiments are often expensive, elaborate, and, in part, even impossible to conduct (Balasubramanian et al., 2006; Sautter et al.,

2015; Takahashi, 2007). Research approaches may also be evaluated and validated in real disasters, even though testing using human beings seems to be too dangerous, and disasters cannot be controlled to occur when testing is the objective.

Another common approach for evaluating and optimizing real-world scenarios with minimal effort is the use of computer simulation (Arai and Sang, 2012). Furthermore, a proper simulation of SUVs enables disaster managers to forecast citizen participations under given circumstances to better manage disaster situations and, beyond that, to visually track potential operating-site utilizations.

Nevertheless, the simulation of SUV's has not yet been intensively researched (Lindner et al., 2017). In our prior work (Lindner et al., 2017), we, in particular, have identified agent-based simulation as a sound approach for simulating SUVs' behaviors in disasters since it has already been proven to be appropriate for simulating human and social behavior as well as many entities (Mas et al., 2012; Pan et al., 2007; Takahashi, 2007; Wagner and Agrawal, 2014). Simulating SUVs' behaviors requires the development of software agents, and therefore, it first requires the analysis of their real-world behaviors and all behavior-affecting attributes (Macal and North, 2007). Secondly, the behaviors of SUVs have to be conceptualized in order to be implemented and run in simulation software.

Based on the attributes for representing and influencing SUVs' behaviors identified in our prior work (Lindner et al., 2017) this paper aims to develop a conceptual model that represents the behaviors of SUVs in disaster situations and represents the foundation for a later implementation in simulation software.

To achieve this aim, in the first section, related literature is discussed and a summarizing overview of SUV attributes is given. A common representation of behaviors in agent-based simulations is the statechart notation (see, e.g., Emrich et al., 2007; Fujisawa et al., 2014; Garifullin et al., 2007). To ensure broad applicability for implementing the model in simulation software, we provide the conceptual model following the statechart notation based on the Unified Modeling Language (UML) standard, which, as well as the method, will be described briefly in the second section of this work. In the third section, behavioral attributes according to our prior work will serve as the foundation for deriving behavior-affecting states, events, and transitions and, thereby, for developing a conceptual model to represent SUVs' behaviors. To prove its applicability and ability to be implemented in simulation software, in the following section, the proposed model will exemplarily be implemented in a simulation software. A conclusion with an outlook for further research is offered in the final section.

This contribution is part of a research project following the well-established methodology for Design Science Research proposed by (Peffers et al., 2006). According to this methodology, this research paper refers to the third phase of the Design Science Research Process (DSRP), i.e. the "Design and Development" phase. The results of this paper provide an indispensable foundation for the implementation and thereby the next DSRP phase "Demonstration".

RELATED WORK: ATTRIBUTES FOR SIMULATING SPONTANEOUS ON-SITE VOLUNTEERS

In our paper "Attributes for Simulating Spontaneous On-Site Volunteers," we described the enormous potential of spontaneous unaffiliated on-site volunteers (SUV) for disaster mitigation and confirmed the requirements for the proper coordination of these SUVs in order to avoid nonproductive and even counterproductive help.

Comprehensive research support for developing coordination approaches and, accordingly, the necessity to test, evaluate, and validate these approaches triggered our research efforts. Since the current practice in testing, evaluating, and validating research efforts in regard to the topic of disasters requires either real disasters or field experiments and is thus expensive, elaborate, and/or partially impossible to conduct, new opportunities to address these issues need to be explored. In (Lindner et al., 2017) we therefore, suggested developing a multi-agent-based simulation framework to simulate SUVs' behaviors.

Our literature review based on a keyword search in scientific databases resulted in a large number of research papers and practice reports. It revealed that agent-based simulation is a major topic in disaster related research, whereas many research efforts focus on evacuation scenarios: e.g. evacuation impacts on traffic flows from disaster areas (Chen and Zhan, 2008), evacuation scenarios for concert venues (Wagner and Agrawal, 2014), evacuation behavior of pedestrians and car drivers in a tsunami scenario (Mas et al., 2012). It further revealed a massive amount of research efforts on SUVs: e.g. research on their interaction, cooperation, and communication especially via social networks (e.g. Peary et al., 2012; Starbird and Palen, 2011), the role of digital volunteers during the Haiti earthquake in 2010 (Starbird and Palen, 2011) or research approaches and applications to improve communication or coordination (e.g. Reuter et al., 2015; Hofmann et al., 2014). Nevertheless, none of the related works applied simulation for SUVs in the disaster context and, hence, fostered our effort in developing a multi-agent simulation framework for simulating SUVs' behaviors.

The evaluation of the search results further led to the identification of 25 attributes (Table 1), which were then briefly described. In the process of analyzing behavior-affecting attributes, we further identified numerous dependencies and interrelations among these attributes that were initially described yet need to be analyzed in greater detail in future research. In accordance with the definition of software agents by Lind (2001), we grouped the attributes into individual, social, and environmental attributes as an indispensable step for understanding the behaviors.

Consequently, the groundwork is an adequate source for developing a conceptual model to represent SUVs' behaviors, as we have already identified and described all the attributes that affect SUVs' behavior. Furthermore, the state-of-the-art literature review has led to many literature sources that may confirm the assumptions we make within our model.

Table 1. SUV Attributes

Number	Attribute	Description
A1	Age	age of the SUV
A2	Group Affiliation	e.g. clubs, religious groups
A3	Motivation	trigger to participate in disasters
A4	Concern	emotional reactions to disasters
A5	Information Channel	e.g. social media
A6	Personal Connections	e.g. friends, family
A7	Social Networks	characteristics of the individual social network
A8	Perception	how SUVs perceive the situation
A9	Kind of Disaster	size, scale and type
A10	Weather	temperature, rainfall
A11	Experience	in prior disasters (positive, negative, non)
A12	Time of Day	e.g. day, night
A13	Supporting Tasks	e.g. filling sandbags
A14	Task Preference	preferences on what to do
A15	Capabilities	physical capabilities/ability to be led by officials
A16	Resources	provided resources (e.g. shovels)
A17	Working Time	time (in h) per day
A18	Time Preference	e.g. to work on day/night
A19	Working Duration	days somebody wants/can help
A20	Operating Site	locations where SUVs are needed
A21	Kind of Information	e.g. number of needed/current SUVs at operating site
A22	Location	current location

A23	Operating Site Preference	where an SUV is willing to help
A24	Travelling	e.g. car, walk
A25	Randomness	something unexpected happens

METHOD: CONCEPTUAL DESIGN

We constructed the proposed conceptual model for the SUVs' behaviors in consideration of the methodological notes on models of (March and Smith, 1995). Conceptual models can be constructed based on domain knowledge and can be used to represent new theories or phenomena through domain-specific elements and their associations (March and Smith, 1995). Accordingly, the concern of such models is utility, not truth (March and Smith, 1995). The model is based on our attribute identification, derives behavioral characteristics of it and was constructed under use of the Unified Modelling Language (UML). Since this conceptual model is descriptive and part of the early design phase, the evaluation is part of the subsequent iterative implementation (Gleasure, 2014).

Our recent research revealed that there is no universally valid modeling convention for developing software agents. However, based on other research outcomes in the field of agent-based simulation (see, e.g., Dawson et al., 2014; Ozik et al., 2015; Uhrmacher and Kullick, 2000; Verma, A. and Singh, Y., 2017), the UML statechart modeling notation by the Object Management Group seems to be a common conceptualization of behaviors. Furthermore, UML statechart modeling is used in early-bird representations before functional assignments in the implementation phase are made (Borshchev and Filippov, 2004) and is, by far, the most often used formalism for modeling the behavior of object systems (Fortino et al., 2004). Since our research effort is currently in the pre-implementation phase, statechart modelling is an appropriate method for descriptive purposes.

The general purpose of statecharts is to specify, visualize, construct, and document the artifacts of a software system (Latella et al., 1999). The artifact in the present research will be the software agent that represents the behaviors of SUVs. Additionally, statecharts represent a sequence of states through which an object passes during its life cycle (Khriss et al., 1999). As our aim here is to represent the behaviors of SUVs in disaster situations, the life cycle comprises all the supporting activities undertaken during a disaster.

In general, UML statecharts consist of the following (Murray, 2004):

- states that are considered as a period in the life of a system or agent during which a certain condition holds or an activity is performed;
- events that trigger state changes; and
- transitions that connect states and change states based on external events and conditions.

UML as specification and modeling language is already widely accepted (Murray, 2004) and is thus a good foundation for a broad acceptance of the model and its implementation.

The next section discusses the actual development of the conceptual model and, as a consequence, the derivation and identification of all required states, events, and transitions featuring SUVs in disaster situations based on the proposed attributes and their descriptions. The reference to the original attributes will further be given as "*<name of the attribute>* (A ##)."

DEVELOPING THE CONCEPTUAL MODEL: SUV AGENT BEHAVIOR MODEL

UML statechart diagrams require an initial state to trigger the behavioral process (Object Management Group, 2015). Perceiving a situation as emergency or disaster has been identified as a precondition for spontaneous volunteering (Geißler, 2014; Reuter et al., 2013). The perception (A 8) can, therefore, be seen as the trigger to participate in a disaster as a spontaneous volunteer and is thereby the trigger and initial state for behaving as an SUV (***attention***). It is clear that one has to recognize a disaster; otherwise, there would be no need to volunteer. In (Lindner et al., 2017), we identified several additional attributes that may influence perception, e.g., social networks (A 7), information channels (A 5), or personal connections (A 6). As perception may be further triggered by other attributes, we summarize this first state as *"**has attention.**"*

To summarize, *"**has attention**"* means that, first, a disaster must strike as a precondition for participating in disaster relief, and, secondly, the agent must perceive this situation as an emergency. Starting here, the behavioral process of an SUV begins. Based on the attribute of location (A 22), we assume that the SUV agent is initially located at a distance from the disaster, most likely at his or her home. Furthermore, the location has a

behavior-affecting influence, especially in the upcoming operating-site (A 20) search process.

After triggering the behavioral process, the first state is *"**has attention.**"* As previously described, this state requires the perception of the disaster and may be triggered/influenced by (social) media coverage or by friends or associates, more precisely other agents, who communicate with the SUV. It is crucial to be aware that broad media coverage and personal communications from friends motivate citizens to volunteer in disasters. We assume that the agent is then informed about the situation and a decision-making process about whether to participate in the disaster or not must be initiated. The transition to the next state will be triggered by a time-out event consisting of the motivation and the respective decision-making process of the volunteer agent.

We identified motivation (A 3) as the trigger to participate in a disaster response and revealed that motivation could either be increased or decreased by dependent attributes. The assumption of being highly motivated to offer support in disaster situations further leads to the assumption that people with a "high" degree of motivation are more willing to help than people with a "low" degree of motivation. We also revealed that motivation is not deterministic and, as yet, cannot be completely simulated. The motivating process has to take into consideration other attributes that affect motivation. Based on this knowledge, we assume two conditions, ***"[motivated]"*** or ***"[not motivated],"*** that determine the following state of being either *"**ready to help**"* or *"**not ready to help.**"* However, the actual logic of deciding is not part of the statechart representation and thus must be considered in the implemented model.

Since the time-out event includes the motivating process, we assume that people won't respond to help instantly after a disaster has struck. Furthermore, the time-out event simulates the recovery phase at home, or particularly at the initial location, that SUVs need to process, perhaps, before continuing to help on another day. This assumption is underpinned by the attribute of working time (A 17), which describes that SUVs usually work between 4 and 8 hours a day (ARC, 2010). Thus, as we attempt to model the behavior of participating in disaster situations, spare-time activities are of no interest to us, and so we assume a time-out.

Some disasters have durations of several days whereby a volunteer who decided not to help initially and thus was in the *"**not ready to help**"* state may decide to help on another day. Given the complexity of the motivation and its interdependencies and relationships, e.g., environmental attributes like weather that may affect motivation and may change over time, we assume that an SUV agent can be *"**temporarily not motivated**"* and, thus, more likely to help on another day. Accordingly, entering the *"**not ready to help**"* state will first cause the agent to enter the *"**temporarily not ready to help**"* state until deciding whether the SUV is conclusively not motivated. A conclusively not motivated state could be caused by very low overall motivation ***([motivation very low])*** due, e.g., to prior negative experiences (A 11) related to helping as well as by the SUV having exceeded his or her working duration (A 19). Depending on other attributes such as age, working duration varies from several hours to several weeks or even months. Deciding to discontinue all supportive tasks will result in the agent's final state and thereby end the SUV's behavioral process. Otherwise (***[else]***), he or she is probably going to help again on another day, will enter the starting state *"**has attention,**"* and, given a time-out, may become motivated again.

If the SUV is motivated, his or her state will then be *"**ready to help**"* and, based on the kind of information received (A 21), will either choose a preferred operating site or move around to search for places to help. SUVs do have operating-site preferences (A 23). Individually, they will consistently show a preference for an operating site where they know help is needed over sites that are described as overcrowded. However, the operating-site preference as well as the final operating-site selection process is part of the implementation phase.

In regard to being *"**ready to help,**"* we identified randomness (A 25) as an important attribute that affects SUV behavior. Randomness is described thusly: even if the *"SUV may have [..] high motivation to help, there is still a probability that something unexpected happens preventing him or her from actual helping"* (Lindner et al., 2017). This randomness is depicted by the decision related to whether *"**[something unexpected]**"* happened or not. If *"**[something unexpected]**"* turns out to be true, the agent is still motivated but will enter the starting state *"**has attention**"* to perhaps provide help on another day. Otherwise (***[else]***), the SUV is going to move to the operating site ***(moving to operating site)***. This assumption is made by the attribute travelling (A 24), which describes how SUVs move to operating sites. Travelling will be integrated in the implementation phase and will then probably affect the time a volunteer needs to move from his or her initial location to the preferred operating site.

Recent disasters have shown that SUVs, after ***[arriving at the operating site]***, could possibly be ***[rejected]*** by operating sites by official forces, especially if the limits for required on-site volunteers are about to be exceeded (Teixeira, 2012). However, rejection leads to frustration and negative experiences that can potentially affect motivation to help on another day or in future disasters (Geißler, 2014; Kircher, 2014). In the past, not all volunteers who have been rejected have immediately lost their motivation and thus discontinued their help. Some SUVs start searching again (***[else]***) and move to other operating sites. As we described in (Lindner et al.,

2017), the probability of being rejected is most closely related to the kind of information SUVs have about operating sites. It is clear that those who have a lot of information about operating sites choose sites where help is desperately needed instead of choosing overcrowded operating sites, and therefore, they are not likely to be rejected by official forces.

At any rate, if SUVs are rejected too often (***[too many rejections]***), their ambition to help on a particular day may decrease drastically, and they may discontinue their supporting activities. If this is true, the SUVs may then return home or at least go somewhere else but without helping (***[moving back home]***). However, rejected volunteers do continue to pay attention to the disaster and will therefore enter the state *"**has attention**"* when they arrive home (***[arriving at home]***). These negative experiences may then affect motivation the next day following the defined time-out event.

Not being rejected (***[else]***) results in helping at the arrived-at operating site and will thereby result in entering the state *"**helping at operating site.**"* As we revealed in (Lindner et al., 2017), the working time (A 17) depends on several other attributes and may vary from agent to agent. Exceeding the individual time preference (A 18) by helping at the operating site is an event that will cause a transition to the next state, namely, the *"**moving back home**"* state. Arriving at home will then lead to the *"**has attention**"* state again, which may lead to another round of participation.

The proposed statechart model is depicted in Figure 1. Based on our prior work, the states in the model were derived from all behavior affecting or featuring attributes and their descriptions. It is clear that spontaneous volunteering in disasters requires disaster situations, and therefore the behavior ends if the disaster situation no longer requires the help of volunteers, if the volunteer is no longer motivated, or if his or her working duration (A 19) preference has been exceeded. The end of the disaster is not modeled as a final state in the model, as the simulation will terminate when the disaster ends.

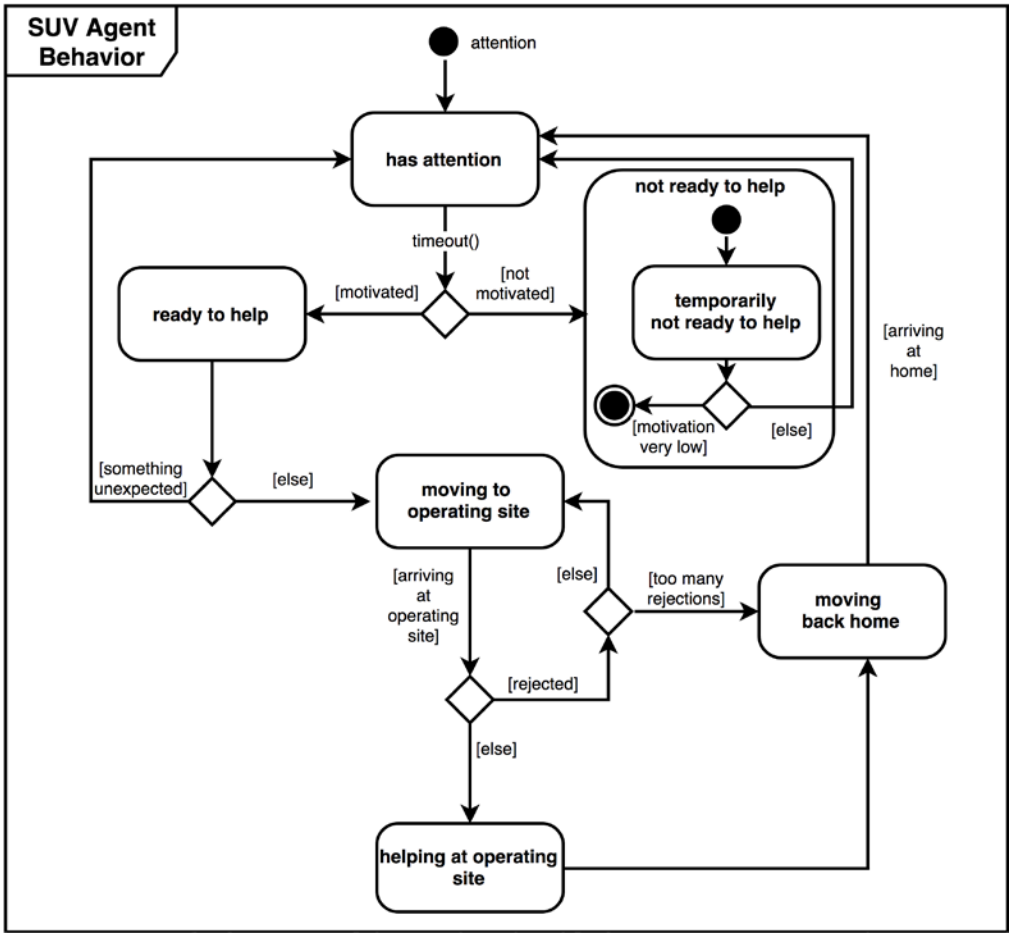

Figure 1. SUV Agent Behavior – A Conceptual Model

EXEMPLARY IMPLEMENTATION OF THE CONCEPTUAL MODEL

As the proposed conceptual model is the basis for implementing an SUV's behavior in simulation software, we exemplarily implemented the model in AnyLogic to show its applicability. Accordingly, the realistic simulation of SUVs requires further research and is not being aimed at by this implementation. AnyLogic is already being used to perform disaster-related simulations in other research projects (see, e.g., Barthe-Delanoë et al., 2015, and Barahona et al., 2013) and appears to be the proper software to test.

We implemented a population of 100 agents representing SUVs. The individual behavior of each agent originates with the behavior-affecting attributes as well as the behavioral model proposed in this contribution. Thus, we implemented the SUV's behavior exactly as the derived conceptual model in the AnyLogic simulation software (see Figure 2).

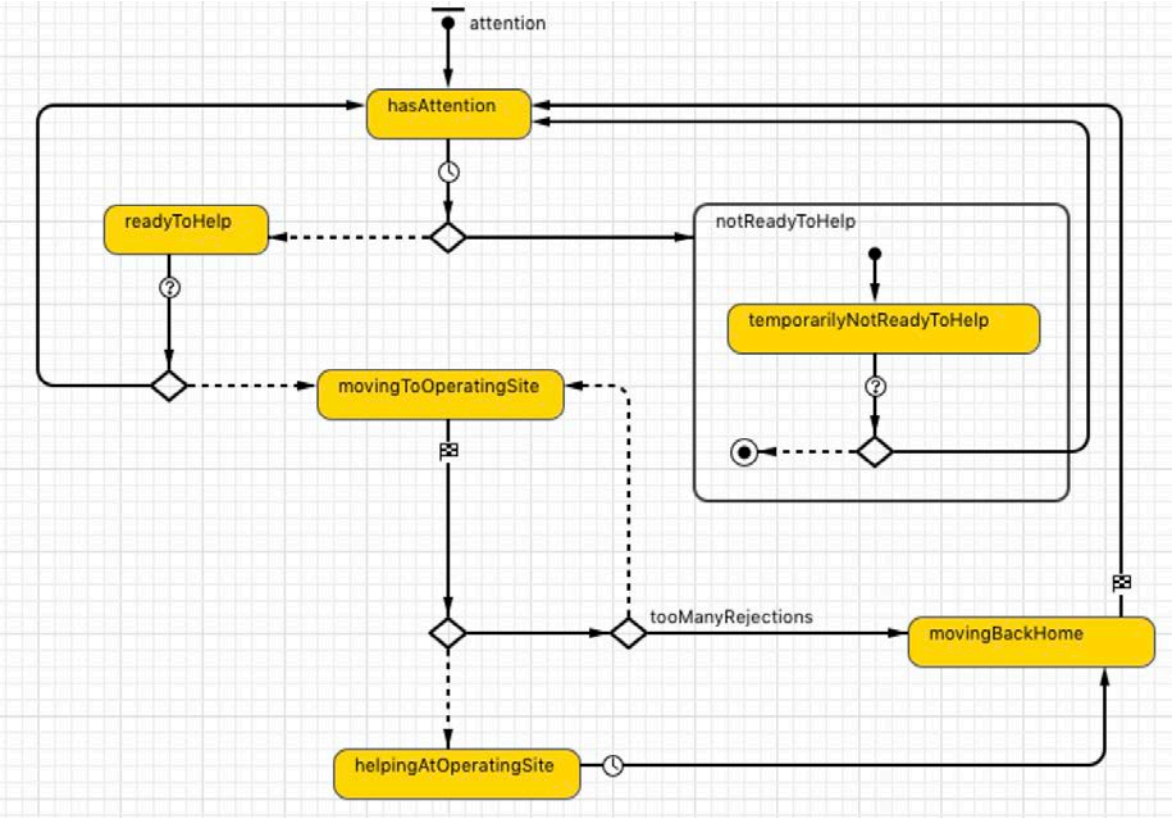

Figure 2. SUV Behavior in AnyLogic

To perform a basic simulation, we proposed the agents initial position to be randomly distributed in the area of "Halle (Saale), Germany" The city was massively affected by flooding in 2013 and where spontaneous volunteering made an enormous contribution to mitigate the scale of the disaster. AnyLogic allows the integration of GIS maps to visualize the agents in their current locations. Furthermore, we need to implement operating sites that simulate places where SUVs may help and can thereby be either empty or overcrowded. Even though operating site agents are not part of this contribution and will not be described in more detail, they are required to run realistic simulations. To show the applicability of the proposed model, the implemented logic is kept very simple, which means that the proposed decisions rely on random distributions. For example, being *"ready to help"* turns out to be true by an equally distributed probability of 50 percent.

By starting the simulation, the initial state pointer *"attention"* will be triggered, and the agent enters the state *"has attention."* The proposed time-out function in this implementation pauses the agent's actions for 8 hours before the decision of *either "ready to help"* or *"not ready to help"* is made. As previously mentioned, the decision relies on random distributions. Performing realistic simulation in the future necessitates the implementation of the decision logic as well as the attributes and their interdependencies proposed in (Lindner et al., 2017).

If the SUV agent is *"ready to help,"* the probability that something unexpected happens is 20 percent; otherwise, the agent is *"moving to operating site."* Regarding the "kind of information", we assume that the agent knows about all operating sites and randomly chooses one (Lindner et al., 2017). In this very basic

example, we represent three operating sites, each with a requirement of 20 SUVs. Arriving at the operating site either leads to being rejected or to *"helping at operating site."* Being rejected will be the result if more than 20 SUVs are already helping at this particular operating site. If the agent has been rejected more than twice, he or she will return home; otherwise, he or she will move on to another of the operating sites. We assume that an agent provides help for 5 hours before returning home.

Running this simulation will lead to defined behaviors that can be proven visually by the simulation representation (see Figure 3). Although this sample implementation is very basic, it can still simulate the SUV's behavior and thereby offers a sound foundation for improving the implementation iteratively.

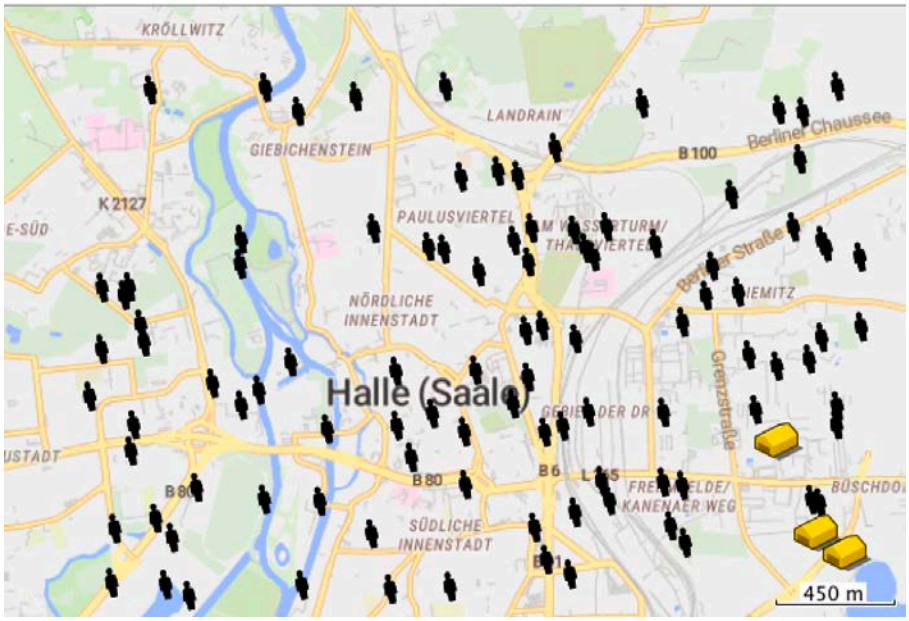

Figure 3. SUV Simulation in AnyLogic

CONCLUSION AND FUTURE RESEARCH

The numerous research efforts that have focused on spontaneous unaffiliated on-site volunteers (SUV) as well as recent disasters have revealed the enormous potential of SUVs for mitigating the scales of disasters. However, there are limitations in regard to evaluating, testing, validating, and also in comparing research approaches concerning the necessity of real disasters or field tests that are expensive, elaborate, or impossible, in part, to conduct. Simulations, in general, and multi-agent simulations, in particular, seem to be a promising attempt to complement existing approaches. Multi-agent simulations require the analysis of the behaviors of SUVs, and therefore we identified, analyzed, and classified all behavior-affecting attributes of SUVs to provide a sound foundation for developing software agents in our prior work.

The next step in simulating software agents is, therefore, conceptualizing the representation of the SUV's behavior for providing a model that can finally be implemented in simulation software. The implementation of a conceptual model in simulation software serves for improving the evaluation and validation of novel research methods and tools aiming at effective and efficient coordination of SUVs in disaster response. Furthermore, it's the foundation to develop tools that enable practitioners such as disaster managers to predict SUVs' behaviors.

Thus, the aim of this contribution was to develop a conceptual model representing the SUV's behaviors. Toward that aim, we recapitulated the attributes of the paper "Attributes for Simulating Spontaneous On-Site Volunteers" in order to identify events, states, and transitions to subsequently be modeled. Accordingly, this contribution provides: (i) a first and sound insight into the behaviors of SUVs and their corresponding states and (ii) a proof for the applicability of the conceptual model to be implemented in simulation software. The identified conceptual model is further expected to be useful for researchers/practitioners who either want greater insights into the behavior of SUVs or to implement the model in their simulations. In addition, this paper is part of a research project that necessitates a proper investigation of the volunteer's behavior as well as the foundations for the upcoming iterative implementation phase.

However, this research paper also has several limitations. Although the proposed conceptual model of this contribution is based on the latest research outcomes of (Lindner et al., 2017) it may be revised if and when

there is an update on the underlying attributes. Furthermore, an implementation requires greater details on how the transitions may be triggered. For example, motivation level is assumed to be high or low, and there is not yet a specific operationalization for implementing it in simulation software. Moreover, a very low level of motivation may lead to an SUV discontinuing to help in a disaster situation and will thereby have a relevant impact on the SUV's behavior. To summarize, the decisions especially are on a high level of abstraction and consequently require further investigations before being implemented. Additionally, performing these simulations requires further agent types such as operating sites. These agents can also be derived by the attributes and, hence, will be addressed in future research.

Since the development of the artifact, i.e., the SUV agent, is based on an iterative process, the quality of the model and the level of detail can be expected to improve. However, the development cycle requires an implementation foundation to further improve the outcomes. In addition, the iterative cycle will involve interviewing a large number of SUVs and disaster experts in order to evaluate the model and to develop and survey a structured equation model for operationalizing motivation and a willingness to help.

Our entire research project follows the DSRP methodology proposed by (Peffers et al., 2006). Accordingly, this research paper is in the third phase, "Design and Development," of the artifact, and its results provide necessary fundaments for the iterative implementation and, thus, the next phase, "Demonstration."

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A Practitioners Guide for C2 Evaluations
Quantitative Measurements of Performance and Effectiveness

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ABSTRACT

Quantitative evaluations are valuable in the strive for improvements and asserting quality. However, the field of Command & Control (C2) evaluations are hard to navigate, and it is difficult to find the correct measurement for a specific situation.

A comprehensive Scoping Study was made concerning measurements of C2 performance and effectiveness. A lack of an existing appropriate framework for discussing C2 evaluations led to the development of the Crisis Response Management (CRM) Matrix. This is a new analysis tool that assigns measurements into categories, and each category display unique strengths, weaknesses and trends. The analysis yielded results proving to be too rich for a single article, thusly, this is the first of two articles covering the results.

In this article, the Practitioners Guide focus on results valuable for someone interested in evaluating C2. Each evaluation has specific requirements to be met, for example, whether it is a real response or an exercise, or what competencies the evaluator has. For best result, these requirements ought to be reflected in the chosen measurement.

Keywords

Performance, Effectiveness, Evaluation, Crisis Response Management, Command & Control, Quantitative Measurements

INTRODUCTION

Feedback is key for increasing performance, it enables the receiver to effectively learn from their experiences. Studies have even shown that fields with diffuse or inexistent feedback results in similar performance for novices and experts (Schanteau, 1992). A crisis response is a typical example of a domain with diffuse and inexistent feedback because of the multitude of factors contributing to the effects in the environment. An array of organizations is involved, some collaborating and some not, and the environment itself is even changing as a consequence of time. For teams to understand the consequences of their own actions is, to say the least, problematic. The purpose of the Command & Control (C2) unit is to create direction and coordination for response (Brehmer 2007). They make the strategic decisions to create long term solutions for organizations, personnel and resources. In the absence of naturally occurring feedback, evaluations can serve as a tool to support the C2 unit in their quest to improve performance and effectiveness.

Evaluation is a systematic determination of the quality or value of something. Affirming worth and striving for progress is important in all parts of a crisis response system, and quantitative evaluations serves as a vital compliment to the qualitative. Quantitative evaluations force the evaluator to repeatedly and systematically acknowledge the same aspects, a value not to be underestimated. Just imagine the difficulty in winning a video game that change the scoring systems in each round. Shifting goals is a natural part of C2, but to expect someone to become skilled within a domain while always changing the criteria for what is considered 'good' is unreasonable. A quantitative evaluation is in this article defined as an evaluation offering the result in numbers or on a scale; this includes everything from raw numbers and percentages to more advanced statistical calculations, such as coherence and correlations.

To identify suitable measurements for conducting quantitative evaluations can be a battle. The field is scarce, and it requires a lot of time and effort before realizing whether a measurement is meeting your needs. In this article are the results of a comprehensive Scoping Study, which collects measurements available today for evaluating C2 performance and effectiveness. The measurements are analyzed through a newly developed analysis tool called the CRM Matrix. The final result is the Practitioners Guide for C2 Evaluations, presented in the end of this article. In this guide measurements are assigned into categories, and each category display unique strengths, weaknesses and trends. This presentation allows for easier access in the search for measurements that can meet specific requirements when evaluating C2.

Performance vs. Effectiveness

Performance and effectiveness are two different but related concepts: effectiveness is related to the accomplishment of the set goals, while performance is related to the team's or organizations capacities and processes (Essens, Vogelaar, Mylle, Blendell, Paris, Halpin & Baranski, 2005). A fictive scenario will describe these differences, and how the different concepts relate to each other. Imagine a wartime scenario, two fighting parties are both occupying an area, but important cargo needs to be delivered on route crossing the unsafe region.

- **Team A** initiates by contacting the conflicting parties who both assures that no attacks will take place on the given route for the time of the transportation. Both the cargo and the driver arrive safely at the goal destination. In this scenario the team accomplished the task effectively (the cargo arrived) and showed good performance (how they handled the task).
- **Team B** sends the cargo without taking any precautionary, but the cargo still arrives safely. This team reaches high effectiveness, but the performance was not satisfactory since they did not perform any safety measures.
- **Team C** completes all precautionary measures, however, there is a shooting and the cargo gets hit and the driver is injured. In this situation the team did display good performance since they did everything they could, but the effectiveness was still low since the cargo never arrived.

Two conclusions can be derived from this scenario: Effectiveness is more influenced by external factors than performance, and high performance can increase the probability of higher effectiveness but never guarantee it.

THE CRM MATRIX

The CRM Matrix categorizes measurements based on 2 distinguishing characteristics; the measurements Origin and its Focus (see Figure 1). The Origin dimension represent the logical foundations the measurement is built upon, and it consists of two classes: Expert Knowledge and Theoretical Knowledge. The Focus dimension represent the analytical perspective used for choosing what data to collect, and it consists of three classes: Process, Capability, and Macro-Cognition. The combination of these classes creates 6 categories that inherit their traits from the classes: CEM, CTM, PEM, PTM, MEM and MTM.

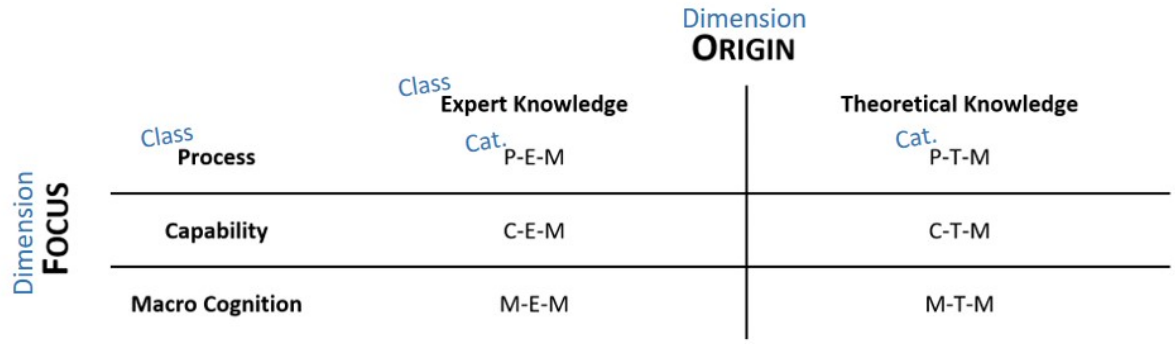

Figure 1. A visual representation of the CRM Matrix.

Each category is named based on an abbreviation of the classes it inherits traits from, then ending with the letter "M" for "Measurement". Hence, if a measurement is focused on Capability and has its origin in Expert Knowledge the abbreviation would be CEM, i.e. Capability – Expert Knowledge – Measurement (see Figure 2).

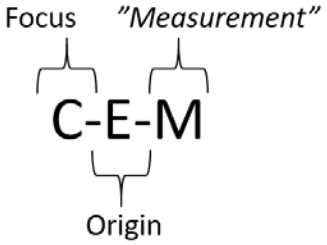

Figure 2: The name of each category is an abbreviation of the classes it belongs to.

The Origin Dimension

The Origin is the logical foundations the measurement is built upon, i.e. the support for why something is considered good versus bad in a specific context. The distinction between them are simple; methods based on Expert Knowledge do not present any theory or model related to the measurement while the methods belonging to Theoretical Knowledge do. One might ask whether the Expert class could be considered a poor scientific standard since it is difficult for a third party to assess the quality of the measurements foundation. However, systematic validity and reliability testing should be seen as a natural part of any form of measurement, and the absence or presence of these controls should instead be the main concern.

Expert (& Doctrinal) Knowledge

The criteria for the measurement is derived from expert opinions or authoritative doctrines, i.e. it builds upon implicit knowledge and experience. A doctrine is a document specifying procedures and rules valid for a certain organization, these are typically written by experts within the field and is therefore suited to be framed within this class as well.

A stereotypical measurement belonging to this class are the indicators from the medical domain (Gryth, Radestad, Nilsson, Nerf, Svensson, Castren, Riiter, 2010; Green, Modi, Lunney & Thomas 2003; Djalali, Carenzo, Ragazzoni, Azzaretto, Petrino, Corte & Ingrassia, 2014):

> An indicator is an observable variable that can be either absent or present, and the presence of the indicator is considered as valuable. These indicators are derived from experts and/or doctrines, however, no theories are presented to explain their relevance.

Theoretical (& Model) knowledge

For a measurement to belong to this class, an underlying theory or model needs to be presented that logically supports the relevance of the measurement. These measurements carry similarities to what Hayes (2012) calls Empirical Measurements; they require substantial planning and investments, and many organizations are unwilling to support them. However, a valid measurement based on Expert Knowledge would require the same efforts.

An example of a stereotypical measurement belonging to this class is the Quantitative Analysis of Situational Awareness (QUASA):

> QUASA is a method developed from the theory of Situation Awareness (SA). This method involves asking the participant about the ongoing situation and the given answer can be correct acceptance, incorrect acceptance, correct rejection or incorrect rejection. (McGuinnes, 2004).

The Focus Dimension

The Focus dimension concerns the choice of data; by choosing what data to collect a statement is made regarding what is important when handling a crisis. Each measurement carries specific assumption regarding its relation to actual performance and effectiveness, assumptions that can only be properly rejected or accepted through statistical testing.

Three classes are identified: Capability, Process and Macro-Cognition. Capability can be described as a more direct measurement, it evaluates the perceived performance or effectiveness. Process and Macro-Cognition can instead be understood as indirect, they measure aspects that influence the performance or effectiveness (see Figure 3).

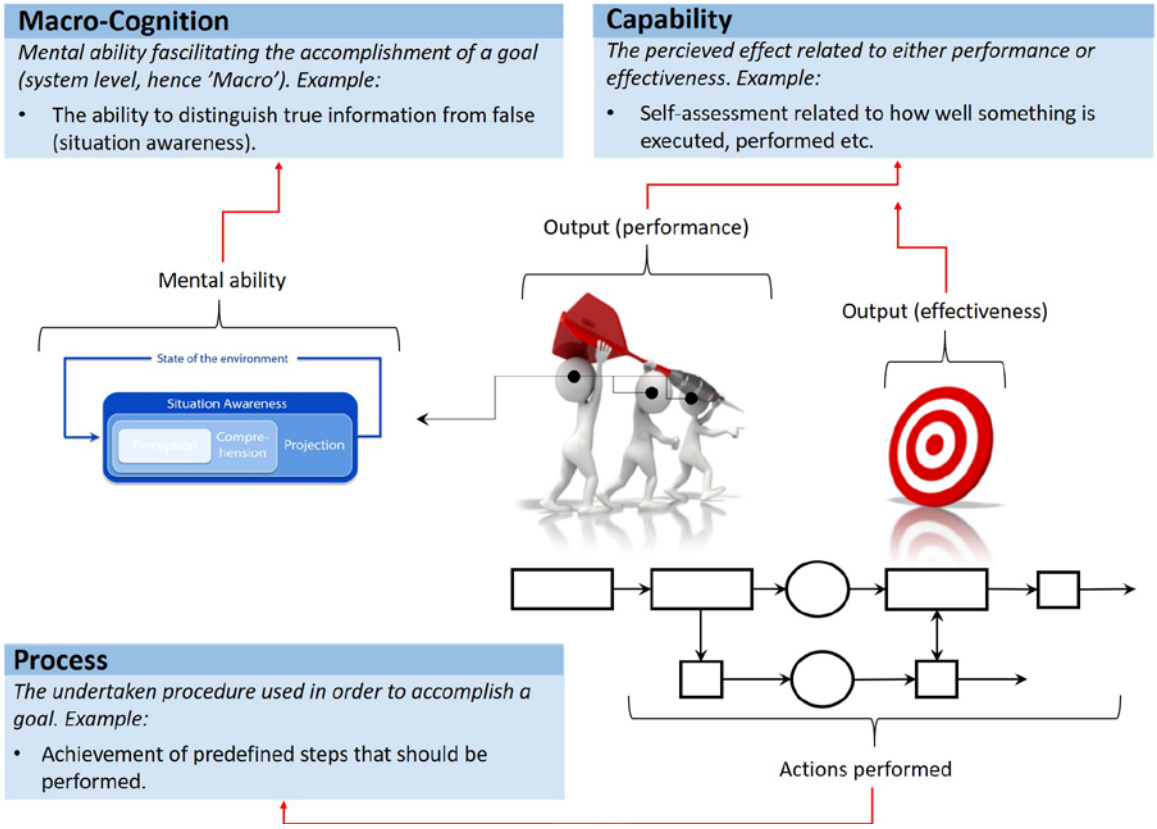

Figure 3. A visual representation of the three classes in the Focus Dimension.

Capability

Capability measurements focus on the perceived effect of either performance or effectiveness, it is important to note that *it is the perceived and not actual effect/performance* since today's measurements are based on subjective opinions. The implicit assumption is that the perceived effect is equal or similar to the actual performance or effectiveness. However, there are many influencing variables that can disrupt this correlation.

A stereotypical measurement is the Command Team Effectiveness (CTEF) questionnaire (Essens, Vogelaar, Mylle, Baranski, Goodwin, Van Buskirk, Berggren, Hof, 2010):

> CTEF is an extensive self-assessment questionnaire concerning conditions, processes, outcomes and feedback factors that influence effective teamwork. The questionnaires ask the participant to grade factors on 6 graded Likert scales.

Process

Process measurements focus on the procedure used to accomplish set goals. The implicit assumption is that a specific work processes or patterns correlate with high performance and effectiveness, and that the desirable process can be predetermined.

A typical measurement is, again, the medical indicators (Gryth, et al., 2010; Green, et al., 2003; Djalali, et al., 2014):

> An indicator is an observable behavior that can be either absent or present, and the presence is considered as valuable. Each observable indicator is part of a standardized procedure that is accepted as the correct one. For example:

Indicator	**Standard (time frame in min)**
Declaring major incident	1
Deciding level of preparedness	3
Decision on additional resources on scene	3

Macro-Cognition

Macro-Cognitive measurements focus on the mental ability facilitating the accomplishment of a goal. Macrocognition concerns the way we think in complex situations (Klein, Ross, Moon, Klein, Hoffman & Hollnagel, 2003). 'Macro' puts the emphasis on the real world setting where multiple individuals collaborate and makes use of tools and their surroundings. For example, if a team's or organizations SA is well in tuned with reality, then they will perform better and the probability of a better outcome increases. The implicit assumption is that system performance and effectiveness is achieved through the fulfillment of higher macro-cognitive functions. Measurements belonging to this class tend to go beyond raw data, such as hits, errors and accuracy, and instead makes use of increases/decreases, changes in range or variance etc.

The Shared Priorities Instrument (SPI) is a classic Macro-Cognitive measurement (Berggren, 2016):

> Shared Priorities assumes teams to be dependent on shared understanding to achieve their joint goal. Each team member generates a list of items and rank the items in order of importance, the items on each list are then scrambled and participants rank order each other's lists. Shared understanding can then be calculated by comparing the rankings.

METHOD

The method contains two individual tracks under the headings '*The Scoping Study*' and '*The Development of The CRM Matrix*'. Articles that are identified within the Scoping Study are analyzed using the CRM Matrix. The analysis yields extensive results, making it more appropriate to divide the results based on the intended reader. In this article are the results intended for practical usage, i.e. for someone planning to evaluate C2. The results are presented under '*THE PRACTITIONERS GUIDE FOR C2 EVALUATIONS*'. Complementing results are planned for a future article that focus on future method development and implications for the scientific community.

The Scoping Study

The Scoping Study was conducted 2015-17, following the 6-step framework proposed by Arksey & O'Malley (2005). The steps are revisited iteratively, as also proposed by the authors. The written presentation follows the logical order from the point of view of the 6-step framework, while the chronological order can be found in Figure 4.

Step 1: Identifying the research question

The study used a broad research question to allow range and coverage: *How can CRM performance/effectiveness be evaluated according to the scientific literature?*

Step 2: Identifying relevant studies

To satisfy the purpose of maximizing range and comprehensiveness, multiple search strategies were used to identify relevant literature:

Scopus database

Scopus a broad database featuring peer-reviewed research in the fields of social sciences, medicine, technology, arts and humanities. Key concepts were identified within the research question and complemented with synonyms (see Table 1). All possible combinations were investigated in the database using Boolean search strings in the form of (TITLE-ABS-KEY (Variable A) AND (Variable B) AND (Variable C)). Exclusion was based on (1) the number of relevant hits, (2) if they produced duplicates of other searches, or (3) if they generated an unmanageable number of articles (i.e. the term C2 generated too many hits to be practically feasible combined with few relevant hits). If the initial hits included multiple irrelevant references, then intervening subject areas got excluded (i.e. (EXCLUDE (SUBJAREA, "MATH"))). This lead up to the final search string presented in Figure 4.

Table 1: Complete list of keywords used within the database search in Scopus.

Variable A: Command and Control
Included synonyms: Coordination, Collaboration, Response Management
Excluded synonyms: Cooperation, Management, C2
Variable A: Evaluation
Included synonyms: Analysis, Measur*, Effect*, Assessment, Performance
Excluded synonyms: Audit
Variable C: Crisis
Included synonyms: Disaster, Accident, Catastrophe
Excluded synonyms: Emergency, Accident

Proceedings of ICCRTS and the C2 journal

Preliminary results from the database search shed light on an absence of relevant references, particularly from the military domain (*see Step 6: Consultation*). ICCRTS and the C2 journal have a military perspective and were believed to cover the gap identified during the consultation. Relevant tracks in ICCRTS and the complete C2 journal were hand searched from 1999-2016. Additional searches included the Information Systems for Crisis Response and Management (ISCRAM) symposium, but these were omitted based on a shortage of relevant articles.

Existing networks

This proved to be an important complement, offering insights to research not found by neither of the other search strategies. Researchers affiliated with the following networks were advised: Swedish National Defense Research Agency (FOI), Swedish National Defense University (FHS), Lund's University (LU), Center for Teaching and Research in Disaster medicine (KMC) and the North Atlantic Treaty Organization (NATO).

Step 3: Study Selection

Because of the comprehensive approach in the searches and research question, numerous irrelevant studies were included into the results. The following inclusion criteria allowed for systematic exclusion of irrelevant studies:

1. Full text is available in English or Swedish.
2. The measurements must be quantitative, i.e. offering the result in numbers or on a scale.
3. The method should be applicable either during an exercise or real event.

It is worth noticing that articles and reports *did not have to be peer reviewed* to be included. To include only peer-reviewed articles would eliminate many relevant references.

Step 4: Charting the data

Each reference was read to identify predefined characteristics, these could either have a set of values to choose from or require an open answer (see Table 2). The references are then divided according to the categories in the CRM Matrix.

Table 2: A list of all characteristics used when charting the data. The open answers in this table are only examples.

Characteristics	Value	Description
Domain	Open answer: *military, medical etc.*	A domain (profession) within CRM
Data collection	Open answer: *observers, questionnaire etc.*	How the data is collected
Data type	Open answer: *indicators, Likert-scale etc.*	Format of the collected data
Analysis	Open answer: *Summarized scores, means, ratios etc.*	How the data is analyzed
Applicability	Real event, Exercise, Both	Circumstances in which the method is applicable
Baseline	Open answer: *Specified not explained, surrogate baseline, etc.*	A benchmark of a certain value used to mark levels of performance
Generalizability	Yes/ No	Whether the method is generalizable across domains
Validation	*Open answer:* Factor Analysis, correlation to performance etc.	If and how the method has been validated
Peer reviewed	Yes/ No	Whether the literature is peer reviewed

Step 5: Collating, summarizing and reporting the results

A total of 253 articles provided the basis for the analysis; 109 articles derived from the database search, 60 from hand searching journals and conference proceedings, and 84 from consulting individuals affiliated with existing networks. In the end 56 articles were included in the analysis, however, this article do not include the crossovers making it a total of 42 references.

Step 6 (optional step): Consultation

A work in progress paper was discussed at a seminar attended by multiple scientists with PhD and professor's titles, all active within the field of CRM research. The paper covered the results from the Scopus searches with merely 12 articles included in the analysis. This proved to be rewarding. Multiple relevant references could not be found among the articles, especially from the military domain. Hence, new search strategies had to be included (see *Step 2: Identifying relevant* studies).

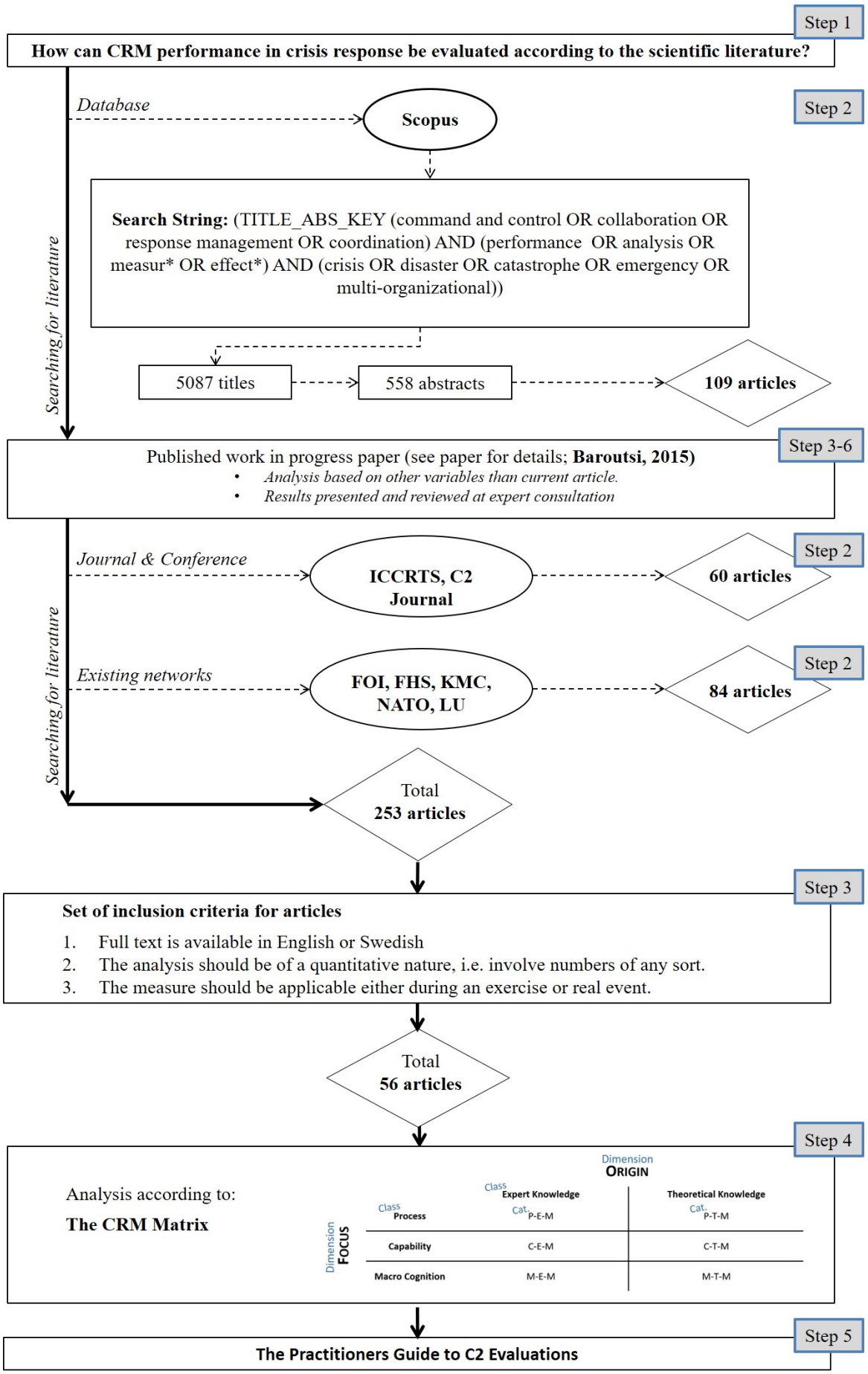

Figure 4: The method described in a chronological order.

The Development of The CRM Matrix

The initial analysis was based on Hayes (2012) classic approaches to evaluate C2, he divided measurements into Doctrinally Driven Assessments (DDA), Process Oriented Measures (POM), and Empirical Measurements (EM). However, categorizing according to these approaches proved problematic since: (1) *They are not mutually exclusive.* DDA and EM are both defined by their origin, DDA relies on expert opinions and EM rests on a theoretical underpinning. However, POM is defined by the focus of the measurement. POM should therefore not be treated as an alternative to DDA and EM, since a measurement can for example be based on expert opinions *and* focus on the process. (2) *They are not covering the range of measures available* i.e. a large portion of the reviewed literature did not fit into the defined approaches.

Attempts were made to alter Hayes framework, including attempts to introduce extra approaches from other authors. However, countless encounters with the reviewed material eventually led up to the realization that a new framework is a better choice. Resemblances might be found between the classes in the CRM Matrix and the approaches from the addressed literature, but the definitions are so far apart that referencing them would be inappropriate. The new framework, the CRM Matrix (see Figure 5), is grounded in the literature from the Scoping Study through the iterative process of altering the categories then revisiting the data. The iterative process can be divided into 3 main steps:

Step 1: Defining the classes

During the analysis two characteristics seemed to group measurements so that trends among the other characteristics became visible. These are the dimensions of the matrix: Origin and Focus. What was more difficult to provide was the definitions of the classes within these dimensions, i.e. to specify the exact feature that categorize a measurement within one class and not another.

Step 2: Investigating fit between definitions and literature

The measurements were sorted according to the defining criteria within each class, and each measurement belongs to two classes (at least). Measurements that did not fit within the classes definitions were investigated further to sort out what is causing the friction; either the measurement did not fit within any of the classes, or it belonged to multiple classes. If necessary, step 1 would be conducted again, and the classes were redefined based on this new knowledge.

Step 3: Conducting the analysis

The literature was divided according to the definitions of the categories, and the differences between the categories explored, i.e. investigating what makes each category unique. During the analysis new contradictions became clear, hence, step 1 and 2 had to be revisited until these contradictions were settled.

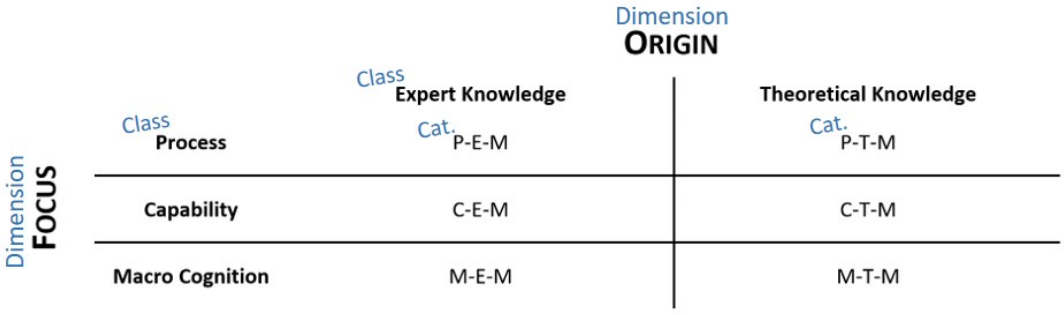

Figure 5. The CRM Matrix.

THE PRACTITIONERS GUIDE FOR C2 EVALUATIONS

This guide goes from the general to the specifics; starting out with an overview of all categories, followed by more detailed description of each one. The individual descriptions are each complemented with a table summarizing the analysis with references to the literature in the Scoping Study. Measurements that belong to multiple classes on a single dimension are called crossovers, these are excluded from the current article but will be discussed in detail in the upcoming article (see '*Conclusions*').

Field overview

Each class and category carry unique strengths and weaknesses (see Table 3), and to choose an unfit evaluation might lead to incorrect conclusions. For example, it would be recommended to choose a measurement that plays to the strengths of the evaluator; if the evaluator is highly skilled within the domain but is a novice in statistics, then it would be preferable to choose from the PEM category rather than PTM. Of course, it would be possible to let one evaluator perform the data collection and another can calculate the statistical analysis.

Measurements that are non-intrusive use data collecting methods that do not interrupt the participants in their work. For a measurement to be usable during real events the data either must be non-intrusive, or the data must be collectable after the event is completed. Post collection of data may however be less reliable, since the participants recollection of an event will become less trustworthy as time passes.

A baseline is a decided value in the analysis that marks that a satisfactory performance or effectiveness have been achieved. Baselines are scarce in all categories, which is problematic. The few that exist are not supported by any logical explanation, with one exception (Farrell, 2004). There are alternatives one can use when baselines are not available. A surrogate baseline can be used, which means that data from another evaluation is used as a standard. Another option is to only make comparisons; either follow the same organization over time to follow progress or investigate whether an organizational or technological change has had the desired effect, i.e. compare the results before and after the change. Not optimal, but these are the only options available today.

Generalizability concerns whether a measurement can be used in another domain than the one it was developed in. Some categories are more problematic to use within new domains, since they focus on procedures or concepts that are domain specific. One example is the Commanders Intent, a concept used within military organizations, but not anywhere else.

Table 3. Overview of all categories in the Practitioners Guide. For references and more detailed information, see the detailed descriptions in each category.

***1 or 2 exceptions are available.**

****This only includes statistical testing, with numbers available for the reader.**

	PEM	PTM	CEM	CTM	MEM	MTM
Non-intrusive	Yes	Yes*	Yes*	No*	Yes	No*
Use for exercises	Yes	Yes*	Yes	Yes	Yes	No
Use for real responses	Yes	Yes*	Yes*	Yes/No	Yes	Yes
Validity and/or reliability testing	No**	Common	No**	Common	No	Common
Baselines	A few	A few	None	A few	None	A few
Generalizability	Low	Medium/High	Low	High	Medium	High
Evaluator skills/ requirements						
Domain	Expert	Expert	Expert	Novice	Intermediate	Novice/ Intermediate
Statistics	Novice	Intermediate - Expert	Novice	Novice	Intermediate - Expert	Intermediate - Expert
Evaluation method	Intermediate	Intermediate/ Expert	Intermediate/ Expert	Novice	Intermediate - Expert	Intermediate - Expert

PEM: Process – Expert – Measurement

All reviewed papers rely on either observers or retrieved documents for the data collection, one did try to use the actors in the exercise, but the researchers deemed the data hard to trust. The methods for collecting data are non-intrusive for the participants, hence, suitable both for real events and exercises. The analysis uses raw scores, such as percentages and summed scores, making these available for evaluators with only basic experience in statistics. The evaluator must be knowledgeable in the domain and receive training on how to conduct the evaluation properly. Only two of the measurements offered a baseline, but neither gave any explanation on why this was a good standard. To generalize the method to new domains is troublesome since most of them focus on domain specific procedures, with a few exceptions being identified (Rüter, Örtenwau & Vikström, 2007; Brown & Galkovsky, 2007; Entin, Entin & Street 2001).

Table 4. Summary of PEM characteristics with reference to specific articles in the Scoping Study: 1. Brown & Galkovsky, 2007; **2.** Cosgrove, Jenckes, Wilson, Bass & Hsu, 2008; **3.** Djalali, et al., 2014; **4.** Entin, et al., 2001; **5.** Green, et al., 2003**; 6.** Gryth, et al., 2010; **7.** Nilsson & Rüter, 2008; **8.** Nilsson, Vikström & Jonson, 2012; **9.** Rüter, 2006; **10.** Rüter, et al., 2007.

***** Refers to the given number to each reference in the Table description.

** The actual numbers and calculations are not available to the reader.

Characteristic	**Value**	**Number of articles** (total 10)	**Articles** (ref. number*)
Domain	Medical	8	2-3, 4-10
	Team	1	4
	Military	1	1
Data Collection	Observer	8	1-7, 10
	Documents	2	8-9
	Actors	1	5
Data Type	Indicators	8	2-3, 5-10
	Matrix	1	4
	N.A.	1	1
Analysis	Raw scores (%, M, Sum, etc.)	8	3-10
	Maturity level	1	1
	N.A.	2	1, 9
Baseline	N.A.	8	1-5, 8-10
	Specified, not explained	2	6-7
Validity & Reliability	N.A.	8	1-2, 4-6, 8-10
	Discussed, not calculated	1	3, 7
	Validity claimed, not supported**	1	9
Generalizability	No	7	2-3, 5-9
	Yes	3	1, 4, 10
Peer Reviewed	Yes	9	1, 3-10
	No	1	2

PTM: Process – Theory – Measurement

The data collection displays a wider variety of methods, including questionnaires, observers and documents. All measurements are non-intrusive, except for DATMA (Berggren, Johansson, Svensson, Baroutsi & Dahlbäck, 2014; Macmillan, Paley, Entin & Entin, 2005). All measurements can be used for evaluating exercises, except two measurements that are using documents. This is because of the nature of the documents, they are not common to incorporate in training, for example patient files, governmental documents, and after-action reports. The analysis requires an evaluator knowledgeable in statistics, the exception being the Sensemaking Process Instrument that simply sums up the obtained score to form a total value (Jensen, 2006). Again, two articles offer a baseline, but no explanation is given. All but one measurement has statistically evaluated the measurements validity and/or reliability, but not all tests are significant. Many of the measurements can with changes become applicable in new domains, but this does require an experienced evaluator.

Table 5. Summary of PTM characteristics with reference to specific articles in the Scoping Study: 1. Abbasi, et al., 2010; **2.** Abbasi, et al., 2013; **3.** Berggren, et al., 2014; **4.** Hossain & Kit Guan, 2012; **5.** Jensen, 2006; **6.** Kapacu, et al., 2009; **7.** Macmillan, et al., 2005; **8.** Serfaty, Entin & Johnston, 1998.

***** Refers to the given number to each reference in the Table description.

Characteristic	**Value**	**Number of articles** (total 8)	**Articles** (ref. number*)
Domain	Civilian	2	1-2
	Medical	2	4, 6
	Team	2	3,7
	Military	1	5
	Maritime	1	8
Data Collection	Questionnaires	4	1-3, 7
	Documents	2	4, 6
	Observers	2	5, 8
Data Type	N.A.	3	1-2, 6
	Indicators	2	4, 8
	Likert-scales	1	5
	Probes	2	3, 7
Analysis	Raw scores (%, M, Sum, etc.)	3	5, 7-8
	Network Analysis Metrics	3	1, 4, 6
	N.A.	2	2-3
Baseline	N.A.	6	1-3, 5-6, 8
	Specified, not explained	2	4, 7
Validity & Reliability	Validity	5	1-5
	N.A.	3	6-8
	Reliability	1	1
Generalizability	No	4	4-6, 8
	Yes	3	1-3, 7
Peer Reviewed	Yes	6	1-6
	No	2	7-8

CEM: Capability – Expert – Measurement

Articles related to Measures of Effectiveness (MoE) are very different from the other articles within the Scoping Study. MoE differs from all other measurements in the study since they are a framework for developing variables, hence, it is not a specific measurement with specified variables (a few examples are often offered in). Many of the characteristics relate to the specific variables, hence, the label 'Not Available' becomes a recurrent theme.

The data collection for *the other articles* involves either observers or questionnaires. The MoE articles do not offer information on how to collect the data, but the results are presented in time, frequencies, ratio, etc. All measurements are applicable in both exercises and real events (MoE should be developed for real events), except for one which uses questionnaires. The analysis includes raw scores, such as means or summarized scores, making these available for evaluators with only basic understanding of statistics. No baselines are provided. One article claims that the validity has been statistically supported, but the numbers unavailable. The measurements are difficult to generalize to new domains.

Table 6. Summary of CEM characteristics with reference to specific articles in the Scoping Study: 1. Bornman, 1993; **2.** Entin, Entin & Street, 2001; **3.** Hone, Whitworth & Farmilo, 2007; **4.** Sproles, 2002.

***** Refers to the given number to each reference in the Table description.

** The actual numbers and calculations are not available to the reader.

Characteristic	**Value**	**Number of articles** (total 4)	**Articles** (ref. number*)
Domain	Military	3	1, 3-4
	Team	1	2
Data Collection	N.A.	2	1, 4
	Observers	1	2
	Questionnaires	1	3
Data Type	Frequencies, time, intervals, etc.	2	1, 4
	Continuous scales	1	3
	Likert-scales	1	2
Analysis	Raw scores (%, M, Sum, etc.)	3	1-2, 4
	N.A.	1	3
Baseline	N.A.	4	1-4
Validity & Reliability	N.A.	3	1, 3-4
	Validity claimed, not supported**	1	2
Generalizability	No	4	1-4
	Yes	1	2
Peer Reviewed	Yes	3	1
	No	1	2-4

CTM: Capability – Theory – Measurement

The data collection almost exclusively uses questionnaires, with one exception that used observers. All measurements do however use Likert-scales, sometimes complemented with other forms of questions. The advantage of this simple approach is that anyone can perform the data collection, questionnaires are simply handed out and then collected again. About half of the measurements are intrusive and should be applied during pauses in the work, hence not suitable for real events. The rest are possible to conduct post event, and one measurement use observer data. Many do not mention how to conduct the analysis or present the results because the focus of the articles is on testing the measurement and not to conduct an evaluation. The references that do mention the analysis use simple techniques, hence, making them suitable for evaluators with basic knowledge in statistics. Only one article specifies a baseline, but the logic behind it is not explained. Validity and reliability calculations are common and are even the main purpose for several of the articles. The high number of studies focusing on validations makes it surprising that this category has the highest number of non-peer-reviewed articles. All measurements are generalizable across domains.

Table 7. Summary of CTM characteristics with reference to specific articles in the Scoping Study: 1. Berggren, et al., 2014; **2.** Essens, et al., 2010; **3.** Essens, et al., 2005; **4.** Hof, de Konig & Essens, 2010; **5.** Macmillan, et al., 2005; **6.** Matthews & Beal, 2002; **7.** McGuinnes & Foy, 2000; **8.** Salmon, Stanton, Walker, Jenkins, Ladva, Rafferty & Young, 2009; **9.** Schraagen, de Koning, Hof & van Dongen, 2010; **10.** Yanakiev & Horton, 2012.

***** Refers to the given number to each reference in the Table description.

Characteristic	**Value**	**Number of articles** (total 10)	**Articles** (ref. number*)
Domain	Military	5	2-4, 6, 10
	Team	4	1, 5, 7-8
	Civilian	1	9
Data Collection	Questionnaires	10	1-10
	Observers	1	6
Data Type	Likert-scales	10	1-10
	Probes	2	1, 5
Analysis	N.A.	6	1, 3, 6, 7, 9-10
	Raw scores (%, M, Sum, etc.)	5	3, 4-6, 8
Baseline	N.A.	9	1-4, 6-10
	Specified, not explained	1	5
Validity & Reliability	Validity	6	1-2, 6, 8-10
	N.A.	3	4-5, 7
	Reliability	1	10
	Reliability claimed, not supported*	1	9
	Discussed, not calculated	1	3
Generalizability	Yes	10	1-10
Peer Reviewed	No	6	2-3, 5-7, 10
	Yes	4	1, 4, 8-9

MEM: Macro cognitive – Expert – Measurement

Seemingly small, but this category was not believed to exist, since Macro-cognition is a theoretical concept and should have a theory behind it. However, decision making is also a concept that exists in everyday language, and no theories or models are presented in the article. A software is used to collect the data, a software that must be used in the working procedures of the actors being evaluated. This measurement is applicable both for training and real events, but it does impose the working procedure that the software supports. A variety of analyses become available through the software, including cognitive workload over time, operational tempo, shared events analyzer, etc. The evaluator needs experience and understanding of both the software and statistics to use it properly. No validations are presented in the article, and no baseline is offered. It is unclear for what domains the software and measurement are suitable.

Table 8. Summary of MEM characteristics with reference to specific articles in the Scoping Study: 1. Buchler, Neill, Sokoloff & Bakdash, 2013.

***** Refers to the given number to each reference in the Table description.

Characteristic	Value	Number of articles (total 1)	Articles (ref. number*)
Domain	Military	1	1
Data Collection	Software	1	1
Data Type	N.A.	1	1
Analysis	Time series, operational tempo, resource management flow, shared event analyzer, etc.	1	1
Baseline	N.A.	1	1
Validity & Reliability	N.A.	1	1
Generalizability	Yes	1	1
Peer Reviewed	Yes	1	1

MTM: Macro cognitive – Theory – Measurement

Almost every measurement relies on questionnaires to collect that data, hence, making them less applicable for real events. A few exceptions use observers and documents, making them applicable also for real events. The analysis shows clever ways of reflecting higher-level functions through many varieties of similarity calculations, cohesion, sensitivity, and so on. For example, a measurement does not compare a participant's result against a checklist with correct and incorrect answers, but instead compares it to the other team members to calculate cohesiveness amongst the actors (which relates to the concepts of Shared Mental Models). These analyses lead to interesting results and insights not available in most of the measurements belonging to other categories (exceptions are available), but they do require an evaluator knowledgeable both in conducting evaluations and statistics. A few baselines are available, and one even explains the logic behind the decided value, making it the only reference in this study (Farrel, 2004). All but two measurements can be generalized across domains.

Table 9. Summary of MTM characteristics with reference to specific articles in the Scoping Study: 1. Berggren, 2016; **2.** Berggren, Johansson & Nicoletta, 2016; **3.** Entin, et al., 2001; **4.** Farrel, 2004; **5.** Gorman, Cooke, Pederson, Connor & DeJoode, 2005; **6.** Hansberger, Schreiber & Spain, 2008; **7.** Höglund & Berggren, 2012; **8.** Leggatt, 2004; **9.** McGuinnes, 2004; **10.** Rencrantz, Lindoff & Andersson, 2005; **11.** Salmon, et al., 2009; **12.** Seet, The, Soo & Teo, 2004; **13.** Weil, Freeman, Carley, Cooke, Diesner & Weil, 2006.

***** Refers to the given number to each reference in the Table description.

** The actual numbers and calculations are not available to the reader.

Characteristic	Value	Number of articles (total 13)	Articles (ref. number*)
Domain	Team	7	1-5, 7, 11
	Military	6	6, 8-10, 12-13
Data Collection	Questionnaires	11	1-4, 6-12
	Documents	2	6, 13
	Observations	1	5
Data Type	Likert scales	6	3-4, 6, 8-10
	Probes	5	4, 8-9, 11-12
	Ranking scales	3	1-2, 7
	Networks	2	6, 13
	Scoring sheet	1	5
	Questions (open, multiple choice)	1	12
	Frequencies, time, intervals, etc.	1	4
Analysis	Coherence	7	1-3, 6-7, 10, 12
	Raw scores (%, M, Sum, etc.)	4	4-5, 9, 11
	Similarity	2	6, 12
	Sensitivity	2	8-9
	Bias	2	8-9
	Consistency	1	4
	Difference	1	4
	Complementary	1	12
	Overlap	1	13
	Prediction	1	13
Baseline	N.A.	12	1-5, 7-13
	Specified, logic explained	1	4
	Specified, not explained	1	4
	Surrogate baseline	1	6
Validity & Reliability	Validity	7	1-5, 10-11
	N.A.	3	8-9, 13
	Validity claimed, not supported**	2	6, 12
	Not significant	1	7
Generalizability	Yes	11	1-3, 5-7, 9-13
	No	2	4, 8
Peer Reviewed	Yes	12	1-9, 11-13
	No	1	10

CONCLUSIONS

Each evaluation has specific requirements and purpose to be met, for example and to accomplish the best result, these requirements ought to be reflected in the chosen measurement. It may be tempting to simply choose a questionnaire, hand it out and then collect it again, but the evaluation will not be more rewarding than the knowledge of the evaluator.

The purpose of the CRM Matrix is to categorize measurements available today and offer guidance. This framework should not be seen as restrictive, and future measurements might not fall within any of the classes or current definitions.

FUTURE WORK

Not included in this article are the crossovers; measurements that belong to multiple classes on a single dimension. These crossovers behave differently depending on which dimension they appear on. For crossovers in the Origin Dimension, the measurement is initially developed based on knowledge from one class, and then knowledge from the other class is incorporated in a modified version (e.g. Jensen, 2016). This seems to strengthen the measurement and have a positive effect. Crossovers in Focus dimension are only present for measurements containing multiple variables. One variable cannot belong to two classes, but the individual variables can belong to different classes. Measurements that show a clear distinction between the two types of variables are included in this article but divided according to each variable (e.g. DATMA, Macmillan, et al. 2005). Some measurements do not show a clear distinction and therefore become difficult to analyse (e.g. HEAT, Hayes & Wheatley, 2001). To not clearly distinguish between these types of variables within a measurement could have negative effects. This will all be covered in the future article that is meant to complement this guide, with a focus on future method development and implications for the scientific community.

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Assessing Inter-organizational Crisis Management Capability - Initial Results of a Systematic Literature Review

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ABSTRACT

The ability to learn from crises is vital in order to strengthen the capability of societies to manage severe events. This paper presents the initial analysis of a systematic literature review regarding capability assessment of inter-organizational crisis management systems. Inter-organizational crisis management capability is a diverse concept, touching on several related concepts such as resilience, situation awareness and operational performance. During a systematic review process 73 publications were identified. The different aspects of crisis management capability found in the publications were clustered, using an exploratory approach. Nine thematic clusters were identified: interaction, relationships, coordination/C2, system performance, preparedness, situation awareness, resilience, decision making and information infrastructure. A conclusion is that crisis management capability encompasses a multitude of aspects associated with a wide range of assessment methods. The identified publications to a large extent explored aspects of collaboration and coordination, while the actual outcome (system performance) was less explored.

Keywords

Inter-organizational crisis management, crisis response, capability, assessment.

INTRODUCTION

Disasters, emergencies and crises - three interrelated terms referring to events that are sudden, unexpected, extra-ordinary and unpredictable; and affect societal functions (Al-Dahash et al., 2016). These events typically demand immediate action, suspension of ordinary procedures, decision making under uncertainty, and coordinated action (Scholl and Carnes, 2016). Crisis management capability involves a multitude of factors, and identification of valid methods to assess crisis management capability is complex. The current study was conducted within a project funded by the Swedish Contingencies Agency. The project aims to develop models for systematic learning from inter-organizational crisis management exercises to improve crisis management capability.

The ability to learn from crises is critical to organizational performance (Wang, 2015). A valid assessment of the crisis management capability is the trigger in a systematic learning process. Lessons learned processes are typically described as gathering observations (issues for improvement or a potential best practice), transforming these into lessons identified and implementing the lessons identified to lessons learned (Nato, 2016; Andersson and Eriksson, 2015). Figure 1 illustrates how detected deficiencies in crisis management capability motivate changes in a crisis management system, and how this corresponds to a lessons learned process.

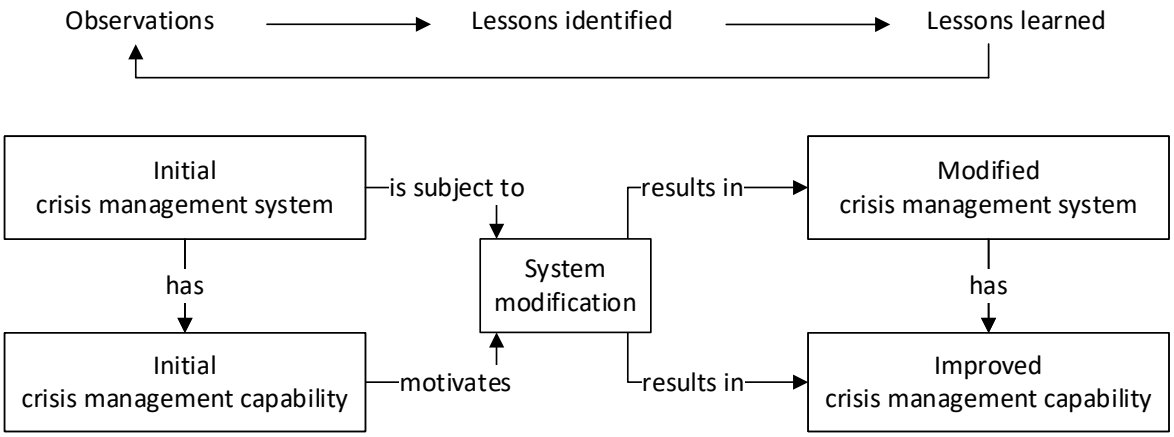

Figure 1. Illustration of how detected deficiencies in crisis management capability motivate changes in a crisis management system.

The objective of the study is to explore inter-organizational crisis management capability and identify capability assessment methods applicable within the Swedish crisis management system. For this means, a systematic literature review was performed.

What is meant by crisis management capability? In its broadest sense, capability is the ability to do something (Oxford dictionary). Lindbom et al. (2015) have identified 13 different definitions of capability used within the crisis management domain. They conclude that capability definitions are commonly related to the easily measured constructs resources and capacity, but generally lack to consider resilience, vulnerability and risk.

During risk and vulnerability analyses, the potential capability to manage future crises is assessed (Lindbom et al. (2015). However, capability can also be assessed in retrospect, that is, how capable organization(s) were to manage an actual (or simulated) crisis, similar to the concept of organizational performance (Wang, 2015; Comfort, 2007). A multi-organizational perspective means that the ability to solve a situation depends on organizations' individual capabilities, as well as their ability to collaborate and coordinate their efforts. The *4C framework* includes essential aspects of inter-organizational performance: cognition, communication, coordination and control (Comfort, 2007). Cognition encompasses the ability to detect risks or malfunctions in a system, which is what triggers action. Communication is essential to convey detected risks and coordinate actions. Through coordination, actors align their actions in order to achieve a common goal. Control encompasses the capacity to keep actions focused on the shared goal of protecting lives, property, and maintaining continuity of operations.

Resilience is a concept closely related to capability that has been widely studied (Woltjer et al., 2015). Woods (2015) structures the meanings of resilience into four approaches: (1) rebounding from a trauma and returning to equilibrium, (2) robustness, (3) graceful extensibility, and (4) sustained adaptability. Woods argues for a definition which is in line with the last two approaches, suggesting that a resilient system is one that is able to adapt and change rather than a system that stands firm in times of changes. In this sense, resilience is closely related to *agility*, a concept mainly used within the military command and control domain (NATO STO-TR-SAS-085, 2014). Béné (2013) concludes that resilience is a multi-component concept. A resilient system is able to balance the cost of the response, the type of response required and the intensity of as well as the cost of the "shock". Thus, resilience is the ability to persist, adapt or transform in the face of a shock or changing environment (Bènè, 2013).

Situation awareness (SA) is a frequently used theoretical concept of the individual's understanding of a situation or a system. SA is commonly described as comprising three levels of understanding: (1) perception of critical factors in the environment, (2) understanding of the meaning of these factors, and (3) understanding, or predictability, of what will happen in the near future (Endsley, 1997). The concept has been developed for applicability to teamwork, where SA, for example, is essential for emergency management organizations that strive to consolidate towards a common goal. Two basic types of definitions are considered for teamwork: team SA and shared SA. Team SA concerns the degree to which every team member possesses the SA required for his or her responsibilities, whereas shared SA concerns the degree to which team members possess the similar SA on shared requirements (Endsley and Jones, 1997). Generally, shared SA provides a richer and more meaningful picture of a teams' ability to work towards a common goal.

This paper presents an initial analysis of a systematic literature review regarding capability assessment of inter-organizational crisis management systems. The inter-organizational scope means that capability in terms of

single-organization capacity and personal skills are not considered. Further analyses will investigate how inter-organizational crisis management systems are modelled and the relations between capability assessment and the inter-organizational crisis management system.

METHOD

The systematic literature review was conducted according to standard procedures for systematic reviews (e.g. Kitchenham, 2004; Okoli and Shabram 2010). The selected methodological approach was to identify a single dataset that was useful for investigating assessment of inter-organizational capability as well as providing descriptions of inter-organizational crisis management systems. The actual literature search was preceded by a pilot study, as described in the following sections.

Pilot study

The pilot study aimed at identifying existing systematic literature reviews assessing crisis management capability or modelling emergency management systems, provide input regarding appropriate search terms, development of a review protocol, and get hands-on experience of the Scopus database. Scopus is a multi-disciplinary database widely used for literature reviews, provides functionality for obtaining an overview of the result and has been proven to result in a sufficient dataset (Yang and Lokman, 2006). The pilot search was based on a limited selection of search terms (table 1), and limited to publications between 2012-2017. A Boolean type of search was used with OR between the rows in a column and AND between the columns. The search was conducted on title, abstract and keywords of the publications in the Scopus database.

Table 1. Search terms for pilot study

Crisis	Management	Assessment/ model	Literature review
Emergency	Preparedness	Assess*	Literature review
Crisis	Management	Analys*	Scoping study
Disaster	Response	Performance	Scoping review
		Measure	
		Model	

The pilot study resulted in the identification of six literature reviews providing inspiration in the continuous planning and execution of the main study. A review of similarities and differences between the terms crisis, disaster and emergency provided insight about the interconnectedness, interdependencies and interchangeable use of these terms in the literature (Al-Dahash et al. (2016). As a consequence, all combinations of emergency/crisis/disaster with preparedness/management/response were included as search terms in the main study.

Two literature reviews found provided particular inspiration, describing literature reviews that methodologically and topic-wise were related to the research questions of the current study (Skryabina et al. 2017; Beerens and Tehler, 2016). Terms describing capability assessment provided a challenge as different terms are used for similar phenomena, and terms such as “assess” may occur in common language without indicating specific assessment methods. The pilot search guided in the formulation of inclusion and exclusion criteria (table 3).

Database search

The search was conducted in the Scopus database. Three categories of search terms were identified (table 2). The time limit was set to publications between the years 2012-2017. Only publications written in English were included. Publications in the following subject areas were excluded; mathematics, biochemistry, material studies, immunology, neurology, pharmacy and veterinary studies.

Table 2. Search terms for main study

Crisis management	Capability assessment	Multi-actor
Emergency preparedness	Assess*	Multi-agency
Crisis preparedness	Analys*	Multi-actor
Disaster preparedness	Performance	Inter-organi?ation*
Emergency management	Indicator*	Coordination
Crisis management	Examin*	Joint
Disaster management	Validat*	Collaboration
Emergency response	Capability	
Crisis response	Eval*	
Disaster response	Concept	
Emergency relief		

Abstract review

The title and abstracts of the 1197 publications resulting from the database search were reviewed according to inclusion and exclusion criteria (table 3). The publications were divided between three researchers so that all abstracts were reviewed by two researchers. Hence, each researcher reviewed approximately 2/3 of the publication abstracts.

Table 3. Criteria for inclusion and exclusion of publications during abstract review

Inclusion criteria	Exclusion criteria
Description of assessment of crisis management capability and/or description of modelling of crisis management system/s Primary focus on governmental organizations Involving more than one crisis management organization	Not relevant for the research questions Focus on personal skills Focus on single crisis management organization Primarily technical focus Focus mainly on preparedness plans

For publications complying with the inclusion and exclusion criteria, each reviewer rated its relevance on a three-point scale: 1) Questionable relevance, 2) Moderate relevance, and 3) High relevance

Initially, two of the reviewers both reviewed the first 50 publications in the dataset. A check of their agreement showed agreement of inclusion/exclusion for 76 percent (38) of the 50 publications. The reviewers solved the 12 disagreements by a common discussion, resulting in that six of the non-agreed publications were included. This discussion contributed to a common understanding of the questions at issue as well as interpretation of the relevance rating and exclusion and inclusion criteria.

The abstract review resulted in 250 publications where both reviewers agreed on inclusion, 682 publications where both reviewers agreed on exclusion (or identified duplications) and 265 disagreements. For the disagreements, if one reviewer had decided on inclusion with relevance rating 1 (Questionable relevance) and the other had decided on exclusion, the publication was excluded. This was the case for 168 of the 265 conflicts. For the remaining 97 publications, the third reviewer performed a supplementary abstract review, resulting in that 44 of these publications were included (45%). This left a total of 294 included publications. Due to time constraints, the dataset for full-text review needed to be further reduced. The sum of the reviewers' relevance ratings was used for this reduction. Since two reviewers reviewed each abstract, the sum of the ratings for included publications ranged between two and six. Publications rated four or higher were included in the full text review (table 4).

Table 4. Sum of relevance rating for included abstracts. Relevance below 4 is shaded since these publications were not included in the full text review

Rated relevance	**6**	**5**	**4**	**3**	**2**
Number of publications	8	36	106	106	38
Accumulated sum of publications	8	44	150	256	294

Publications with a sum relevance of two and three may be reviewed again if the study is extended with a supplementary review.

Full-text review

Full-text review was performed on the 150 remaining publications. Initially, three publications were reviewed individually in parallel by all three reviewers. This was followed by a group discussion to consolidate on agreement of interpretation and understanding of the inclusion and exclusion criteria. The remaining 147 publications were then divided between the three reviewers, thus each publication was reviewed by one reviewer.

The procedure of the full text review was formalized by a review template implemented in an MS Excel sheet. The overall template structure was inspired by a review template developed for a literature review in DARWIN, a European research project aiming to develop generic resilience guidelines for emergency and crisis management organizations (Woltjer et al., 2015). The DARWIN template served as inspiration for the general questions to the material. For questions related to the research questions, two of the reference reviews from the pilot study provided inspiration (Skryabina, et. al, 2014; Beerens and Tehler, 2016). The review template encompassed 34 review questions assessing general information of the described studies, capability assessment, modelling or describing emergency management systems, and information on relevant reference literature (snowballing).

Through snowballing, 37 publications were identified as potentially interesting to include in the dataset. The abstracts of these publications were reviewed according to the same procedure as the other reviewed abstracts. 16 (43%) of the snowballing abstracts were included in full-text review.

This means that in all, 166 publications were included in the full text review. Of these, 106 (64%) were assessed as relevant while 60 were excluded. The selection process from database search to full-text review is summarized in figure 2.

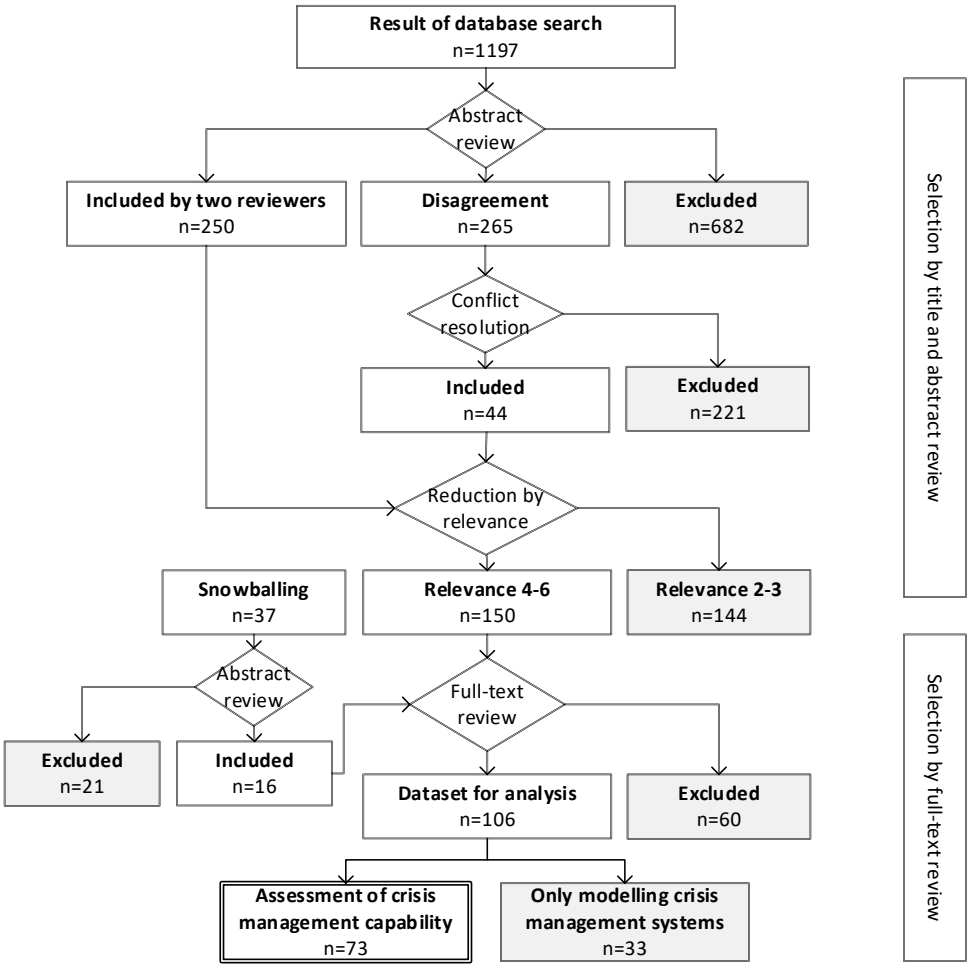

Figure 2. Overview of the publication selection process

Analysis

Using the information in the full-text protocol on the question "which aspect of crisis management capability is assessed," the identified capabilities were clustered. One of the publications in the dataset used a modified version of the 4C framework by Comfort (2007) to structure the results of a review on case studies of multi-agency disaster response (Steigenberg, 2015). However, we found it difficult to match the identified capabilities according to 4C. Instead an explorative approach was chosen, where the clusters were formed based on content. The clustering process was iterative, resulting in that the categories changed along with the capabilities identified. Some publications needed to be reviewed again, to identify the meaning behind the formulations, as the information in the full-text protocol was unsatisfactory. For instance, collaboration was used frequently throughout the publications, however with different meanings. The clustering provided an overview of the different themes in the material.

The analysis further included an investigation of which types of measures that were used for assessing the capabilities. The methods were clustered to investigate if some methods or types of methods were used more frequently. Furthermore, a comparison between assessment methods and the thematic clusters were conducted to investigate whether some methods are more commonly used for certain types of capabilities.

RESULTS

73 of the 106 publications in the dataset included methods to evaluate inter-organizational crisis management capability. The analyses in the current paper are conducted on those 73 publications.

General overview of publications

The distribution of which types of studies that were described in the publications is presented in table 5.

Table 5. Distribution of the types of studies in the publications

Study type	Number	Percent
Empirical study	42	58%
Mixed	22	30%
Literature review	5	7%
Theoretical study	4	5%

Regarding type of data or measures, the distribution was 29 (40%) qualitative studies, 20 (27%) quantitative studies, 21 (29%) including a mix between qualitative and quantitative measures, and 3 (4%) specifying no measures.

A majority of the publications were based on actual incidents, of which a majority referred to natural disasters. The distribution of types of empirical interventions in the studies described in the publications is presented in Table 6. 17 of the publications did not fit into any of the categories, either because empirical intervention was unclear, the type of intervention did not fit any of the available categories, or that the publication was a theoretical study with no empirical intervention.

Table 6. Distribution of empirical interventions in the publications

Empirical intervention	Number	Percent
Real incident/case	41	56%
Tabletop exercise	5	7%
Command Post Exercise	4	5%
Functional exercise	3	4%
Field Exercise	2	3%
Experiment	1	1%

The publications described incidents, exercises or experiments conducted in 24 different countries. Distribution of countries that occurred in three or more publications is presented in table 7. As seen, Sweden is highly represented, considering its small population and low occurrence of natural disasters. This can be explained by three factors. First, since the main focus was on governmental organizations, publications focusing on the work of voluntary organizations in major natural disasters were to a large extent excluded, while studies of disasters or exercises focusing on nation's own capacity to manage the incidents remained in the material. Thus, studies investigating crises in countries where there was a huge need for international aid were to a large extent excluded. Further, in the time scope of the literature review there was a major forest fire in Sweden 2014, resulting in research specifically targeting multi-agency collaboration (Bergström et al., 2016; Bodin and Nohrstedt, 2016). Third, as the result of the systematic literature review is mainly to be applicable in the Swedish context, the acceptance of Swedish publications was somewhat more generous. Still, all publications in the dataset were in line with the inclusion criteria, regardless of location of intervention.

Table 7. Distribution of countries that occurred in three or more of the publications

Location of events (countries)	Number	Percent
USA	15	21%
Sweden	11	15%
Australia	7	10%
China	6	8%
Germany	3	4%
Indonesia	3	4%

The publications included studies from local to international administrative level (table 8). 42 publications (58%) described studies on more than one administrative management level, on average 2 in each study. International organizations were represented to a higher extent in the Scopus search result, however as publications about international organizations mainly focused on volunteer work, most were excluded during the abstract review.

Table 8. Distribution of publications on administrative management scale

Administrative management scale	Number	Percent
Local (communal)	50	68%
Regional (county)	50	68%
National	31	42%
International	6	8%
Unspecified	6	8%

Assessment of crisis management capability

Concerning capability assessment, nine thematic clusters were identified. The clusters identified are presented in table 9, with their related capabilities as described in the publications, and the number of publications represented in each cluster. Each publication included on average 2.2 capabilities. Since publications included terms represented in more than one cluster, the number of publications in table 9 sums to 157.

Table 9. Clustered capabilities

Cluster	Capabilities	Number of publications
Interaction	Communication (responder, crisis, outreach, inter-organizational, rapid), Collaboration (Formal/informal), Relation between collaborative networks and task interdependency, Team disconnects, Information sharing, Collaboration practices, Task interdependency, Inter-organizational crisis management, Participators interaction, Information flow, Intersectional interactions/collaboration, (Intergovernmental) interactions, Managing collaborative activities, Information flow, Cooperation, Social behaviors, Social network, Informal networks	38
Relationships	Formal and trust based relationships, Resource allocation, (Shared) Awareness of knowledge, tasks, roles, material and personal resources, Formal and informal networks, Trust, Shared priorities and goals, Collective accountability, Interoperability (barriers and approaches), Predictability, Common understanding and vision, Multiplexity, Embeddedness, Transitivity, Homiphily, Brokerage, Collaborative initiatives, Creating collaborative culture, Building collaborative institution, Synergies, Partnership development and maintenance, Cooperative attitude, Misalignment between agencies, Organizational structure and practices	24
Coordination/C2	Hierarchies between actors, Shift from information management to interaction management, C2, Coordination, Coordination centers/command posts, Leadership, Identifying formal and emergent coordinators, Clear superordinate goals, Hierarchical multi-agency organizational structure, Inter-organizational coordination, Formal disaster response system, Control mechanisms in coordination, Resource mobilization, Favor monodisciplinary, Strategy	23
System performance	Analysing the situation, Actor and process pre- and post-disaster, Team performance (Requisite variety, Delegation of decisions, Fallacy of centrality, Thematic lock-up, Thematic vagabonding), Network- level outcomes, Client level effectiveness, Network (sensitivity, function), Endogenous and exogenous stressors, Collaboration awareness, System/organizational capacity, Capability and function, (General, organizational) performance, System-wide humanitarian response operations performance, Actions implemented, Operational efficiency, Organizational capacity building, Framework (conceptual, structural, operational, scientific), Self-awareness, Network level competencies	22
Preparedness	Training and evaluating disaster preparedness plans, Contingency planning (effectiveness), Preparedness (Institutional, Individual, collective, local emergency), Network according to prior plans, Framework applicability, Operational experience, Emergency plan,	12

	Learning related work activity	
Situation awareness	Risk awareness, Risk assessment, Situation assessment, Assessment of resource needs, Sensemaking, (Shared) Situation awareness, Disaster assessment, Perceptions of risk and risk management procedures, Situation understanding, Situational picture	11
Resilience	Robustness, Rapidity, Resourcefulness, Redundancy, Innovation and change, Adaptive capacity, Resilience themes in preparedness, Emergent network, (Social) Network evolution, Evolution of social behaviours in a network, Capacity, Integrated disaster resilience, Relationships between resilience and adaptive governance	11
Decision making	Decision making (decentralized), Planning processes and procedures, Plan formulation, Central planning, Evaluation of implementation of emergency plans, Analyse crisis situations, Simulating the effects of different possible actions	9
Information infrastructure	Information and communication technology (ICT), Development and validation of ICT prototypes, Communication technology, Use of coordination technology, Equipment, IT-support, Inter-organizational IT use	7

Interaction was the largest cluster, which was included in 38 publications. Most frequent capabilities mentioned in this cluster were communication and collaboration. The publications used several related terms, inconsistently used between publications. Interaction activities may have both active and passive forms but still be referred to as collaboration (Robinson and Gaddis, 2012). The cluster thus included some publications about information sharing activities from a quantitative perspective, that is, number and patterns of interaction (Ley et al., 2014), while other publications qualitatively addressed how different actors actively engage in collaborative activities (Bergström et al., 2016).

Relationships referred to capabilities relating to knowledge of each other's roles, responsibilities, equipment and tasks, trustbuilding and collaborative institutions. The concept of trust was explored in several publications (House et al., 2016; Gero et al., 2015), while other terms were mentioned only in one publication, such as multiplexity and embeddedness, (Lai et al., 2017).

Coordination/C2 included concepts related to mandates and commanding structures (hierarchical or horizontally organized) as well as leadership issues. Coordination is about aligning different actors' actions towards common goals (Comfort, 2007). The cluster further included capabilities related to activities for structuring the leadership (Bergström et al., 2016).

System performance included capabilities related to the actual outcome of the crisis management response. These were primarily capabilities aiming to give an overall assessment of the total performance of a crisis management system; however, some publications primarily focused on the outcome on client level (Bang and Kim, 2016).

Preparedness included terms related to the evaluation of preparedness plans based on the outcome of a crisis or an exercise. For example if the collaborative network that emerged during crisis response was in line with the preparedness plan (Robinson et al., 2013). The publications that only had focus on the development of preparedness without relating it to a crisis were excluded according to the exclusion criteria.

The *Situation awareness (SA)* cluster was formed based on Endsley (1997). All publications in this cluster did not use the term situation awareness, however they studied capabilities in line with this theme, such as sensemaking or risk perception (Baroutsi, 2016; Holgersson, 2016). The awareness of other actors' tasks and responsibilities is related to the situation awareness, however it was decided to instead include these capabilities as a part of the relationships cluster. This is mainly due to that the awareness of other crisis response actors is highly related to trust and the forming of relationships.

The *Resilience* cluster was formed mainly based on the definitions of Woods (2015) as well as Bené (2013). This means that publications could focus on robustness aspects or on adaptation aspects. One example is Jung (2017), viewing resilience as a function of the capabilities robustness, rapidity, resourcefulness and redundancy. Similar to the situation awareness cluster, not all publications specifically mentioned resilience. For instance, the cluster included a publication assessing adaptive capacity (Gero et al., 2015).

Decision making included capabilities relating to the decision making process such as analysing the situation,

creating plans and simulating the plans to investigate the possible outcome (Bañuls et al., 2013).

Information infrastructure gathered terms dealing with technical equipment, mainly communication equipment. As publications focusing purely on technology were excluded, the publications in this cluster addressed for instance how communication technology is used in the emergency management situation and the effects of insufficient technology on crisis management (Hall et al., 2012).

Figure 3 illustrates types of measures (quantitative, qualitative, or mixed) used for assessing the capabilities in each cluster. Three of the publications did not specify any measures. In total, 72 capabilities were assessed using qualitative measures, 40 capabilities were assessed using quantitative measures and 39 contained a mix. The bars in figure 3 illustrates that the number of publications with qualitative measures is larger for most categories, except for the clusters preparedness and resilience. This indicates a general preference for qualitative measures for assessment of emergency management capability. Qualitative capability assessment was based on e.g. analysis of reports, interviews, questionnaires, observation and workshops. For quantitative or mixed measures, Social network analysis (SNA) was most influential, representing 38% of the quantitatively measured capabilities and 28% of the mixed measures. SNA is commonly used to investigate which participants/functions that were most influential in an organization or organizational cluster (Bisri, 2017). SNA analysis is conducted mainly through quantitative measures, however in order to extract the data needed for the analysis, qualitative measures may be used. SNA was highly represented in the coordination/C2 cluster, where SNA represented 100% of the quantitative measures and 50% of the mixed measures, followed by the interactions cluster (44% of quantitative measures and 15% of mixed) and relationships (17% of quantitative measures, 40% of mixed).

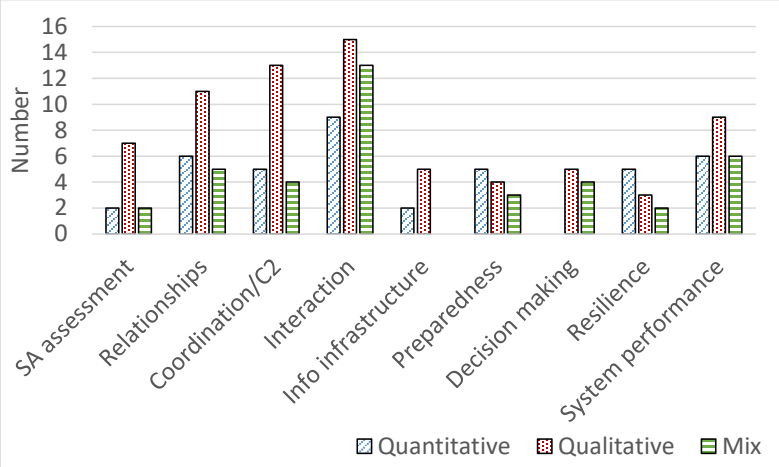

Figure 3. Types of measures used for assessing capabilities within the different clusters.

DISCUSSION

This paper presents an initial analysis of a systematic literature review aiming to investigate assessment of crisis management capability in inter-organizational crisis management systems. The dataset was diverse, including a multitude of perspectives relating to the topic. The broad scope on capability fulfilled its purpose to open up for different perspectives, however demanded an iterative and exploratory analysis and a thorough investigation of the meaning behind the terminology used by the authors of the publications. The clusters resilience and situation awareness were formed based on reference literature, which was particularly useful regarding publications that did not specifically use the terms situation awareness or resilience, (e.g. adaptive capacity, Gero et al., 2015). The interaction cluster was a "giving up" on trying distinguishing between interrelated terms concerning collaboration, cooperation, communication, interaction etc., as the authors of the publications used these terms very differently. By creating a broad cluster for interactive activities, this problem was reduced. It is hardly surprising that the most common capabilities clustered in the analysis were related to interactions, relationships and coordination/C2 considering that the multi-agency perspective was included both in the literature search terms and in the review criteria. Publications were mainly focused on the interaction between actors, while the actual outcome (System performance cluster) was less explored. It is assumed that improved collaboration will result in improved performance, however few studies have investigated whether the actual response and actions taken were appropriate.

As different terms and concepts overlap, and some terms encompass broad phenomena there are not absolute boundaries between the clusters, and capabilities are clearly related to each other. One identified example is knowledge of other actors' responsibilities and tasks, which was assigned to the relationships cluster, although it

can be argued that this knowledge is part of SA. Still, the nine clusters are, to us, quite intuitive, and useful for the further analysis, when trying to identify applicable methods and measures as well as understanding which different themes are included in the concept of inter-organizational crisis management capability. The 4C Framework (Comfort, 2007) initially seemed applicable, however when assigning capabilities, we found it difficult to distinguish between the C's, especially between coordination and control. The resulting set of clusters is not definite, and if it is found that the boundaries between capabilities is blurred, clusters may be merged. Further research on the dataset will include deeper investigations of the specific concepts and methods.

The systematic review approach was found useful, although time consuming. The pilot study indicated that terminology in this subject is diverse, which was further confirmed by the results of the main study. In retrospect, the search terms seem sufficient. We have not identified how we could have adjusted search terms or used Scopus features to more efficiently sort out irrelevant results, while keeping the relevant results. The relevance rating facilitated prioritization of which publications should be read in full-text for this initial analysis, although we have already identified several publications with low rating that are relevant to read for a more comprehensive result in the further analysis. The fact that 60 publications were excluded during the full-text review shows that the assessed relevance of the abstracts did not always correlate with the relevance of the full-text publications. The diversity in researcher background was fruitful for the understanding of the different perspectives of the publications. Synchronizing the review assessments by co-reading abstracts as well as publications, and discussing the review criteria as well as the protocol was a criteria for success.

CONCLUSION AND FUTURE WORK

The systematic literature review have definitely resulted in an understanding of the concept of inter-organizational crisis management capability. The nine different themes, or clusters, summarizes the recent research and shows that the capability concept is broad with a diverse, sometimes confusing, terminology. The analysis shows that research is mainly focused on the interaction between actors, while the actual outcome (System performance cluster) is less explored

Hopefully, the terms identified within the different clusters can guide researchers to identify related research within their topics of interest. The next step will be to conduct a more thorough analysis of the methods and measures used for capability assessment within each cluster. As figure 1 in the introductory section illustrates, crisis management capability is connected to a crisis management system. Thus, the links between the types of capabilities assessed and the types of crisis management systems will be investigated. Exploring capability assessment in relation to crisis management systems will hopefully give valuable insight into how crisis management systems can learn from crises. The dataset will further be used to explore how inter-organizational crisis management systems are described and modelled. Since a significant amount (35%) of the so far included publications contain both the capability assessment dimension and the system modelling dimension, the dataset gives a good foundation for these analyses.

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Reflection in Teams for Training of Prehospital Command and Control Teams

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ABSTRACT

Prehospital command and control (PS) is a structure for handling medical accidents in Sweden. It includes terminology, command structure, roles, and performance indicators. The concept is taught and trained at the Centre for Teaching and Research in Disaster Medicine and Traumatology (KMC). The concept is trained using a mixture of lectures, simulation based exercises, and scenario designed by the participants. The scenarios are ran in Emergo Train System (ETS), a versatile and flexible table-top simulation platform, where medical command and control can be trained and evaluated. The purpose of this study was to develop structure for feedback and reflection by using a measure of shared understanding. The empirical study presents how the Shared Priorities instrument can be used to provide structured feedback for training. The paper is concluded with a discussion on how the empirical findings can be integrated in training prehospital medical command and control.

Keywords

Emergo Train System, training, pre-hospital, medical command and control, emergency response

INTRODUCTION

If the emergency response organisation is unclear in case of an accident, suffering and unnecessary mortality may occur. In the 1990ies two accidents took place in Sweden that made this distressingly clear. Those were the Estonia accident in 1994 (Socialstyrelsen, 1997) and a fire in a discotheque in Gothenburg in 1998 (Riddez & Dellgar, 2005). Both accidents included many deaths and injured patients. The national evaluation of these accidents called for a novel approach to handling medical accidents and response. In 2003 the National Board of Health and Welfare (Socialstyrelsen) gave the task of implementing the suggested solution to the Centre for Teaching and Research in Disaster Medicine and Traumatology (KMC) that since then have developed and administered a concept called Prehospital command and control (PS; a Swedish acronym for *Prehospital sjukvårdsledning*). PS is a concept for a national model including a shared terminology, command structure, roles, and defined states of preparedness (cf. https://www.psconcept.se/om-ps; Rüter, Nilsson, & Vikström, 2006). The C2 model is a clarification of the healthcare system's responsibility on a regional level (the county council in Sweden). The concept is based on SOSFS 2005:13, the Swedish national regulations for handling disaster medicine preparedness, and is since 2014 replaced with SOSFS 2013:22. Today there are more than 8000 users trained in the PS concept. The PS concept is a framework for conducting medical command and control. The first ambulance to arrive at the incident scene will be the one to establish medical command and

control, where the persons assume the roles of Ambulance Incident Commander and Medical Incident Commander (Rüter, Nilsson, & Vikström, 2006). However, to maintain the capacity for prehospital medical command and control new operators need to be trained. An important part of the training is the feedback and reflection that the course participants

An important aspect of the medical command and control team is having the knowledge of how to effectively resolve the situation. As many disaster-related deaths are preventable (Cropper & Sahin, 2009), providing a structured approach ensures that unnecessary measures and erroneous interactions are avoided, hence avoiding avoidable deaths and complications. Emergency preparedness is a way to reduce the physical and psychological consequences of an incident. Prehospital command and control is therefore an important part of the medical teams' working structure as the right treatment can reduce future complications, avoid unnecessary suffering, and in the most severe cases avoid possible death. Prehospital medical command and control is the first step regarding health care and thus very important to include in order to assure the best possible outcome (Nilsson & Kristiansson, 2015).

Purpose

In this work in progress paper the aim is to describe the testing of a novel approach for providing feedback and reflection as a part of a training course for prehospital medical command and control personnel using a simulation called *Emergo Train Systems* (see below). This is done by assessing a team's shared understanding and using the team members' perceptions as input for reflection regarding the pros and cons of the Emergo Train Systems PS training conducted at the Centre for Teaching and Research in Disaster Medicine and Traumatology. Shared understanding is assessed using an instrument called *Shared Priorities.* The research question posed in this study is:

Does the outcome from the Shared Priorities Instrument provide a sound basis for feedback and reflection among teams being trained to lead and organize the handling of an accident scene? Consequently, can Shared Priorities be a useful tool for the instructors to promote reflection?

THEORETICAL BACKGROUND

Prehospital medical command and control

Organizational learning (Crossan, Lane, White, & White, 1999; Pilemalm, Andersson, & Mojir, 2014; Drupsteen & Guldenmund, 2014; Lick, 2006) and collective learning (Decuyper, Dochy, & Van den Bossche, 2010; Dochy, Gijbels, Raes, & Kyndt, 2014) are theoretical frameworks for training and learning. This frames how training is achieved and also how training is transferred to performance in the real world. The frameworks also provide guidance on how reflection and feedback can be used to increase learning and transfer (Gabelica, Van den Bossche, De Maeyer, Segers, & Gijselaers, 2014; Drupsteen & Guldenmund, 2014). The PS concept is such a training framework. It is used today in Sweden by all but one county council, which is implementing the concept and will be fully using it from 2019.

The prehospital command and control training program is divided into three parts: PS, PS plus, and PS refresh. PS is an introductory course covering the basics ensuring that the participants have a solid foundation when acting in the prehospital command and control role. PS plus is the advanced course for acting in situations with higher demands. PS refresh is a rehearsal course. The courses are structured as team training and have similarities to the effect based approach to training (EBAT; Fowlkes, Dwyer, Oser, & Salas, 1998). The courses include lectures and workshop elements where the participants execute prehospital command and control in table-top scenarios. All course components are supervised by PS instructors who use the behaviors and experiences from the scenarios to have a dialogue with participants so that they can reflect upon their development.

As response in medical emergencies needs to be quick and appropriately executed, performance indicators have been central to the PS concept. These indicators include timely responses and correct use of terminology, reporting, and behaviors (Rüter & Vikström, 2009; Wakasugi, Nilsson, Hornwall, Vikström, & Rüter, 2009; Rüter, Örtenwall, & Vikström, 2007). After having attended a course in prehospital command and control a participant should be able to establish medical command and control at the scene of the incident, report according to standards, collaborate with other agencies, direct and coordinate the medical operation according to recognized goals, decide on medical orientation in relation to triage, organize transport to hospital, handle information sharing for the medical operation, and assure documentation.

The Emergo Train System

The Emergo Train Systems (ETS) is a Simulation based training approach for improving PS command and control skills. ETS is used for training medical teams, both prehospital and in-hospital, and for collaborative exercises with Police and Fire departments. ETS has been developed, is administered, and owned by Region Östergötland (the County Council of Östergötland) (Nilsson, 2013; Rybing, Nilsson, Jonson, & Bång, 2016; Rådestad et al., 2012; Nilsson et al., 2013; Nilsson et al., 2010).

ETS consists of a paper-based patient database along with resources specific for disaster management. The patients in the ETS belong to an injury category that requires a certain treatment within a specific timeframe. If the caregiver fails to treat the patient in time, he or she might have an unwanted outcome, such as risk for preventable death and complications. The performance indicators from ETS, such as the outcomes of the patient and what treatment they were given (Nilsson et al., 2013; Rüter, Nilsson, & Vikström, 2006) are assessed regularly and are used for evaluation of the participants performance. The goal in a training session is to simulate the whole process, beginning at the accident site unto getting to the hospital, and also the intrahosptial logistics. Throughout the scenario, the patient is supposed to get the correct treatment while keeping recourses in mind (Rybing et al., 2016).

In order to conduct a scenario using ETS, whiteboards are used to represent the accident/incident and hospitals. Magnetic symbols represent patients (see Figure 1), personnel (see Figure 2), and other resources. There are several pre-designed sets: Basic set, Hospital set, Burn set, Decontamination at Hospital set, Psychosocial set etc. The instructors who manage the scenario are responsible for the whole process, from set-up to the after-action review. For a course, several scenarios are used to train different aspects within the same domain. Complexity and difficulty is easy to alter between scenarios.

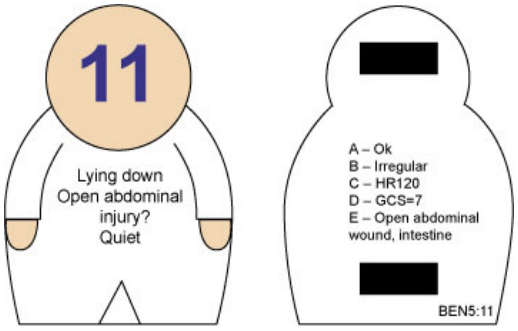

Figure 1. ETS patient. Copyright Emergo Train System.

Figure 2. Example of actors in ETS. Copyright Emergo Train System.

Reflection as a means for learning

Using the items from the Shared Priorities can be used for the teams to reflect upon their shared understanding. According to Daudelin (1996), reflection is a way to step back from an experience and through this eventually learn for future events, to have a guide line in similar events. This process is spontaneous and can occur without any personal awareness. Others (Järvinen & Poikela, 2001; Knipfer, Kump, Wessel, & Cress, 2013) have argued that reflection is the most important aspect of individual, team and organizational learning as it can lead to a better understanding of how one might act, and can act as guideline for future behavior.

Shared Priorities

Maynard and Gilson (2014) explain that shared mental models are positively associated with team performance because they enable team members to build complementary schemas that allow team members to make predictions and understand situations. Shared understanding has been shown to affect team performance (Berggren, 2016). In order to effectively communicate, cooperate, and coordinate, a team needs to maintain a shared understanding of shared goals (Rosen, Fiore, Salas, Letsky, & Warner, 2008). This can be assessed with the Shared Priorities instrument (Berggren, 2016; Berggren, Johansson, & Baroutsi, 2017). This instrument was developed by Berggren (2016) to assess a team's shared strategic understanding. The first step in the method begins with every member of a team writing a list of five items that are important for the team to succeed. These items are then prioritized from 1 to 5, 1 being the most important and 5 being the least important. In the second step one list is chosen randomly and the task for the team members is to prioritize the chosen list in the same way as during the first step. When the two steps are completed, the shared understanding in a team can be computed. In addition, the items and the order of the items on the lists can be used for discussion so that the teams' perception of goals in the situation becomes transparent. The Shared Priorities instrument has been used to provide additional information for instructors during training in both nuclear power plant teams (Berggren, Johansson, & Ekström, 2016) and when training interprofessional teams (Berggren, Johansson, Allard, & Torensjö, 2016).

METHOD

The research question points the method towards a qualitative approach. This data collection was conducted during three different course occasions, namely PS, PS plus, and PS refresh. The organization of the courses was two days of lectures combined with workshops in the ETS environment. At the later part of simulation training the teams had become comfortable and achieved a higher skill level in acting in the prehospital medical command and control roles. At this point the teams responded to the Shared priorities instrument.

The data collection can thus be seen as focusing on teams with different levels of experience in prehospital medical command and control. It should be noted that the scenarios differed between courses and occasions. However, the scenarios were there to expose the participants to situations where they could learn, not to test their ability to resolve the situations. Instead, the study focus on how reflection can be supported by using the Shared Priorities instrument as a mean for providing feedback to the participants in the PS training.

Participants

There were 53 course participants, 31 men and 22 women. PS, PS plus, and PS refresh were represented with 4 teams from each course. All participants were trained nurses, some with a further specialization. The average work experience was 12,7 years. All participants worked in teams with 4 or 5 members during training sessions. The teams used the Shared priorities measure for assessing the teams' shared understanding as feedback to instructors and participants. For some of the teams the generated factors from the Shared priorities measure were used as input for feedback and reflection during the post scenario discussion.

The five instructors who worked in this study were experienced PS instructors (80% had more than 5 years of experience as teachers of PS). Four of the instructors were men. Three of the instructors participated in the interviews.

All participants, both course participants and instructors were informed about the study and signed an informed consent form.

Material

A background questionnaire, the Shared Priorities instrument (Berggren, 2016), and questions to promote learning through discussion of the shared priorities items were used to evaluate the approach. The questions

were:

- Is it the correct factors that are on the lists?
- Is there any list that is more aligned with reality?
- Why are certain factors important for the situation?
- What does **a chosen subject from the lists** mean for your teamwork?

Also, there was an interview protocol for interviews with the instructors.

Procedure

The teams got to practice different scenarios using ETS. Each scenario lasted approximated 30 minutes. After a scenario was finished a Shared Priorities sheet was handed out and the participants responded to step 1. The instructor then randomly chose one of the participants' Shared Priorities sheet for the other participants to rank. In doing this the participants finished step 2. The process with SP took approximately 5 minutes to complete.

Interviews with instructors were conducted after each session. The interviews took approximately 10 minutes each. The questions asked were:

- How is feedback structured today?
- Is it different in between the courses? (PS/PS-refresh/PS-Plus)
- You have now been presented Shared Priorities during the scenarios. Do you think it can contribute to learning? If yes, how?
- Does Shared Priorities contribute to reflection that increases learning?
- Can Shared Priorities support you as an instructor? How?
- Is Shared Priorities more appropriate for some courses/parts?
- Do you see any disadvantages with Shared Priorities? For either the participants or the instructors?
- Would you consider using Shared Priorities as a tool in the courses?
- Something you want to add?

RESULTS

The use of Shared Priorities for reflection

At the PS refresh course the participants were given time to reflect upon the Shared Priorities items. This was done for every team. Four questions were asked and a summary of these questions is presented below:

1. Is it the correct factors that are on the lists? Almost every team said explicitly that the factors on their lists were correct. In two cases, they identified that the factors were similar but that different wording had been used to describe the same thing, which they saw as a good thing. One team explained that the list might differ because they had different roles during the scenarios and therefore focused on different things. The factors in one team were explained as success factors.

2. Is there any list that is closer to reality? Many of the teams agreed that the lists were equally close to the truth and therefore answered "No" to the question. One team emphasized that the lists are dependent on what role one might obtain and therefore becomes more relevant in some cases. Another team argued that they had similar lists, which was good. Another team found their lists to be complete.

3. Why are certain factors important for the situation? Some of the teams mentioned communication as an essential factor for handling the situation. One team mentioned that the factors are important because they are supposed to experience similar situations while working but then actual lives are at stake. Another team pointed out that some of the factors are important as they are the reasons why the situation can be solved in a good way. One team underlined the fact that it does not work without communication, but that communication does not work without information. They meant that the factors complement each other.

4. What does **a chosen subject from the lists** mean for your teamwork? For one team the factor communication was chosen. All members agreed that communication should be adequate information that one

gives but also adequate information one receives. Communication was also chosen in another team, which discussed the fact that communication is key within the team and pointed out it is crucial that communication is clear. One team got to discuss the factor leadership. They mentioned that leadership should be clear, since it is through leadership that the operation can be managed in a good way.

Evaluation with instructors

The interviews with instructors were analyzed using thematic analysis (Braun & Clarke, 2006). The analysis resulted in three themes (Pros and Cons, Approaches, and Education Initiative).

Pros and Cons

The theme *Pros and Cons* consists of four sub-themes. This theme illustrates the better and poorer aspects of the courses and Shared Priorities. One person mentioned that the time aspect matters, which accords with another person's statement "too little time for that". This is an example of the sub-theme *Liability*. They try to point out that Shared Priorities must be better integrated for participants to be able to use it properly. Looking at the positive aspects, there are comments from the sub-theme *Contribution* as "helpful in the evaluation" and "overview of important thing". This can be interpreted as how Shared Priorities can be a tool to support the instructors during the course, especially in their evaluations. It is also pointed out that it helps the instructors provide an overview of what is important and in that way. The indicators from the ETS are also mentioned as a good tool during the interviews. One comment involved the chronological order the indicators provide and that it is very helpful to have them. The indicators become a tool that facilitates the work of the instructors. These statements are a part of the sub-theme *Support*. Another important part of the theme is the sub-theme *Relevance*, were the comment "the feeling that is helps" from an instructor indicates that it is important for the instructors that see the benefit of the Shared Priorities instrument. In the same sub-theme, another person stated that it is important to keep in mind that quality is more important than quantity. This suggests that Shared Priorities is not appropriate for all types of scenarios and it could become a nuisance in the long run, more than a helpful tool. It is important that the instructors find it useful as they are the ones engaged in the course and are the ones who are in direct contact with the participants.

4.3.2 Approaches

The theme *Approaches* consists of two sub-themes. This theme covers the approaches the instructors take on at the courses at KMC. The first sub-theme, *Usage*, refers to when it is appropriate to use Shared Priorities. One important comment is "the more complex the exercise, the more rewarding it is (*to use Shared Priorities*)". Furthermore, another comment aligns with this idea, "where there is a greater ambiguity". This indicates that it is better to use Shared Priorities when the scenarios are more complex rather than for small, quick scenarios. This could be interpreted to that some of the scenarios were being too easy to bother using Shared Priorities and then it is not worth it. For Shared Priorities to be an aid the scenario must be challenging, which then would result in carefully considered lists rather than unreflected lists. The second sub-theme, *Adapted Working Method*, brings up how the instructors work during the courses in different respects. Comments that highlight how they work towards the teams are "asks the team" and "asks counter-questions". These statements show how the instructors try to point out that the participants are in focus and are pushed to reflect on their decisions while also challenging them by asking questions. Another important aspect of the sub-theme is the amount of experience the people taking the course obtain. An example that imply this is "We try to adapt to the participants". This means that depending on whether it is a returning team or a beginner-team the instructors adapt their way of teaching. Regarding feedback, which is another part of the sub-theme, comments were given that involved how the instructors worked during the courses. It could be by giving concrete feedback or directing focus if the participants are heading in the wrong direction.

4.3.3 Education Initiative

The third and last theme is *Education Initiative*, which consists of two sub-themes. *Lesson*s refers to how the instructors see Shared Priorities as a learning tool. Example from this sub-theme are "When you are forced to reflect on different things, I think there will be an increase in learning", "more of an aha-experience" and "filling in them without reflecting". This implies that the instructors believe that the use of Shared Priorities could increase learning for the participants if it is done correctly. However, there is a risk of the participants filling them in without really reflecting about the scenario which would meant that the point of Shared Priorities is lost. The second sub-theme is *Findings*, where examples are "useful as a reflection tool", "identify additional success factors", and "there are success factors but other types of success factors". This implies that the

instructors believe that Shared Priorities would work, especially as a reflection tool during the courses. Shared Priorities seems to be able to identify further success factors, but that those factors differ from other success factors, mainly the factors used in the ETS, which have been stated as success factor by an instructor.

DISCUSSION

Can Shared Priorities be a useful tool for the instructors to promote reflection? The interviews and the thematic analysis indicate that Shared Priorities can be a useful tool to encourage reflection if there is time set aside.

Looking at the result and discussion from the interviews where the participants were asked to voice their opinion it is difficult to estimate the value of using Shared Priorities as a tool. The instructors, who are the possible users of Shared Priorities, seem to have a positive attitude towards Shared Priorities. The time aspect must be kept in mind, to make it valuable for the courses time needs to be set aside for the usage of Shared Priorities. It would help the instructors mostly during evaluation but also as a reflection tool for the participants. Daudelin (1996) argued that reflection is a process that will result in learning, which would be good for the participants as they would have an opportunity to learn even more.

Three themes emerged from the interviews with the instructors: *Pros and Cons*, *Approaches*, and *Educational Initiative*. The main points from these themes are that SP can be used as a reflection tool in the PS-courses if the course is planned to include Shared Priorities. The instructors believe that it can be a helpful tool for them. Considering the instructors' perspective, anything that will facilitate teaching is worth to keep in mind. It is important to have their opinion on what to add during a course as they are the ones who need to feel that it is contributing for the better rather than having a tool that steals time from learning.

The contribution of this paper is that by offering a systematic approach for feedback this provides instructors and trainers a way of directing feedback to teams and participants which in turn is expected to enhance learning.

Future work

An experiment where team learning is measured and where controlled use of the Shared Priorities instrument for providing feedback is contrasted to a control condition (no Shared Priorities input) would be a noteworthy continuation.

Conclusion

Improving training is a constant challenge. The small steps bring you forward at a steady pace. When training teams to master prehospital medical command and control, reflection is important as a means to learning. The Shared Priorities instrument seems promising in providing a sound basis for reflection if used correctly. The possible use can easily be extended to other crisis response training situations as the instrument is not dependent on technology and only requires a short introduction for both participants and instructors.

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Towards an Organizational and Socio-Technical Context-Aware Adaptation of Emergency Plans

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ABSTRACT

In France, facilities listed under environment protection regulations are required to draw up emergency plans. During a crisis situation, facing an unexpected event, these plans may be irrelevant. They have to be adapted to the current crisis situation and its observed or anticipated evolutions, using data emitted by the crisis ecosystem. But this adaptation requires lots of effort and is time-consuming. This article aims at presenting an approach to ensure the dynamic adaptation of emergency plans. We propose to identify generic configuration variables (representing interactions of physical phenomena and human factors on the facility) and to feed these configuration variables by collecting and processing data emitted by sensors, social networks, official reports, etc. Therefore, emergency plans could natively integrate agility by their ability to detect and take into account a change in the crisis situation and decision makers will be supported since the early stage of the crisis response.

Keywords

Agility, context awareness, emergency plan, preparation, response.

INTRODUCTION

In France, any facility –from industrial sites, farm businesses to universities – that is likely to result in hazards or pollution, especially regarding the health and safety of the border residents, is a classified facility(*Code de l'environnement - Article L511-1* 2011). The French national government defines and frames the procedures related to ICPEs ("Installations Classées pour la Protection de l'Environnement")[1]. The government requires from (i) operators to draw up an internal emergency plan and (ii) competent authorities (Prefect) to draw up an external emergency plan. This is to minimize and reduce the risks and their associated consequences in the case of the most hazardous ones: ports, refineries, nuclear plants, underground gas storages, large dams, microbiology laboratories, upper tier sites of the SEVESO III Directive, and any facility that has been classified by decision of the Prefect[2].

All these emergency plans are based on risk assessment and alert pattern analysis. They describe human and material resources to be deployed to coordinate action for rescue and relief facing a crisis situation. The Internal

[1] This can be understood as "Classified Facilities for the Protection of the Environment", meaning facilities requiring environmental impact assessment.

[2] State's representative of the lowest level of administrative divisions of France.

Operation Plan (implemented by the operator) has to define the organization and internal resources to control an accident within the boundaries of the site. It prescribes the organization, resources and intervention strategies by analyzing potential accidents. These potential accidents can be specific to one facility or generic. The Specific Response Plan, established by the Prefect, involves public emergency services (firefighters, police, emergency medical services), all State services, municipalities and private players (associations, network operators, etc.). To define the operational measures and scope of the Specific Response Plan, all hazardous phenomena and their effects should be taken into account through scenarios, regardless of their intensity and probability. These scenarios determine the population protection and intervention strategies to be adopted, according to the nature and scale, seriousness and kinetics of the effects. In the case of an accident exceeding the boundaries of the facility, the Prefect assumes leadership of emergency operations by implementing the measures prescribed in this plan. Cities and villages close to classified facilities are also required to draw up emergency plans called Community Protection Plan and Specific Safety Plan. The following Table 1 presents the vertical granularity of the French emergency plans. Levels are activated upon the perimeter of the crisis situation.

Table 1. French emergency plans (by decreasing granularity)

Level	Leadership	Emergency plan(s)
National	Ministry of the Interior	ORSEC plan (national level)
Zonal	Prefect	ORSEC plan (zonal level)
Departmental	Prefect	ORSEC plan (departmental level) Specific Response Plan Specific Safety Plan
Municipal	Mayor	Community Protection Plan Specific Safety Plan
Local (ICPE facility)	Plant operator	Internal Operation Plan

Based on this, several observations are made. First, facing an unexpected event, new scenarios appear, and the established strategies (i.e. crisis response) corresponding to the defined scenarios may be not relevant (either immediately or after a while). As it is not realistic to describe and cover all potential situations to define all potential crisis responses, it is necessary to provide agility to the prepared emergency plans. In our research work, we understand the concept of agility as defined by Barthe-Delanoë et al. (2014), i.e. the ability to detect a mismatch to a given situation and to set up the required adaptation, as quickly as possible. Moreover, in a Command and Control context, agility is also seen as the ability for an organization to meet the challenges of uncertainty and complexity, as defined by Alberts (2007). Applied to emergency plans, agility is the ability to detect evolutions of the crisis situation to accurately assess risks and anticipate their effects on the selected strategies to adapt the above-mentioned strategies.

Then, as underlined by the French official report regarding feedback on crisis management, emergency plan information are underused (even during training), especially in the case of the Specific Response Plan (Direction Générale de la Sécurité Civile et de la Gestion des Crises (DGSCGC), Ministère de l'Intérieur 2013). The stakeholders ignore the prepared plans, and so the related issues (e.g. environmental concerns) and data. The same applies to the dedicated tools (mainly Geographical Information Systems) to support crisis response management, even if they are a mean to share information and visualize issues. This is due to several factors: complex documents (not necessary up to date), lack of clarity regarding the major scenario and its concerns, human factor.

The methodological and technical framework proposed in this paper is to two-fold: it aims (i) to provide agility to emergency plans to support the reconfiguration of these plans dynamically, and (ii) to make emergency plans scenarios clearer and easier to follow by the stakeholders. This framework is intended for facility operators and public authorities, both for crisis preparation and response phases. The paper presents these early stage research works as follows: first, we present in two sections respectively the need for the agility of emergency plan from the risk assessment point of view, and for context awareness. Then, the decision support platform to support the emergency plan agility is presented. Finally, the concept of configuration variables for risk assessment is detailed, before concluding in the last section.

AGILITY OF EMERGENCY PLANS

Providing agility to emergency plans comes first with the ability to detect the changes and evolutions in the

description of the crisis situation, to accurately assess risks on which emergency plans are designed. In industrial processes, risk assessment is conducted through systematic risk analysis (as explained by (Kaplan and Garrick (1981)), which aims to identify possible adverse events then estimating their likelihood and their consequences.

Several methods are used to conduct such an analysis: HAZOP (HAZard and OPerability studies) (Kletz 1999), FMECA (Failure Mode, Effects and Criticality Analysis), What-if, etc. One of the main weaknesses of such methods is that they are qualitative, expert dependant, and represent risks as discrete events.

Besides, weak signals may be ignored, as methods like HAZOP cannot cope with events resulting from a combination of failures. The idea developed in this paper is thus to deduce risks or cascading effects based on the existing knowledge (from the previous situation) or capitalized knowledge from experts. This deduction could allow us to create risks' model. Moreover, modelling risks using fuzzy logic can help to define more general risks, quantitative evaluation of risks, and will facilitate reusing existing knowledge. Finally, it will also help to deal with incomplete or uncertain data regarding risk assessment, as shown in recent research works (Jamshidi et al. 2013; Petrović et al. 2014).

The social dimension and the time dimension of risks are not necessarily taken into account during the risk assessment step (Zánická Hollá et al. 2012). But social habits, the evolution of the population, the time of the day or the year may have a significant influence on the gravity of risk or the adopted crisis response. For example, an explosion occurring in a plant (with a beltway located nearby) on a Monday at 8:00 am will not have the same consequences as the same one occurring on a Monday at 11:00 am. The water level of rivers evolves depending on the time of the year and can endanger cooling systems fed by rivers. Or in some countries, during the period before Christmas, there are much more traffic jams on the roads, which will possibly delay timely rescue. It will be valuable to take into account studies, and research works about human factor and social behaviors such as the use of temporal profiles of population distribution as described in (Osaragi 2016).

The first pillar of the idea we aim to develop in our future research works is to provide agility in the design of the emergency plans through risk assessment that will (i) describe risks as continuous functions of time rather than discrete events, and (ii) take into account physical phenomena, human factor, and their possible interactions. This will help to anticipate a wider range of evolutions of the main crisis characteristics given the current situation with fewer efforts and to predict the consequences of the selected strategies.

RECONFIGURATION BASED ON CONTEXT AWARENESS

By nature and by effects of the selected crisis response to solve (or at least) reduce the crisis, crisis situations are unstable and evolutionary phenomena. Moreover, an emergency plan involves numerous stakeholders who have to work together: this is a collaborative situation. According to Camarinha-Matos et al. (2009) and Pingaud (2009), evolutions of such situations can be classified as follows: (i) evolution of context (i.e. the crisis' environment differs from the one taken into account to define the strategy) ; (ii) evolution of network (this kind of evolutions concerns the stakeholders, their abilities and or their resources) ; (iii) failure (one or several activities do not lead to the expected results, due to an incomplete initial definition of the emergency plan or an improper execution of them). It is, therefore, necessary to take into account the possible changes that can influence the emergency plan, to change it if required and to support the decision-making process of the stakeholders.

It is now acknowledged that context-awareness (Castillo 2016) is crucial to get an accurate view of an ongoing crisis situation. It can help to detect and define the evolutions of the occurring crisis situation. Various data sources emit data from the field: Open Data, social networks, sensors located in and around the facility, reports from stakeholders, local and national authorities, volunteers, etc. Moreover, new and evolving technologies are coming on the stream to allow processing of real-time measurements and information like Complex Event Processing (Etzion et al. 2015), mobile phones embedding sensors (not to mention the whole Internet of Things phenomenon). Some research works have explored this way in the domain of crisis management, as in the PRONTO project (Kaarela et al. 2011) or the PLAY project (Truptil et al. 2012).

But context-awareness should not be limited to the monitoring of technical characteristics of the crisis situation, as underlined in the NATO's technical report on C2 Agility (SAS-085 2014). It should also capture social and cognitive aspects that can challenge the defined response process, as rumors and misinterpretations of forecasts and official messages. For example, the 'cone of uncertainty' of hurricane track is often misinterpreted by the general public (Broad et al. 2007). During the hurricane Irma episode, people commented on social networks that areas out of the cone would be safe. But the cone does not represent the size of the hurricane; it is only a projection of a storm's path. In this case, these people will be reluctant to follow mandatory evacuation orders in these areas (Padilla et al. 2017) while they are not safe.

A DECISION SUPPORT TOOL TO RECONFIGURE EMERGENCY PLANS

Based on the previous observations and ideas, a decision support tool is proposed. This Dynamic Reconfiguration Platform lies in two dimensions: first, time (preparedness and response); second, agility (adaptation, detection, context awareness) (see Figure 1).

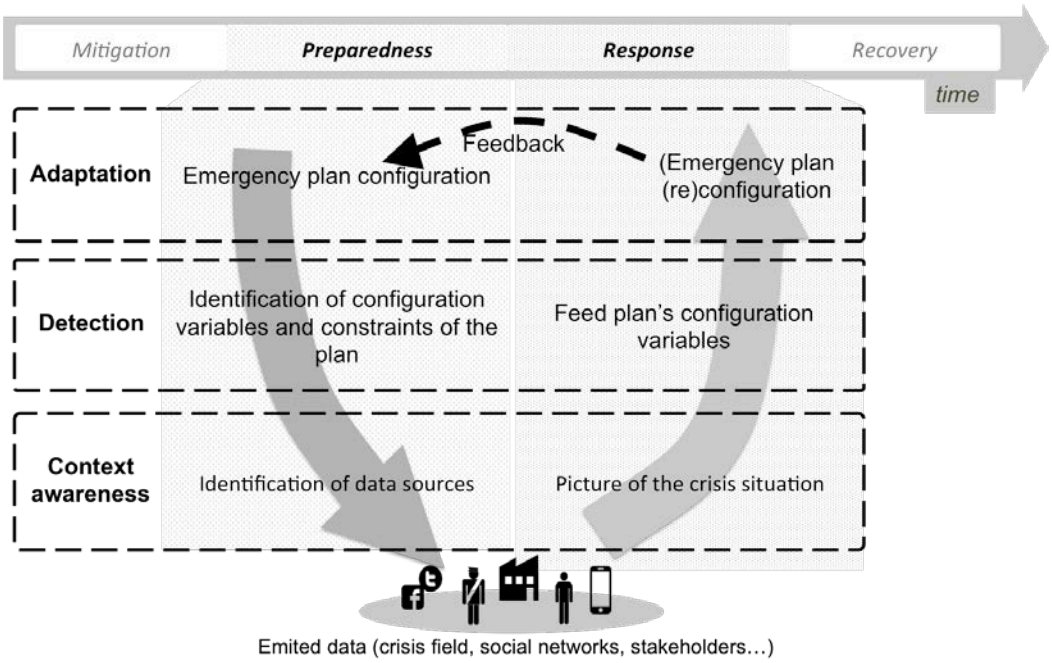

Figure 1. Principles of the proposed Dynamic Reconfiguration Platform process

At first, during the mitigation and preparation step, a generic emergency plan is designed. The emergency plan is seen here as a Constraint Satisfaction Problem (CSP). CSPs consist of a set of variables X with a set D of respective domains of value and a set C of constraints that describe allowed value assignments for variables. A solution to a CSP consists of an assignment of values to all the variables in a way that none of the constraints is violated. The variables represent physical, technical and social characteristics of the crisis situation, and the constraints the dependencies among variables. The solution is an adapted emergency plan. More evolved CSPs allow altering the original formulation of the problem to take into account evolutions of the set of constraints: constraints can be added or removed (Dynamic CSPs); constraints can be partially relaxed and the solution can comply with only a part of them (Flexible CSPs). As in crisis situation we face uncertainty and complexity, it can be difficult to satisfy all the constraints to solve the problem. This is why Flexible CSPs like Fuzzy CSPs where the satisfaction of a constraint can be a continuous function of its variables' values might be relevant to our context.

Then, potential data types and data sources are identified to feed and value these variables. When the crisis occurs, the data emitted regarding the crisis situation is gathered from these various sources (as evoked in the previous sections). All this data will provide context awareness to the emergency plans.

Indeed, it is crucial to collect relevant data. Regarding data aspects such as the volume, the variety and the velocity of the data sources, and also human factors such as the veracity and the validity but also the crowdsourcing and volunteering efforts, this part of the proposal is clearly related to the Big Data phenomenon applied to a crisis situation (Castillo 2016; Meier 2015). This will imply the use of Big Data techniques to identify, collect and process data to get a picture of the situation, which is relevant to feed the configuration variables. This picture of the situation can be a model of the current crisis situation. It has to represent at least the crisis cell (stakeholders and their activities), the crisis system itself (environment, goods, people, civilian society, risks, consequences, etc.). This model is an instance of a meta-model that has to meet the requirements of the French emergency plans regarding the crisis situation and the stakeholders' description, like the one presented in Benaben et al. (2017).

This model of the current crisis situation feeds the configuration variables. Using a constraint-programming solver engine (like Choco, http://www.choco-solver.org/), the emergency plan is configured to fit with the current crisis situation characteristics. It is then submitted to the decision makers.

From a user interface point of view, the emergency plan modelled as a CSP can be presented as a dynamic tree, with questions/answers, using the visualization interface of the constraint-programming interface. The nature and number of questions will evolve, depending upon the answers, as some decisions to be taken are only relevant depending on a previous choice.

IDENTIFYING CONFIGURATION VARIABLES

As presented before, we aim at using configuration variables and constraints to adapt the emergency plans to the current situation. The major issue here is to identify relevant configuration variables and constraint. What are the relevant risks based on physical phenomena, human factors, combination of both, etc. that can be identified in crisis situation implying ICPEs? Solving this problem requires exploring a large amount of data, from experts' interviews, existing emergency plans, to feedbacks from past crisis situations. Then, once identified, they have to be defined quantitatively, as function of time, etc. (as explained previously).

Finally, we also have to identify the "winning strategies", i.e. the relevant answers facing an identified risk and also their possible interactions, in order to build the constraints of the CSP. As stated before, the constraints represent the dependencies among variables (i.e. the physical, technical and social characteristics of the crisis). This way, with the help of consistency algorithms, the size of the search space is reduced. To this end, we envision to combine various techniques to automate knowledge retrieval from text documents (such as the existing plans and official reports from past exercises and accidents), using Natural Language Processing, as in (Zhang et al. 2017) combined with the ontology based on the above-mentioned meta-model (Benaben et al. 2017), and knowledge alignment (Wang 2015). Interviews of stakeholders (in the broad sense: authorities, plant owners, rescue services, citizens) are also envisioned, especially to capture knowledge about human factor.

CONCLUSION

In France, internal and external emergency plans are required for all classified facilities requiring environmental impact assessment. The strategies for crisis response are based on predefined scenarios that do not necessary take into account organizational and socio-technical factors. So, facing an unpredictable situation these plans have to be adapted, which is a time consuming and complex task. The idea developed in this paper is to identify configuration variables (both generic and domain specific) that influence the decision makers when it comes to define an adapted crisis response. This not only help them to have a clear picture of the planned scenario and of its issues, it is also a way to ensure the context awareness dimension of the emergency plans and to support their dynamic reconfiguration in real time.

The presented methodology and tool are at their early stages. In addition to the work to achieve on the risk assessment and configuration variables, further works also include the development of the Dynamic Reconfiguration Platform tool and its assessment through realistic use cases provided by practitioners. These use cases will be based on existing emergency plans from the industrials plants located in one of the major French ports with the help of stakeholders in charge of the port security. Moreover, the assessment will also be supported by the measure of Key Performance Indicators (embedded in the meta-model by Benaben et al. (2017) we plan to use).

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Track 3

Ethical, Legal, and Social Issues

Analysis of Core Social Actors in Nine Types of Mass Incidents Based on Social Network Analysis

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ABSTRACT

This article studies on the cases of nine types of mass incidents happened in China during the past decade, and studies the relationships among various social actors in different types of mass incidents based on the methods of Social Network Analysis from the perspective of relational theory. By constructing the social network of mass incidents, we statistically analyzed the relationship intensity between social actors in different types of mass incidents, and calculated the centrality degrees of social actors, which can be regarded as index to characterize the social risk of social actors. Meanwhile, we also analyzed the cliques and "core-periphery" structure in the social network of mass incidents to get the core social actors in mass incidents, thus providing decision-making references for social leaders to effectively deal with mass incidents and improving emergency response capabilities.

Keywords

Mass incidents, Social Network Analysis, social risk, cliques, core-periphery structure.

INTRODUCTION

Social conflicts more or less exist in every country and social stage, and they are manifested in social safety incidents. As a typical type of social safety incidents, mass incidents have many forms, such as strikes, collective petitions, illegal rally, mass gatherings, demonstrations, riots, mass panic, etc. In different countries, the specific forms are related to the state's system, economic level and so on (Nicole et al., 2013; Xavier et al., 2017; Hua, 2014). In this study, the incidents are all from China at the present stage (from 2004 to 2017).

There are many ways to classify mass incidents. Zhang investigated mass incidents from the perspective of genesis and typology (Zhang, 2010); Xiao discussed the categorization of mass incidents from the historical perspective (Xiao, 2012); Xiang study on the participant types and cluster mechanism of mass incidents (Xiang, 2012). Considering China's national conditions and the classification principle of mutual exclusion, inclusion and diversity, Liu divided the mass incidents in China into nine types (Liu, 2011): (1) the collective struggle related to economic or material interests; (2) the collective struggle related to environmental rights and interests; (3) the collective outraged incidents against the powerful; (4) the collective outraged incidents against the rich; (5) mass incidents caused by the deterioration of local political ecology; (6) industrial collective action; (7) mass incidents caused by "death factors"; (8) mass incidents with ideological or politically motivation; (9) endogenous mass incidents in cyber-fields. The types and representative cases are shown in Table 1.

Table 1. Classification of mass incidents in China

	Description	Representative cases
E_1	collective struggle related to economic or material interests	mass incidents in Gansu, Longnan, 2008
E_2	collective struggle related to environmental rights and interests	mass incidents in Guangdong, Maoming, 2014
E_3	collective outraged incidents against the powerful	mass incidents in Wangzhou, Chongqing, 2004
E_4	collective outraged incidents against the rich	mass incidents in Chizhou, Anhui, 2005
E_5	mass incidents caused by the deterioration of local political ecology	mass incidents in Weng'an, Guizhou, 2008
E_6	industrial collective action	strike of taxi drivers in Jilin, Changchun, 2015
E_7	mass incidents caused by "death factors"	medical dispute in Nanping, Fujian, 2009
E_8	mass incidents with ideological or politically motivation	mass incidents in Tibet, Lhasa,2008
E_9	endogenous mass incidents in cyber-fields	mass incidents of Zhou Jiugeng, 2008

To be more specific, for E_1, the causes are the economic or material interests mainly in the rural land compensation, urban demolition and resettlement, enterprise restructuring, debt disputes and project immigration; for E_2, the main grudges concentrated in the rural industrial pollution of drinking water and air, toxic waste treatment stations, refuse collection sites, high voltage radiation, communication base station radiation, high-risk industrial sites and other parties; for E_3, this type involves a generalized resentment in Chinese society, that is, confrontational sentiment based on the distribution of benefits, the awareness of social power and lifestyle differences between officials and civilians; for E_4, this type involves another generalized resentment in Chinese society, namely the confrontational sentiment constructed by multiple reasons such as relative deprivation, presumption of sin and social segregation between the rich and the poor; for E_5, this type of mass incidents is caused by the deterioration of local political ecology, even though this type of mass event participants did not have direct prototypical resentment as a pro-active agent and propellant, they all indirectly belonged to the member of the local oppositional community being deprived of their continued benefit or suffered from continuing social injustice; for E_6, this type is based on the same career experience and situation, aiming at improving the occupational treatment and policy directly related to career development; for E_7, this type is caused by "death factors", the trigger for the mass incidents is the loss of life (or severe disability and major health impairment of the body) for individual families or small groups, and meanwhile it is probable that this type will involve a public sector (grassroots Government, public security agency or medical institution) or its agent; for E_8, the main manifestations are ethnic conflict and urban terrorism; for E_9, it refers to the mass incidents of which the origin, process and result are all within the internet media space.

The social network is a collection of social actors and their relationships. In the social network diagram, the social actor is represented by the node, and the relationship is represented by the line. Social Network Analysis (SNA) is a mathematical method to study social relations. After decades of research and development, SNA has made great progress in both theoretical research and practical application. The introduction of matrix algebra makes it possible to analyze the quantitative indicators of social actors, including density, centrality, cohesion and relevance. Ucinet, ORA and other computing tools also make the social network analysis more convenient (Liu, 2014; Everett, 2002; Carley et al., 2011). There are quite a few studies using SNA in the field of social security. In anti-terrorism, Bohannon et al. analyzed the members and structures among different terrorist organizations, then put forward effective methods to combat it (Bohannon, 2009). Some scholars also conducted social network analysis by analyzing the participation of different terrorist organizations in terrorist attacks (Sageman, 2004; Sun et al., 2011; Fu et al., 2011). In the network public opinion analysis, Sun et al. and other scholars analyzed the formation of

opinion leaders and the spread of rumors with Social Network Analysis methods, and put forward effective methods of public opinion monitoring (Sun et al., 2011; Zhao et al., 2011; Deng et al., 2011). In the analysis of mass incidents, Huo put forward a dynamical model with two delays to exhibit the interaction evolution between the public and official opinion fields in network mass incidents in order to get the golden time for the government to release official information (Huo et al., 2017), Song researched the role of social network in the group perception and decision-making, then divided the dynamic system of mass emergency into media environment control subsystem, population behavior evolution subsystem, government intervention system, and the SD model of the evolution system (Song et al., 2017). However, these studies are mainly research on the information spreading, and it is obviously inadequate. It is also necessary to analyze the network structure to get the risks of each social actors and identify key social actors, and it will be more helpful in risk management and crisis response.

This paper used the classification method of Liu (Liu, 2011), and analyzed the relationship among social actors in nine types of mass incidents with SNA to find out the risky social actors and the core group with strong ties, providing a reference for the risk analysis and emergency response to mass incident.

STUDY CONTENTS AND METHODOLOGY

In order to facilitate the expression, all kinds of organizations, departments and personnel studied in this paper are called social actors. In this article, social actors are not specific individuals but a group of persons or organizations with common characteristics (such as police, officials, etc.). The classification of these social actors is based on their roles or behaviors in mass incident, ignoring the differences in space and time, and holding the structural equivalence of the same social actors. There are 10 social actors that may emerge in mass incidents: casualties, family, criminal, onlookers, media, rumormonger, police, officials, fireman, and enterprise. The 10 social actors are divided from the perspective of social management and according to the role and behavior characteristics. The following is some explanation:

Casualties include those who are injured or died before the mass incidents (as the cause of mass incidents) and during the incidents;

Family refers to the most immediate stakeholders in mass incidents, including those who struggle for their own rights or interests, and their relatives, friends or colleagues;

Criminal: The "criminals" discussed in this study target only those who deliberately destroy public facilities, property, robbery and intentional injury in mass incidents. Other types of crime do not fall into this category.

Onlookers refers to those involved in mass incidents, but the incidents are not directly related to their own interests, they just vent dissatisfaction, anger or hold the wait and see attitude;

Media reveal the information before the incident (such as official misconduct, pollution in the enterprise, victim's experience, etc.), or report the incident during the incident and interview the relevant personnel;

Rumormongers refer to those who make rumors, spread untrue news, cause public dissatisfaction and make matters worse in mass incidents;

Police: To maintain the order, disperse the masses and so on;

Officials: Depending on the size of the mass incidents and the extent of the clashes, whether there are government officials coordinating, negotiating or explaining to the public;

Fireman: In some mass incidents, the conflicts are serious and there will be burning of vehicles and building, and need fire department to give aid;

Enterprise: In some mass incidents, enterprises may cause conflicts because of their business or working environment. Including schools, hospitals and large-scale enterprises (such as nuclear power plants, landfills) and so on.

Definition of relationship

The definition of a relationship is that if two specific social actors appear in a mass incident, and there is cooperation, dominance, support, resistance, contact between them, then there is a relationship between them.

Then we constructed the relation matrix A of social actors in each mass incident. This paper analyzed 10 types of social actors, so A is a 10-th order matrix. The value of element a_{ij} is defined as follow:

$$a_{ij} = \begin{cases} 1; \ there\ is\ a\ relationship\ between\ node\ i\ and\ j \\ 0; \ there\ is\ no\ relationship\ between\ node\ i\ and\ j \end{cases} \quad (1)$$

where i and j refer to the node sequence number of social actors, the corresponding sequence number is shown in Table 2. Meanwhile, the values of diagonal elements are 0, because the analysis of the network is the relationship between the actor and another actor, the values of diagonal elements do not affect the analysis results. In order to simplify the analysis, the positive and negative of the relationship is not defined.

Table 2. Correspondence between the node sequence number and social actors

Sequence number	Social actors
1	casualty
2	family
3	criminal
4	onlookers
5	media
6	rumormonger
7	police
8	official
9	fireman
10	enterprise

Now taking the Gansu Longnan incident (E_1) as an example to construct the relation matrix. On November 17, 2008, more than 30 relocatees from Dongjiang Town of Longnan City petitioned for a visit to Longnan Municipal Party Committee. The relocatees heard about the rumor that the municipal government should relocate to Chengxian County, they worried about their interests would be impaired after the relocation of the administrative center. Around 20 o'clock that night, a number of troublemakers attacked the Longnan Municipal Committee, sixty-nine police officers, two police officers and three reporters were wounded. Troublemaker also smashed houses and vehicles. In this case, the social actors are casualty, family (relocatees), criminal, onlookers, media, rumormonger, police and official. The reporter and the police were injured, so $a_{15} = 1,\ a_{17} = 1$; some relocatees hit and smashed, so $a_{23} = 1$; some onlookers supported the relocates, so $a_{24} = 1$; the relocatees were interviewed by reporters, so $a_{25} = 1$; the relocatees were bewitched and incited by rumors, so $a_{26} = 1$; police evicted and suppressed the relocatees, so $a_{27} = 1$; government officials received the relocatees, so $a_{28} = 1$; some criminals also came from the onlookers, so $a_{34} = 1$; criminals wounded reporters, so $a_{35} = 1$; the criminals heard the rumor, so $a_{36} = 1$; criminals arrested by police, so $a_{37} = 1$; criminals robbed office property, so $a_{38} = 1$; onlookers were reported by the media, so $a_{45} = 1$; onlookers were gathered by rumors, so $a_{46} = 1$; onlookers were dispersed by police, so $a_{47} = 1$; onlookers surrounded the government office sector, so $a_{48} = 1$; media reported government officials' measures, so $a_{58} = 1$; rumormonger was arrested, so $a_{67} = 1$; the object of rumor is the government officials, so $a_{68} = 1$; police obeyed the transfer of government officials, so $a_{78} = 1$. To sum up, the relation matrix of Gansu Longnan incident is:

$$A_{\text{Gansu Longnan}} = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Relationship intensity and centrality degree

We are concerned about the relationship intensity among the various social actors in each type of mass incidents. If the sample size of each type of mass incidents is N, the relationship intensity matrix B can be calculated by:

$$\mathrm{B}(E_k) = \frac{\sum_{n=1}^{N} A^{(n)}(E_k)}{N} \quad (2)$$

where E_k represents the type of the incident, as shown in Table 1, k is from 1 to 9; $A^{(n)}(E_k)$ represents the relation matrix of the n-th sample of E_k.

The element $b_{ij}(E_k)$ reflects the intensity of relationship pairs between i and j actors in E_k, and it is between 0 and 1. However, the centrality of each social actor can't be observed in the social network. In other words, the position of social actors in mass incidents is unknown. Therefore, the centrality of social actors needs to be calculated. The centrality index used in this paper is point centrality degree weighted by relationship intensity. The centrality degree measures the ability of nodes directly relating to other nodes, and it is calculated by:

$$C_i(E_k) = \sum_{j=1, j\neq i}^{9} b_{ij}(E_k) \quad (3)$$

Theoretically, the maximum of the centrality degree is 9, which means that there is the highest relationship intensity among the node and the other nine nodes, and the minimum value is 0, indicating that the node is not associated with any other nodes. Because of the same number of nodes for each type of incidents, we can directly use the centrality degree to characterize the risk of social actors.

Cliques

In Social Network Analysis, the definition of cliques is the maximal complete subgraph that includes at least three points. It means that any two points (social actors) in the clique are directly related to each other, while any node outside the clique is not directly related to all points within the clique. In mass incidents, with the analysis of cliques, the importance of social actors can be revealed.

First, whether there is a clique in the social network of mass incident. If not, it shows that the social network is relatively loose. When this type of mass incidents occurs, the solutions may be relatively moderate, and the resources required for response (police force and public opinion regulation) are few.

Second, what are the cliques. Why do these social actors form a clique? what is the reason for their close relationship with each other directly? What are their common goals or common interests they share?

As there are 10 social actors, with the help of clique analysis program in Ucinet, the results of cliques classification can be obtained quickly.

Core-periphery structure

Through the analysis of cliques, we knew the main structure of social networks, but the relationship between different cliques is not clear. On the other hand, social actors who are in multiple cliques can be regarded as the core actors, but there is no quantitative analysis of the core level. Therefore, the core--periphery structure analysis of social networks is needed.

First, the social actor's relation matrix B can be transformed into partitioned matrices as shown in Figure 1 through a series of elementary transformations.

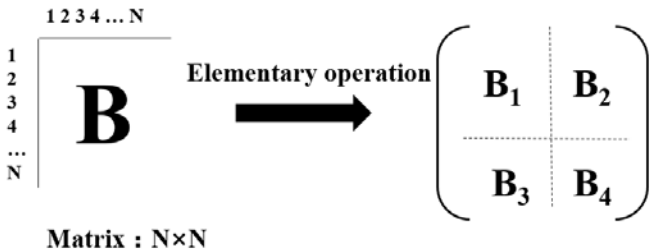

Figure 1. Theory of core-periphery structure analysis

For the ideal core-periphery model, B_1 is a matrix whose elements are all 1 except for diagonal elements (zero), which means that the matrix elements are related to each other, and the social actors corresponding to the matrix subscripts are core social actors. When B_2 and B_3 are 0 matrices, it indicates that the core actors are not associated with the periphery actors; when B_2 and B_3 are 1 matrix, it indicates that the core actors are completely associated with the periphery actors. When B_2 and B_3 are sparse matrices, it indicates that the core actors are partly associated

with the periphery actors. B_4 is the relationship matrix between the edge nodes, which is a sparse matrix.

In fact, the block matrix B_1 obtained by the iterative transformation will not be an ideal all-one matrix. The degree of fit was expressed by the correlation coefficient between the actual and theoretical results. The higher the correlation, the higher the degree of agreement with the ideal model. In this research, the algorithm for the core-periphery structure is given by Ucient program (Borgatti et al., 2002).

CASE COLLECTION AND ANALYSIS

This study collected a large group of mass incidents in China from 2004 to 2017. The incident types are the nine types of mass incidents mentioned above, with 30 cases in each type, for a total of 270 cases. According to the definition of relationship in formula (1), the relationship matrices in each type are obtained through the network and the investigation reports published by the government. The normalized relationship intensity matrix of each type is obtained according to formula (2). For example, $B(E_1)$ is:

$$B(E_1) = \begin{pmatrix} 0.00 & 0.4 & 0.27 & 0.10 & 0.00 & 0.00 & 0.13 & 0.17 & 0.00 & 0.23 \\ 0.40 & 0.00 & 0.43 & 0.67 & 0.40 & 0.03 & 0.60 & 0.87 & 0.00 & 0.43 \\ 0.27 & 0.43 & 0.00 & 0.13 & 0.03 & 0.03 & 0.40 & 0.23 & 0.00 & 0.17 \\ 0.10 & 0.67 & 0.13 & 0.00 & 0.20 & 0.07 & 0.57 & 0.47 & 0.00 & 0.30 \\ 0.00 & 0.40 & 0.03 & 0.20 & 0.00 & 0.00 & 0.10 & 0.37 & 0.00 & 0.20 \\ 0.00 & 0.03 & 0.03 & 0.07 & 0.00 & 0.00 & 0.07 & 0.03 & 0.00 & 0.03 \\ 0.13 & 0.60 & 0.40 & 0.57 & 0.10 & 0.07 & 0.00 & 0.70 & 0.00 & 0.30 \\ 0.17 & 0.87 & 0.23 & 0.47 & 0.37 & 0.03 & 0.70 & 0.00 & 0.03 & 0.30 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.03 & 0.00 & 0.03 \\ 0.23 & 0.43 & 0.17 & 0.30 & 0.20 & 0.03 & 0.30 & 0.30 & 0.03 & 0.00 \end{pmatrix}$$

In the same way, the relationship intensity matrix of E_2-E_9 can be obtained. The relationship intensity matrix can be visualized as a network graph, as shown in Figure 2. a-2. i. The intensity of the relationship pair is represented by color, and the relationship between various social actors in different types of mass incident can be seen from the figures.

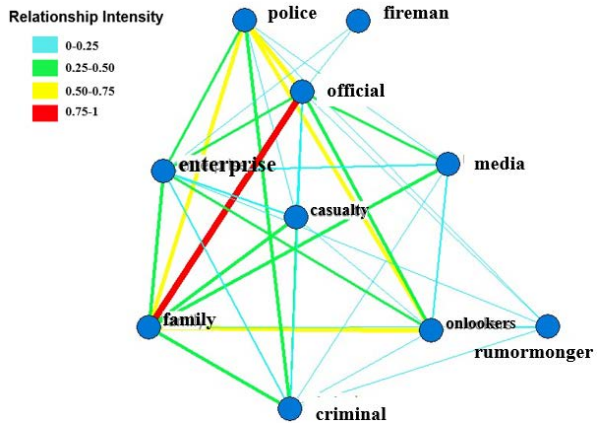

Figure 2. a. Social network diagram of E_1

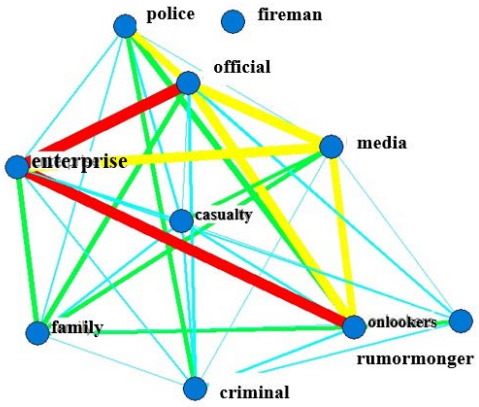

Figure 2. b. Social network diagram of E_2

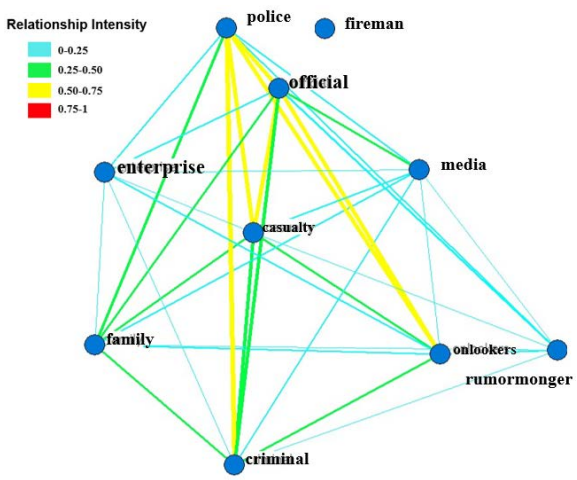

Figure 2. c. Social network diagram of E_3

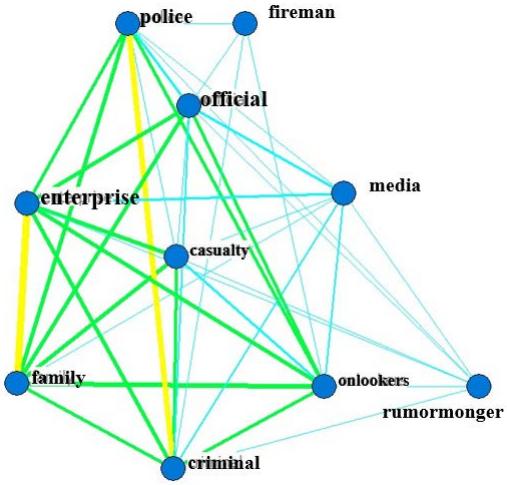

Figure 2. d. Social network diagram of E_4

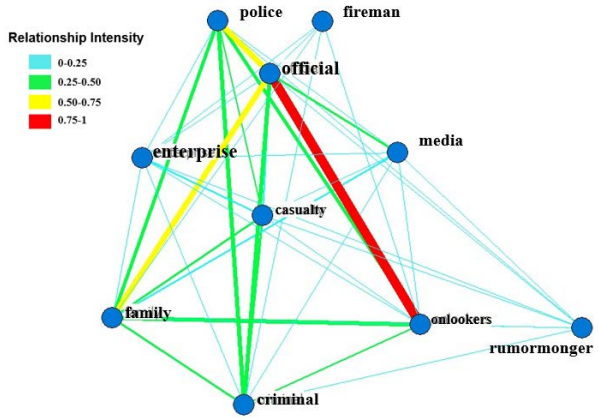

Figure 2. e. Social network diagram of E_5

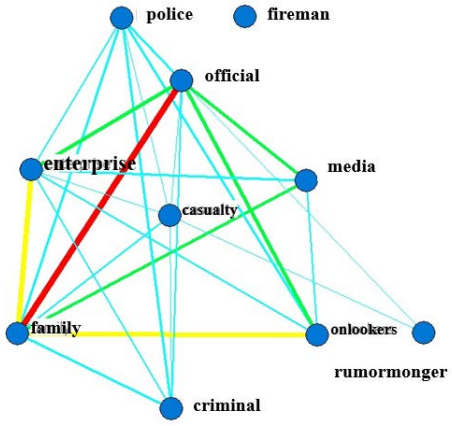

Figure 2. f. Social network diagram of E_6

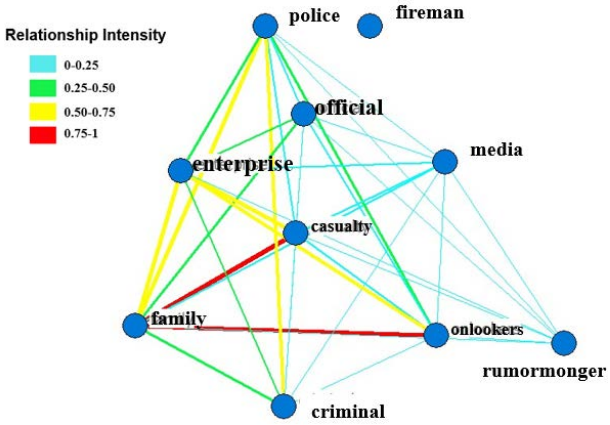

Figure 2. g. Social network diagram of E_7

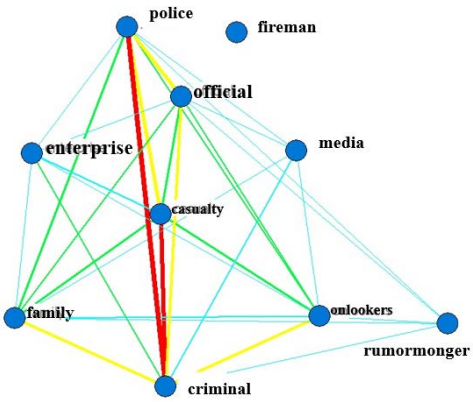

Figure 2. h. Social network diagram of E_8

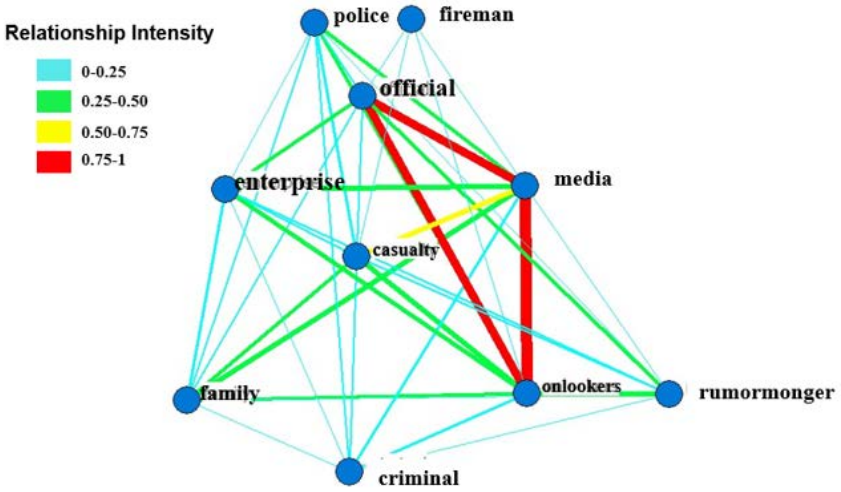

Figure 2. i. Social network diagram of E_9

From the figures above, we can see the differences of the relationship intensity in several types of mass incidents. For E_1 (the collective struggle related to economic or material interests), the strong relationship is " official - family", that is, the government and rights-related subjects.

For E_2 (struggle related to environmental rights and interests), the strong relationships are " official - enterprise" and "onlookers - enterprise", the reason is the interest involved in the case is the living environment of the whole public, and such problems are often caused by the pollution of enterprises, so the strong relationships are the dissatisfaction of the masses against the enterprises, and government investigate the enterprises.

For E_3 (outraged incidents against the powerful) and E_4 (outraged incidents against the rich), no strong relationships were found because of the big differences in the scale of social actors, the object of public anger and the pattern of public anger. Therefore, the statistical results of these types don't show a strong correlation.

For E_5 (mass incidents caused by the deterioration of local political ecology), the strong relationship is " official - onlookers ", because the direct contradiction is that the local residents are dissatisfied with the deterioration of political ecology.

For E_6 (industrial collective action), the strong relationship is " official -family", industry practitioners (we think they form a group like family) strike to expressed the dissatisfaction with compensation and benefits to the government.

For E_7 (mass incidents caused by "death factors"), the strong relationships are " casualty - family" and "onlookers - family", as the relatives are dissatisfied with the way of compensation for accidental casualties and take the way of mass incidents to attract more people's attention, in the hope that they will get a more reasonable treatment.

For E_8 (mass incidents with ideological or politically motivation), the strong relationships are "police -criminal" and "casualty -criminal", mainly due to extreme violent acts of terrorism committed by the separatist and the anti-socialists causing large-scale unrest and terrorist activities. The government dispatched police officers to settle the insurgents (criminals).

For E_9 (endogenous mass incidents in cyber-fields), the strong relationship is the " official - onlookers -media". With the media's extensive spread, there will be a wide range of dissatisfaction or anger with the bad behavior of the official, such as corruption, bribery and flaunt.

From the social network, we can only see the relationship intensity between the actors, but for each social actor, we also need to calculate the intensity of the relationship among all the other social actors and himself/herself, and use it to characterize the degree of risk throughout the mass incidents.

RESULTS AND DISCUSSION

Centrality degree

According to formula (2), we can calculate the centrality degree of each social actor in different types of mass

incidents (dimensionless, reflecting the total relationship intensity). The calculation results of the centrality degree are shown in Table 3, and the image is shown in Figure 3.

Table 3. Centrality degree of social actors in mass incidents

	Casual-ty	Family	Criminal	Onlookers	Media	Rumormonger	Police	Official	Fireman	Enterprise
E_1	1.3	3.83	1.7	2.5	1.3	0.27	2.87	3.17	0.07	2
E_2	1.3	1.83	1.3	3.43	2.7	0.9	1.93	3.7	0	3.3
E_3	2.37	1.77	2.47	2.27	1.27	0.83	3.07	2.93	0	0.83
E_4	1.67	2.93	2.43	2.4	1.03	0.33	2.23	1.9	0.17	3.03
E_5	1.73	2.7	2.3	2.8	1.23	0.8	2.47	3.53	0.33	1.23
E_6	0.23	2.7	0.67	1.4	0.97	0.07	0.83	2.27	0	1.67
E_7	2.4	4.33	1.6	2.5	0.73	0.5	2.53	1.23	0	3.17
E_8	2.63	2.03	3.8	1.93	0.47	0.27	2.97	2.23	0	0.93
E_9	2.13	1.7	0.97	3.9	3.8	1.37	1.43	2.77	0.17	1.77

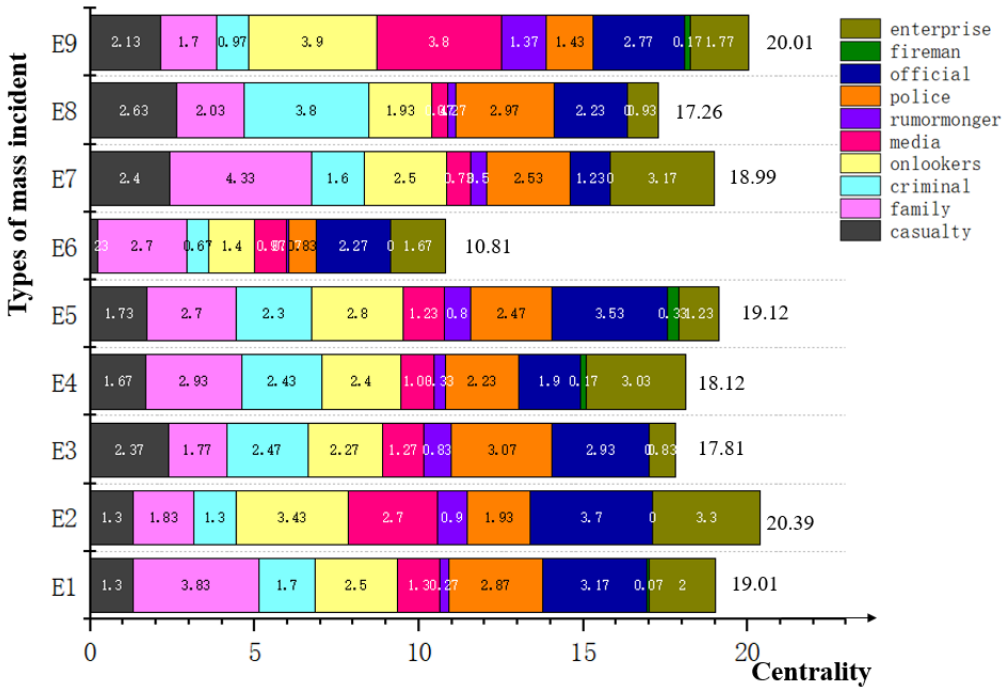

Figure 3. Centrality degree of social actors in each types of mass incidents

It can be seen that the sum of the centrality degrees of all social actors in E_2 and E_9 are the two largest, as the two types of mass incident are larger in scale and influence. E_2 is environmental rights protection incidents, and there is more public participation; E_9 is happened in the network field, it spreads widely. For E_6 (industrial collective action), there are fewer social actors involved, and the conflict forms (assemblies, marches) are also less devastated. So the risk is the least in general.

The centrality degrees of officials, family, onlookers, enterprise and police are higher, indicating that they are of higher risk. For E_9 (endogenous mass incidents in cyber-fields), the spread of media should not be neglected. In addition to E_7 (mass incidents caused by "death factors", the casualties are incidents triggers) and E_8 (mass incidents with ideological or politically motivation, cause high number of casualties), close attention should also be paid to the casualties in E_3 (outraged incidents against the powerful), as E_3 is related to the stability of the regime with high level of violence. In E_9, the centrality degree of rumor became higher. In most types of mass incidents, the criminals will take the opportunity to take criminal actions, especially in E_8, since such cases are

caused by perpetrators. The fireman has a lower centrality degree on the whole, as in most mass incidents, there is no serious arson criminal behavior. On the other hand, if there has been arson, the mood of the community has become more emotional and extremist attacks on the police have emerged. If the firemen are to be dispatched again at this time, they will only increase the bloodshed of fireman. Therefore, the government departments have not sent firemen.

Cliques and core-periphery structure

Select the set of social actors that are related to each other as a clique, and determine the core actors with the Core-periphery structure model in Ucinet program, the final cliques and core actors of each type of mass incidents are shown in table 4 (for the correspondence between social actors and numbers, see Table 1):

Table 4. Cliques and core actors of each type of mass incidents

	Cliques	Core-periphery structure analysis	
		Core actors	**Correlation coefficient**
E_1	{2,3,4,5,7,8,10},{1,2,3,4,7,8,10},{2,3,4,6,7,8,10},{8,9,10}	{2,4,7,8}	0.930
E_2	{1,2,3,4,5,6,7,8,10}	{4,5,8,10}	0.949
E_3	{1.2,3,4,5,6,7,8},{1,2,3,4,5,7,8,10}	{1,3,7,8}	0.941
E_4	{1,2,3,4,5,7,8,10},{1,3,4,5,6,7,8,10},{3,4,7,8,9}	{2,3,4,7,10}	0.89
E_5	{1,2,3,4,5,6,7,8,10},{2,3,4,7,8,9,10}	{2,3,4,8}	0.886
E_6	{1,2,3,7,8,10},{2,4,7,8,10},{2,4,5,8,10},{1,6,7}	{2,8,10}	0.940
E_7	{1,2,4,5,6,7,8,10},{1,2,3,4,5,7,8,10}	{2,4,7,10}	0.933
E_8	{1,2,3,4,7,8,10},{2,3,4,6,7,8},{2,3,4,5,7,8}	{1,3,7,8}	0.934
E_9	{1,2,3,4,5,6,7,8,10},{1,4,5,8,9}	{4,5,8}	0.948

The correlation coefficient between the actual core-periphery structure and the theoretical model is high (in the Social Network Analysis, the 10 nodes are small-scale social networks, so the correlation coefficient obtained will not be too low). Compared with Figure 3, it is also clear that core actors in different types of group events are also with high risk degree. It is necessary for the government decision-makers to clarify the types of mass incidents, and focus more on the corresponding core social actors first. It will help to effectively deal with mass incidents.

Generally, 4 (onlookers) and 8 (official) are the core actors in most mass incidents, which are also the main features of mass incidents. That is, regardless of the cause of the incident, there will always be onlookers. The purpose of actions is to attract the attention of the government and exert pressure on the government to satisfy their appeals.

Specifically, in E_1 (the collective struggle related to economic or material interests), the core social actors are {2,4,7,8}, namely family, onlookers, police and official. Therefore, in the response of this type of mass incidents, it is most important for the government to solve the demands of the family as soon as possible and dispatch the police carefully and control the number of onlookers to avoid the situation from expanding. In E_1, there are four cliques. According to the social roles of different social actors in the cliques, we can distinguish different cliques. In the first three cliques, the common social actors are {2,3,4,7,8,10}, namely family, criminal, onlookers, police, official, enterprise, they are interrelated and are subject to 5 (media), 1 (casualty), 6 (rumormonger) effects. {2,3,4,5,7,8,10} can be seen as informational clique, the media report the development of the incident and need to contact with other social actors; {1,2,3, 4, 7, 8, 10} is deteriorating clique, that is, the casualties occur; {2,3,4,6,7,8,10} is rumors spreading clique, rumors spread to other social actors in the clique. Finally, {8,9,10} is crisis response clique, including the different kinds of government department.

There is only one clique in E_2(struggle related to environmental rights and interests), there is no fireman because of the modest conflict in such cases (no arson). The other actors constitute the largest faction; it can be seen that the close relationship between all the actors exist in environmental rights protection incidents. In this type, the core social actors are {4,5,8,10}, i.e. onlookers, media, official, enterprise. Onlookers protested to government, opposed the problem of polluting and endangering public health during the operation of enterprise, and draw more attention through media. Therefore, to solve the problem of enterprise and correctly guide the media coverage are the key to disposal.

In E_3 (outraged incidents against the powerful), the core social actors are {1,3,7,8}, i.e. casualty, criminal, police,

and official. The main problem in this type is the agitation of the group's emotions. Criminals appeared onlookers, triggering violent clashes with the police and the official, and resulting in casualties. There are two cliques in these cases, {1,2,3,4,5,7,8} are social actors influenced by 6 (rumormonger) or 10 (enterprise), indicating that government departments are likely to arouse public dissatisfaction when dealing with enterprise -related issues, and this need to be properly handled;

In E_4 (outraged incidents against the rich), the core social actors are {2,3,4,7,10}, i.e. family, criminal, onlookers, police and enterprise. This type mainly due to the anger of the family on the economic power, leading to the destruction of the enterprise, and at the same time some onlookers become criminals, involve in the reprisal of enterprise. Police need to calm down. There are three cliques: {1,2,3,4,5,7,8,10} is deteriorating clique, {1,3,4,5,6,7,8,10} is rumors spreading clique, {3,4,7,8,9} is crisis response clique. For the response of this type of mass incidents, the government is required to quickly resolve conflicts and avoid rumors that continue to aggravate the public's dissatisfaction.

In E_5 (mass incidents caused by the deterioration of local political ecology), the core social actors are {2,3,4,8}, i.e. family, criminal, onlookers and official. This cases are mainly caused by local residents' dissatisfaction with the local government, the public's emotions are rather agitated and criminal activities are easy to occur. There are two cliques: {1,2,3,4,5,6,7,8,10} is deteriorating clique, {2,3,4,7,8,9,10} is crisis response clique. This type of mass incidents needs quick response, timely communication with the public, controlling the number of onlookers, and easing the mood of the masses.

In E_6 (industrial collective action), the core social actors are {2,8,10}, i.e. family, official and enterprise. In this type, the family are not satisfied with the wages or benefits of the enterprise, and then they express their demands to the government. There are four cliques: {1,2,3,7,8,10} is deteriorating clique, casualties and criminals emerged; {2,4,7,8,10} is crisis response clique, police intervened for the crisis management. {2,4,5,8,10} is informational clique, as there are media; {1,6,7} is rumors spreading clique, there are rumors of police and casualties. Therefore, in the emergency management of this type, attention should be paid to the influence of rumormonger and media, and to avoiding the occurrence of casualty and criminal.

In E_7 (mass incidents caused by "death factors"), the core social actors are {2,4,7,10}, i.e. family, onlookers, police and enterprise. This type mainly because of the death in enterprise (such as hospitals, schools, construction sites), the deceased's family filed for compensation and led to conflict, onlookers gathered, and police calm down. There are two cliques: {1,2,4,5,6,7,8,10} is rumors spreading clique, {1,2,3,4,5,7,8,10} is criminal clique. So the government needs to pay attention to the impact of rumors and the occurrence of crime.

In E_8 (mass incidents with ideological or politically motivation), the core social actors are {1,3,7,8}, i.e. casualty, criminal, police and official. For this type, criminals intended to undermine the stability and unity of the country, the terrorist attacks and other criminal acts caused a lot of casualty, and it is a provocation to the government. There are three cliques: {1,2,3,4,7,8,10} is deteriorating clique, {2,3,4,6,7,8} is rumors spreading clique. {2,3,4,5,7,8} is informational clique. In the emergency management of such events, it is necessary to timely and accurately transmit information, pay attention to the influence of media and rumor, and timely rescue the casualties.

In E_9 (endogenous mass incidents in cyber-fields), the core social actors are {4,5,8}, i.e. onlookers, media and official. In this type, Internet and other media exposed the bad behavior of government officials, triggering large-scale attention. There are two cliques in this type: {1,2,3,4,5,6,7,8,10} is rumors spreading clique, {1,4,5,8,9} is crisis response clique. Government needs to control the spread of rumors, especially about the casualties.

CONCLUSION

This research uses Social Network Analysis to study nine types of mass incidents to get the relationship intensity matrix, and find the strong relationship in each type of mass incident, validating the rationality of classification. Then we calculate the centrality degree to characterize the social risks of social actors. With the analysis of cliques, there are mainly four cliques in mass incidents: the deteriorating clique of the incidents, the rumors spreading clique, the crisis response clique and the informational clique. Finally, we get the core social actors in different types of mass incident with the core- periphery structure analysis, the obtained core social actors are different in different types of mass incident, and they correspond to social actors with high risk degree. This research will help the government make rapid decision of crisis response and management after judging the type of mass incident.

However, the social actors involved in this article are not specific social actors in a particular area, and the relationship between them is based on statistics. The analysis of the error when applied the model to a specific mass incident is not covered in this research. In the meantime, although social actors have the same

social role in terms of social roles, whether there is any difference in time and space in the mass incidents also needs further study.

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The Symbiotic Relationship of Crisis Response Professionals and Enthusiasts as Demonstrated by Reddit's User-Interface Over Time

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ABSTRACT

Since the Aurora, Colorado movie theater shooting of 2012, the web aggregation community Reddit has been an enthusiast-driven, public-facing source of information about crisis response efforts. We describe the evolution of Reddit's software from the Boston Marathon Bombing of 2013 to the Ferguson unrest throughout 2014. Initially, Reddit was built to aggregate verified news but beginning with the Aurora movie theater shooting, Reddit began to aggregate and verify breaking news. In response to criticism of Reddit's actions during the Boston Marathon Bombing, Reddit re-designed their software in an effort to more accurately mimic crisis response professionals by fostering rigor, information control, and tighter bureaucracy. Reddit's ability to swiftly change its software serves as an example of the possibilities of crisis informatics in practice. We highlight the processes that Reddit has taken to maintain its efficacy even within the current issues surrounding information verification and automated spreading of rumors and falsehoods.

Keywords

Reddit, Crisis Informatics, User-Interface, Communities, Social Networks.

INTRODUCTION

This research contributes to understanding how the actions and media coverage of crisis response professionals influence the practices of crisis response enthusiasts over time. We situate our research using two concepts–publics or public groups and communities of practice. Publics are groups of people indirectly associated with a topic or event (Liu et al., 2011). The events that bring these people together can often lead to the establishment of a community of practice (Lave & Wenger, 1998) as participation in a group over time will often lead to routinized community norms and methods. Specifically, we examine the community of practice that formed in the web aggregation community Reddit during the Boston Marathon Bombing of 2013. The community of practice that developed during the Boston response influenced changes to Reddit's user-interface (Potts & Harrison, 2013) that were deployed during the Ferguson Riots (or Ferguson Unrest) of late 2014.

The Boston Marathon Bombing is our starting point as much of the current state of the crowd's place in crisis response begins there. During the Boston Marathon Investigation, Reddit-users processed all publicly available information in and around the Boston area in an effort to identify the then unknown bombers. The efforts of Reddit lead to two attempts to name the bombers–both attempts were incorrect and highly publicized. The vociferous public response led to a clash between crisis-response professionals and the public about the nature of crowdsourcing crisis response (Konkel, 2013; Nhan et al., 2015; Potts & Harrison, 2013; Tapia & LaLone, 2014). At the center of the clash were the place of citizen journalists in crisis response (Tapia & LaLone, 2014). To situate this clash, we use the three types of public groups that appear within crisis response.

First, there are those impacted by the disruption that lead to a crisis. The nature of the disruption defines these

public groups. The second kind of public are crisis-response professionals. The nature of the professional is well-defined (e.g. (Bruning et al., 2004; Bruning & Ledingham, 1999)). The third type of public is loosely defined as a collection of groups that emerge near or outside the impacted area. Recent technological developments have created public groups that are bound by software and represented by a user-interface. The groups bound by software could be bound by a Twitter Hashtag like #Pray4Boston or a group devoted to a specific cause like pet recovery in Hurricane Sandy (White et al., 2014). This third type of group the focal point of the present research. Reddit is a loosely defined group bound together by software.

During a crisis response event, interested Redditors (members of Reddit) gather around that topic and often establish a topically-oriented sub-section of Reddit called a subreddit. This moves Reddit from public groups to communities of practice (Lave & Wenger, 1998). It establishes a community of practice because each subreddit has its own set of norms, practices, and rules. Reddit's public failure during the Boston Marathon Bombing is the sole event responsible for changes to Reddit's user-interface (Leavitt, 2016; Potts & Harrison, 2013). Reddit focused on codifying the practices that worked and using their interface design to ensure those practices that did not work well were no longer possible. The communities of practice from previous events provided the practices that needed to be represented by the interface and those practices were attempts to mimic crisis responders themselves.

PUBLIC GROUPS, NETWORKED PUBLIC GROUPS, AND CRISIS RESPONSE

According to Moynihan (2009), crisis-oriented public groups have historically been organized in one of two ways (Figure 1, next page): command and control (top down) and networked governance (central command with autonomous, hierarchically organized groups). Credential-identified professional responders act within a rigidly hierarchical network maintained by official authority in the form of training, licenses, and certificates. These methods of response were created during the Cold War. They established a military style command structure that operated much like a military unit. In addition to the command structure, this credential-bound public group would typically act in near privacy. The privacy afforded by credentials began to wane as new types of communication technologies allowed the public to keep track of responders and their activities. Technologies like police scanners, social media, cheap cameras, and the ability to broadcast to the Internet via telephone, removed a significant amount of crisis responder privacy. The loss of privacy was innocuous. However, as those tools that the citizens used became more powerful and widely available, the loss of privacy began to matter in significant ways.

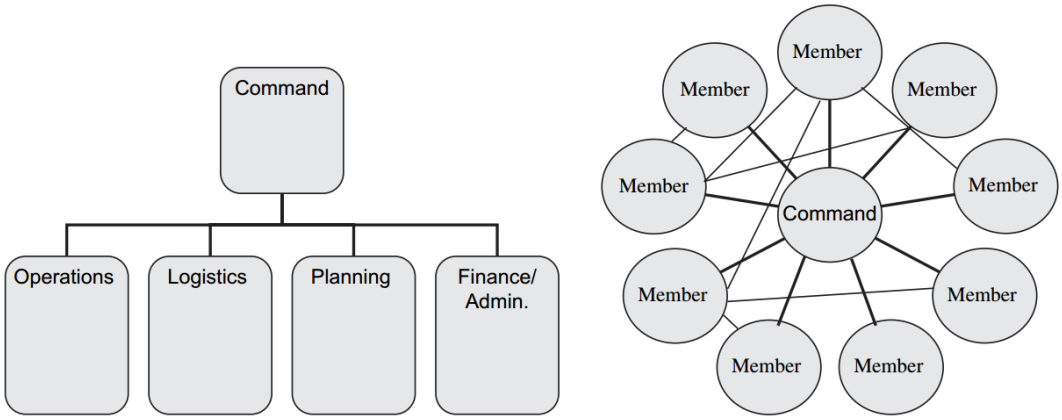

Figure 1 - Command and Control hierarchy versus Networked Governance (Moynihan, 2009)

Given these two structures, it was previously impossible for the (untrained) public to participate in a crisis response. The public was also unable to gain information about the response from the responders themselves. In the past, responders will typically only discuss response efforts with other responders. Now, response professionals release information through social media via official accounts or through official media sources. In addition to receiving information, it is similarly difficult to provide information to response professionals. Generally, responders only accept information through official methods such as interviews or tip lines. Pre-established information-sharing channels like those mentioned above are what software-mediated groups like Reddit are confounding.

For example, during the Boston Marathon Bombing, the official methods of interacting with responders nearly collapsed under the weight of over 10 terabytes of images, videos, and tips (Konkel, 2013). This deluge of data paired with internet-accessible police blotters and scanners meant that an active criminal investigation was

under the scrutiny of enthusiast groups with high-levels of technological expertise (Büscher & Liegl, 2014). Groups of citizens bound by software like Reddit, began to organize around aiding criminal investigation. The public responded to initial activity favorably. Many began to feel that the crowd could solve crimes without professional intervention (Konkel, 2013; Tapia et al., 2014). Reddit seemed to have an ability to traverse crisis informatics in ways previously unobtainable.

CRISIS INFORMATICS

Citizen use of social media and other kinds of software during crisis response has been an active research domain for several years and has fallen under the moniker, "crisis informatics" (Palen & Anderson, 2016). This research often engages the practice of average citizens reporting on activities "on-the-ground" during a disaster (e.g. (Dailey et al., 2016; Dailey et al., 2018)). Research focuses on the data these citizens produced because it is potentially valuable to real-time response efforts (e.g. (Palen & Vieweg, 2008; Palen et al., 2007; Starbird et al., 2012; Starbird & Stamberger, 2010; Sutton et al., 2008; Terpstra et al., 2012; Vieweg et al., 2008)). As the potential value of these data has become more evident, the need to make social media data useful to emergency responders has become a strong research focus (see Tapia et al. (2013)). However, this research is unbalanced and has focused primarily on the challenges of processing and sorting social media data (MacEachren et al., 2011).

Interestingly, most research about crisis response and social media centers on the use of Twitter data. Each point of data within a Twitter corpus is brief. Therefore, it represents a unique opportunity for researchers to find information that may or may not contain about certain situations on the ground (Kaufhold & Reuter, 2016). However, recent polls about social media use during a crisis found that most users (73%) would turn to Facebook for help and maintain their privacy restrictions on their communication, thereby reducing the effectiveness of social media significantly. Just 21% of their respondents claimed to use Twitter (Reuter & Spielhofer, 2016). While groups on social media are often described in great detail post-event (e.g. (White et al., 2014)), more work is needed to understand other types of online communication like the web aggregation community Reddit. This work is still nascent but many generalities can be seen with crisis response and social media.

Fifteen years of crisis informatics research has revealed three important developments. First, social media use during a crisis events has become commonplace. More and more people use social media to both communicate and organize during events. Next, the geographical representation of crisis informatics research can be found globally now versus its initial focus on the United States. Attempts to organize online denizens through efforts like virtual and technical communities (Van Gorp, 2014), incident management teams (McLennan et al., 2006), and Virtual Operations Support Teams (VOSTs) (Büscher & Liegl, 2014) continue to be attempted but never fully realized (Reuter & Kaufhold, 2018). Mistrust and expectations continue to provide barriers to accepting social media data in real time. The recent growth of "Fake News" has further confounded these efforts (Starbird, 2017). And additional developments have called into question the ethical nature of using social media data at all (Grassegger & Krogerus, 2017). We offer our case study not as an answer to the growing issue of fake news but as an effort to describe efforts to correct the spread of misinformation for crisis informatics and crisis response professionals to learn from.

CONTEXT OF CASE STUDY

Reddit is considered a "social news" website that affords its users the ability to link to other websites, post pictures, vote (positive or negative) on other posts, and post multimedia content in "live threads." The tagline for the site is, "the front page of the internet" and as the ninth most popular webpage on the internet, it nearly is. Reddit can also be considered a tool for reporting and awareness to a limited degree due to the specific type of user that it attracts. The audience of Reddit is majority male (53%), between the ages of 18-29, and from the United States (54%). Nearly 6% of all Americans have an account on Reddit (Duggan & Smith, 2013). As of 2015, Reddit has received over 70 million user submissions, over 700 million comments about those submissions, nearly 7 billion votes, and over 80 billion page views (Leavitt, 2016).

The site is organized topically, with each overarching topic (e.g. politics, gaming, python) is referred to as a subreddit. Each item on a subreddit is referred to as a post and each subreddit are organized via date or popularity (ratio of positive votes to number of votes). Users can also organize their interface by subreddit, message other users, and gain access to hundreds of independent systems connected (unofficially) to subreddit communities. These systems include chat tools like authentication servers for other forums, Imgur, Internet Relay Chat, Discord Chat, or Slack Chat. These services allow Redditors to organize and act in tandem in many ways. When all of these tools are assembled, Reddit has four qualities that make it a target of opportunity for research: 1) a desire to act, 2) significant levels of participation, 3) time, and 4) technical skill (See: (Duggan &

Smith, 2013)). During a crisis response effort, the sheer volume of data processing often dwarfs the capacity of professional response efforts.

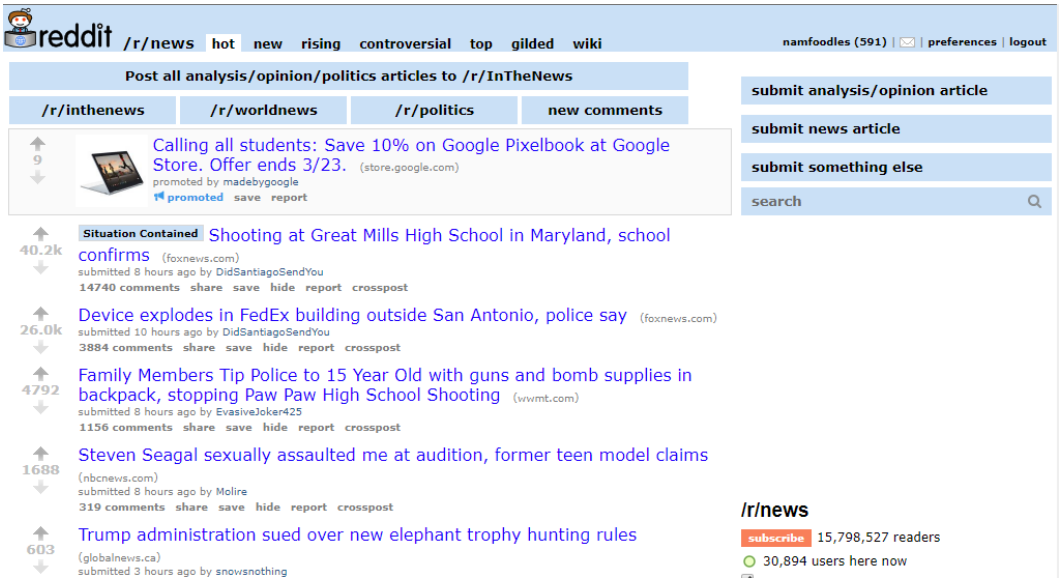

Figure 2 – Reddit's Normal Interface

The selection criteria for this research was selected as a "before and after." If interface and affordance represent the internal discourse about the place and nature of a community, then these two cases need to reflect two different modes of thought (Potts & Harrison, 2013). We also wanted two cases whose gaps and attrition-based data loss over time could be remedied by news media and supplemental discussion on other sites. The first choice was the Boston Marathon Bombing. This case represents the most public interaction between professional crisis responders and enthusiasts. By most accounts, the interaction ended in failure (Madrigal, 2013; Nhan et al., 2015; Tapia et al., 2014). After this encounter, the administrators and members of Reddit began developing new tools deployed during the Ferguson Unrest.

Case Summaries

The Boston Marathon Bombing and Ferguson Unrest are two cases wherein professional crisis responders were the focus of Reddit's response efforts. During each event, Redditors used web-accessible police scanners, hand-coded Google Maps, and video streams from individuals on the ground to fill situational knowledge gaps. An inventory of the data collected and examined within these case studies shown in Table 1. The following examines what Redditors did during the Boston Marathon Bombing that caused their software to need to change. We then discuss Reddit's activities during the Ferguson Unrest.

The Boston Marathon Bombing

On Monday, April 15, 2013, at 2:49 pm, two bombs exploded 210 yards (190 m) from the finish line of the Boston Marathon, abruptly terminating the race. These bombs killed three people and injured 264 others. Within hours of the initial event, the FBI called for bystanders to share images and video of the event (Tapia et al., 2014). Reddit was actively involved with aggregating and disseminating information about the situation in Boston and the hunt for the bombers. Their involvement manifested in a manner that was available to Redditors, through their user interface. In total, their work spread out over 21 individual threads, several chatrooms on Internet-Relay Chat, countless supplemental posts, and private messages.

The narrative of these posts tells a story about the birth of a community of practice from the public groups of Reddit. When the event occurred, the author of the original post posted a thread in the wrong subreddit. This thread was immediately deleted. The creator of the second thread, this time in the correct location, established the procedure for breaking news using the Reddit User Interface. The creation of 20 more threads using this structure appeared over the next 10 days. As thread 2, 3, and 4 came and went, the discussion of where to discuss the Boston Marathon Bombing and if its subreddit would dominate the threads. This began to change as the threading stabilized and content moved from "What is going on?" to "What do we do now?" and "Who did this?"

The discussion of how to verify information immediately became a problem. Starting in thread 3, discussion of

too much speculation began to pepper the threading. Different news media began to discuss contradictory information and so Reddit began to dig deeper. Groups listened to the police scanner and other camera feeds around the area. By thread 11 (2 days after the bombing), two themes dominated the discussion. The first was that Reddit was becoming a problem. Concepts like, "beware the insomniac Reddit army!" warned of possible pending disaster. Another theme was that some of the efforts to catch the Boston Bomber were getting out of hand. Many comments begged the FBI to release the names and identities of the bombers as to avoid drama.

Event	ID	Activity	Likes	Major Event	Sub-Event
Boston	1	1914	3632	Transcribing Scanner	Talk about thread being removed
Boston	2	3936	3089	Worldnews Mod Anger	Praise for threads
Boston	3	3728	3006	Please not to click unless needed	Calls for facts, not speculation
Boston	4	4398	2871	Moroccan national speculation	Why this subreddit?
Boston	5	205	879	Slower verification.	Thread not fully created
Boston	6	2107	1824	Number of injuries and deaths	New York Post isn't trustworthy source
Boston	7	998	1410	Hospital discussion	What was the bomb made of?
Boston	8	1631	1544	Original Post Deleted	Bag discussion, bomb speculation
Boston	9	822	1527	Should start witch hunt, it's getting bad	Deleted
Boston	10	906	1399	Victim of Blast Needs Support	Photo dump discussions
Boston	11	184	806	Need to be wary of "Insomniac Reddit Army!"	Please FBI release soon or witch hunts out of hand
Boston	12	3705	1536	Please no Speculation	Random Acts of Pizza article on CNN
Boston	13	1804	1515	Original Post Deleted	Press Briefing Cancelled, no new news
Boston	14	1960	2280	Thank you for doing this	Pictures are heartbreaking
Boston	15	375	795	Victim of Blast needs support	no need to keep speculating
Boston	16	3802	1218	Reddit DDOS	Ferilizer Explosion
Boston	17	3688	990	Picture Quality	Discussion of finding suspects
Boston	18	3667	798	Discussion of incorrect suspects	Mike Mulugeta, Sunil Tripathi
Boston	19	1850	863	Original Post Deleted	Posts to Tasranaev twitter account
Boston	20	3212	783	Discussion of staying off streets	Police asking not to broadcast search
Boston	21	2787	834	Investigation Over	Police Band not being encoded
Unrest	1	1530	1447	Political Discussion dominated	
Unrest	2	384	386	Going to sleep, read live thread	
Unrest	Live	8000+	N/A		

Table 1 – Post and Comment Inventory with Emergent Themes from Each

On thread 16 (3 days after the bombing), Reddit's public support ran out when it released photos of the bombing suspects. During this thread, Reddit was the target of a Distributed-Denial of Service attack (DDOS). By thread 18, Reddit's goodwill would expire. The names Mike Mulugeta and Sunil Tripathi originated from a single tweet:

@KallMeKG: BPD scanner has identified the names:
Suspect 1: Mike Mulugeta Suspect 2: Sunil Tripathi.
#Boston #MIT [5]. [April 19, 2:50pm, cited in (Starbird et al., 2014)]

The news media would repeat these names after they were offered by Redditors. However, this tweet seems to have been an effort to sabotage the public's efforts. Mike Mulugeta did not exist and Sunil Tripathi had tragically committed suicide before the bombing but his body was not found for several more days. After the

Boston event, Reddit began work on their graphic interface.

Ferguson Civil Unrest and Riots

On August 9, 2014, police officer Darren Wilson shot and killed Michael Brown outside of a convenience store in Ferguson, Missouri. This shooting sparked numerous protests and riots across the city that continued until November 2014 after Darren Wilson's acquittal. Redditors started a thread about the Ferguson Unrest as normal. However, Reddit had begun its shift from simple aggregation of existing information and began to supplement it with, "Live Threads." Many comments on the initial thread were simply, "Go to the Live Page for more information."

Live threads, unlike the old threads that required careful handoffs paired with focused manipulation of the Reddit voting system, were controlled by an administrator who could distribute thread editing rights. There were approximately 10-15 administrators throughout the event. Live Threads functioned as an interactive canvas capable of accepting all types of multimedia data. Many of the data for these maps came from Vine, Facebook Live, and several other streaming services. Other Redditors created "fire maps" via Google Maps that showed real-time estimates of where fires were currently blazing. Throughout this event, the only "drama" was about how slow or fast the page was updated. The page kept clear of little more than information aggregation in real time. The difference between Ferguson and Boston Marathon Bombing activity shown in Figures 3 and 4.

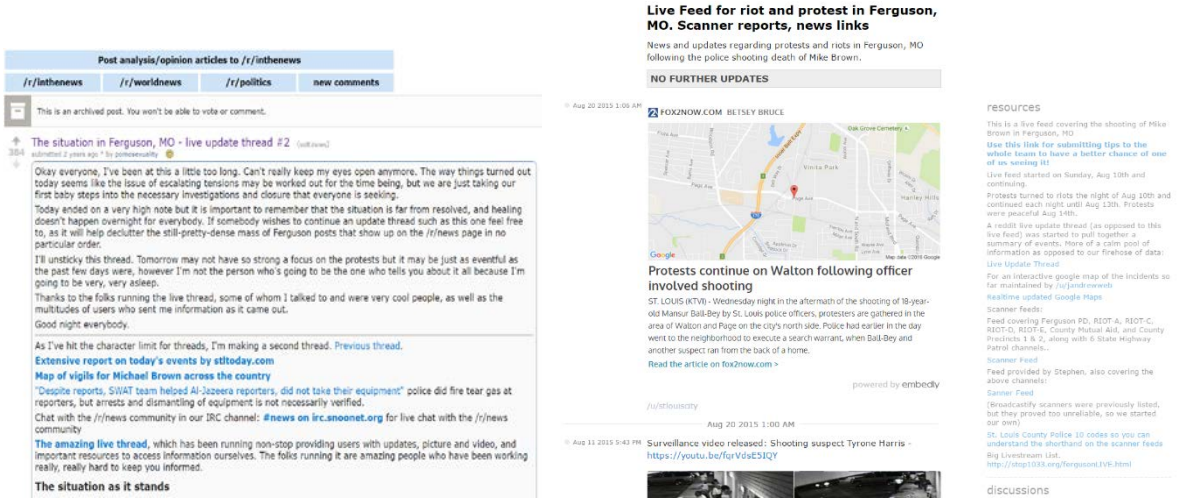

Figure 3 & 4 - Standard Reddit Page versus a Live Page

METHOD AND DATA

In this research, we evaluate enthusiast groups within the confines of an information communication technology. For work on media, it is important to deploy a method that can include dynamic content like affordances, multimedia content, individuals, groups, rhetoric and how these things change over time. This research used two methodological approaches. The first approach is Qualitative Media Analysis (QMA) or as it was previously known – Ethnographic Content Analysis (Altheide & Schneider, 2012). QMA uses a technology or group of texts as a culture that a researcher must get to know.

As that researcher comes to understand the norms and values within that text given the technology used to generate the text, the researcher's ability to discuss and ask questions of the text deepens. The second approach fills in gaps of the first by incorporating the general user interface as the result of discourse about the nature of a community. User Interfaces and the method in which information is delivered are direct reflections of internal discourse about internal norms and things of importance (Potts & Harrison, 2013). By assembling the rhetoric and computational elements of how that rhetoric delivery all aspects of Reddit are simultaneously represented.

Data

In total, our data inventory contains:

- 21 threads with an additional 33,599 comments that represent Reddit's public activity during the Boston Marathon Bombing;
- 2 Static Threads about Ferguson created before August 11, 2014 when the Live Thread Began;

- Several discussions of the development of the Live Thread tool;
- 1 Live thread representing Reddit's activity during all phases of the Ferguson Unrest with over 8000 updates.

Each thread was frozen through tools that translated HTML to a PDF. The iOS application, *iAnnotate* (https://www.iannotate.com/), facilitated coding of the PDFs on three occasions by a single researcher. Data evaluation occurred in three passes to allow the researcher to learn a little more about the nature of Reddit and the various groups at work within these disparate events. Color coding is used when identifying a theme. *IAnnotate* examines each color for further detail.

The researcher can compare what they coded each time. Meta-events and sub-events where assigned to threads as applicable. Establishing a meta-narrative spread out across the various threads helped the researcher make sense of where and why some aspects of Reddit's efforts began to stray from its original intent. The Live Thread is where a majority of this re-coding took place. To augment the Live Thread, additional discussions among the CEO of Reddit and the community at large provided context for the development of these tools (e.g. (Koebler, 2016; Leavitt, 2016; Potts & Harrison, 2013)). Throughout our analyses, three themes emerged that display how Reddit changed over time.

DISCUSSION

Reddit's software exemplifies the rhetorical composition of what Reddit is and how their communities of practice can act. There are three points of discussion through our two crisis events that exemplify how crisis responders changed Reddit and Reddit's software. First, we will discuss how Reddit, a site meant to aggregate information has moved from established events to breaking news. Breaking news was a source of controversy during the Boston Marathon Bombing efforts. Second, we discuss how the move to breaking news has adjusted the hierarchy of the user base. By centralizing all information into a multimedia feed not part of any subreddit, Reddit needed to adjust its affordances to address issues of abuse, power, and cliques. Finally, we discuss how Reddit absorbs and sometimes protects against counter-groups that seek to disrupt and destroy information verification efforts. As a popular web community, Reddit has essentially inserted itself between the public and crisis response professionals to focus the flow of information in a standardized way Reddit controls.

From Aggregation to Breaking News

Reddit's design to allows users to post about an item of interest and discuss it with others. This is the formation of the public groups. As the, "Front page of the Internet" Reddit meant to reflect established, stable content in a way that was useful for people to access. The site grew quickly, and behaviors stabilized. However, as Redditors began to cover breaking news rather than stabilized events, behaviors started to change (Singer et al., 2014). Instead of curating and aggregating content, Redditors began to look for content that was not from routine sources like news sites or officials (Leavitt, 2016). They began to look for content on social media that indicated ground-level activity.

This shift began slightly before the Boston Marathon Bombing, but became the norm after the posting of the first stable thread. The impact the different affordances Reddit has deployed to meet stablized versus breaking news are of interest. In this section, we break down how each point of origin reflected the needs of stabalized events and breaking news. Next, we describe the manifestation of effort as seen by a random passerby (often called a lurker). Finally, we will describe how these differences address concepts of rigor needed to cover breaking news.

Reddit during Boston

The normal set of affordances (shown in figure 3) of a Reddit post is simple. The post contains a title, a body of text, an up or down arrow indicating how a user rates its value (up for positive, down for negative), and a numeric score indicating the number of positive votes it has received. Each post can receive a reply and each response has the same affordances as above. These responses are from other Redditors and are additions to the discussion. Each central post (independent of responses) can hold approximately 10,000 characters. Once the threshold is met, the post it is not possible to edit further. These posts would reach 10,000 characters because as Redditors found new information, they would edit the original post to reflect new content.

The creation of a new thread occurred once that post reached the limit. Over the course of the 10-day Boston Marathon Bombing investigation, there were 21 threads. Each of these threads contained their own internal controversies, events that were speculative and later voted down. Reddit's emergence using its standard

affordance package (vote up to express *like* or if this information is correct) was difficult to follow during the speed and information-rich nature of this event. In addition, the maintaining the threads is a single original poster (OP) who could then ask administrators of the Subreddit to give editing rights to the current post. A post can make it to the top of a Subreddit if it receives the most votes in the thread.

With the normal affordance package of the time, there were scores of actors to keep in check. The necessity to create a new thread when a rate limit was reached created 21 opportunities for sabotage of the Redditors maintaining these threads to lose control of their progress. Over the course of the response, a counter group formed. This group of Redditors formed a Subreddit called: r/findthebostonbombers. As the response progressed, this group received rapidly increasing attention from the press. The public's perspective from the press challenged Reddit's possibility and the effort was inevitably seen as a failure (Leavitt, 2016; Madrigal, 2013; Nhan et al., 2015; Tapia et al., 2014).

Reddit during Ferguson

As an effort to make it easier to engage breaking news-style posts, Reddit introduced the Live Threads (shown in figure 4). These threads were based on behaviors from previous crisis responses and news reporting incidents. Live Threads are meant to reflect the criticisms and design flaws that became evident throughout the Boston Marathon Bombing Investigation. They afford for a series of moderators to curate a single page with no character, page, or voting limitations.

According to the developer of the tool:

> *The "reporters" for a stream can post updates and anyone watching gets sent those updates in real time. Unlike with self-post or comment based live updates, there's no limit to how many updates can be posted during the course of an event. Liveupdate streams exist outside of subreddits and are designed to be submitted like any other link to whatever (multiple) subreddits are relevant to the stream.* (Spladug, Reddit Developer)

The first two tests of this system were the United States State of the Union Address in 2014 and the beginning of the conflict in the Ukraine. Once those tests were complete, Reddit opened the creation and administration of these pages to all Redditors. The first full-scale deployment of these new affordances was the Ferguson Live Page. The initial page created during the first wave of Ferguson Unrest and continued through the last wave. Live pages represent a step away from interfering with investigative efforts while also attempting to address issues of authority and rigor within the Reddit community.

Instead of speculation through comments or notes of discussion within the thread itself, the moderators maintain a stream of data without any other style of response allowed. In the wake of these threads, traditional posts are created to discuss the content that is on it. However, these threads are independent of the Live Pages themselves. Each Live Page also contains a sidebar with information on who is updating the page and other information deemed pertinent by the team administrating the Live Page. This closed system addresses nearly every aspect of weakness identified by the press, the public, and the credential-bound public groups of professional crisis response.

The Consequences of Authority and Rigor within Reddit

Credential-bound public groups like professional crisis responders are often identifiable by badges, by training, and by credentials. Redditors have attempted to emulate the training these credentials indicate by adjusting their software. Interestingly, through Reddit's Interface, discussions form around an event. Being an administrator for a Live Thread is essentially being a part of a credential-bound public group. The curators the Boston Marathon Bombing Investigation and Ferguson Unrest efforts were enthusiastic about data gathering. They used their resources to gather more data, more quickly than professional responders. Many curators indicated that they wanted to get involved because it was a way that they could apply their feelings of sadness and anger created by the tragedies. Reddit's new behavior exhibited in Boston was adopted quickly and many of the users who were aggregating data appropriated the tools they had available. As is often the case with emergent groups within a crisis, appropriated technologies (Dourish, 2003) and procedures were the norm (White et al., 2014).

Reddit during Boston

By helping to organize information, the curators indicated that they felt as though they were helping everyone come to understand the events a little better. Unfortunately, there are disagreements between groups about the helpful nature curation activities. Because each of the 21 threads on the Boston effort took place over a period of 10 days, the crowd posting information and the reasons for posting information fluctuated. From the beginning

of the investigation until around the 9th thread, two days into the event on April 17th, a poster noted,

> *"Hey OP, I notice as time goes on these threads are more and more speculation and response as opposed to breaking news (which is natural, considering new info is coming in less and less frequently). Has there been any talk about how much longer these live update threads will keep happening?"*

As time went on and photos of suspects were added, the spirit of speculation and the desire for facts eventually dwindled. The split between those who wanted to gather information and those who wanted to find the suspects resulted in the creation of a subreddit: r/findbostonbombers. This subreddit sought to do what the main pages would not: name suspects, find information about them, and release that information to the public. Initially, the public welcomed the drive to find and identify the perpetrators. In one article, a reporter noted:

> *"The subreddit, r/findbostonbombers, …is at least slightly more responsible. Threads are dedicated to confirming people as innocent, and highly up-voted posts call on the media not to spread images, remind redditors of the dangers of false accusations, and lay down pretty stiff rules of conduct." (Hern, 2013)*

However, the Reddit community was publicly shamed after falsely accusing an individual by the name of Sunil Tripathi to be the Boston Bomber. As a result of being accused, Sunil's parents, who had been searching for their son for a number of days, began to receive death threats and targeted harassment (Kotenko, 2013; Nhan et al., 2015; Starbird et al., 2014; Tapia et al., 2014). The accusation was the result of bad information, a mistake, or sabotage. Discussions such as the one displayed in Figure 5 speak of a purposeful sabotage from a group citizens formerly of the community 4chan called /Pol/ (Dewey, 2014). /pol/ or the Politically Incorrect board of a rival web community called 4Chan has been the center of numerous controversies as well as the starting place of the alt-right (Nagle, 2017).

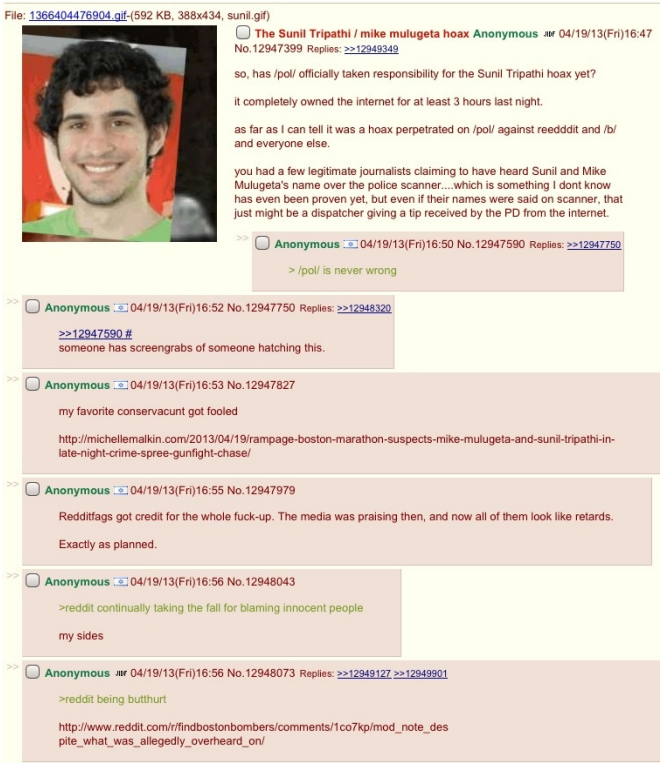

Figure 5 - Screenshot from 4Chan about possible sabotage and fraud on Reddit

Regardless of the reason for the false accusations, it tarnished Reddit's reputation, and citizen engagement within crises. In-person detective work of professionals later produced the identity of the Tsarnaev brothers. Additionally, the work of Reddit forced the FBI to quicken their investigation while struggling to maintain command and control as a whole (Montgomery et al., 2013). This negative reaction forced Reddit's leadership to offer an apology to all those wrongly accused. Parallel to that shame, the FBI also reprimanded the press for their role in wrongly identifying suspects (Leavitt, 2016; Potts & Harrison, 2013).

Reddit during Ferguson

Between the end of the Boston Marathon Bombing and the Ferguson Unrest, Reddit created a new tool for emergent events. Live Threads are real-time tools that can display all manner of multimedia content but cannot be commented on. Instead, these pages are carefully curated by volunteers who have sole administrative access to their contents. By centralizing efforts onto one living document, the content of the page and not the politics control and flow processes management become more important. Reddit does not permit multiple Live Threads, which decreases likelihood of dissention and errors. However, dissention does still occur. In fact, it may become more personal. Throughout the Ferguson Unrest, there were many tense moments within the Live Thread.

For example,

> *Please don't yell at me if it's not updating fast enough for your liking. As I've stated to pretty much everyone who's complained/griped at me for something they didn't like, if you don't like how we do it, you're perfectly welcome to go start your own life absorbing/time sucking/relationship stressing/learning too much about how racist and terrible people can be/exhausting live feed and run it however you want. If you do a good job, I'll close this one up and let you have the center stage and I'll go back to getting more than a few hours sleep each night. /u/TheDeech*

By decreasing the likelihood of the interference of counter-groups, Reddit directly addresses the issues of rigor that levied against Reddit during the Boston Marathon Bombing. The Live Thread showed aggregated content only. Through the Live Threads, users move from defending their content and processes to assembling information in real time as centralized administrators.

Protection Against Other Emergent Citizen Groups

Citizen groups differ in intent, makeup, and ability and not every group is out to be helpful, at current (McMahon et al., 2016). Reddit is able absorb aggressive groups seeking to spread rumor. There have been numerous "battles" or "encounters" between Reddit and other internet communities like it (e.g. SomethingAwful, 4Chan, Anonymous, etc). Each time, the end of the encounter leaves plans for sabotage when the opportunity presents itself later (e.g. (Massanari, 2015)). Reddit's interface has changed over time to meet the weaknesses these past encounters have manifested. In changing its interface, it has enabled protections against sabotage and invasion. During the Boston Marathon Bombing investigation, Reddit was not the only networked public groups engaged. To give more context to Reddit's activities, it is important to describe how each additional public approached the investigation differently and how each group interacted each other.

Reddit during Boston

The Boston Marathon Bombing response attracted interested enthusiasts from numerous other spaces online. Briefly, we describe the actors. The hacker-activist (hacktivist) group Anonymous was present during the event pursuing an agenda that the Boston Marathon Bombing was a "False Flag" operation meant to distract from the passing of the Cyber Intelligence Sharing and Protection Act (CISPA) (Tapia et al., 2014). Anonymous was also present before the event due to a post made on the website 4chan that predicted the bombing. As the Boston Marathon Bombing investigation began, the web community 4Chan took to seeking out the same suspects that everyone was (Hern, 2013; Konkel, 2013; Montgomery et al., 2013).

Over time, as the public interest in citizen-groups grew, the discussion between groups soured. Reddit was declared to be a, "sleuthing circlejerk" and when Sunil Tripathi was mis-identified as the Boston Marathon Bombing suspect, a Distributed Denial of Service (DDOS) attack was performed on Reddit (Kotenko, 2013). It is unclear if the mislabeling of Tripathi was the result of acting too quickly or sabotage, but it remains the single event that changed the public's opinion of crowdsourcing criminal investigations (Tapia et al., 2014). Between that moment and the start of the Ferguson Unrest, Reddit's public encounters allowed them to frame the Live Threads.

Reddit during Ferguson

By moving the discussion from the standard posts to the Live Threads, the likelihood that another group could interfere with the investigative efforts of that crowd is much lower. However, it still happens. For example, during the Ferguson unrest the hacktivist group Anonymous continually released the public information for each member of the relevant police department. This "doxxing" or public releasing of documents containing sensitive information has become more routine as the ability to find those data has become easier (Leong & Morando, 2015). Discussion on the posts about Ferguson were often about trying to find the police officer. Yet, none of the activities from these other communities made it into the Live Thread other than administrator notes saying, "We will not post that information." Throughout the Ferguson Unrest, the administrators of the Live Thread

maintained a constant feed of information. The realization of these pages is little more than information flow without controversy and they succeeded…for a time.

CONCLUSION

In the introduction of this article we stated that we would contribute to understanding how the actions and media coverage of crisis response professionals change the practices of enthusiasts over time. After examining the history of Reddit and its user-interface, the relationship should seem straight forward. Reddit seeks to harness their resources to provide accurate, verifiable information to anyone who wants it. Redditors use their software to focus the flow of information during a response effort. While these efforts have yet to officially become a representative of crisis response professionals, spaces and communities like Reddit are providing more reliable of information with each response. Reddit is constantly re-working its software to define what matters to information flow within a crisis. It also defines what is important for crisis response professionals to do and what information verification requires.

We contribute to an understanding of the relationship between enthusiasts and professionals a bit further. We provide a case study of a moment in time wherein multiple enthusiast publics and crisis professionals clashed. The result of this clash resulted in re-defining, or forcing enthusiast group categories to form. By highlighting the shape of that clash through the lens of crisis and Reddit, we also highlight the rigid nature of professional crisis responders and how they may eventually need to accept the capabilities of the crowd more officially. How the rigidity of crisis response professionals influences the entanglement of enthusiasts is deserving of further inquiry.

Also of interest is something that occurred noticeably, but inconsistently throughout our two case studies. Periodically, Redditors mention crisis response professionals giving information to Redditors directly, though anonymously. These crisis response professionals who use back channels to communicate with Redditors allows Reddit to gather certain kinds of on-the-ground information at speeds that may be faster than professional news media. The existence of individuals who are members of public groups like Reddit and crisis response professionals is deserving of further inquiry.

Each electronic improvement can unintentionally create new exploitative opportunities. Shortly before and continuing through the election of Donald Trump, aggressive campaigns that seek to control information flow have become more regular. During the Orlando nightclub shooting response of 2016, the tech-savvy and exploitative subreddit r/the_donald stepped in to aggregate the information online about the attacks. This group deleted mention of the victims and ways to help. Other Redditors tried to sabotage the Live Thread itself. This took the form of deleting any mention of the shooter being referred to as a radical Muslim (Koebler, 2016). The confrontation is the latest attempt to game the system Reddit uses to control the appearance of politically-motivated threads in more public areas of Reddit (Leavitt, 2016; Mills, 2018). Reddit has begun to change their software again to stop these types of attacks in the future.

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Managing inter-organizational breaks in a context of cross-border crisis

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ABSTRACT

Dysfunctions in interactions can impede communication between crisis responders. The literature in crisis management partially addresses this practical issue by outlining several types of "breaks" (Milburn, 1983). Breaks refer to social disruptions between organizations involved in crisis response that result in erosion of social links, conflicts amplifications and unstructured responsibilities allocation. However, research falls short of details about specification of these social breaks and how to address them, thereby leaving practitioners who need to handle this issue without clear practical guidelines. We draw on the concept of authority to help dealing with the occurrence of these breaks. The empirical analysis of this article focuses on a cross-border region between France and Germany, that is very likely to encounter inter-organizational breaks. This research in progress will contribute to understand the influence of authority on inter-organizational breaks and crisis response. We discuss the expected contribution of this research.

Keywords

AUTHORITY; INTER-ORGANISATIONAL BREAKS; SOCIAL INTERACTIONS; STRUCTURE OF COMMAND; RESILIENCE

INTRODUCTION

Disasters and accidents are part of the many events that can generate societal and organizational crises. Pauchant and Mitroff (1990), for instance, have emphasized that any crisis can " *threaten the core of its social identity*" and tear down a social system, both in terms of group, organization or society. In the latest years, both international organizations and scholars have embraced the concept of resilience as a valuable lens to deal with growing worldwide issues. From the Latin words "re" and "salire" which respectively mean "backward movement" and "jump", the term resilience would thus correspond to the ability to get out of a crisis, to break free of its effects and to begin to recover after the shock (Tisseron, 2007).

In the meantime, the literature has highlighted that resilience is not that simple, in particular due to multiple interdependencies between systems involved in or impacted by crisis (Boin, Van eaten, 2013). Not only organizations have to develop quick collaborative ties in response, but they also have to share or mutualize their resources (Kapucu et al. 2010). They might also have developed competing prerogatives, institutional beliefs and rigidities over time that aggravate the likelihood of inter-organizational collapse (Turner 1976). In addition large-scale events can involve hundreds, if not thousands of organizations (Butts et al. 2012), which implies on overall complexity generated by large amounts and diversity of interdependencies.

Inter-organizational interdependencies, in addition to strong unpredictability of incident response, account for inter-organizational breaks, that refer to social disruptions and interactions failures between multiple organizations facing an unexpected event (Boin, T'hart,2010; Moynihan, 2009; Ansell, Boin, Keller, 2010). They can take several forms, coming from the sudden erosion of social links to conflicts' brutal amplifications between responders. Despite extensive documentation on the nature of inter-organizational breaks, knowledge regarding how organizational and social systems manage such disruption and possibly lever resources to address them remains under developed.

In line with this view, this research seeks to address the following question: "What are the organizational, social and legal levers to avoid inter- organizational breaks in crisis response?"

We suggest in this article authority as a valuable lens to investigate how uncertainty, pressure and complexity can generate inter-organizational breaks that impede information transmission and coordination yet essential in order to formulate a structured and effective response to the crisis. Authority in our context can be defined as an institutionalization of power. It "implies an acceptance of the need to comply with a set of commands or rules" (Koppell, 2008). Our assumption is that all the inter-organizational breaks developed in this article are linked to the absence of a clear "problem owner" (Boin, Rhinard, Ekengren, 2014) that can 1) lead to a lack of organizational empowerment in the realization of some tasks which, at the end, remain undone or 2) lead to conflicts between several authorities that consider themselves as more competent to deal with the crisis. As a consequence, Boin, Keller and Ansell (2010) compare crisis management to a "hot potatoes" by suggesting a constant movement of authorities during the process.

INTER-ORGANIZATIONAL BREAKS IN CRISIS RESPONSE

Considering the concept of inter-organizational breaks has been the result of a literature review which emphasized that 1) during a crisis, actors involved in crisis response are often belonging to a network of distinguished organizations (Boin, T'Hart; 2010) and that 2) the reason too often exposed to understand a bad crisis management lies in inter-governmental and inter organizational failures (Kapucu, Arslan, Collins, 2010). On a practical perspective, the report named " The Federal Response to Hurricane Katrina : Lessons Learned » (2006) also emphasized the importance of social interactions by presenting several recommendations that highlight how a lack of coordination between inter-organizational actors can explain the ineffectiveness of a crisis response. In this sense, difficulties during a phase of response to a crisis appear to be essentially social and have to be considered on an inter-organizational dimension.

These relational breaks occur during crisis defined by Deliaune (2015) as the result of the combination between two processes : a process of vulnerabilities that occur in the organizational environment and secondly by managerial unawareness of actors who lack competences. This definition suggests two things. First of all, crises occur in a context of high vulnerabilities made of uncertainty, improvisation and complexity that disturb traditional organizational systems (Shrivastava, 1988). Second, this suggests that organizational responses often seem to be inappropriate or uncoordinated and actors cannot necessarily agree on the way of facing a disastrous situation causing then inter-organizational breaks.

Inter-organizational breaks as social system collapse

Inter-organizational breaks mainly suggest that inter-organizational interactions happen in a climate of conflicts and lack of confidence among crisis responders. According to different authors, organizational breaks are thus a social issue that emphasize difficulties to consider relations between actors who have to work together often for the first time and in a stressful environment (Boin, t'Hart ;2010). Because crisis implies to urgently deal with a temporary and new organization of work among unknown actors who have to coordinate their actions, Moynihan (2009) suggest that the social cohesion in a crisis situation is particularly hard to achieve, each actor staying more loyal to its own organization.

On a theoretical background, the non-adaptive group behavior theory from Mintz (1951) first highlighted the notion of breaks: in a situation of high uncertainty with strong pressure on resources, a group is more willing to act independently in order to satisfy its own needs, mainly because the success for collective action cannot be taken for granted. By taking the example of a fire in a theater where emergency services were unavailable, Mintz suggests that, beyond psychological factors such a panic or stress that slow down the evacuation, high uncertainty was at the root of the group's cohesion collapse and compelled its members to act independently. This collapse in the group cohesion can be suggest in a context of crisis as inter-organizational breaks.

In particular, breaks in inter-organizational relations take several forms: i) a resistance to respond, ii) an erosion of social links and iii) inadequacies in responsibilities' allocations.

Resistance or incapacity to respond

First of all, obstacles to good inter-organizational relations can be materialized by a resistance to respond, often in the first phase of response to the crisis. These resistance forms threaten the social system by creating tensions between several actors. For example, because of the pressure, some actors who are overloaded can eventually spread their anxiety on others and on media making the adequate response less possible to achieve

(Lagadec,2002). The spread of anxiety and actors demotivation can then become collectively generalized. This resistance takes several forms: from an avoidance strategy (Forgues,1993) to actors' paralysis that lead them to adopt a withdrawal behavior for different reasons (focus on personal and family safety, over-solicitation of some actors, pressure and anxiety leading to burnout) (Quarantelli,1988). On an organizational level, this withdrawal behaviors are problematic because it emphasizes an incapacity or an unwillingness to occupy some strategic functions leaving a gap in tasks that are however essential in order to formulate a coordinate response to the crisis. This is the idea of strategic evasion (T'Hart and al, 1993).

Conflicts amplification and erosion of social links between actors

Breaks in inter-organizational relations can also be seen primarily by conflicts amplification, especially those which existed before the beginning of the crisis (Hermann, 1963). In this particular case, this supposes that responders know each other anteriorly to the crisis which is rarely the case (Ansell, Boin, Keller; 2010). In fact, literature has shown that in this second situation, a lack of cohesion among the network of responders emerge, especially in the case of external crisis. As a fact, groups within the same organization can show more solidarity, trust and mutual support in opposition to other groups in different organizations (Dunbar, Goldberg, 1978; Milburn,1983, Boin, T'hart; 2010). For instance, after a natural disaster, actors working in the health sector but also firemen and policemen can be required to help victims. According to this approach, inter-organizational relations between firemen and medical staff for example will be defined by suspicion whereas actors within the same structure will act as one and cooperate easily.

In this perspective, interactions between responders occur in a context of suspicion, conflicts of interest and dynamics of power that have to be considered. This erosion of social links during the crisis (Deliaune,2015) emphasized that crisis do not necessarily make organizations work for a commune cause in order to formulate a response to the crisis but it rather appears as a "battle of good Samaritans" (Boin, T'Hart; 2010) that threaten the quality of the response.

Inadequacies in responsibilities allocation and structure of command vulnerability

The issue addressed here is that during crisis, traditional responsibilities no longer match the needs generated by the disaster. For example, in the case of cross-border crisis, conflicts can occur among established organizations who are used to deal with crisis management and "emergent" groups (e.g volunteers) or organizations who would like to help on traditional tasks assigned so far to experts' actors. This is considered by some established actors as an "identity usurpation" (Quarantelli , 1988) and thus contribute to weaken social relations. This suggest that there is then a need for organizational adaptation in a situation where roles and responsibilities have to be renewed between different stakeholders (Leifer, Huber, 1977)

Also beyond traditional tasks that new actors want to contribute to, there is also bigger flexibility in tasks management during crisis. This causes disagreements around new tasks generated by the crisis and which were not anticipated and inevitably not accomplished by any defined group at the beginning. In this extreme situation, some actors can consider that formal rules for example cannot be efficient and have to be violated (Faraj, Xiao; 2006).

The issue here is that the tasks distribution and responsibilities allocation become very changing during the crisis. This unclear command structure which constantly evolves depending on political conflicts between stakeholders need thus to be clarified in order to answer very basic questions: who is in charge and who is responsible?

Inter-organizational breaks consequences on information

Inter-organizational breaks are important to consider because they have operational consequences on information. In crisis management, several studies show that information management is a strategic dimension however particularly complex to consider (Scanlon,1982). Generating urgent needs (population displacement, emergency care) when resources tend to be scarce make indeed the transmission of information in real time a prior necessity. In a context of crisis, breaks are then materialized by information and communication flows challenges on three dimensions. The first issue is related to HOW information is communicated. In a conflictual environment, information flows can often be fuzzy and un-optimized (delay in the transmission, information overload) (Lagadec,2002). The challenge is also on WHAT is communicated. Inter-organizational breaks emphasizes issues related to a lack of cohesion and conflicts amplification which can be materialized by rumors and false transmission of information(Ansell, Boin, Keller,2010). Finally, the third challenge on information is linked to the actors who communicated (WHO). In most crisis situations, actors face partial, biased information flows or have to deal with information retention that impede coordination (Deliaune, 2015).

Heterogeneity and complexity as a context of inter-organizational breaks emergence

Inter-organizational breaks are embedded in a context of crisis made of high uncertainty concerning the access to resources and complexity as well as heterogeneity of actors involved in crisis management. Because of complexity, responders cannot cope with the needs and problems they are facing (Fink, Beak, Taddeo;1971) making breaks in these situations inevitable. In fact, actors have their own way of responding to this complex environment without necessarily harmonizing actions between heterogeneous responders.

Heterogeneity generates tensions in inter-organizational collaboration. At an inter-organizational level, divergences between the responders' objectives and contributions can generate breaks (Quanrantelli,1988). In a crisis, responders come from diverse cultural and professional backgrounds, they also have different vocabulary and do not necessarily share the same comprehension of the command structure. This can thus weaken ties eventually by causing inter-organizational tensions and political conflicts between stakeholders. Cross-border context also occurs as a source of additional heterogeneity by mobilizing several cultures and work practices. First of all crisis response necessitates interventions of organizations which work in different fields (healthcare, firefighters, police, …). Also, there is a different type of organizations that are involved in the crisis response. We then distinguish emergent organizations(group of volunteers or non-professional NGO) versus established organizations which are used to deal with crisis situations. Finally, there is a global need for taking into account the cross-border context and the own institutional and cultural environment of each country.

Complexity can also exacerbate tensions between responders that can result into breaks. As crisis are hardly predictable, responders have to redefine some of their objectives, their goals on short but also on long term and reconsider resource allocation, which can conduct people to lose abandon procedures that routinely structure their actions (Roux Dufort, 2000).The major challenge will be for organizations to outline and redefine the sense that actors previously gave to their actions.

The disruption in sense-making within the organization can, in an extreme case, lead to an identity crisis and then aggravate the vicious circle of the crisis. By losing their common references, responders do not only question their modus operandi and their skills but also their values and social attachment to the organization (Milburn, 1983). These dimensions are exacerbated in our case in a cross-border crisis where the response is even harder to consider because actors do not share the same cultural context (Maury,Richard,2011).

AUTHORITY : A VALUABLE LENS TO INVESTIGATE INTER-ORGANISATIONAL BREAKS

Uncertainty, complexity and heterogeneity inherent to a critical situation can result into breaks and a social collapse within a response system. Despite resilience being an appealing concept to reflect about emergence, it fails to outline the circumstances and factors for breaks. We suggest that the concept of authority, as formalized in the field of organization science, can then offer a new perspective to address this need in the field of crisis management.

Authority in critical situations as a valuable lens to consider inter-organizational breaks

We pose in this research that consideration of authority provides new avenues for investigation of inter-organizational breaks. First of all, the resistance of some responders reflect their unwillingness (or incapacity) to deal with the current situation and then manifest their non-responsibility to the execution of some tasks. No one seem to feel responsible nor in charge of the tasks which remain at the end undone. The risk of this undefined structure of command and an unclear acceptance of who have the authority has been theorized with the concept of strategic evasion. This concept developed by 'T Hart, Rosenthal, Kouzmin (1993) show that actors behaviors and personal interests lead to a situation where actors considered not to be responsible of the current situation and that managing the crisis is the duty of others[1]. Secondly, the erosion of social links are mainly caused by a lack of cohesion between actors with different protocol of intervention, interests and dynamic of power. Contrary to the first point where neither authority can be defined, this lack of cohesion is explain by a duality of several authorities that intent to impose their authority on the others. Police for example will consider that evacuating a dangerous zone after a disaster should be the first step while professional in the health sector will consider that helping victims is the priority. In this case, the problem is not that no one feels responsible but rather that too many people consider themselves as being responsible and in charge of the tasks. This point is

[1] T'Hart P. ; Rosenthal U. ; Kouzmin A. 1993. Crisis decision making : the Centralization Thesis Revisited. Administration & Society, 25 No. 1, 12-45.

particularly exacerbated in a cross border context where differences in jurisdictions and political authorities appears (Boin et al, 2010). Finally, the vulnerability in the structure of command suggests that because of the urgent needs, flexibility is considered as being essential for some traditional or new actors who will then ignore some formal orders (Trouselle,2014).

In a sense, reading inter-organizational breaks through the perspective of authority conflicts and consider how they can be avoided can thus be a way to structure and coordinate a response to the crisis. In fact, in the field of management, what we know in the literature about authority and its application to organizations is that it can provide from three sources: formal, psychological and pragmatic (Simon, 1981; Koppell,2008). First of all, formal authority refers to legal authority (laws, organizations charter). This is the most unambiguous type of authority because it allows an objective traceability of rules (Simon, 1981). This kind of authority is not linked to the concept of legitimacy : in reality a leader for example can have authority without being considered by the community as having "the right to rule" (Koppell, 2006) . Second, the psychological authority is based on confidence of actors towards the one who has authority. This can be the result of a good expertise or a superior status that confer legitimacy to this actor. Legitimacy is then a "perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs and definitions" (Suchman, 1995). Finally, pragmatic authority is driven by self-interest and not on a moral basis (Koppell,2008).

If we apply the concept of authority to the field of crisis management it remains obvious that Quarantelli (1988) was among the only researchers that mention the exercise of authority and the command structure that occur during a crisis. So far, much uncertainty still exists about how to deal with interactions issues and the allocation of responsibilities in a context of crisis where numerous and heterogeneous actors are involved in the formulation of a response.

METHODOLOGY

As this work aims to thoroughly investigate multiple aspects of inter-organizational breaks, the most adequate design of inquiry in this work is qualitative. Our rationale is double. First, we intend to identify the conditions of emergence of inter-organizational breaks during crisis response. To do so, we need to explore a large spectrum of contextual features likely to account for inter-organizational breaks, in particular all the contextual features that contribute to complexity and heterogeneity within crisis response such as professional, regional and national culture, political and social settings, etc. A qualitative design supports the discovery of potential variables that were not reported in the literature yet. Second, we plan to examine in which manner they impact crisis response and how crisis responders address them. A qualitative design, inspired from a processual perspective (Langley, 2011) allows the analysis of such dynamics.

This empirical case under study will be part of a wider research project entitled INCA that will be completed by a French-German academic and professional consortium. INCA aims at the development of a decision support framework to improve cross border area resilience to disasters. Started in Spring 2017, this work will take into account several challenges such as organizational complexity, management of multi-cultural dimensions, volunteers integration and organizational interactions. This work will help achieve INCA's objectives, e.g. elaborate a multi agent model on cross-border coordination during the phase of response to a disaster.

Empirical examination of a cross-border region is particularly relevant to further understand inter-organizational breaks, to what extent they occur, their impact on crisis response and how they are addressed because inter-organizational breaks are very likely to occur in cross- border regions due to the important levels of complexity and heterogeneity that characterize cross-border regions.

Our research design is also relevant to study inter-organizational breaks in that we will focus our data collection on surprising behaviors and the surge of emergent organizations on the stage of the crisis (e.g volunteers). Organizational emergence is very likely to occur because of strong unpredictability of cross-border areas. Connections between France and Germany are indeed numerous nowadays and are the results of major conflicts which occurred over the past centuries. It is also a borderland particularly vulnerable to natural disasters such as earthquakes or industrial accidents due to the presence of chemical wastage.

This is also suggest by the involvement of many actors with different natures (public authorities as well as private organizations) or different expertise due to diversity in equipment between organizations or differences in organizational autonomy and diverse expertise to deal with the crisis (Boersma & Engelman, 2012; Adrot, Fiedrich, F., Lotter and al; 2018). This then address the question of heterogeneity of responders.

The example of a cross border disaster between France and Germany can emphasize this dimension and illustrate inter-organizational breaks. Responders' behaviors and mechanisms to answer the crisis are in fact not the same from each side of the border. This multi-cultural context allows us to highlight different crisis

management systems, and different social practices and procedures for example in the way France and Germany take into account civil protection. These countries have also different languages that can make the knowledge and information flows more complicated to achieve between organizations. Finally, on a national level, administrative and institutional barriers in France or in Germany can threaten the ability of responders to formulate a global response to a disaster occurring in a cross-border area. As a consequence, cross border authorities and command structure are sensitively different. This remains problematic because if authorities and organizations involved in the response do not take into account these differences, crisis response remains too vulnerable. Investigations have then to be done on this project in order to reach a mutual understanding and a strong collaboration to formulate a coordinate response to the crisis.

Based on a cross-border blackout scenario, our analysis seeks to understand how organizations involved in a blackout behave and to what extent achieve inter-organizational resilience. This scenario is being constructed by INCA team and targets several participants with different authorities levels and who contribute differently to crisis management (in their everyday activities or in a punctual way). This includes professional of health sectors, policeman or professional NGOS as well as unprofessional groups or organizations such as volunteers which are necessary to optimize a crisis response.

This scenario will be completed by several interviews with this same actors coming from different sectors (health sector, civil society, NGOs), with different expertise (professional actors versus volunteers) and with different cultures (French and German side). These methodology will also include a work on secondary data (such as reports on historical examples of organizational cooperation between the two countries) in order to understand potential inter-organizational breaks and the way authority conflicts are coming from.

We will also lead a second case by investigating another type of crisis linked to the fire of the Mont Blanc tunnel which occurs in 1999 at the border of France and Italy. Data collect will mainly remain on archives (radio records, press release, official reports from both Italian and French sides) and will be, if possible, completed by interviews with actors who was in charge of the tunnel management at this time.

EXPECTED CONTRIBUTIONS

At this time, our work remains at its very beginning and we are still refining its design in order to address the theoretical gap that we identified. There is no doubt that crisis response is fragile. Due to the complexity and heterogeneity of the set of crisis responders, actions initiated to address a crisis response remain completed on the edge of the razor. The whole response can easily collapse due to organizational breaks and the loss of social cohesion among actors (Milburn,1983). Despite the dramatic material, social and political costs associated to inter-organizational breaks, some uncertainties still remain regarding their management. In particular, the literature suggests that power and leadership are important to prevent inter-organizational breaks but does not specify the organizational levers nor the practices that can practically contribute to alleviate or reduce the risks of inter-organizational breaks. We hope that this work will contribute to address these uncertainties.

To do so, we first want to contribute to inter-organizational breaks and the different forms they take during a crisis. Also, to answer to these failures, we propose in this article the concept of authority as a valuable lens to address the research question of this work and its application to unanticipated situations. In fact, much of the searches up to now have been descriptive in nature of authority without taking into account the particular context of crisis. In crisis management, Quarantelli (1988) addressed the stakes of authority exercise during crisis but our knowledge on this specific topic remain scarce, while desperately needed : authority embodies differently and conflicts appears to be more severe in critical than in common situations. In fact, in a common organizational situation (for example doing unwanted tasks asked by a given authority) people are able to accept to conform to the situation because the cost of obedience is very low. This means that their actions may have no consequences on the organizational reputation for example or won't cause ethical tensions. This can be different in a context of crisis where there are important stakes (helping victims, avoid death,..). Actors in charge of formulating a response to a situation where people lives are threaten, will then be less supportive to authorities they do not want to follow even if this authority is formally defined (Koppell,2008). This question the three forms of authorities defined earlier. First, if legal authority is defined by formal rules, the stake here is not whether laws or rules are traceable but rather to understand what can be done when this same rules are inapplicable because of the situation. This does not mean that rules or standards have to disappear but rather to be more flexible (Bigley, Roberts, 2001; Faraj, Xiao, 2006 ; Pichaut, Nizet; 2011). Also, few writers have carried out the concepts of psychological and pragmatic authority in relation to critical settings. When authority is not based on formal rules, psychological and pragmatic authority are in fact particularly important. But, because they are based on interpretations and subjectivity rather than formal rules, they can foster behaviors that generate conflicts within the command chain and endanger crisis response.

As a result, lack of knowledge on authority can become a serious issue. We thus seek to build practical

guidelines in this work to help build an appropriate structure of authority and command in order to avoid inter-organizational breaks. These examples in a context of cross border crisis seem to be very necessary to study because crisis response coordination much depends on crisis responders' behaviors. A lack of consideration of psychological and pragmatic authority can lead actors to misleading decisions and affect the civil society. This work thus plans to bring this contribution to practitioners and scholars.

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The IsITethical? Exchange Responsible Research and Innovation for Disaster Risk Management

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ABSTRACT

This paper describes the *IsITethical? Exchange*, a European knowledge and service hub we are developing with and for diverse parties involved in crisis and disaster risk management. Their commitment to European values and fundamental rights underpins the rationale of the initiative, which is to support European societies' need for high quality innovation to balance the benefits of IT with fundamental human rights and values, especially privacy and data protection. The initiative is led by researchers at Lancaster University and builds on many years of collaborative design research with a wide range of international practitioners, academics, and commercial IT designers.

Keywords

IT-Ethics; ethical, legal, and social issues (ELSI); disaster risk management, service design, human rights

INTRODUCTION

Societies worldwide are at a crossroads. To realise the potential of Information and Communication Technologies (IT) effectively and responsibly, we must design, use, and govern IT research and innovation with more respect for human rights. Otherwise, human values that are central to human flourishing will be hollowed out, and disenchantment with IT will spread (Wu 2016). In the European Union, fundamental rights regarding the protection of personal data, non-discrimination, and the presumption of innocence underpin values of dignity, freedom, democracy, equality, the rule of law and respect for human rights. People's abilities to enact these rights and values are recognised as critical for peace and justice in Europe and beyond.

Within the European Union, a strong commitment to these rights and values defines policy. European citizens are, for example, 'reassured by developments such as the 'Safe Harbour' decision of the European Court of Justice, [and] the EU is becoming a magnet for digital rights activists and initiatives in search of legal and political openings for challenging uncontrollable mass surveillance and vindicating human rights in cyberspace' (Kaldor, 2016). There is a move towards recognising respect for fundamental rights in IT research and innovation as a key component of high quality innovation and 'human security' policies, which combine a global perspective and a focus on 'prevention, early warning, crisis response and reconstruction as intertwined' (Kaldor 2016). For example, the *Comprehensive Assessment of EU Security Policy* (EC, 2017b), explicitly expresses the European Union's commitment to fundamental rights. Yet, it is extremely difficult to translate such commitments into action, because current forms of IT design, use, and governance do not adequately support people's abilities and practices of enacting or safeguarding fundamental rights and values.

The *IsITethical? Exchange* takes action to support these abilities and practices. It is an initiative led by an interdisciplinary group of scholars at Lancaster University in collaboration with a growing group of international researchers, practitioners, and technology developers, and the Public Safety Communications Europe Network, a community of practitioners, researchers and commercial developers of IT. This alliance builds on completed and ongoing research, including research undertaken in a range of EU projects (please see www.isITethical.eu and Acknowledgements for details). The *IsITEthical? Exchange* combines an online community knowledge exchange platform with a table-top exercise in the form of a board game, services for Responsible Research and Innovation (RRI), and Continued Professional Development.

In this paper, we discuss the background to this initiative, explain the focus on crisis and disaster risk management, and briefly describe the *IsITethical? Exchange* components. We conclude with a discussion of the socio-economic value and future direction of this research, and a brief summary.

BACKGROUND

Increasing numbers of people live in e-societies where 'more information is gathered, collected, sorted and stored about the everyday activities of more people in the world than at any other time in human history' (Andrejevic, 2012: 91). This cuts across a range of different sectors (Figure 1).

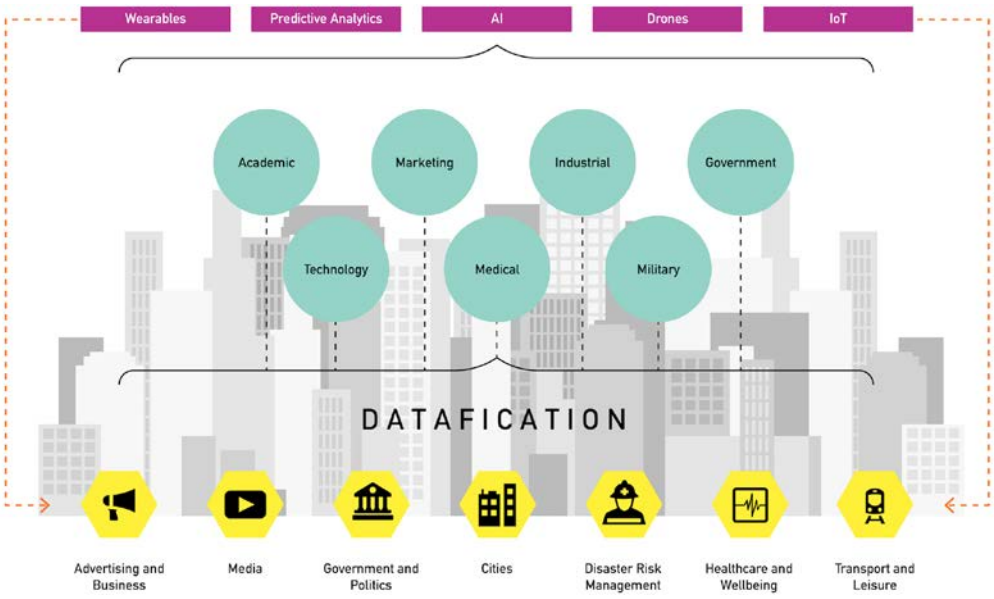

Figure 1 Motivation for building the *IsITethical? Exchange*

To leverage the positive potential of this 'datafication' (Van Dijck, 2014) for comfort, health, jobs and growth, and security, it often seems inevitable that 'trade-offs' against fundamental values, rights and freedoms are made. As datafication cuts across different sectors of society (from advertising to transport and leisure), technologies (from wearables to social media), and arenas of research and innovation (from academia to medical, policy and social innovation), the effects of trade-offs can cascade and magnify.

For example, data produced as a by-product of everyday life could be life-saving in a disaster situation. The city of Amsterdam has been experimenting with techniques to track people's mobile phones within the impact area of a chemical accident (Steenbruggen et al. 2013), and there are now many such contextual sensing and 'Internet of Things' innovations to better detect crises, to dynamically target warnings to mobile populations, and enable faster and more effective evacuation (Dlodlo, 2016). However, such sharing of data in exceptional circumstances also raises complex ethical tensions.

Some examples drawn from the intersection of everyday consumption, political engagement, and security policy will explain key motivations for our *IsITethical? Exchange* concept:

Consumption: Experian's Mosaic synthesizes over '850 million pieces of information to create an easy to understand segmentation of the UK consumer market that allocates 49 million individuals … into 66 detailed Types' (www.experian.co.uk, Lanchester, 2017). Experian is one of Facebook's third-party data partners, enabling Facebook to incorporate offline activities in its analysis of its users' behaviour. Advertisers can thereby target consumers with ever greater precision and even secure 'trusted referrals', the holy grail of advertising (Taplin, 2017). Facebook's Safety Check App tracks its users (and their friends' and families') involvement in disasters, capturing information at a highly emotional and vulnerable time. No data protection regulations are being broken (cf CJEU, 2015), and yet, these activities challenge fundamental rights and values of informational self-determination, and 92% of Europeans are concerned about the use of personal information (Wood and Ball, 2013; 2016 Eurobarometer 443).

Politics: Knowledge production is political. Scientific and commercial research methods of the survey and interview assumed and co-produced the opinionated individual subject of democratic society. New digital capacities to map, track and interrogate people's everyday lives allow governments, the media, businesses, political parties, and the emergency agencies to mobilise forms of population knowledge that constitute a very different 'doing subject' (Ruppert et al, 2013). Knowing this 'doing subject' intimately brings great potential for personalised services, but also means that populism and manipulation can take hold. Political 'hyper targeting' of sections of the electorate can undermine democracy (Grayling, 2017), and established models of public protection. For example, *Cambridge Analytica*, a UK based company that 'uses data to change audience behaviour' has used Facebook 'Likes' for psychosocial profiling to influence elections in the US and Kenya, as well as the UK Brexit referendum (Bright, 2017). Disaster risk management is affected by such practices, because it depends on democratic mediation and public trust. Recent violent attacks against French emergency responders, and the withdrawal of support from humanitarian agencies following news about misconduct attest to the power of mediation, and sensationalist or simplistic media reporting can also fuel a culture of fear focused on terrorism that detracts attention from other dangers, such as extreme weather.

Security: A perceived increase in terrorist attacks underscores a focus on IT as a core part of counter-terrorism strategies, and this has engendered serious controversies. European citizens and civil society organisations are concerned about intelligence and law enforcement agencies, encryption, passenger name records (PNR) (FRA, 2017), and facial recognition in public spaces (Hill, 2017). While fundamental rights are a core concern in EU security policy (EC, 2017b), such concerns are difficult to translate into responsible innovation that respects these rights. In a recent meeting of the high-level expert group on information systems and interoperability for security, the European Data Protection Supervisor found, for example, that he was 'not in a position to endorse all the conclusions' reached by the group (EC, 2017a). He especially raised concerns about the intention to create a common (centralised) identity repository and to 'flag' individuals across different systems, due to 'serious issues in terms of data protection', and concerns about 'purpose limitation and access rights'; elaborating that 'the existence or lack of flag(s) constitutes as such personal data since it contains already some information about an identifiable person (e.g. the person is subject to an alert in the Schengen Information System' (EC 2017a:50) (Figure 2).

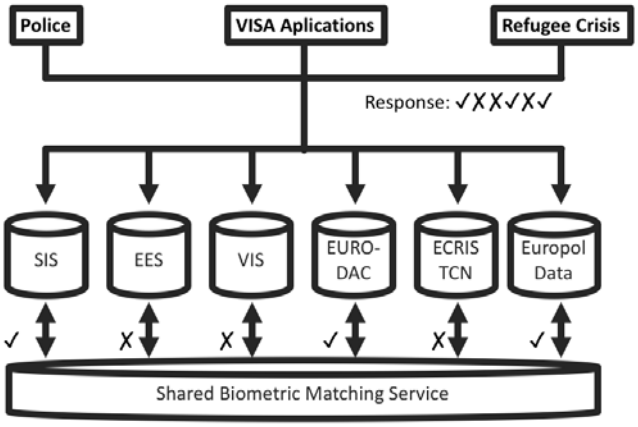

Figure 2 Shared biometric matching service with "hit flags" as discussed in EC 2017a: 31.

These debates highlight how difficult it is to translate respect for human rights into responsible innovation in interoperability and collaborative information management. Many other domains of society, including health, transport, work, and leisure intersect with disaster risk management in ways that exacerbate these challenges. The exceptional circumstances of emergency situations may require that exceptions are made, but they also demand exceptional care lest such exceptions damage important fundamental rights and principles. Crisis and disaster risk management is a domain where ethical tensions arise in particularly significant ways. Most prominent issues are inadequacies of IT design, use, and governance in relation to purpose-binding, informed consent, profiling, surveillance, interoperabilities, and common data repositories. Data breaches and cyber security also pose critical problems, especially around mission critical communications and critical infrastructure.

The *IsITethical? Exchange* addresses these issues, including one of the most significant governance issues: the disparate nature of the legal bases of different information systems. Established EU systems, such as the Prüm System for automated exchange of DNA profiles, fingerprint data or vehicle registration data or new systems such as the European Travel Information and Authorisation System (ETIAS) have been emerging over decades under different institutional contexts, for different (and originally clearly defined) purposes, and there are different legal instruments that regulate the processing of data in relation to each information system, which might impose divergent requirements, notably for the further processing of data. This means that sometimes it is much easier to make something 'technically interoperable' than 'legally compatible' (EGE 2014). Yet, while the diversity of legal bases brings some potentially inconvenient uncertainties, it also creates useful safeguards, as divergences and incompatibilities might be in place for good reasons. Similarly, it is easier to make things technically interoperable than organisationally and culturally shared.

IT research methodologies and innovation also engender new epistemologies that move away from a focus on causation, towards relying on data analytics that highlight patterns (Kitchin, 2014). They are assumed to have the ability to yield new forms of knowledge – embedded in the notion that data is objective and anonymous, and that the more data you collect, the closer you get to the truth. This 'dataism' (Van Dijck, 2014) can not only be difficult to understand and thus make the bases for decisions opaque, it can also introduce machinic forms of reasoning into human affairs in ways that are difficult to align with human rights and values.

In the context of these tensions, ideas of trade-off are coming under attack. Alternatives, such as 'positive sum' approaches (Cavoukian 2013) embed fundamental rights 'in' the technology, for example through 'privacy by design'. Ideas of data stewardship are more alert to the socio-technical, transformative nature of ICT research and innovation. They demand that gains must be balanced transparently against losses and risks, based on a deep and broad-based understanding of what is at stake (EGE, 2014:80, British Academy and Royal Society, 2017). Coupled with ongoing risk analysis (Wright, 2011) and careful regulation that re-locates responsibility for data protection mechanisms, these are promising, but difficult to realise responses.

The *IsITethical? Exchange* approach starts from the premise that attention to ELSI is not a constraint on IT innovation, but, on the contrary, the key to creating high quality IT for human flourishing. The initiative asks how more ethically, legally, and socially circumspect and flexible IT research and innovation can be achieved with a view to the 'big picture', and with detailed attention to abilities and practices of balancing the benefits, losses, and risks of IT research and innovation in crisis and disaster risk management.

IT IN CRISES: BROADBAND, NET-CENTRIC NEW PARTNERSHIPS

Crisis and disaster risk management relies on IT, including personal data routinely processed as part of everyday life with mobile digital technologies in 'smart' cities. There are fears of a data deluge and significant investment in IT is underway (Ferrãos and Sallent, 2015; Lund, 2015). In the UK, for example, a £1.2bn budget is allocated for the transition of public safety communication technology to broadband. This is heavily criticised by the UK National Audit Office (2016) due to the lack of maturity of the technology and the risks associated with acceptance of the technology. Many European countries are embarking on a similar transition path. France aims at developing new communication capabilities to safeguard the public during the 2024 Paris Olympic games, and across Europe, there will be total investments in new broadband communication capabilities for public safety likely exceeding €100's billion. In the US, the recently formed First Responder Network Authority FirstNet has a budget of 7bn $ to develop a nation-wide broadband network over 25 years.

Broadband data promises richer awareness of risks, predictive analysis, more agile response capacity for emergency agencies and communities affected by disasters, better coordination in multi-agency operations, new ways to create a common operational picture and share data, more targeted warnings and broader and richer communications with the public. As the complexity and intensity of risks increase in a '21st Century of disasters' (eSCience, 2012) and budgets tighten, IT can bring much needed new efficiencies and efficacies.

But innovation in this domain is transformative. Disaster risk management models are changing from 'authoritative' and publicly funded command and control to 'datafied', and net-centric approaches (Boersma, 2011). This involves increased monitoring and surveillance of people, assets, and environments, as well as increased public scrutiny of emergency agencies, including 'as it happens' commentaries on response operations live on social media. It enables a focus on prevention, as well as dangers of profiling and social sorting; it gives rise to community risk assessment, crisis mapping, self-organised crisis response, and digital humanitarianism, sometimes coming into conflict with formal agencies. New forms of researching disasters are becoming possible, especially with citizen science (Plantin 2011) and social media data (Palen, et al 2010). At the same time, new public-private partnerships, and new collaborations between formal emergency agencies, volunteers and civil society organisations become possible. These forms of social, organisational, and scientific innovation are disruptive, transforming established responsibilities and accountabilities, including responsibilities for data. Complex ethical tensions arise very concretely and urgently at these junctures between IT research, innovation and fundamental human rights.

In the past, billions of Euros and innumerable hours of work have been 'sunk' into failed IT projects in crisis and disaster risk management across the European member states. Examples include the half a billion-pound failure of the UK Firecontrol project (Committee of Public Accounts, 2011; Yeo, 2002). Research ethics and integrity issues arise, such as in the contest around interviewee confidentiality in a Boston College study of IRA terrorism (Palys and Lowman, 2012), undermining trust in, and influence of, research.

METHODOLOGY

IsITethical? takes a design-led service co-creation approach (Büscher et al 2004, Sanders and Stappers 2008) that draws on methodologies from the newly emerging field of social futures research (Urry 2016). This means that we use creative methods, such as value scenarios (Nathan et al et al 2007) and play (Lujan Escalante and Büscher forthcoming, Figure 6) to collect, assess, and validate rich descriptions of ethical tensions. Methods of controversy mapping and public experimentation (Felt et al 2007, Marres 2009) are part of knowledge exchange workshops, as are methods of 'infrastructuring' for debate and contestation of diverse interests (Le Dantec and Di Salvo 2013). These methods allow practitioners and diverse stakeholders to co-produce, and make concrete, knowledge about tensions and regulatory frameworks, articulate and share guidance, principles, innovative responses, protocols, and standards, as well as recommendations for improvements in regulatory frameworks. Methods from service design (Sangiorgi and Prendiville 2017) are used to co-create these resources within the *IsITethical? Exchange* for Responsible IT Research and Innovation in Crisis and Disaster Risk Management. These also include methods (e.g. Ethical Impact Assessment) and facilitation of value sensitive design, and research integrity protocol implementation. *IsITethical?* partner PSCE (Public Safety Communications Europe Network) facilitates a practitioner-led approach.

THE ISITETHICAL? EXCHANGE

At the heart of the *IsITethical? Exchange* is the fact that ethical, legal, and social issues are complex. As the European Group on Ethics in Science and New Technologies concludes in their assessment of privacy by design, 'embedding ethical reflectivity, … inside a technology … [risks] neutralization of all individuals' ethical potency' (EGE, 2014:80). In other words, 'simplification of issues and solutions, populism and disregard for

evidence in decision-making' are unacceptable (Juncker, cited in FRA 2017:157). The *IsITethical? Exchange* seeks to frame meaningful questions about ethical tensions, and to build evidence-based capacity for reflective practice in the design, use, and governance of IT research and innovation (Figure 3).

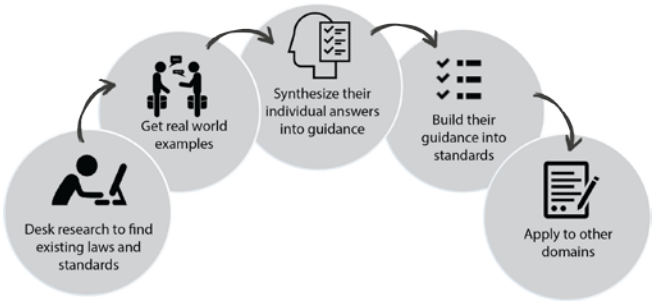

Figure 3 IsITethical? Building guidance for responsible IT research and innovation

The *IsITethical?* knowledge exchange platform curates knowledge about existing and emerging ethical tensions, regulatory frameworks, and responses in an open transnational knowledge base. Its digital and material components and services facilitate broad-based dialogue and make knowledge actionable through examples of innovative pro-active practice, technological design, and regulatory responses. We also contribute to processes of standardisation and are exploring avenues for certification for products and services that proactively develop awareness of, and creative response to, ethical, legal and social issues, without allowing those to become ossified (Balmer et al, 2016). The *IsITethical? Exchange* online community platform is available at www.isITethical.eu. It is a living resource, continuously developed in collaboration with its users. It is designed to underpin the development of a more broadly conceived Hub for responsible IT research and innovation.

There are currently over 40 guidance entries on issues such as 'Access and Fairness', 'Codes of Conduct', 'Data Quality', 'Exceptions and Lawful Processing', 'Goal Diversity', or 'Producing Meta-Data', gathered into five chapters (see Figure 4). Associated with the guidance are definitions of 'Key terms', which are cross linked with the guidance (yellow circles in Figure 5). In addition, we have developed novel methodologies to utilise this co-created guidance to enable creative ethical impact assessment as an iterative process alongside socio-technical innovation, improving the quality of technology and the practices they are meant to support. A mobile '*EtiKit*' helps to build awareness of ethical, legal, and social issues, and capacity to address them creatively and proactively, as a form of continued professional development. The *EtiKit* comprises an *IsITethical?* table-top exercise (Figure 6), techniques for working with the online knowledge exchange platform, and creative ethical impact assessment. *IsITethical?* team members can act as Responsible Research and Innovation Advocates to facilitate knowledge exchange, creative ethical and privacy impact assessment, value sensitive design.

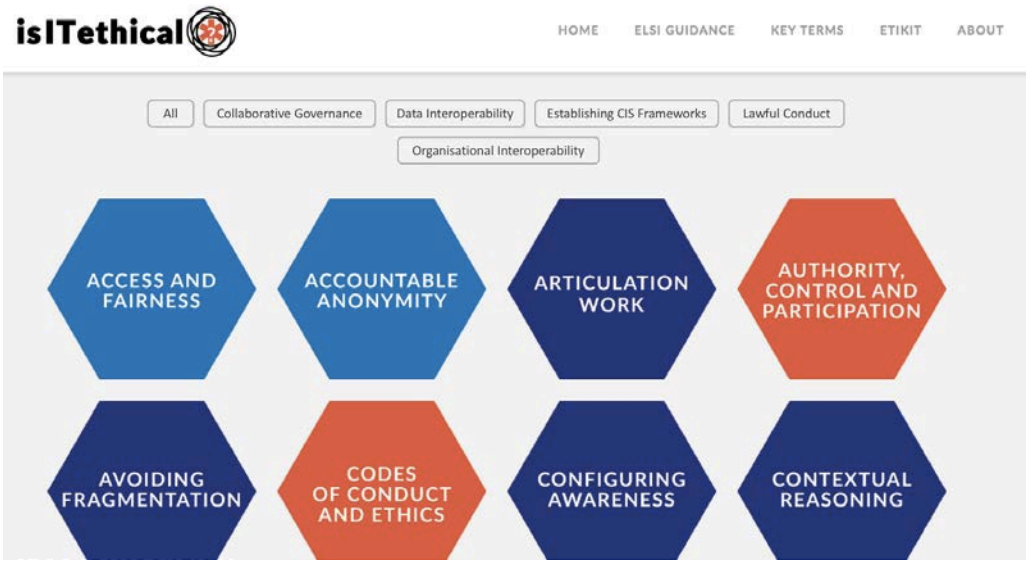

Figure 4 The isITethical? Guidance Overview Page

By inviting participants to discuss examples of how they have encountered and addressed ethical, legal, or social tensions in IT design or implementation, the *IsITethical? Exchange* brings together available knowledge and expertise to take stock of existing, emerging, and future ethical tensions, regulatory frameworks, and responses to develop approaches that place human flourishing at the centre of data governance for the 21st Century. It gathers rich descriptions of tensions and responses to them through real world examples, synthesizes them into guidance that is centred around reflexive questions An excerpt is shown in Figure 5.

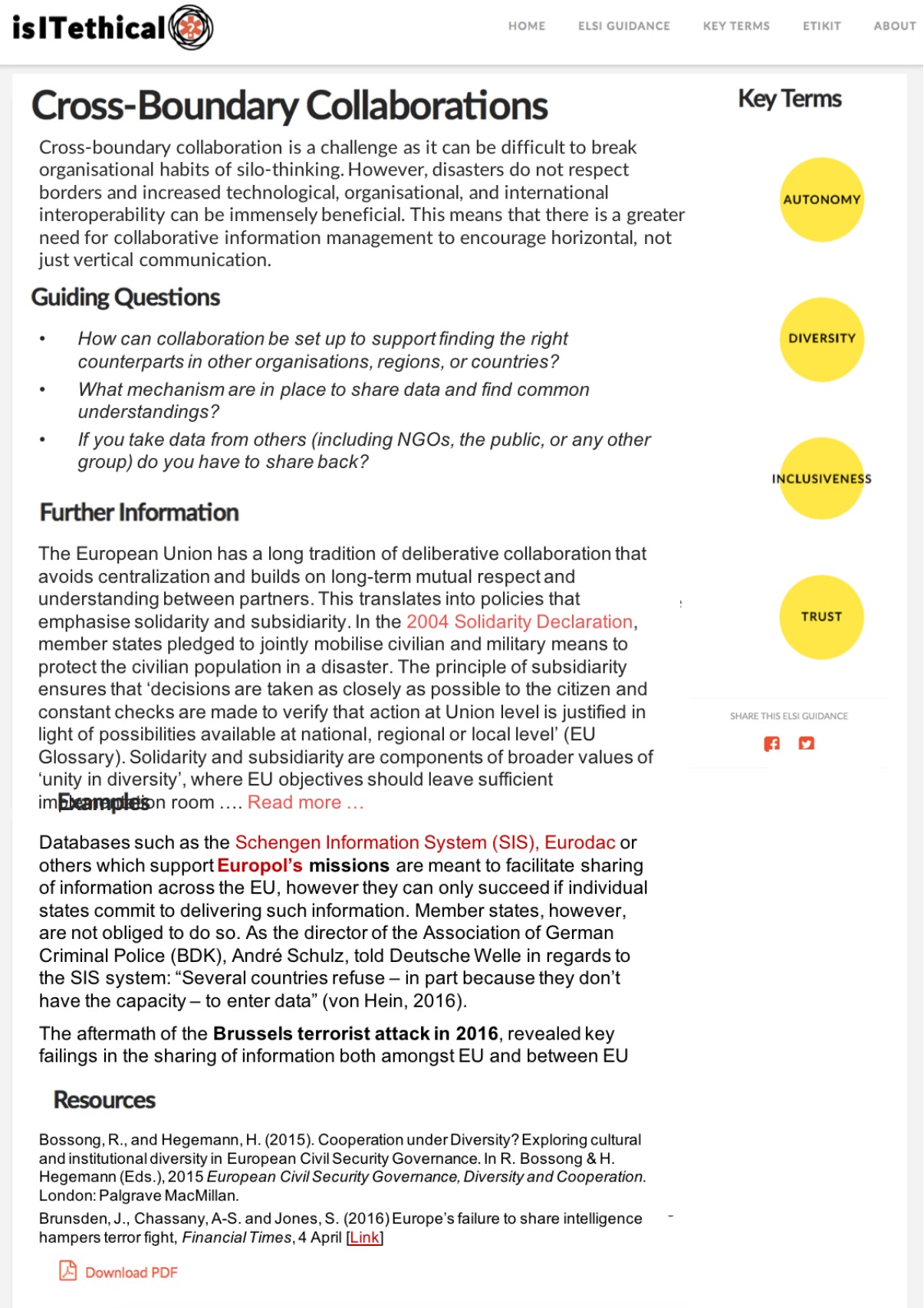

Figure 5 IsITethical? Guidance excerpt.

Building on the knowledge base and guidance on ethical tensions and regulatory frameworks, reflective questions prompt articulation of creative and innovative, proactive responses in IT design and use as well as protocols and standards for responsible research and innovation. The overall aim of the initiative is to build capacity for anticipating, noticing and addressing ethical tensions to facilitate high quality IT research and innovation that goes beyond box ticking and reflexively to pro-actively consider ELSI (Balmer et al, 2016). This is further developed through the *IsITethical? Tabletop Exercise*, which takes the form of a board game that creates opportunities for exchange of expertise and examples, and exploration of the guidance in a collaborative setting, allowing participants to 'step into the shoes' of different roles in disaster risk management (Lujan Escalante and Büscher, forthcoming, Figure 6).

Figure 6 The IsITethical? Table-top Exercise.

The *IsITethical? Exchange* currently focuses on collaborative information management, building on the work of EU projects BRIDGE, SecInCoRe, EPISECC, SECTOR, REDIRNET and ConCORDe, but the initiative builds a broader vision of an open European Hub for Responsible IT Research and Innovation for Crisis and Disaster Risk Management, where services are continuously developed around these resources (including consultancy and facilitation of ethical impact assessment). The initiative recognises the potential and need for engagement with other domains, such as transport, healthcare, e-government, and is developing a framework for this.

SOCIETAL AND SOCIO-ECONOMIC VALUE

Since 2007, 'approximately EUR 980 million have been invested in security research on issues such as CBRN protection (EUR 75 million), explosives (EUR 68 million), critical infrastructures protection (EUR 55 million), intelligence against terrorism (EUR 35 million), preparedness, prevention, mitigation and planning (EUR 150 million), recovery (EUR 17 million), energy, transport and communication grids (EUR 116 million)' (EC 2017b). IT research and innovation that effectively balances security and privacy clearly matters socially, politically, and economically. It is difficult, not just because the issues are complex and contextual.

Traditional modes of public safety communications research and development, and investment are in turmoil. Public safety has conventionally applied monolithic technologies, developed by major industry providers. The combination of specific requirements, limited volume of business and need for significant R&D effort created high entry barriers, and this created specific technological ecosystems operating outside mainstream telecommunication business. All this is changing with broadband, as mainstream standardization (3GPP) and technologies (mobile networks, Apps) are applied and mainstream device ecosystems begin to also address Public Safety (Ferrãos and Sallent 2015). Incorporating attention to balancing the potential of IT with human rights and values early and with awareness for how different sectors are connected can avoid costly failures or retro-fitting.

Moreover, the benefits of Responsible Research and Innovation can help secure maximum benefit of IT potential, address social concerns and achieve good 'alignment' with social values. Responsible research and innovation makes for high quality research and innovation, because it:

> ensures that research and innovation deliver on the promise of smart, inclusive and sustainable solutions to our societal challenges; it engages new perspectives, new innovators and new talent from across our diverse European society, allowing to identify solutions which would otherwise go

> unnoticed; it builds trust between citizens, and public and private institutions in supporting research and innovation; and it reassures society about embracing innovative products and services; it assesses the risks and the way these risks should be managed. (Rome Declaration on RRI, EC, 2014)

IsITethical? supports more transparent, accountable, and inclusive balancing of the benefits, losses and risks of IT research and innovation in relation to fundamental rights and values (Figure 7).

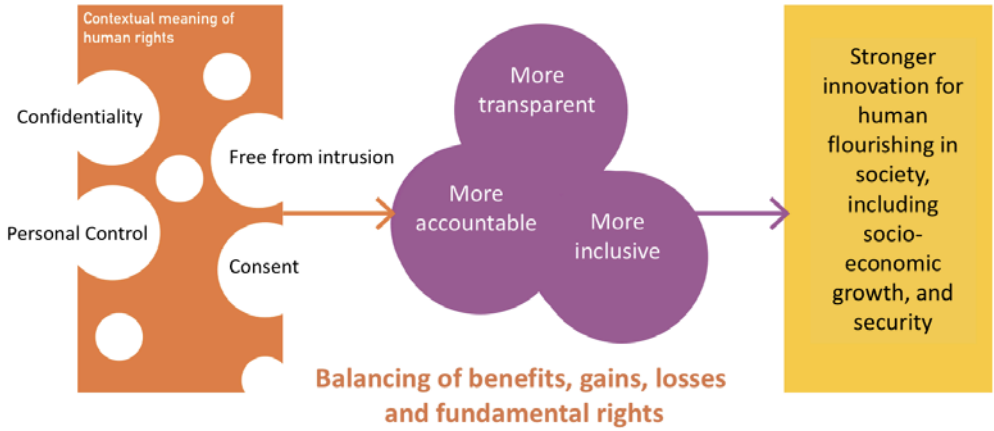

Figure 7 Value added through IsITethical?

It supports stronger, high quality research and innovation for human flourishing, including strong civil liberties, democracy, socio-economic growth and human security. Benefits are not just monetary, but also include making the EU a more attractive environment for a good life, and international investment and innovation.

To sum up, the *IsITethical? Exchange:*

- Brings together a critical mass of stakeholders for practitioner-led co-creation of principles, guidance and standards for responsible IT research and innovation in disaster risk management.
- Creates a space and methodologies for constructive knowledge exchange, critical dialogue around controversies, and articulation of creative and pro-active responses.
- Develops an open knowledge base of existing, emergent, and future ethical tensions in IT research and innovation building out from a concrete focus on the use of common information spaces in crisis and disaster risk management.
- Iteratively co-creates guidance, principles, protocols, and standards through knowledge exchange, where stakeholders evaluate existing guidance, identify gaps, harmonise approaches and bridge differences with reference to concrete examples, technological, social, and regulatory responses and best practice.
- Develops ideas for a European Hub for Responsible IT Research and Innovation that cuts across different sectors.
- Formulates recommendations for improvements of EU Level Regulation.

A CORNERSTONE FOR FUTURE RESPONSIBLE RESEARCH AND Innovation

IsITethical? seeks to accelerate efforts that pursue these aims by building on existing work and the results and networks of the partners in the initiative, including:

- incorporation of ethical, legal and social issues (ELSI) in standard Terminologies for Crisis and Disaster Management (e.g. CEN/WS TER-CDM -2017)
- standards for ethical impact assessment in RRI (e.g. SATORI CEN CWA 17145-2 2017)
- guidance on research integrity (e.g. through the European Network of Research Integrity Offices ENRIO and the European Network of Research Ethics and Research Integrity ENERI)

As part of these plans, *IsITethical?* aims at the institutionalisation of comprehensive guidelines and standards for persons and organisations that are involved in the development and/or application of crisis IT systems, as

well as for the systems themselves. Compliance to these standards could be made visible and accountable by certificates that can be obtained by interested persons and organizations, and that can help to ensure the quality and success of ethically-circumspect technology development projects.

Basis for the certification could be a maturity model in the style of CMMI or Spice (ISO 15504), that would allow to measure the conformity of IT research and development processes to best practices and requirements for ethical IT that are defined in the guidance, the knowledge base that is produced in the project.

For persons, the certificate would confirm that he/she is knowledgeable about the reference process as well as the guidance, and competent in the practice of developing, choosing/deploying and/or using crisis IT systems. For organizations, the certificate would confirm that the organizational procedures and processes implement the requirements of the reference model, which would usually require active involvement of at least one certified employee. For crisis IT systems, the certificate would confirm that the technology has been developed and that it is used within the standards of the reference model, usually requiring the organization to be certified.

In the long-term, certificates could be granted by an independent European certification authority. In order to guarantee the credibility of certificates, accreditation for the certification authority is needed. That ensures that the certification practices are tested and suitable quality assurance processes are employed, e.g. according to ISO/IEC 17024 or related standards.

CONCLUSION

Crises do not respect borders – certainly not in a digital society. Therefore, the aim of improving protection of citizens is intrinsically multi-agency, Pan-European, and global. However, it is often much easier to make things technologically interoperable than legally, socially, and culturally compatible. European values and fundamental rights are immensely valuable to EU (and other!) citizens and highly regarded internationally. The fact that fundamental rights, including privacy and data protection are at the heart of current security policies (EC 2017b) is a case in point. There is a need to expand the role of European approaches in the context of international security policies. E-privacy can be seen as integral, for example, to human security (EGE 2014, Kaldor 2016), and already, the EU is highly attractive for pioneers of high quality innovation in international IT research, technological development and policy innovation. Many who are 'in search of legal and political openings' for alternatives to mass surveillance and datafication (Kaldor 2016), pursue innovation in Europe.

The European Group on Ethics in Science and New Technologies highlights that to achieve better, more transparent, accountable, and inclusive balance and high quality IT research and innovation, it is critical to support 'ethical reflectivity, the perplexity, the pause for thought, the evaluative critical gesture, the valuation and the choosing' that are an essential part of 'all individuals' ethical potency' (EGE 2014:80). *IsITethical?* provides unique leverage by building evidence-based capacity and by connecting organisational, industrial, and research-led innovation through a novel service for responsible research and innovation in disaster risk management. The *IsITethical? Exchange* combines an online knowledge exchange platform with a table-top exercise, and services for creative ethical and privacy impact assessment. This opens up new opportunities for more creative, proactive, and ambitious responsible research and innovation. Making innovation that is not just 'technically interoperable' but also 'legally compatible' and responsible requires finding a balance and 'good' responses to controversies. This is not easy. The *IsITethical? Exchange* enables dialogue between a wide range of parties, who contribute their diverse experiences, interests, and forms of expertise. *IsITethical?* thereby provides guidance that is 'live' in the sense of being available at a click, 'lived' because it is based on practitioners' real world lived experience, and 'living' by virtue of the fact that it engages and involves a diversity of European users, developers, citizens, and researchers to dynamically capture emerging trends.

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Ethical, Legal and Social considerations surrounding the use of Facebook groups during Hurricane Irma in Cuba

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ABSTRACT

While Hurricane Irma struck the Cuban Southern coasts, thousands of tourists were evacuated from this area and relocated in the Varadero peninsula. In a couple of days, all means for families and friends to connect with the tourists were down, leaving them without any information about the on-site situation. This paper focuses on the volunteer citizens' initiative to take advantage of social media, to enhance their own situational awareness in Varadero area, supporting fellow citizens to identify and localize their relatives. In particular, two Facebook groups that were created at the time are analyzed and their messages' content and objectives categorized. We will show that once more, social media has constituted opportunities for citizens to engage a specific response to the crisis, but at the same time has raised specific ethical and social issues. On one hand, social media has constituted a virtual space of care supporting self-help and psychological help between citizens, fostering at the same time community resilience. On the other hand, its use has also put at stake governance, responsibility, equity and privacy principles.

Keywords

ELSI, Social Media, Volunteers, Citizens, Hurricane Irma

INTRODUCTION

On September the 8th the eyewall of the hurricane Irma moved over Cuba from the South east. Initially, meteorologists hadn't predicted a direct hit for this Island. As prevention, nearly one million people from low-lying areas, including thousands of Canadian and European tourists were evacuated mostly in the Peninsula of Varadero (province of Matanzas), the northernmost point of the island of Cuba. The intensity of the hurricane was varying between categories 4 and 5 while moving through the island. By late morning on September 9, Irma had weakened to Category 3 but continued to cause significant damage for the next 24 hours while heading to the North, affecting all the northern Coast-Cayes and the provinces of Sancti Spíritus, Villa Clara and Matanzas (where tourists were displaced) until reaching Havana.

Looking for the events regarding Cuba's situation at that time, little information is available on the Internet. The chronology we propose here is mainly based on the exchanges we had through social networks with relatives

having experienced these events from inside (in the eye of the storm). On Wednesday the 6th, in Europe, Hurricane Irma is followed and announced as potentially dangerous for Cuba – At that time tourists were not aware of the threat. On Thursday the 7th, tourists had been informed that they would be moved to Varadero area in prevision of the Hurricane –forecasts were predicting that the hurricane would impact the south of the island before rapidly moving to the United-States coasts. On Friday the 8th, tourists have been placed in the several hotel complexes in the Peninsula of Varadero. At noon, they were informed that in prevision of the storm, they would be confined in their rooms (and more specifically, in the bathrooms during the highest point of the storm) upstairs. Irma was still supposed to move quickly to the coasts of the USA.

This is the last and direct contact with tourists until Monday the 12th. In the meantime, Hurricane Irma had changed its trajectory and had kept moving West until the region around Havana. On September the 9th, European families, without any news from their relatives, were aware of this change of situation discovering through the Internet that flooding had worsened, and the storm surge had been pushed to Varadero area.

This paper focuses on what happened on the social media between the 10th and 14th of September: indeed, while communication was not possible anymore and news media were not covering the event, citizens started to organize themselves to overcome this absence of information and answer the worried family demands. In absence of official visualization about what was going on during the crisis, we analyze how social media has been used by citizens to overcome this issue by collecting, gathering and providing by themselves relevant information. More specifically, we will show that, once again, social media has been used to build and engage an immediate response to the crisis by supporting the identification and localization process concerning tourists "absent from the map" and the update of the state of hotel complexes after the hurricane. Mainly based on the analysis of the content of two Facebook groups created at the time of the hurricane, we will categorize the content and objectives of these posts in order to better understand how social media can support and foster cooperation between citizens and authorities in order to define and engage a specific response to a crisis, in that case a better visualization / localization of the tourists on the ground. We will also discuss what we consider as the main ethical and social issues raised in this case in order to support a better visualization if that type of events would happen again.

STATE OF THE ART

In this section we present briefly the main findings related to the use of social media in crisis management from an ethical and social perspective. Without being exhaustive, we frame our case study in order to discuss these findings and draft some recommendations at the end of the paper.

It is nowadays acknowledged that the use of social media in crisis management presents opportunities in terms of situation awareness i.e. "accurate, complete and real time information about an incident" (Lanfranchi et al., 2014). The past decade has been attesting about the significant increase of social media use for crisis management through several activities: seeking information, receiving timely information, determining crisis magnitude, checking in with relatives, self-mobilizing for both citizens and crisis managers (Ngamassi et al., 2017). Moreover, social media information constitutes an added value for crisis managers and affected or concerned people when traditional channels of information are not available (for instance, news media, radio, etc.), which is often the case in the first few hours of a crisis (Aupetit and Imran, 2017). Nevertheless, it has been established for a long time that citizen-generated content presents challenges such as data quality, trust and format content, which do not guaranty a "complete control over the internal flow of information concerning the crisis from source to organizational decision maker respectively" (Tapia et al., 2013). Despite the concerns about the legitimacy of such shared information, at the time of a crisis, social media constitutes backchannels supporting peer-to-peer communications which are positioned in contrast with the official or formal communications to the public (Sutton et al., 2008).

Whilst a traditional approach to crisis management and situation awareness relies on official communications channels and promotes a passive role for citizens considered as target rather than partners (Lanfranchi et al., 2014), the proactive role of citizens through social media has been becoming an essential support for the crisis management process (Romano et al, 2014; Palen et al., 2010). For instance, in "ecology of participants" established by (Diaz et al, 2013) citizens (initially "persons receiving information about a crisis") can become sensors (i.e. witnesses or victims aware of information useful for the response activity), trusted sensors (i.e. citizens that crisis managers consider as reliable for specific reasons), nodes (i.e. citizens having accredited expertise supporting them to evaluate damages or to find the kind of required assistance) or agents (i.e. citizens able to execute actions following crisis managers directives).

(Taylor et al., 2012) have specifically assessed how, during the tropical cyclone Yasi, social media (mainly Facebook pages) has been mobilized by citizens to provide psychological first aid (defined as a psychosocial support delivered, as community-based activity, in response to crises in order to reduce initial distress, meet

current needs, promote flexible coping and encourage adjustment) and build community resilience. Interestingly, their findings underline that even if social media were popular in their sample, there was a strong interest for traditional media such as television. Social media were also orienting people to official sources and amplifying such sources' messages to a broader audience. On social media, people were seeking information, directly asking people for specific information, providing general information or responding directly to questions, explaining what was going on or directing people to further information, requesting help or offering help or practical assistance, and posting messages of support. Lastly, people overwhelmingly reported "feeling a sense of connectedness and usefulness, felt supported by others and felt encouraged by the help and support being given to people" (p. 25). To that extent, Rizza and Guimarães Pereira (2014) have illustrated how social media allowed citizens to answer competently to the 2011 Genoa flooding, hence to support the building of community disaster resilience. Social media, initially a backchannel has been integrated to the crisis management process by local authorities, and consequently have constituted a virtual space of care for citizens to exercise their care and solidarity by organizing rescue activities, reconstructions, etc. Then, social media also constitutes a means to foster community resilience defined as "the ability of a community to not only resist and recover from a disaster but also to improve as a result of the changed realties that the disaster may cause" (Dufty, 2011). Among the fundamental changes (Dufty, 2011) identifies, sharing responsibility with community groups and individuals constitutes a critical aspect.

Nevertheless, the use of social media for "self-help" purposes (i.e. a spontaneous peer-to-peer communication between citizens to overcome the crisis) leads also to privacy infringements, inequality, and it questions the responsibility of the actors involved. As an illustration, Watson and Finn (2013) discuss some of the privacy and ethical implications surrounding the use of social media during the 2010 Eyjafjallajokull volcano eruptions. On one hand social media have supported citizens stranded in Europe to communicate, organize their postponed travel, or get information from the aviation industry, and the aviation industry (i.e. airlines companies and authorities such as Eurocontrol or the European Organisation for the Safety of Air Navigation) to get information from its consumers and to communicate with them. But on the other hand, users were not given enough information about how their personal data was being used by service providers, social media companies and technology companies. In a meantime some travelers may not have had access to internet or mobile phone services (as they would have had if they have had been in their own country). Lastly, while social media may have been seen as a support to enhance citizens' empowerment and to foster their resilience, corporate and public entities should not have been exempted of their duties and responsibilities with regards to their citizens-consumers.

While social media constitutes a virtual space of care supporting self-help and psychological help between citizens, fostering at the same time community resilience, and an additional means of communication between stakeholders and affected citizens, its uses also put at stake governance, responsibility, equity and privacy principles, which will be discussed at the end of this paper.

METHODOLOGY

Shortly after Irma struck the Varadero peninsula, families of people confined in the hotels of the area lost contact with their relatives. On September 10th, two Facebook groups emerged, aiming to help people communicate about the situation in Varadero. The first one, created as a public group, "Varadero Hotel Contact" (further named Group 1), is defined by its creator as "a space to share information or ask questions about family and friends staying or working in Varadero." The second one, "Family And Friends Of Tourists Evacuated To Varadero" (further named Group 2) is a private group, with a name explicit enough for people to find it easily.

Although information is used to be spread on Twitter, it seemed that Facebook was used by people to follow it up and to organize their researches in the longer term. Indeed, whereas Twitter allows citizens to share and spread information from official accounts or to give brief news from the ground, Facebook has been the place for citizens to gather this information, and to go into further details to help the recovery via a co-construction process. Thus, we decided to focus our analysis on the two abovementioned Facebook groups to explore the profiles of messages sent by people all along the crisis response.

While traditional media focused on places where the hurricane made victims and more serious damages, people wondering about the crisis in Cuba created their own non-professional communication channels to share information. In France and the USA, the traditional media focused on the crisis happening in their own countries (French Overseas Departments and Territories, USA coasts). Thus, it is interesting to observe these two groups to get a better understanding of the way citizens bypass traditional media, thanks to social networks, to communicate and investigate… We started our observation at the first posts on each group, on September 10th, and we stopped at the beginning of September 15th. Throughout this interval, we looked at the messages posted by the members, the comments, but also the links, photos and videos shared by users, and we observed the way

people organized themselves to exchange information.

We gathered a dataset of 580 posts on the two Facebook groups (70% coming from Group 1, and 30% from Group 2). We processed messages in English, French and Spanish, which together accounted for over 95% of the dataset. Then, we classified these messages depending on their content (information, question, link, picture…).

As all data that has been gathered from these Facebook groups were fully anonymized, it is important to note that we did not defined user profiles, but message profiles. Therefore, we can assume that a citizen can post messages that correspond to several classes, depending on his/her objectives and when he/she acts during the crisis. Thus, all the results presented here preserve the anonymity of individuals, and focus on the types of communication within the Facebook groups during the crisis.

RESULTS

After having analyzed these posts, we distinguished three main types of messages:

1. The messages asking for information
2. The messages giving information
3. The messages managing communication

Then, we saw that the two first classes could be divided in subclasses, which can be described as follows.

Messages asking for information

In this class, we have two types of messages, depending on the information they are looking for:

- The *Questions –Q-* are written by relatives and friends of people evacuated to Varadero. They post messages asking for information about loved ones they have lost contact with. Their posts are often shorts and, most of the time, expose the name of the person they want to find, the link they have with them and the last place they know they have been.
- The *Travel –T-* messages ask questions with a really different objective: the authors wonder about the damages the hotels have suffered, and about the airlines traveling from and to Cuba. Indeed, these users have planned to visit Cuba and are wondering about the logistical troubles their trip might be affected of.

Messages giving information

These messages are slightly different regarding the sources of the information they provide, reflecting sometimes the accuracy of their testimony:

- The *Observations –O-* are messages of authors directly present on the ground. They have lived or seen the disaster, and share information, pictures and videos from Varadero to show others the situation progress.
- The *Relays –R-* are written by users that are directly in contact with any instance on the ground. They often had phone calls or text messages from relatives or hotel members, and share on Facebook the information they have obtained.
- The *Shares –S-* are messages of members that act only on the Internet. They share content posted by others on websites and social networks, such as articles, Twitter posts or information from other Facebook pages.

Messages managing communication

Finally, these messages *Manage* – M- the way people interact within the groups. They structure the comments, thank those giving information and encourage others to share information they obtained. They sometimes summarize the information of the day in synthetic posts and help people find the good contact for their investigation. In addition, in Group 2, they share and frequently update a file with a list of hotels that were confirmed safe – *i.e.* no victims.

Thus, we obtained six categories of messages, which are represented differently in the public and private groups. The distribution of these types of messages is presented in the table below.

Table 1. Distribution of the posts on both groups according to the types of messages

	Profiles						
	Observer	**Relay**	**Sharer**	**Questioner**	**Traveler**	**Manager**	**Total**
Group 1	**8**	**65**	**104**	**161**	**39**	**28**	**405**
	2,0%	**16,0%**	**25,7%**	**39,8%**	**9,6%**	**6,9%**	
Group 2	**6**	**88**	**8**	**44**	**2**	**27**	**175**
	3,4%	**50,3%**	**4,6%**	**25,1%**	**1,1%**	**15,4%**	
TOTAL	**14**	**153**	**112**	**205**	**41**	**55**	**580**
	2,4%	**26,4%**	**19,3%**	**35,3%**	**7,1%**	**9,5%**	

The second step of the analysis was to look at the way these types of messages evolve during the event, from September 10th when no one had contact with their relatives, to September 14th, when the communication networks are back between people.

In *Figure 1*, we can see the relatively different evolution of the types of messages all along the analysis, which represents the state of mind of Facebook groups' users at each moment of the situation management.

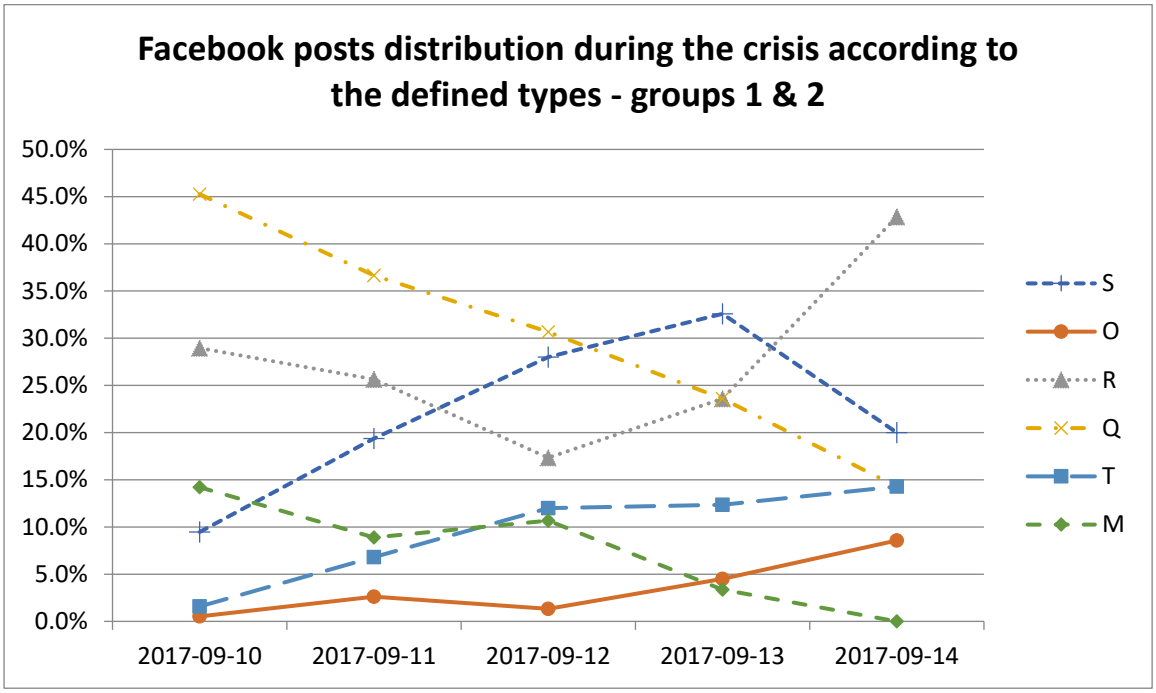

Figure 1. Facebook posts distribution during the crisis, according to the defined types.

About the evolution of the types of messages during the event

At the beginning of the crisis, we see that most of the questions are about family and friends. People are trying to contact their relatives, but cannot find any information, so they worry about them. Then, we progressively note more questions regarding the flights, the damages to the hotels. These questions are asked by people who had been planning to travel to Cuba and want to know whether they will have to change their bookings.

At the end of the crisis, from September 13th, the fact is that people are more relaxed, and they start to thank everyone who helped them get news about their families. From this time, and with an increasing representativeness, the emotions are being revealed. People ask fewer questions about their relatives, and those who relay information from the ground are more positive.

About the functions

It is important to remember that we are not dealing here with people profiles but with message profiles. In fact, all authors of messages take a specific function each time they publish something within the group, depending

on the type of message

The *Share* messages help information to be spread, and make the Facebook groups a crisis management tool for the citizens. They share information from traditional and non-traditional media such as other Facebook pages, Twitter accounts, links from articles and some YouTube videos. Here is the idea of using social networks as a backchannel.

Among these identified messages types, those creating a link between volunteer citizens and professionals are the *Manage* and the *Share types*. Indeed, the *Manage* messages sometimes communicate about useful contacts for people looking for information, and the *Share* ones can disseminate information sent by professionals through other communication channels such as press, or Twitter official accounts.

About the information gathered by the groups' members and its confrontation

One of the main concerns of the members within the two groups has been to update the status of the hotels in Varadero. More precisely to keep a list of hotels that could be considered as safe. As a result, Group 1 ended up with a list of 27 hotels that were confirmed to be safe, and the Group 2 with a list of 25 hotels. However, after having checked the spelling and location of these two lists, it appears that 23 different hotels were confirmed by both groups as safe, while the remaining actually referred one of the 23 hotels (wrong name or syntax mistake).

Still, four hotels were not confirmed and kept several members worried, even after the 14th. However, what was not proposed among the messages was to create and update a map of all hotels. Once done, as illustrated in *Figure 2*, one can quickly note that some of the 'unconfirmed' hotels (in yellow) were actually closely surrounded by 'confirmed' hotels (in blue), which could have been a relief for the friends and families of concerned tourists.

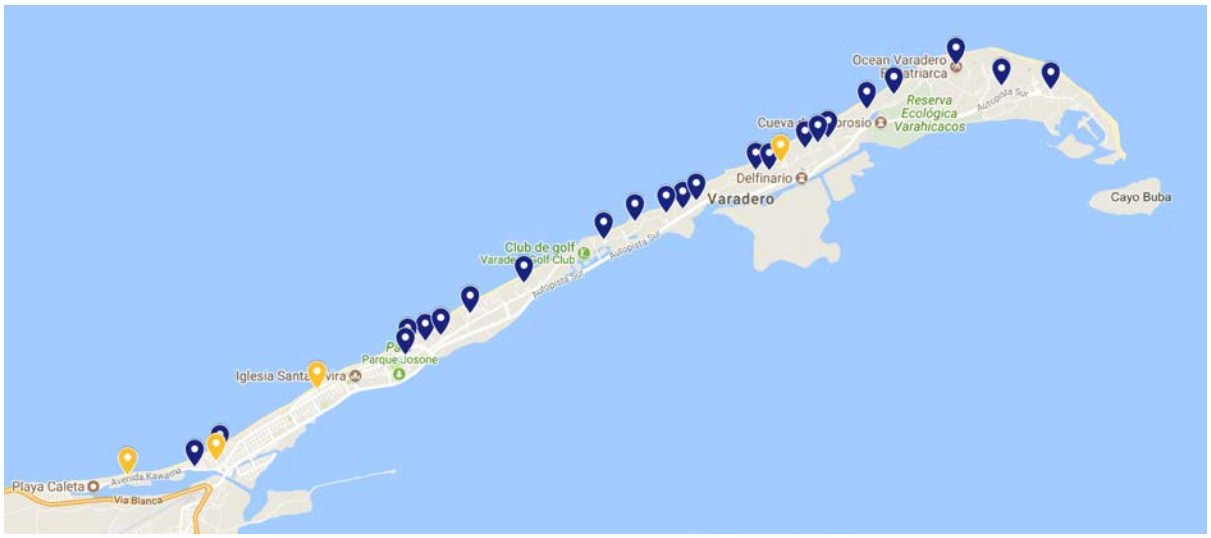

Figure 2. Map of all confirmed (blue) and unconfirmed (yellow) hotels, September 14th.

DISCUSSION AND PERSPECTIVE

A do-it-yourself visualization that remains non-professional

What we have seen about the use of social media during the hurricane Irma in Cuba reaches the conclusion of the state of the art. Fellow citizens have been able to provide psychological first aid to each other (Taylor et al., 2012): they tried to reduce initial distress and meet the actual needs that emerge at the time of crisis, for instance by localizing persons in the hotel in the absence of information about the Varadero area. As we have shown, the lists that have been established covered almost all the hotels. Social media, once again, has constituted an additional and virtual space of care, supporting citizens to express their solidarity and exercise their care (Rizza and Guimarães Pereira, 2014). The episode of the hurricane Irma in Cuba illustrates the panel of opportunities offered by social media in crisis management to obtain a situational awareness of an event while traditional channels are not available and to foster community resilience by constituting a tool easily used by fellow-citizens to engage their own response (Dufty, 2011).

Nevertheless, while specifically looking at the events, ethical, and social considerations can be drafted: privacy, governance, responsibility and equity have been put at stake during the crisis.

First of all, the way the lists of hotels have been created and updated illustrates the amateurism of these volunteers, which might have led to misinformation. These lists have been useful for worried people, supporting them in the idea to act to find their relatives; but they presented errors and may have also lead to more concerns (specifically, when people has started to post messages saying they had received news while others were still waiting and were not understanding why they had not received yet any news from their relatives supposed to be in the same hotel). Furthermore, in the case of the public group (Group 1), personal information about tourists and their family was posted and consequently available for third parties (such as service providers, social media companies and technology companies). Consequently, transparency and consent principles may have been infringed, creating an information asymmetry between people opening their personal data to localize their parents or friends and third party collecting it for business purposes (Watson and Finn, 2013).

Secondly, if the two Facebook pages have clearly constituted backchannels supporting peer-to-peer communications to overcome the absence of official or formal communication to the public about the crisis in Cuba (Sutton et al., 2008), they also called for more, or for a specific attention from part of the crisis managers. From Monday the 11th, people started to call official authorities to report their relatives as missing persons or to support authorities to establish their localization. Reactions when they were explaining from where they got news or specific information demonstrate that mistrust with regard to social media remains despites advantages they present. Thus, since social media support affected communities to organize a specific and immediate response to a crisis, they should be considered by crisis managers as a means to co-construct this response. What we are arguing here is that the integration of social media in the crisis management process may support a co-responsibility and a more agile response to the crisis: looking at what was going on social media when Irma impacted Cuba might have supported authorities to identify distress from fellow citizens who were worried about their family and friends (even if their lives were not endangered). Doing so, it could have supported local authorities in defining a more adequate and inclusive answer: for instance, focusing on social media, we do not know much about the persons who were not connected or had not a Facebook account and who probably remained without any news or any psychological first aid provided through these pages.

To conclude, social media in crisis management keeps rising ethical, legal and social concerns which call for more attention from part of crisis managers. Each time they are mobilized during a crisis, it is for better or worse, or at least, unintended consequences may emerge and call for a framework. Nowadays, Virtual Operations Support Teams (VOST) are acting on social media as soon as a crisis occurs. In the French-speaking countries, and more specifically in France, they are called VISOV ("Volontaires Internationaux en Soutien Opérationnel Virtuel"). We have started a three-year-project in collaboration with the VISOV and institutional partners such as Zone de Défense et de Sécurité de Paris and Ministère de l'Intérieur and other academics and private partners to better frame these issues and integrate efficiently volunteers and social media in the crisis management processes[1]. This paper presents the very beginning of the case study around the hurricane Irma. Deep interviews with the persons involved in the Facebook pages (at least, the administrators and some active users) will support us to understand the motivations behind the creation of these pages at the time of a crisis, as well as the profile(s) of volunteers during the crisis – we don't know yet if, for instance, a person changes of functions during the crisis. Last but not least, interviews with the service in charge of the monitoring of the crisis in official institutions will be also conducted in order to confront the two perspectives.

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Track 4

Logistics and Supply Chain Management in Crisis Response

A Sustainability Maturity Assessment Method for the Humanitarian Supply Chain

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ABSTRACT

The Humanitarian Supply Chain (HSC) is key to successful relief operations. Today, HSC managers faces many challenges: (1) the increasing gap between funding and appeals; (2) donors ask for more transparency and accountability; (3) the growing pressure to switch to sustainable development. To maintain a competitive position (order winner) in the near future, considering sustainability becomes a fundamental addition to the established effectiveness and efficiency measures. In literature, the lack of Decision Support Systems for planning and achieving of sustainability objectives is described as barrier to sustainable humanitarian operations. We propose a sustainability maturity assessment method to improve the sustainability of HSC operations. Using the information gathered from field research with the IFRC as well as from the literature a proof of concept is presented to demonstrate the relevance of the proposal.

Keywords

Sustainable performance, maturity assessment, Humanitarian Supply Chain, decision support

INTRODUCTION

Humanitarian Supply Chain (HSC) management has evolved over the past decades from a reactive 'fire-fighting' to a performance-oriented approach that is focusing on efficiency and effectiveness. To this end, Humanitarian Organizations (HOs) have invested in the professionalization of HSCs, the respective tools and skills (Jahre 2008). Until now, the main objectives of the management of an HSC have consisted in improving competitiveness by effectively managing supply flows, while minimizing costs.

However, there is increasing recognition that efficiency and effectiveness alone are not sufficient to address the global sustainability challenges. The HSC needs to evolve and consider sustainability for near-future operations management. Thus, sustainability is a new paradigm for HSC managers that has been identified as a future requirement to maintain an "order winner[1]" position.

HOs are concerned about the sustainability of disaster response, but difficulties remain for HSC decision-makers to integrate sustainability into their decisions. Therefore, there is a call for more research that addresses issues of sustainability in HSC planning and decision-making (Haavisto and Kovács 2014; Klumpp et al. 2015; Kunz and Gold 2017).

[1] The terms "order winners" and "order qualifiers" refer to the factors that may lead to competitive advantage and market success.

This paper answers to this call by exploring a maturity assessment approach to quantify the maturity level of a HSC system's sustainability. Based on literature review, we propose a maturity assessment model, and illustrate it with a use case based on the IFRC HSC network.

This contribution is part of a research project, which aims to develop concrete solutions to support sustainable decision-making in HSCs with a scientific, applied research approach. The main difficulty is to develop decision-support systems adequate for humanitarian needs and uses. One of the biggest criticisms in the HSC literature review is the barrier between scientific proposals and field acceptance (Holguín-Veras et al. 2012). Several authors conclude that field-grounded research should allow for building more adequate proposals (Chan and Comes 2014; Laguna Salvadó et al. 2015). Kunz et al. (2017) highlight the importance for both academics and practitioners to "jointly define research projects". Field-oriented research is a requirement for adequately developing applied research proposals to enhance a Sustainable HSC (SHSC). Therefore, this research process has been carried out in close relation with the IFRC, which explicitly shared the interest in moving towards an SHSC, and has contributed by providing information and feedback.

The paper is structured as follows: a background section provides an overview of HSC sustainability and maturity models. Then, a proposal section details the maturity model, which is illustrated in the IFRC use case section. Finally, a discussion and conclusions section discusses limitations of this work and outlines future research opportunities.

BACKGROUND

HSC Sustainability

Sustainability is a young topic in the field of SCM. Academic publications have appeared since the year 2000, but they are primarily of qualitative nature. Ashby et al. (2012) show that even though the concern for sustainability is widespread, there is a gap between intentions and implementation. They also warn of the gap between management research and practice.

Based on the Triple Bottom Line (TBL) model, it is widely accepted to present sustainability as the balance between environmental, societal and economic dimensions. TBL is a systemic approach developed in the mid-90s by John Elkington to "*capture the essence of sustainability by measuring the impact of an organization's activities including its profitability and shareholder values and its social, human and environmental capital*" (Savitz 2012). It stresses the need to achieve a minimum in performance for the three dimensions. However, there is no consensus regarding the trade-offs and synergies across the economic, environmental and social objectives in a humanitarian context. Moreover, there is not a standard definition for each dimension.

However, previous research set up concrete criteria, objectives and KPI sets for assessing the operations impact in the TBL approach. Figure 1 illustrates the proposed approach with the "House of Sustainable HSC Operations" (Laguna Salvadó et al. 2017).

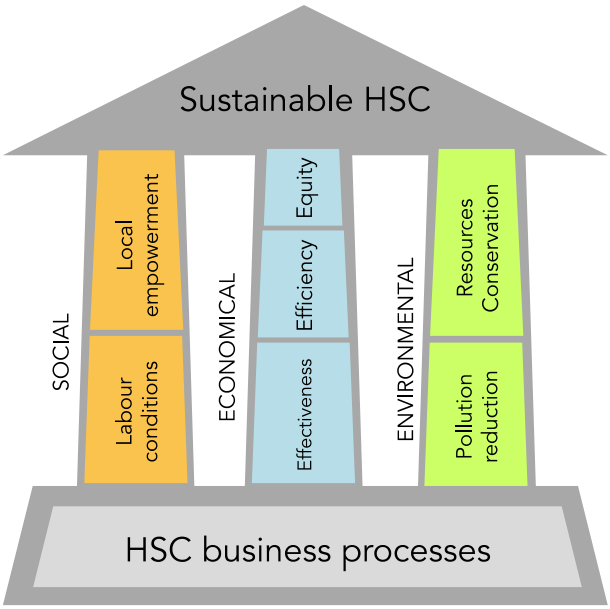
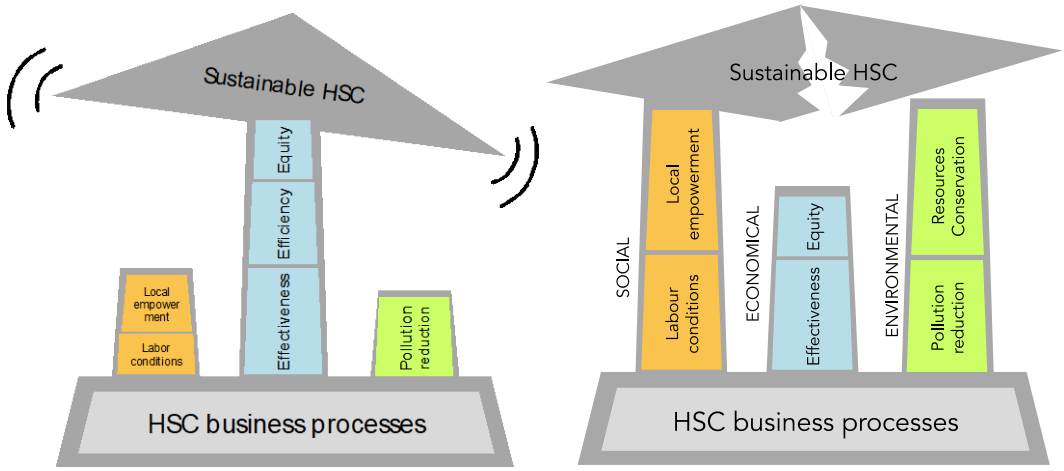
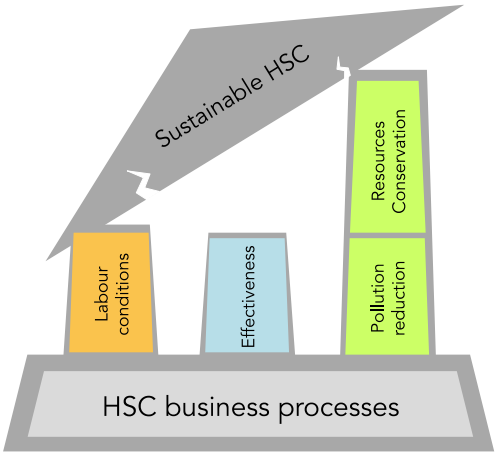


Figure 1 The House of HSC Sustainable Operations

The House of Sustainable HSC (SHSC) Operations is based on the HSC operational processes: Procurement, Warehousing and Transportation. Each pillar is built on one of the TBL performance criteria. To enhance an overall sustainable performance, the three pillars have to be balanced, so the roof is in equilibrium. This image reflects the importance of considering all the TBL performance objectives to enhance an overall sustainable performance. Carter and Rogers (2008) emphasize that organizations that seek to maximize the performance of all three pillars simultaneously will outperform organizations that only maximize the economic performance, or the ones that attempt to achieve high levels of social and environmental performance without explicit considerations of economic performance. Therefore, bypassing one of the dimensions, or focusing on just one of them does not contribute to the overall sustainability performance. Figure 2 illustrates some disequilibrium scenarios where the HSC dimensions are not balanced.

The first scenario (a) illustrates the current HSC management approach, where the economic dimension objectives drive HSC decision-making during all the disaster cycle and at all decision levels. There is little awareness of the social and environmental dimensions. This image suggests that the HSC system is not sustainable in the long term. Even if during the response the main driver of operational decision-making are the economic dimension aspects, the consideration of social and environmental dimensions is relevant, for example, at strategic decision-making level, to ensure that humanitarian operations do not jeopardize the livelihoods of communities on the longer term. The second scenario (b) is the opposite case, where the focus is only on environmental and social dimensions, but neglecting the economic sustainability of the organization. The sustainability cannot be enhanced without ensuring the economical prosperity of the organization. The third scenario (c) is a "green HSC" approach, where all efforts are put into reducing the environmental impact. As with the previous scenarios, the sustainability of the HSC is not ensured.





(c)

Figure 2 Illustration of HSC operations sustainability conceptual "disequilibrium"

Finally, Figure 3 illustrates the case where all the dimensions are considered, without reaching the maximum performance expectations in any of them. The sustainability is then reached, without excelling in any of the dimensions.

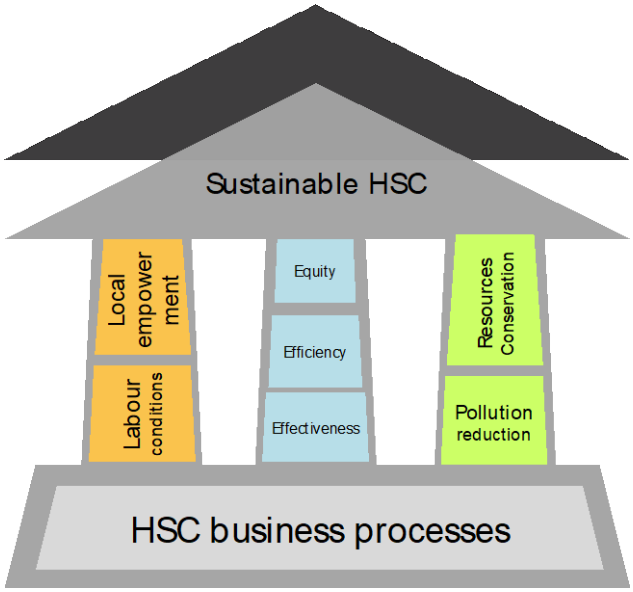


Figure 3 A balanced SHSC performance

Maturity Models

A maturity model is defined by (Battista and Schiraldi 2013) as:

> "*A framework conceived to evaluate the maturity of an organization through the definition of a set of structured levels that describe how well behavior, practices and processes can reliably and sustainably produce required outcomes*".

The origin of maturity models comes from the "Capability Maturity Model" (Paulk et al. 1993), which is used to assess an organization on a scale of five process maturity levels. Each level ranks the organization according to its standardization of processes in areas as diverse as software engineering, systems engineering, project management, risk management, system acquisition, information technology (IT) services and personnel management (Correia et al. 2017).

The use of maturity models to analysis and optimize processes has seen exponential growth in recent years, with encouraging results. Therefore, many authors have focused on the development of SC sustainability specific domain models (Baumann 2011; Golinska and Kuebler 2014; Kurnia et al. 2014; Okongwu et al. 2013; Reefke et al. 2014; Srai et al. 2013). (Correia et al. 2017) recently published a literature review on the topic, and identified the potential uses of Maturity Models as:

- A descriptive tool for the evaluation of strengths and weaknesses
- A prescriptive instrument to help develop a guide (roadmap) for performance improvement
- Comparative tool to evaluate the processes/organization and compare them with standards and best practices from other organizations
- Enablers for internal and external benchmarking

Typically, a method to assess a maturity level consists of measures and questionnaires, which allow the organization to perform self-assessment and benchmarking of their sustainability level. However, there is no standard definition of maturity levels. As an example, Baumann (2011) proposes an analytical evaluation model to characterize the global performance of an SC based on performance measurement aggregation, which is built on the TBL dimensions. The maturity of sustainable practices is defined on 4 levels proportional to the degree of implementation.

PROPOSAL: SHSC MATURITY ASSESSMENT

In the background section, we have defined the elements that impact the sustainability of a HSC. Once sustainable performance dimensions and sub-dimensions have been defined with the "House of HSC sustainable

operations", the challenge remains to measure them. This section suggests a maturity assessment model that enables quantification of SHSC performance.

The assessment model it involves both benchmarking and monitoring SHSCs. Benchmarking allows internally or externally different systems or sub-systems to be compared, for example disaster responses, or for the case of the IFRC, the Regional Logistic Units (RLUs) (Laguna Salvadó et al. 2016). Monitoring enables the evolution of a system over time to be assessed, and therefore drive the performance.

Assessment model

A performance maturity level assessment, based on the TBL dimensions and sub-dimensions, is a way to measure the sustainability of the HSC. For this specific purpose, we suggest using a quantitative and symbolic modeling approach (Figure 4). The SHSC maturity is built on the maturity of each of the TBL dimensions, defined here by five levels:

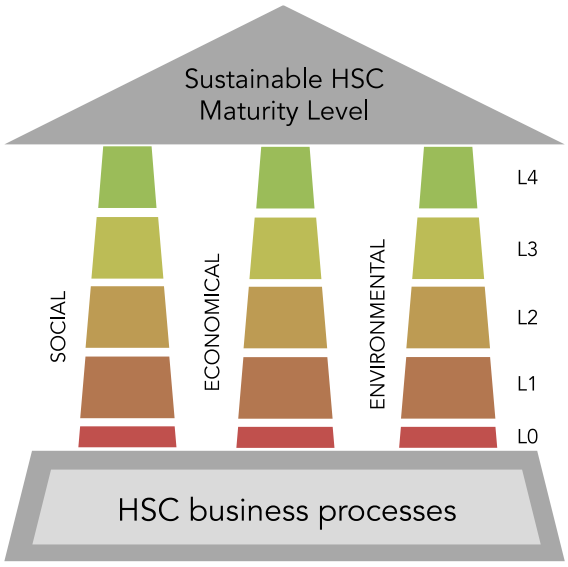


Figure 4 HSC sustainable performance maturity levels

- L0 – Unaware: The sustainable performance dimension is not considered at all by decision-makers. There is no information.
- L1 – Beginner: Decision-makers are aware, but quantitative/qualitative results are not satisfactory.
- L2 – Medium: The performance dimension results are mitigated or insufficient.
- L3 – Good: The performance dimension is well considered and results are satisfactory.
- L4 – Expert: Decision-Makers are able to make decisions in alignment with the objectives of this dimension and considering the whole HSC (upstream and downstream). The quantitative results are excellent.

Assessment method

To define the maturity level of the SHSC, first of all, each of the maturity sub-dimensions has to be assessed. The suggestion is to use either qualitative or quantitative metrics, with an assessment grid that makes it possible to define one maturity level per sub-dimension.

Secondly, once the sub-dimensions are assessed, the maturity level of each dimension of sustainability is deduced by taking the lowest sub-dimension maturity level. All the sub-dimensions are considered of equal importance because the objective is to enhance equilibrium.

Finally, a global HSC sustainability maturity level can be deduced. Based on the House of SHSC principle, which encourages equilibrium within the TBL dimensions, the method to deduce the global level is also to take

the lowest dimension level. Therefore, as long as one of the dimensions is mostly ignored, the symbolic global level will remain at L0. The objective is to highlight which are the dimensions that should be improved as a priority in order to improve sustainability with a balanced approach.

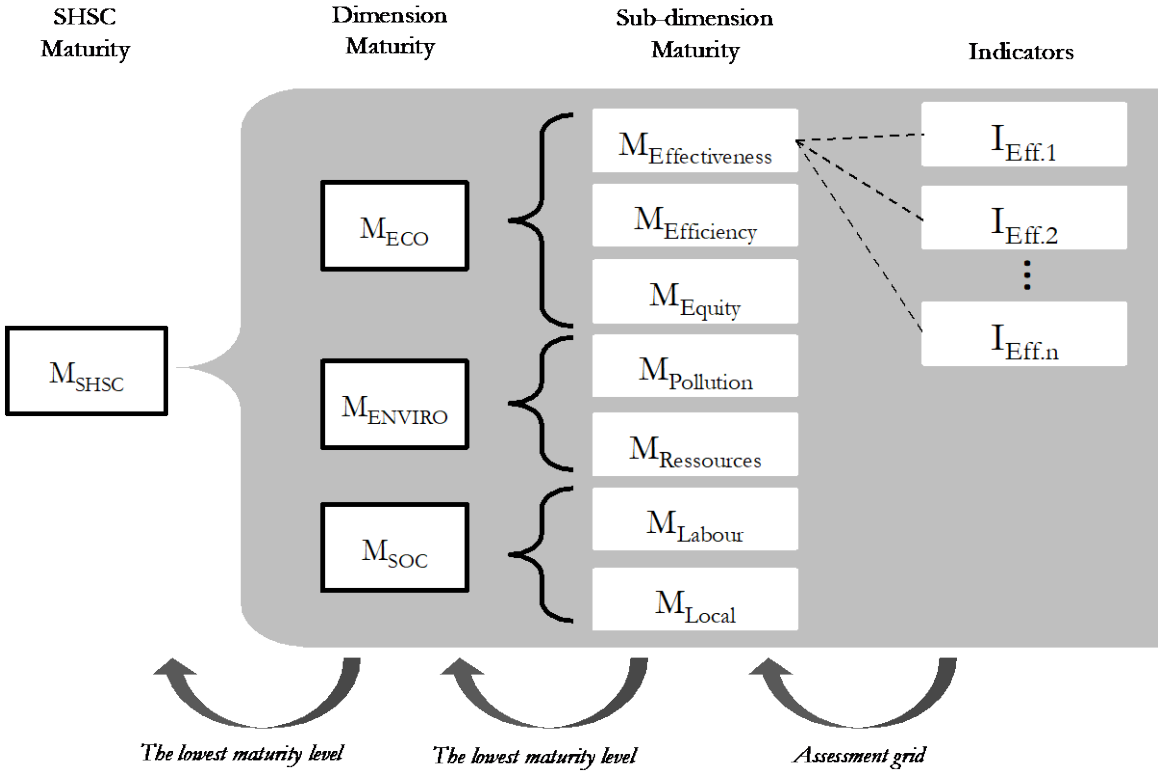


Figure 5 SHSC Maturity assessment method

A PROOF OF CONCEPT: ASSESSING THE SUSTAINABILITY OF IFRC HSC

The network of the IFRC HSC upstream is composed of five Regional Logistics Units (RLU) strategically located in Panama, Kuala Lumpur, Nairobi, Beirut and Budapest, which holds contingency stocks to respond to humanitarian needs. Moreover, sub-regional logistics units (LU) based at the country level with the support of the NS are connected to each RLU. This second layer, which responds to the need to get closer to beneficiaries, is still under deployment. LU stocks are located inside (IFRC National Societies) NS warehouses as part of the RLU contingency stock. The operational mode is linear: the regional hub manages all warehouse procurement, and each sub-regional warehouse distributes only to internal country needs.

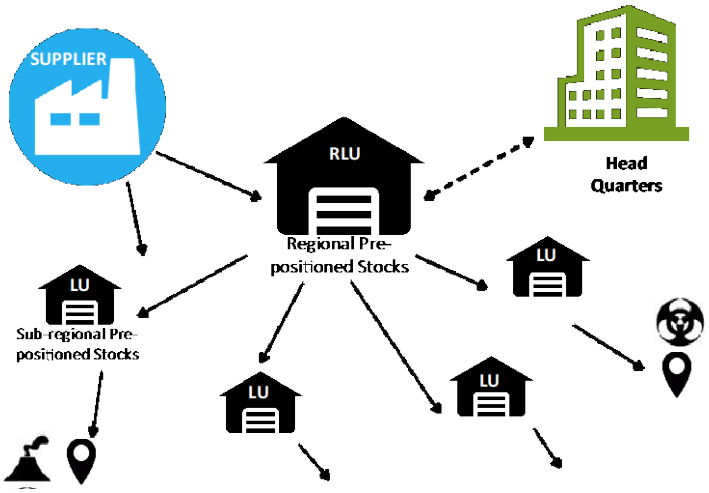


Figure 6 IFRC Regional HSC network design

To illustrate how to use the SHSC maturity assessment model, we built a use case based on the IFRC American & Caribbean (A&C) RLU operations. First, a set of the metrics and the assessment grid are defined, and secondly, the results are given and interpreted.

Assessment metrics & grid

The metrics to assess the sustainability performance can be either quantitative or qualitative. As long as the objective is to define a performance level for each of the sub-dimensions, we consider a quantitative measure if possible (a ratio can be defined). Otherwise, we have defined a qualitative assessment of the criteria, which is based on the practitioner's appreciation of the dimension (i.e. for the labor conditions). The metrics are inspired by previous discussion, and are illustrative. Depending on the HO, the criteria to define each of the sub-dimensions, as well as the measures, may be different.

Table 1 Sustainability performance metrics per dimension

TBL	Sub-dimension	Criteria	Typology	Measurement
Economic	**Effectiveness**	Demand satisfaction	quantitative	$\frac{\text{Needs coverage on time}}{\text{total demand}}$
	Efficiency	HSC Cost ROI	quantitative	$\frac{\text{(Net incomes-HSC Cost)}}{\text{Net incomes}}$
	Equity	Non-discriminatory distribution	quantitative	Gini Index (beneficiary inequality)
Environmental	**Pollution reduction**	Carbon footprint	qualitative	Appreciation
	Resource conservation	Reduction resource consumption	qualitative	Appreciation
Social	**Local community development**	Local procurement	quantitative	$\frac{\text{CHF expended locally}}{\text{CHF total expenses}}$
	Labor conditions	Employee management	qualitative	Appreciation

All economic sub-dimensions are quantifiable. For effectiveness, the ratio between the total needs over a time period, and the needs covered on time are considered. For efficiency, we consider a HSC Costs RoI (Return of Investment). A negative RoI result implies that the HSC system loses money, and a positive gives the margin that is generated. The equilibrium is around 0, considering that the objective is not to make a profit but to maintain the activity. For equity we propose using the Gini Index, as suggested by (Tzur 2016). It allows the inequalities within the distribution to be determined, where 0 indicates that there is no inequality.

The environmental sub-dimensions are both qualitative. The overall objective is to reduce both the carbon footprint and the consumption of resources. Given that it is not possible to normalize these absolute values, we define different maturity levels in Table 2. The Carbon Footprint levels are based on the LCA assessment approach, which seeks to include the whole product lifecycle (from raw materials to end of life). For resource conservation (reducing consumption) the levels are similar, considering consumption of resources such as water, energy, packaging, etc. Therefore, expertise is reached when the Carbon Footprint and LCA sub-dimensions are managed upstream and downstream. The high level is also reached by using LCA and resource consumption assessments while planning operations.

Last but not least, for the social sub-dimension, we consider one quantitative and one qualitative factor. Local community empowerment (local procurement) is measured as the ratio of local investment over total investment. At the IFRC, it is not expected that 100% of local investments will be reached in the short term, due to the difficulties in finding some emergency items locally owing to strict requirements, and also because of the framework agreements the organization has with global suppliers. Labor conditions (employee management) are assessed through internal and provider audits. The high level is reached when the labor conditions are

considered in the planning phase.

Table 2 SHSC performance assessment grid

TBL	Sub-dimension	UNAWARE L0	BEGINNER L1	MEDIUM L2	GOOD L3	EXCELLENT L4
Economic	Effectiveness	<10%	10% ≤ Indicator <50%	50%≤Indicator <75%	75% ≤ Indicator <90%	≥ 90%
	Efficiency	<-10%	-10% ≤ Indicator < -5%	-5% ≤ Indicator < 0%	0% ≤ Indicator < 5%	≥ 5%
	Equity	>50%	50% ≤ Indicator >30%	30% ≤ Indicator <10%	10% ≤ Indicator <0%	0%
Environmental	Pollution reduction	no info	The Carbon footprint is assessed occasionally	The Carbon emissions are assessed systematically	LCA-The Carbon emissions are assessed internally + externally (upstream and downstream)	SC flows are planned based on LCA impact
	Resources conservation	no info	Resources use is assessed occasionally	A management system for pollution and energy use is in place systematically	A global management system is in place (upstream and downstream)	SC flows are planned to reduce resources consumption
Social	Local community development	0%	0% ≤Indicator <30%	30% ≤Indicator <50%	50% ≤Indicator <70%	≥ 70%
	Labor conditions	no info	Occasional Internal assessment	Systematic Internal assessment	Suppliers assessment	SC flows are planned based on labor conditions

Illustrative results

Based on the IFRC A&C field observations and discussion with practitioners, the following illustrative data set was built, with its related sub-dimensions maturity levels.

Effectiveness

Table 3 Data set to assess effectiveness

Order #	Lead time	Grand Total (CHF)	Value delivered on time (<1 week)
1	10.00	650	
2	8.00	9107	
3	7.00	554	554.00
4	28.00	17831	
5	22.00	15000	
6	36.00	5000	
7	5.00	50000	50000.00
8	18.00	50000	
9	9.00	58000	
10	5.00	5000	5000.00
11	1.00	16000	16000.00
12	11.00	28000	
13	15.00	17000	
14	5.00	35000	35000.00
15	5.00	136000	136000.00
16	5.00	32000	32000.00
	TOTAL	**475142**	**274554**
	RATE	**58%**	

The effectiveness is computed as the proportion of orders delivered on time. The data from 2015 A&C IFRC operations do not consider an expected delivery time. For the illustration, the hypothesis is made that an acceptable delivery lead-time is one week (7 days) since orders placed will usually be urgent (Table 1).

Efficiency

In a standard year, it is obvious that response to crises does not generate enough rotation to cover the fixed cost of RLUs. Based on the data of the A&C RLU activity between January and September 2015, an amount of nearly 760,000 CHF was charged to customers for a total number of 41 orders. From this total amount, 56,000 CHF corresponds to a service fee (around 7%), and the rest to the procurement costs (704,000 CHF). The income value, extrapolated over a year, results in a total income of around 1,000,000 CHF, and the procurement costs 940,000 CHF (Table 4).

The holding inventory costs correspond to the expenses generated due to the inventory's existence (i.e. waste, infrastructure, handling). This value is evaluated at between 20 and 30% of the mean inventory level value for the industry, depending on the deterioration and obsolescence risks. Considering that the A&C IFRC infrastructure is of basic standard, and that emergency items are robust, and only hygiene kits are perishable in the long term, we diminish this value to 10% to make the estimation. Appendix A contains the A&C RLU contingency stock value on September 2015. Considering the hypothesis that this value is close to the mean over the year, the Holding Costs of the region are around 90,000 CHF over the year (Table 4).

Table 4 Data set to assess efficiency

	HSC Costs (year)	HSC Incomes (year)
Procurement costs	940,000 CHF	
Holding costs (including handling, waste and infrastructure)	90,000 CHF	
Service Provision Income		1,000,000 CHF
TOTAL	1,030,000 CHF	1,000,000 CHF
RATE	-3%	

If we compute the effectiveness indicator with this data set, considering that the HSC annual Costs are around 90,000, and that the net income (without the procurement costs) is around 75,000:

$$HSC\ Cost\ ROI = {(1{,}000{,}000 - (1{,}030{,}000 +)}/{1{,}000{,}000} = -3\%$$

Without a full data set, it is difficult to establish an exact value for the effectiveness indicator. However, the A&C RLU has clearly stated the difficulties it has in covering the costs (IFRC 2013, 2014)

Equity

In the assessment grid it is suggested that the equity should be assessed based on the Gini Index. The value of this index is between 0 and 1, and represents the level of inequality within a studied population. In this case it is the satisfaction of the customer orders of the HSC. The red line in Figure 7 represents the Lorenz curve (Gastwirth 1972), which plots the proportion of the variable observed of the population (y axis) that is cumulated by the bottom x%. The Gini index is equal to the A area divided by the sum of the A and B areas, that is to say: Gini = A / (A + B). The bigger A is, the higher is the level of inequality.

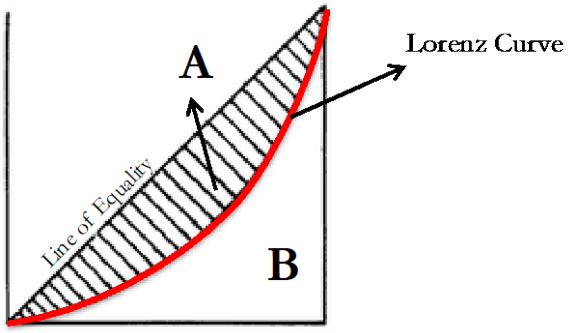


Figure 7 Gini Index

The IFRC A&C decision-makers ensure that if there is a situation where they have to share the upstream resources within different demand points, this will be done equitably (although this situation is not common upstream). Therefore, the Lorenz curve of such a situation is at 45°, and the Gini Index equal to 0, with a perfect equality.

Pollution reduction

There is no data available to compute the CO2 emissions.

Resources conservation

There is no data available to assess the resource consumption.

Local community development

The indicator for this sub-dimension is the proportion of procurement value from local suppliers. Let us consider the following dataset:

Table 5 Local procurement data set

Order #	Origin	Grand Total (CHF)	Value from local suppliers
1	International	5000	
2	International	2000	
3	International	36000	
4	International	2500	
5	Local	300	300
6	International	2100	
7	International	3000	
8	International	1000	
9	Local	580	580
10	International	600	
11	Local	3000	3000
12	Local	2500	2500
13	International	6000	
14	International	260	
15	Local	1000	1000
	TOTAL	**65840**	**7380**
	RATE	11%	

Labor conditions

There is a general standard for the staff rules at the IFRC, approved by the general assembly in 1976. Therefore, it is assumed that there is a systematic internal assessment of the Labor conditions. As part of the supplier selection process, it has to be guaranteed that suppliers:

- Adhere to the Fundamental Principles of the International Red Cross and Red Crescent Movement
- Maintain ethical business practices always
- Are not involved in any form of corruption or any fraudulent activities
- Do not engage in any collusive or coercive practices

The sub-dimensions maturity levels can be deduced using the assessment grid (Table 2).

For the economic dimension, both effectiveness and efficiency performance are well developed, but still far from optimal. The high immobilization of stocks, and the low turnover of inventory cause the level of efficiency to be negative. Regarding effectiveness, the response time is still long, in most cases. Equity is considered as achieved, given that it is considered as a constraint by IFRC decision-makers.

For the environmental dimension, nothing is done to assess and reduce the carbon footprint and resource consumption.

For the social dimension, local procurement is being developed, but it is still difficult to find suppliers that satisfy the requirements in most countries. This indicator could be improved with the development of sub-regional LUs. Regarding the Labor conditions, the IFRC standards are satisfactory, but no information was found on the assessment of their supplier's labor conditions.

Table 6 Illustrative assessment of the A&C RLU

TBL	Sub-dimension	L0	L1	L2	L3	L4	Dimension Maturity level
Economic	**Effectiveness**			x			**L2**
	Efficiency			x			
	Equity					x	
Environmental	**Pollution reduction**	x					**L0**
	Resource conservation	x					
Social	**Local community development**		x				**L1**
	Labour conditions				x		

To increase the readability of the assessment grid, these results can be presented in the form of a radar graph (Figure 8). Each TBL dimension is then assessed as the lowest one within its sub-dimensions levels (Table 6). The global maturity level of the A&C RLU is also defined by the lowest dimension level (L0), as showed in Figure 9.

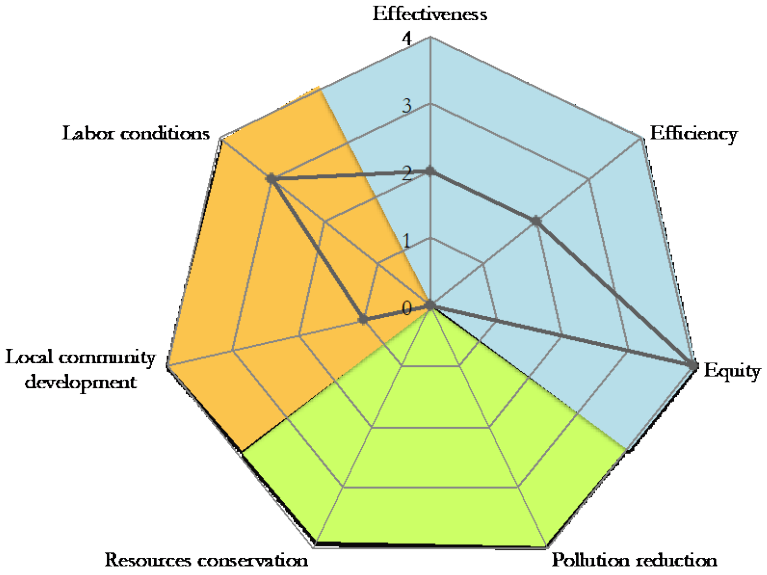


Figure 8 A&C RLU SHSC sub-dimensions performance maturity level (radar graph)

A simple analysis of the results from the SHSC maturity assessment allows us to identify the sub-dimensions that have to be prioritized in order to achieve a more balanced sustainability performance.

This result shows that the environmental dimension is completely overlooked by decision-makers at the A&C RLU. Based on this model approach to improving the overall SHSC performance, the priority should be to work

on both environmental sub-dimensions. The social dimension also remains in a lower maturity level than the economic dimension, as is predictable, given that the SHSC is still in its infancy.

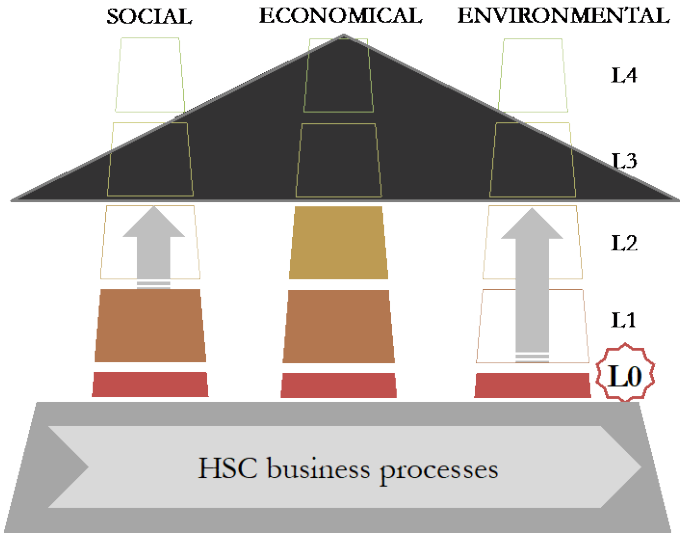


Figure 9 A&C RLU SHSC performance maturity level

DISCUSSION & CONCLUSIONS

The literature review and previous research show the challenge for HOs to consider sustainability in their decision-making processes. Based on the TBL performance approach, environmental and social dimensions should be added to the economic performance dimension. The objective of this paper is to use the "House of SHSC operations" framework for assessing the performance of SHSC operations.

The "House of SHSC operations" is a general framework that stresses the need to consider the three TBL dimensions to enhance SHSC operations (procurement, warehousing, transport). The criteria have been defined considering the literature review on sustainable SC and the impact that HSC processes (procurement, warehousing and transport) have on the different sub-dimensions. With this inputs, a model and method to assess SHSC performance maturity is suggested. To illustrate the use of the maturity assessment model, a proof of concept has been built based on the IFRC HSC use case.

This paper contributes significantly to the discussion of HSC sustainability. It bridges the gap between high-level sustainability theory and the concrete assessment of HSC operations sustainability, which still seems difficult in many disciplines.

The contributions have been developed thanks to inputs from IFRC field research. The practical application to various humanitarian relief operations is yet to be done.

The SHSC maturity model presented in this chapter is a decision-support system that allows measuring and benchmarking the sustainability of a HSC system "a posteriori". The main practical implications of using this method are to make evidence of the sustainability weakness on a given HSC system, and encourage a continuous improvement dynamic towards sustainability.

Nonetheless, it does not permit to anticipate the sustainable performance of decisions (i.e. operations planning). Therefore, as sustainability is a multi-dimensional concept, with conflicting objectives, the next step is to address these trade-offs and synergies across the economic, environmental and social dimensions.

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Track 5

Cybersecurity Issues and Innovations for Crisis Response

Cyber security flaws and deficiencies in the European Rail Traffic Management System towards cyber-attacks

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ABSTRACT

Recent events have shown the vulnerability of IT systems of companies, organizations or even governments to hacker attacks. At the same time, information technologies are becoming increasingly established and important in various industries (digitalization). With a view to the modern development of terrorism, cyber-attacks can be used to physically damage critical infrastructures (CI). This leads to a new dimension of cyber-attacks, which are called terrorist cyber-attacks.

The following research contributes to the identification of weak information technology components of railway operating systems and thus improves the safety of public transportation in the context of the European railway traffic management system (ERTMS). The core of this paper is an extended literature research on security flaws in the ERTMS. The future introduction of a methodology for evaluating the criticality of information technology system components will build on this using cyber threats and public transportation as examples. Such a method may serve as a basis for further risk assessments and management measures.

Keywords

Cyber Attack, (Counter-) Terrorism, Vulnerability, European Rail Traffic Management System (ERMTS), Railway Transport

INTRODUCTION

The threat to railway companies or other CI from cyber-attacks is increasing in the course of the ongoing digitalization of society and industry (Settanni et al. 2017). In addition to the increasing complexity of attacks, companies are also becoming increasingly aware of the vulnerability towards cyber threats (German Federal Office for Information Security 2016). In the years from 2012 to 2017, the probability of becoming a victim of a cyber-attack - according to the companies surveyed - has risen by around 45 percent.

In the years 2007 to 2010, the Stuxnet attacks have already caused physical damage (Bambauer 2014). The basic principle of the Stuxnet code is also transferable to other sectors such as energy or transport, since similar protocols are often used due to industrial standardization (Karnouskos 2011; Lakshminarayana et al. 2016). Using the Black-Energy code, for example, it was possible in 2015 to successfully attack the Ukrainian

electricity grid and cause several hours of power outages (Khan et al. 2016). A similar vulnerability to the Stuxnet attacks has been exploited. However, not only these advanced and highly specific attacks pose a threat to CI. Large-scale damage to CI has also been caused by comparably unspecific attacks, such as WannaCry in the recent past. Worth mentioning here are the breakdowns of hospitals of the National Health System in Great Britain and in the rail traffic of the Deutsche Bahn, but also in many other companies (Volz und Auchard 2017).

The increasing threat posed by cyber-attacks is amplified by increasing digitization of industry and the associated transport sector (World Economic Forum 2016). With the introduction of the European Rail Traffic Management System (ERTMS) and its planned components Global System for Mobile Communications-Railway (GSM-R) and European Train Control System (ETCS), rail traffic systems are becoming even more digitally interconnected and thus potentially more susceptible to cyber-attacks.

Therefore, an indicator set is to be developed within the framework of the present work, which can be used to investigate which components of the ERTMS are particularly susceptible to cyber-attacks and on which factors this susceptibility is decisively dependent or via which vectors the ERTMS is vulnerable.

METHODOLOGY

Based on an extensive literature research, the threat of cyber-attacks to rail traffic respectively ERTMS is described in the following sections. For this purpose, potential attackers as well as the types of attacks and the corresponding threatened protection targets are identified and described. A comprehensive analysis of the ERTMS and its four essential components GSM-R, ETCS, ETML and INESS follows, which so far have only been examined individually and not in an integrated context.

The results of the literature research presented will serve as the future basis for adapting and extending the existing approach for assessing terrorist threats in urban transportation from the German research project "Risks and costs of terrorist threats to railbound public transportation" (RiKoV). In this context, the existing set of indicators for assessing the vulnerability of physical infrastructures is to be adapted and extended in order to be applicable to information technology environments as well. Experts from the public transportation sector are to be involved in this development process in order to develop a tool for information technology risk assessment and management that is as close-to-practice as possible.

CYBER THREAT AND INFORMATION SECURITY

Rail transport is an attractive and soft target for terrorist attacks (Strandberg 2013; Strandh 2017) due to its importance for the functioning of society and the economy (World Economic Forum 2016). The reason for this is, among other things, the comparatively simple availability of the necessary technical means of attack and the poor traceability to a specific attacker. This also makes cyber-attacks a potential tool for asymmetric warfare (Bens 2011). The following section therefore describes the threat to rail traffic from cyber-attacks by various attackers and the associated protection goals and risks.

Attacker types

The threats to rail transport posed by cyber-attacks can be manifold. Generally, cyber-attackers can be assigned to five categories:

a. Unsatisfied employees or other internal attacker (recruited for this purpose):
   - majority of cyber-attacks from the inside until 2001 (Diaz-Gomez et al. 2011; McLaughlin et al. 2016), since then increasing activity of external attackers (Nicholson et al. 2012)
   - threat can be much greater, since internal attackers have no barriers to pass/remain invisible, since they are legally present in the system
   - principle of perimeter protection is only partially applicable (Diaz-Gomez et al. 2011; Nicholson et al. 2012)

b. Governmental or state-affiliated organizations:
   - must overcome security barriers, which requires appropriate expertise, sufficient time, adequate financial/human resources
   - resources are available to an almost unlimited extent (Nicholson et al. 2012)
   - future conflicts may include cyber-war scenarios (Robinson et al. 2015), as cyber-attacks

allow to remain undetected/exploit ambiguities in international law (Bens 2011).

- usually have a political component

c. Cybercriminals:

- increasingly important factor (German Federal Office for Information Security 2016)
- typically based on enrichment intent (Robinson et al. 2015).
- scenarios typically include identity/data theft and selling of data as well as extortion - for example by data encryption.
- codes and exploits can either be self-developed with appropriate expertise or purchased
- development of dark web markets fosters the availability of tools for technically less skilled criminals (Persi Paoli et al. 2017)

d. Cyberterrorists:

- increased exchange between cybercriminals/cyberterrorists called Crime-Terror-Nexus (Makarenko 2012)
- favors the development/acquisition of expertise and secures the financing of terrorist groups
- European Police Office warns of growing threat from cyberterrorism, possibly accompanied by conventional terrorist attacks (European Police Office 2016)

e. Hacktivists and hobby hackers:

- no financial background/technical expertise for the acquisition/development of exploits
- fall back on freely available software/carry out largely automated attacks (Nicholson et al. 2012)
- can cause considerable damage (Baker 2008) if appropriate security measures are not in place

Protection goals

In order to ensure information security in computer systems, the three basic principles of confidentiality, integrity and availability must be guaranteed. These basic protection goals can be extended to include authenticity, accountability, non-repudiation and reliability of information. (Bedner and Ackermann 2010; Bless et al. 2005; Eckert 2014; DIN ISO/IEC 27000:2017)

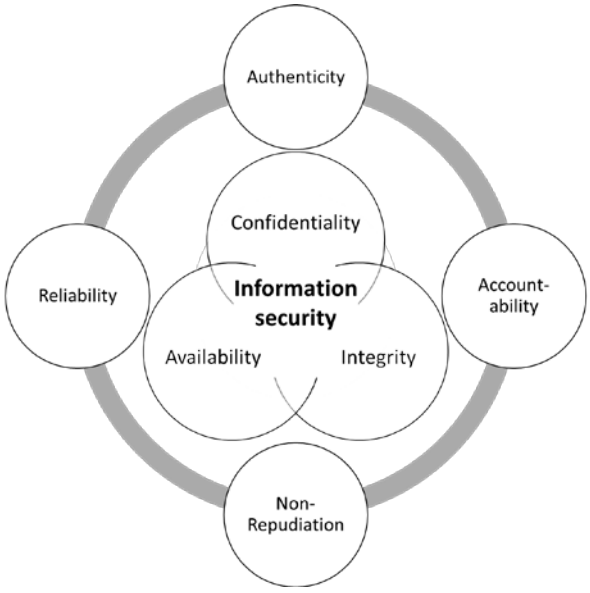


Figure 1. Basic and extended protection goals of information technology (Source: Author according to DIN ISO/IEC 27000:2017)

Table 1. Protection goals of information technology

Protection goal	Description
Confidentiality	making information accessible only to authorized and protecting it from unauthorized access
Integrity	assurance of authenticity/completeness of the particular values
Availability	usability of a subject/information by an authorized user at any time
Authenticity	ensuring that the information actually represents what it claims to be and the verifiability of it
Accountability	traceability of the responsibility for the origin and treatment of the information
Non-Repudiation	ability to prove events/trace them back to a place of origin without this being denied in retrospect
Reliability	ensuring that the intended behavior that triggers an information is consistent with the results

From a legal point of view, operators of CI in Germany are only obliged to take precautions to avoid disturbances of the availability, integrity, authenticity and confidentiality of their IT-systems to ensure the proper functioning of the CI (Section 8a (1). Law on the German Federal Office for Information Security). However, these precautionary measures are not specified; the concrete definition of protection goals is thus incumbent on the companies and is therefore part of each companies´ internal IT security policy. This gives companies the opportunity to define different levels of achievement and almost inevitably leads to different levels of security.

For application in the context of rail transport as CI, it can be assumed that compliance with the basic protection goals and the extended protection goals must always be demanded.

Threats and types of attacks

Information security is exposed to a variety of threats, each of which aims to compromise one or more of the aforementioned protection goals (Robinson et al. 2015). These threats to the protection goals can be divided into unintended threats from natural hazards, external influences or human error and intentional threats. The last form includes both active and passive cyber-attacks by the various attackers, as well as physical and combined forms of attacks that allow access to information technology.

This results in characteristic types of attacks with which the attacker's individual target is to be achieved through the impairment of one or more protection goals. In cyber-physical systems - such as rail traffic – the attack options can be divided into six different types according to Orojloo and Azgomi (2015):

a. Attacks against the truthfulness of the sensor data before it is read: e. g. manipulation of the sensor calibration or environmental parameters, so that the sensor delivers false data.

b. Attacks on the integrity of the measured or transmitted sensor data and control signals: e. g. manipulation of the communication between sensor and control unit or control unit and actuator, so that the transmitted data are modified.

c. Attacks on the availability of sensor data and control signals: e. g. flooding with requests, so that the sensor or control unit is overloaded.

d. Attacks on the control instructions: e. g. exchanging the instructions of the control unit so that it contains incorrect limit values.

e. Attack on the human-machine interface: e. g. manipulation of the operator display so that the operator makes a faulty decision.

f. Combined attacks: all the above-mentioned attack types can be combined and varied almost arbitrarily.

Further classification approaches differentiate between the attacked or affected domains in physical and cyber-side (Orojloo and Azgomi 2015). All types of attacks have in common that the attacker must have acquired a very detailed knowledge of the physical-technical and IT processes, protocols and interfaces in the attacking system to execute his attack successfully.

The threat of cyber-attacks poses various risks to a railway transport operator. Successful cyber-attacks can lead to considerable financial losses and damage to the companies´ image (German Federal Office for Information Security 2016; Nicholson et al. 2012). Most serious, however, are possible physical effects, which can be caused by a cyber-attack (Robinson et al. 2015).

INTRODUCTION TO THE ERTMS

One of the European Union's political objectives is the creation of trans-European rail networks which form the basis of the European Rail Traffic Management System (ERTMS). The ERTMS consists of four main components: the train communication system *Global-System for Mobile Communication-Railway* (GSM-R), the train control system *European Train Control System* (ETCS), the traffic management system *European Traffic Management Layer* (ETML) and the *Integrated European Signaling System* (INESS). However, the implementation of these sub-components has progressed to varying degrees so far (European Commission 2006).

GSM-R train communication system

GSM-R is largely based on the established mobile communications standard GSM. As the GSM network is only to be supported by network operators until 2030, efforts to develop a successor standard are currently being intensified (International Union of Railways 2016).

The GSM-R network is a cellular network, whereby the radio cells can have different geographical dimensions due to radio field attenuation and for capacity reasons. Usually they range from 7-15 km along the railway tracks (He et al. 2016) whereas in tunnels, they are usually reduced to 1-2 km (Kastell et al. 2006). The radio cells are uniquely identifiable. In addition to the features and specifications available in the public GSM network, the GSM-R network has a number of additional requirements, which take into account the special demands of rail traffic. The architecture of the GSM-R network is thus very similar to that of the GSM network and has only been extended by a few components (Winter 2009). General information regarding GSM architecture and functionality can be found in Eckert (2014) and Ruesche et al. (2008).

The GSM-R network and the network subscribers are protected by two essential security mechanisms: Network authentication and encryption of communication. A uniquely assigned subscriber identity module (SIM) is required for each handset in order to take part in the GSM-R network. Each handset is additionally uniquely identifiable via a device number. If a handset tries to establish a connection to the network, a personal identification number must be entered, and the device number must be registered as valid. The handset is then identified using a challenge-response procedure. (International Union of Railways 2015; Sorge et al. 2013; Winter 2009) This challenge-response procedure uses various keys, some of which are transmitted in plain text via the air interface. Once the connection is established, the communication is encrypted with a 64 bit key. (Eckert 2014)

Pre-computed tables allow the keys to be broken within a few minutes, especially since the keys are partially used for several days and 64-bit encryption is no longer a sufficient protection for the computing power available today (Barkan et al. 2008; Nohl und Paget 2009). This vulnerability also offers the possibility of "hijacking" the attacked handset, i. e. redirecting the data traffic destined for a handset (Barkan et al. 2008; Golde et al. 2013). Physical access to the SIM opens up numerous other possibilities for side-channel attacks, including cloning of the SIM (Brienco et al. 1998; Pagliusi 2002; Rao et al. 2002).

Since only one-way authentication of the handset takes place on the network, but not vice-versa, base stations can be imitated in an unauthorized manner (Eckert 2014; Sorge et al. 2013). The cryptographically unprotected backbone as well as the signaling channel and the update over the air (OTA) function lead to further shortcomings (International Union of Railways 2015; Sorge et al. 2013). Like all wireless networks, GSM-R is exposed to the threat of intentional jamming, parallel to the already existing frequency overlaps and bottlenecks in channel availability (He et al. 2016; Lindström 2012; Mili et al. 2013; Ruesche et al. 2008; Sniady and Soler 2012).

European Train control system (ETCS)

To improve the interoperability of trains, it is intended to replace the 20 different national train control systems throughout Europe with one ETCS. The ETCS also consists of several components, which can be differentiated into track-side and on-board infrastructure. Both components communicate with each other via air interfaces and will be implemented in three levels. The track-side infrastructure comprises the radio block centers (RBC) connected via GSM-R, which monitor the position of trains and form the interface to the interlockings issuing the movement authorities. These movement authorities are transmitted to the train´s ETCS on-board computer via beacons in the tracks or via GSM-R (Winter 2009).

Since security-relevant data, such as movement authorities, are transmitted via the ETCS, the integrity and authenticity of this data is especially sensitive. Therefore, this data is particularly protected by a cryptographic message authentication code. For this purpose, the triple data encryption standard is used in block cipher mode according to ISO 9797-1 MAC Algorithm 3 (ISO/IEC 9797-1). The keys required for this are generated in a key management center and brought to the handsets by couriers on physical storage devices (DB Netz AG 2014). In order to register a train, these keys must be exchanged between the handset and RBC using a challenge-response method with pseudo-random numbers. The connection is also encrypted after establishment, only emergency messages are excluded from this procedure. In order to make messages distinguishable in the ETCS, they receive a time stamp and sometimes require an acknowledgement of receipt. (Chothia et al. 2017; DB Netz AG 2014; European Railway Agency et al. 2016a; Ruiter et al. 2016; Union Industry of Signalling 2015a, 2015c; Winter 2009)

The transmission of messages from the beacons in the track can also be safety-relevant, so that these should be secured. Each beacon has an individual number and "knows" its successor beacon. This information is transmitted by induction when passing over the beacon. (European Railway Agency et al. 2016b; Union Industry of Signalling 2015b)

In addition to the security issues in the GSM-R network, shortcomings can also be found in the ETCS. Although the triple data encryption standard is still considered relatively secure, an attacker could search for collisions in the message authentication codes and thus deduce the key. Since the algorithm CBC-MAC is based on a 3DES encryption and this encryption uses three different keys KS1, KS2 and KS3, of which KS1 is used in each DES encryption round, in combination with the knowledge that two messages in EURORADIO with the same MAC have the same input for the last 3DES block, a conclusion can now be drawn for KS1. In a conceptual proof, it has already been shown that forged movement authorities can be sent to the train that it accepts. Since the emergency messages are not protected it is possible to use faked emergency messages to induce unintentional emergency braking (Chothia et al. 2017).

Furthermore, the pseudo-random numbers used to establish the connection are a possible starting point for attacks. If the random number generator is not cryptographically secure, the number generated by it can be calculated in advance if necessary, thus establishing an impermissible connection to the train, in which the attacker acts like an RBC, since the random numbers of train and RBC are transmitted at least once in plain text (Lopez and Aguado 2015).

The systematics of the key distribution by physical data carrier makes it particularly susceptible to social engineering. Since the keys are delivered manually on a physical data carrier, distributing the keys to the individual trains is correspondingly cumbersome and time-consuming. This can result in railway companies using few keys for large train fleets in order to reduce the effort. Furthermore, the use of a key over a longer period of time is favored by the complex procedure (DB Netz AG 2014; Lopez and Aguado 2015).

The introduction of the time stamp is intended to prevent a message from being sent multiple times, but the procedure is only used after the connection has been established, not during this process, so that it remains vulnerable to replay attacks. Furthermore, the recipient of a message must decrypt it first and check the MAC before the correctness of the attached time stamp can be checked. This could serve as a possible starting point for an attack with the aim of compromising availability. For this purpose, old messages can be resent that would be rejected by the system but increase workload, possibly resulting in system performance limitations. The messages do not have to be decrypted by the attacker, as their content is of no interest in this case, which is why EURORADIO does not offer a protective function. The only protection against this form of attack consists only of GSM-R encryption, which - as shown in the previous section - can be broken comparatively easily (Lopez and Aguado 2015).

Other forms of attack are physical replacement or modification of beacons or - since the ETCS depends on the GSM-R network - intentional jamming of the network (Mili et al. 2013).

European Train Management Layer ETML and signaling system INESS

The ETML aims to standardize the interfaces between railway companies so that the exchange of operational

data is possible, especially for cross-border train connections. The system will allow data to be shared between participating railway undertakings in terms of position, expected schedule, delay information and reasons, and estimated arrival times. These data are sent directly from the respective national operations centers to ETML headquarters in Vienna/Austria. The prepared data is available for all railway companies through a web interface via virtual private network access after registration (Winter 2009).

The aim of the INESS is to develop a uniform data format and a standard of requirements for interlocking systems. Since the interlocking transmits movement authorities via the RBC to the trains, controls the track switches or establishes direct communication with the drivers via GSM-R, the interlocking is highly security-relevant. The interlocking computer forms the interface between the dispatcher and the track-side ETCS equipment and RBC and consists of two independently operating computers (Deutsche Bahn AG 2016). They process the data entered by the dispatcher and pass their results on to a comparator, which checks whether the results match, after which the safety-relevant switching process is carried out. The display on the screens is also generated and calibrated by two computers. If there is no match, the display starts flashing and shows the lack of signal security. In addition, a second configuration with two computers or more computer is provided as hot standby (Fendrich and Fengler 2013; Maschek 2013).

Since INESS-compliant interlockings are still in development, it is only possible to draw general conclusions on security issues. In addition to the susceptibility to attacks by means of social engineering, attacks by introducing infected hardware - also by insiders - are conceivable. Attacks can also directly target the integrity and authenticity of the circuit diagrams displayed, the forwarding of switching commands and, last but not least, the availability of the entire interlocking system (Gordeychik und Timorin 2015).

CRITICALITY ASSESSMENT

The vulnerabilities described in the previous sections must be evaluated with regard to their criticality in a subsequent step using criteria. These criteria must be developed in close consultation with information technology experts and with the public transportation authorities. The intended methodology is based on a methodology developed as part of the RiKoV research project. Within the framework of RiKoV, a methodology for scenario-based vulnerability and risk assessment of terrorist threats was developed at the Cologne University of Applied Sciences in cooperation with the Karlsruhe Institute of Technology (Brauner 2017). This methodology will be briefly introduced in the following section.

INTRODUCTION OF THE RIKOV METHOD

Vulnerability in RiKoV is determined using a semi-quantitative approach, which evaluates the effect of preventive security measures according different scenarios and the hazard category of the target object. These two factors then determine the scenario-specific vulnerability of a target in a public transportation system.

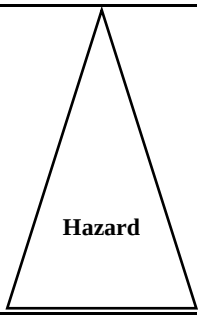
This approach has been designed in order to be applicable to different target objects, which makes it suitable for a transfer into this research. The system to be considered was defined with its direct environment as an observation space and evaluated for the four aspects of performance, structure, environment and time with a number of indicators.

These indicators can be rated with one to three points each and then add up to a risk score. This score is between the minimum of 11 and the maximum of 33 points (cf. Table 2) and will then be ranked in one of seven hazard categories using Table 3, whereby category 1 is the highest hazard category and category 7 the lowest. The numerical value of the hazard category is then used in a formula to calculate the vulnerability of the target object in combination with the qualitative effectiveness of selected preventive security measures in the environment (Brauner et al. 2014).

Table 2. Indicators for the determination of hazard categories (Brauner et al. 2014)

Aspect	Hazard indicator	Score		
		1	**2**	**3**
Performance	Number of travelers (per day)	Low	Medium	High
	Number of trains in service	Low	Medium	High
Composition	Number of floors	1 floor	2 floors	>2 floors
	Tunnels	Non-Existence	-	Existence
	Bridges	Non-Existence	-	Existence
	Geographic peculiarities (river, mountain, …)	None	-	Existence
	Supply facilities (electricity, consumables, …)	None	-	Existence
Environment	Special buildings with symbolic effect (cultural, political, religious)	None	-	Existence
	Direct airport connection (area proximity)	None	-	Existence
	Local attack relevance (official warnings, assessments by Federal Agencies)	None	Medium	High
Time	Major events (high fluctuation in the number of travelers)	None	Rare	Frequent
	Total score:	**Min./Max.: 11/33 points**		

Table 3. Hazard categories (Brauner et al. 2014)

Hazard category	Total score	Hazard
7	11 – 13	
6	14 – 16	
5	17 – 19	
4	20 – 22	
3	23 – 25	
2	26 – 29	
1	30 – 33	

Since the RiKoV approach presented above with its indicators only refers to physical infrastructures, it is necessary to develop a new set of indicators for assessing the vulnerability of information technology systems. This forthcoming work will be carried out in consultation with public transport operators and information security experts. The results of the literature research presented in this paper and the deficiencies found in ERTMS provide the necessary theoretical basis for such research.

CONCLUSION AND OUTLOOK

The authors demonstrate that, although numerous security measures have been implemented in the ERTMS, there are still some security problems and correspondingly vital threats to the protection targets. These have so far only been investigated separately and not yet described for the entire ERTMS. The extension and adaptation of the current RiKoV approach will therefore be a first step towards a comprehensive systemic vulnerability assessment for cyber-attacks on the ERTMS.

When developing a set of indicators, it should be noted that the selected criteria can provide a holistic picture of vulnerability and that the weighting takes into account the needs of end-users. In addition, the evaluation of the security flaws identified in this paper has to be carried out by experts in a real application-scenario and corresponding ambiguities need to be clarified in a panel discussion among experts. The practical application on the basis of a real example, taking into account the existing security measures, may be considered in cooperation with the Cologne Public Transportation Services.

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Track 6

Geospatial Technologies and Geographic Information Sciences for Crisis Management (GIS)

Mapping Mobility to Support Crisis Management

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ABSTRACT

In this paper we describe a method and an infrastructure for rapid mapping of mobility patterns, based on a combination of a mobile mobility tracker, a large-scale data collection infrastructure, and a data and visual analytics tool. The combination of the three enables mapping everyday mobility patterns for decision makers, e.g. city council, motorways authorities, etc. and can support emergency responders in improving their preparedness and the recovery in the aftermath of a crisis. The technology is currently employed over very large scale: (i) in England it is used by a public body to incentivise physical mobility (400,000 app downloads and hundreds of millions of data point since September 2017); (ii) in Sheffield UK, through the MoveMore initiative, tracking active mobility of users (5,000 downloads); and (iii) the European project SETA, to track multimodal mobility patterns in three cities (Birmingham, Santander and Turin).

Keywords

GIS, mapping, mobility tracking, large-scale data and visual analytics.

INTRODUCTION

A detailed understanding mobility pattern is a major need for emergency responders and in general for decision makers such as city councils, governments, etc. Apart from the importance for the day to day management of the territory, large environmental emergencies (e.g. storms, earthquakes, flooding) affect mobility first and foremost which in turn affects life and the economy of the area, as well as the ability to bring emergency relief where needed. People tend to have very regular mobility patterns and altering adjusting mobility behaviour to deal with crisis events can be problematic, particularly when the crisis can disrupt the usual mobility infrastructures. Rapid mapping of the changes in mobility allows a range of benefits: from planning changes to provision of services, to planning of remedial actions, etc. Mobility issues can have a major impact on the effectiveness of crisis management, as it can impact on the effectiveness of response and relief operations, and in particular evacuations (Wang and Taylor, 2016; Pan et al; 2007).

There is however a lack of studies on how mobility patterns can be studied to support crisis management. Most studies concerning human mobility patterns and crisis management are focused on prediction models (Yan et al; 2014; Ye and Chen 2013) and tend to focus on a specific type of disaster or disease (Cova, 2005; Eubank et al, 2004). The collection methodologies for human pattern analysis tend to vary between household surveys, census data and more efficient and powerful techniques such as crowdsourcing, mobile phone GPS data (Yan et al; 2014) and social network data (Song et al, 2014). Mobile phone billing data has been used by Bagrow et al (2011) to track communications between individuals during emergency events. Crowdsourcing techniques have

been employed to analyse group activities and behaviours in emergency situations using aggregated mobility patterns (Cardone et al, 2013). Song et al (2014) have worked on analysing individual movement data extracted from Twitter to study population movements after the Great East Japan Earthquake to predict population movements in urban areas impacted by the earthquake.

Previous studies have focused on discovering motorised mobility trends and do not discuss different types of mobility and their associated behaviours (e.g. walking vs driving). Studies on pedestrian behaviours have been carried out in the past, mostly using manual survey techniques (e.g. direct observations, photographs, surveys, etc.) for simulation purposes.

Standard world-wide emergency protocols are based on predefined response and evacuation plans to provide response and relief. Although these plans are carefully constructed, taking into account all potential risks and mitigation strategies and working towards optimization of resources, they may fail when dealing with unpredictable human behaviour (Wang and Taylor, 2016). Previous studies analysed the impact of mobility conditions on the success of evacuations from wildfires, demonstrating how traffic queues and road blockages caused people to lose their lives (Church and Sexton, 2002; Cova, 2005).

Human movements can be efficiently tracked on a very large-scale using low-cost sensors integrated in smartphones – analysing this data can enable the detection of patterns and situations that can influence mobility (Zhang et al. 2014) and therefore can impact crisis management, as they can collect high granularity mobility data from hundreds of thousands of citizens. This data can be qualified and quantified, i.e. it is possible to collect detailed geolocated vehicular and active mobility (walking, cycling, running, etc.) so to allow insights well beyond simple location patterns, and to extend tracking to multimodal mobility and life patterns, inclusive of analysis of stay points (where people carry out activities), purpose of travelling (shopping, commuting, free time, etc.), usage of infrastructures such as shopping centres, etc. This would allow a very detailed assessment of the everyday life patterns as well as their changes in the face of crises.

This work aims to identify patterns of human movements in rural and metropolitan area by collecting data from apps that track movements for different purposes (e.g. health and wellbeing and sustainable mobility, with explicit acknowledgement of data reuse in the Terms and Conditions of the apps) and by using large scale data and visual analytics techniques to support decision makers, in particular to both support the next generation emergency plans, and to assess the effect of a crisis. Collected data could also be used as input to simulation algorithms.

In this paper we describe and discuss a large-scale framework for mobility patterns tracking. The framework is composed of a mobile tracker (Android and iOS) that has been distributed to citizens and volunteers as an add-on to existing apps, a distributed large-scale data collection architecture and a data and visual analytics tool. The framework allows mapping mobility in normal times, but has the potential to become key to support emergency response and reconstruction after a crisis, providing (i) quasi real time situation awareness on the ground; (ii) qualifying and quantifying the effects of the crisis by comparing patterns pre and post crisis (iii) gauging the effectiveness of the recovery action by quantifying and qualifying the level of return to normality.

The framework has been used in real world applications, collecting hundreds of millions of data points from hundreds of thousands of citizens as part of three mobility tracking programs: (i) a public body in England (which we cannot name for legal reasons) is using it to support better physical mobility in the population. The resulting app has been downloaded over 400,000 times and the infrastructure has collected over hundreds of millions of data point since September 2017. (ii) MoveMore, in Sheffield, UK, has released it to track the physical mobility of the citizens of Sheffield (5,000 downloads). (iii) as part of the EU project SETA, the infrastructure is being used to track multimodal mobility patterns in three cities: Birmingham, Santander and Turin, where its potential for planning has been tested and successfully verified by local decision makers.

In this paper we describe the methodology, the architecture, the release to hundreds of thousands of users and the results of the preliminary release as part of the SETA project.

REQUIREMENTS

Awareness of transport network conditions and mobility patterns are of fundamental importance for all phases of emergency management, from preparation to response to recovery. In particular government emergency organisations have a duty to consider transport in terms of:

- Devising strategies for evacuations
- Facilitating fast, flexible and effective response and recovery
- Gauging the level of recovery and return to normality

To understand requirements for the infrastructure, we have consulted with decision-makers from three European cities (Birmingham, UK; Turin, Italy; Santander, Spain) during stakeholders workshops for the EU project SETA[1] and we have derived the following requirements:

- High granularity, widespread coverage of mobility patterns: while most of the knowledge about mobility patterns tend to be concentrated on major roads, knowledge of minor roads is less common. It is however fundamental to be able to collect rapidly detailed mobility patterns at very high granularity (i.e. both major and minor roads, both central urban and peripheral rural areas, etc.) so to have complete picture of the situation and to plan urgent and planned remedial actions.
- Tracking different types of vehicular mobility as well as active mobility (walking, cycling, etc.): understanding the modes of transport used in different areas and moments could prove of fundamental importance during and after a crisis, when availability of certain means of transport may be restricted (e.g. major roads are closed, railways are unavailable, etc.). Being able to track the way people move (e.g. building rapidly typed (by vehicle) Origin/Destination matrices and trajectories) would allow rapid appreciation of the effects of the crises, understanding changes and needs of the population, etc. This will allow analysis of the impact of any disruption, well beyond the effect of simple transportation, to inform a number of stakeholders on e.g. effects on everyday life patterns, usage of infrastructures such as station and shopping centres, etc.
- Resilience: to be useful in an emergency a tracking solution must be robust to communication loss in the affected areas, providing caching and a distributed data collection architecture to be deployed locally and/or in the cloud;
- Energy and data conscious: any technology running on citizens' phones must be low impact with respect to the user's phone availability, in terms of battery usage and data allowance. In this way, any emergency app can be kept on the user phone indefinitely, available to collect data when needed.

FRAMEWORK

Our solution is composed of:

(i) A mobile data collection tool (iOS and Android apps) that has been distributed to thousands of citizens and able to track their mobility in terms of geo-located patterns (walking, cycling, use of vehicles, etc.). Movements are also qualified in terms of intensity (intensity of walking, speed of cycling and vehicles, etc.). The tracker works in the background and comes as a self-contained library that can be included in any existing application; there are three apps currently available for download from the iOS and Android app stores that include the tracking library: SETA[2] and MoveMore[3].

(ii) The data collection architecture achieves a combination of scalability, efficiency and flexibility for mobility Big Data management. The resulting infrastructure created is distributed, scalable, highly robust, able to handle huge number of sensors (**>500,000** users), processes multiple high velocity data streams (avg. **500,000** daily requests), and provides scalable and reliable backend for mobile applications (with **0.247ms/12.6ms** minimum/maximum response time, serves **>24 million/day** query and **>1 million/hour** query, with **>30K/hour** write throughput[4]). The Service-Oriented Architecture (SOA) is developed and further scaled out to provide real-time read and write access to structured and semi-structured big data. The leading-edge computing technologies developed allow the balancing of data collection and distributed processing performing on both local servers (near the source of the data or locally) and remote cloud servers.

(iii) A data and visual analytic platform that enables to identify mobility patterns from large scale GPS data traces; in terms or path usage, stay points, area-to-area mobility (i.e. Origin/Destination matrices).

In the next sections we will go into the details of each module.

Mobile Tracker

The tracking technology is implemented as a low power library that can be added to different types of

[1] setamobility.eu

[2] https://itunes.apple.com/us/app/seta/id1195607470 / https://play.google.com/store/apps/details?id=oak.shef.ac.uk.abstractcityactivity

[3] https://itunes.apple.com/gb/app/movemore-sheffield/id1093481731 / https://play.google.com/store/apps/details?id=uk.ac.shef.oak.ActivityRecognition.WeSenseIt.MoveMore

[4] Numbers are from our AWS master database nodes based on the statistics in December, 2017

applications, such as mobility apps, health and wellbeing apps, routing apps, etc. It runs in the background and senses mobility features through a range of sensors (e.g. step counters, activity recognition, accelerometer, gyro, etc.) as well as from location services (GPS, network, etc.). It fuses the data to create geolocated multimodal mobility segments (user trips), which are then sent to the central server. The tracker is designed to identify both vehicular and active mobility (walking, cycling, running, etc.) so to allow insights well beyond simple traffic patterns, and to extend tracking to multimodal mobility and life patterns, including the analysis of stay points, purpose of travelling, usage of infrastructures such as shopping centres, etc.

The underlying algorithms include sensor data collection, data fusion, as well as segment identification, classification and fusion. The library is generic and provides a set of combinable logics to track mobility according to needs: for tracking vehicular mobility, for tracking walking and running, for tracking cycling, etc. They are composable, so applications covering different types of mobility are possible, while allowing the creation of strategies for specialised trackers (for example we recently created an application optimised for cycling detection). On top of these, sit the data processing methods for specific applications, i.e. user services based on the detected patterns, such as stats and motivational messages for health and wellbeing apps, routing, mapping for mobility apps, etc.

The tracker is designed to work 24/7 with limited impact on the battery so not to affect the phone's availability to the user, which is crucial during emergencies but is equally essential for everyday life. The app works unobtrusively in the background tracking mobility while turning itself off when the user is inactive. The sensors accessed are low power and their activation is based on consumption levels: for example only one type of sensor is active when the phone is still and these have virtually no power consumption. An example of these is the Significant Movement Detection Sensor, which is centrally managed by Android and hence low cost battery-wise. Location tracking, a major source of battery drain, is optimised in terms of frequency of polling, as well as via use-only-when-strictly-needed strategies. For example, dynamic geofencing (Pongpaichet, 2013) is used to restart geolocation only if specific conditions are met (e.g. the user is leaving the area where they stopped): geofencing is a technique that allows to set a trigger when the phone moves inside or outside a geographic area of fixed radius (e.g. 500m), it uses low power strategies based on network information rather than full location services. Geofences are set dynamically every time specific conditions are met, e.g. the phone has been still for a period of time. We also make reuse of already detected locations: the phone regularly polls locations for its own use and we always reuse any location when it becomes available through other apps, avoiding turning off the GPS. We can also vary the accuracy of location detection according to needs: for example if a user is following a previously recorded frequent pattern, there is no need for precise geolocation and tracking if the timing and the way of travelling is compatible with the previous patterns, as there is no sensible change. The exact location can be predicted from previous data. This brings high battery savings.

Data sending is also a major source of power drain in mobile phones. This is optimised by the tracker: sending of large chunks of data is preferred over frequent sending of small packets; so during normal periods and when following usual patterns, data is sent infrequently (e.g. every six hours), hence reducing considerably power usage. During specific periods (e.g. emergencies) or when moving through dynamically defined geofences, data can be sent in real time, if necessary.

The algorithms interpreting the sensor data are based on a cascade of weak classifiers fusing and cleaning sensor data polled at regular intervals (depending on application but typically a few times a minute) to create larger aggregates of coherent single mode activities (e.g. vehicular segments) that are then combined into multimodal segments (e.g. walking, followed by vehicle, followed by walking). Methods used are low and high pass filters[5] to clean sensor data, maximum entropy modelling and weighted moving average for aggregation, as well as Kalman filters for trajectories. These methods are designed to provide reasonable results to the user in real time, while using limited battery power: data is then sent to the central server where it is analysed with more powerful algorithms to provide full scale accuracy for decision makers (se below).

The tracker has a local database where data is stored when communication to base is impossible, which is a frequent event in everyday life (especially in rural areas) and of course during crises. Network availability polling is performed strategically to avoid sending data (and using both power and data allowance) when connection is unavailable or unreliable.

Precision of tracking has been verified by an independent testing company, as well as by the usage by hundreds of thousands of users.

Data Collection Architecture

[5] https://www.w3.org/TR/motion-sensors/

Figure 1 shows the general architecture of data collection infrastructure. Because the user mobility data are geographically distributed and produce multimodal and multidimensional data at high rates, a distributed data management infrastructure is required. In emergency situation, with this architecture, data can be stored near its source, and data processing and filtering can be performed locally, and synchronised to the central server at a later time. Such an architecture reduces bandwidth requirements and enables parallel processing of high volume streams. Although queries can be posed from anywhere in the world, in practice the requester and the data of interest will be in a proximate geographical region (for example, local city council will query data about citizens in their vicinity).

Meanwhile, Cloud computing technologies play a pivotal role in the infrastructure and offer a solution to coordinate, integrate and manage large volume of data stream. The major part of infrastructure is hosted in a public cloud (Amazon's *Elastic Compute Cloud*, EC2), where a virtual data centre/cluster is created. This is based on the consideration that multi-dimensional spatial indexing, data/request load balancing, and data clustering can be quickly combined and deployed so that the performance can be optimised effectively across the clusters with low overhead cost. Specifically, *Amazon Route 53* is adopted as DNS hosting solution, which provides reliable and cost effective way to route web and API requests to our RESTful based application layer. Then, Amazon' *Elastic Load Balancing* automatically distributes incoming traffic across multiple EC2 web servers. Multiple web servers are set up and take request assigned from load balancer. Every EC2 server runs a Node.js application managed by PM2[6], and provides users with secure access to the application through an Nginx reverse proxy. To maximise requests throughput capacity, the data processing method is optimised by a asynchronous pipeline. The continuous stream of raw data is collected and immediately stored into a database (the "master" node in the figure). This process is to minimise the data collection latency and transmission errors (packet corruption or loss) due to various network and memory issue. The original dataset collected are extracted, validated, analysed and filtered asynchronously by a set of I/O and computation intensive extract-transform-load (ETL) tools (parallelized with multiple "processing nodes") in order to allow sophisticated data mining and pattern recognition. The solution of separating data collection and data ingestion splits two problems: 1) processing high velocity of data; 2) handling the value and validity of data. The formal problem concerns the speed of handling data stream and latter one focuses on the usefulness, quality and accessibility of the data. This becomes more important when data streams from multiple heterogeneous platforms and sources.

Concretely, the data collection infrastructure addresses four key challenges:

Query processing - For large-scale data collection, the "**master**" server must be write-intensive, high volume, and often time critical. The data that support emergency management is often multimodal (from spatio-temporal location readings to rich multimedia data), and the system itself will be heterogeneous in its mix of data processing platform, storage platform, communication capabilities, and administrative domains. The design of architecture enables low-latency continuous processing of data streams from geographically distributed sources. The engines on EC2 cloud provides sophisticated fault-tolerance, load-management, and federated-operation features for distributed data streams. "**Slave"** nodes serves as highly available read replicas and can be easily scaled out horizontally to more commodity servers on-demand (e.g., standard db.t2.large RDS instance used in our current infrastructure[7]).

Integrated processing - Traditional databases only support one-time queries over stored data. The system is designed to recognize the need to support integrated queries over live and historical data (see the "**Backup Node**" in the figure). Such query support is critical to help users understand new events in the context of pass observations, while ensuring high availability of live database. To enable queries over live and historical data, the infrastructure has additional ETL components to decide where to store data, how much data to store, what data to summarize, and when to discard data. Additional challenges are the data archive size and the high aggregate data rate, which can be mitigated by vertical and horizontal scaling, and the use of big data technologies depending on needs (e.g., replace the "Backup Node" with Apache HBase[8])

Reliability - It is well known in big data analysis that a large-scale architecture must have built in failure mode, as a subset of the nodes will encounter components and communication failures. Suddenly increasing the number of users can increase the failure rate of the server. Thus, the infrastructure is designed to quickly react to large-scale load variations and it provides redundancy so to avoid Single Point of Failures.

Data privacy and security - The sensor data must be highly private (for example, location information). A set of mechanisms has been developed to control access to this data, keep it secure, and regulate its use. First, no user identity information (e.g., phone number, name, home address) will be collected. Additionally, a security

[6] http://pm2.keymetrics.io/
[7] https://aws.amazon.com/rds/instance-types/
[8] https://aws.amazon.com/emr/details/hbase/

layer is built based on Secure Socket Layer (SSL) and Transport Layer Security (TLS) 3.0 protocol to the data with scalable and efficient encryption algorithms. SSL/TLS certificate is issued and used to establish identity and trust between server and client apps, ensuring privacy and security whenever communicating sensitive data. GPS data is never sent to the client, preventing any possibility of 3rd party requests for location information.

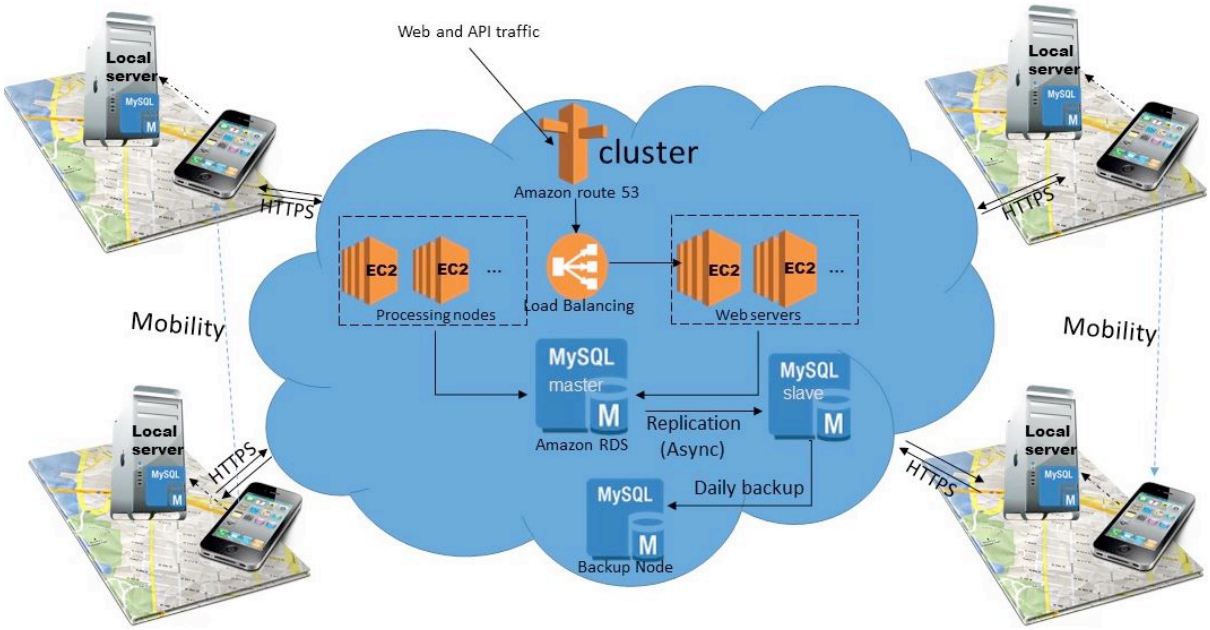

Figure 1: General Architecture of Data Collection Infrastructure

Data Processing

The server-side data processing mirrors a number of processes which are performed on the mobile device, however on the server there are fewer constraints in terms of processing power and time, and historic and population data can be considered. The server can be used to experiment with the algorithms for noise-reduction, activity recognition, etc. and these can then be transferred to the phone during the regular updates. The data analysis framework has four interacting sub-processes:

Noise detection and removal

The precision of a GPS signal is primarily affected by the quality and location of the GPS unit and the number and position of satellites, which produces both random and structural noise. The noise detection process involves identifying GPS traces, which are both feasible and expected, i.e. removing outliers, determining common paths, etc.

Stay-point detection and clustering

Identifying the journey start and end points, as well as intermediate stops and mode transitions is a crucial process in determining mobility patterns. In general, a stay-point is defined in spatio-temporal terms, i.e. a GPS signal staying in a given location (e.g. within a circle) for a given about a time using experimentally fine tuned threshold values for location size and duration of stay. The stay-points are then clustered together, currently clusters are defined by postal regions, in the UK these have four levels of granularity: (~1.75 million) units, (11,199) sectors, (2,983) district and (124) areas. The clustering of stay-points allows for the creation of Origin-Destination matrices, which, given the various levels of granularity, allows for the analysis of intra- and inter-urban movements.

We adopted the PIE algorithm (de Graaff et al, 2016) and the algorithm proposed by Li et al (2008) to extract stay points from user trajectories. The steps to extract stay points from user trajectories can be seen in the algorithm 1 below (Figure 2).

Algorithm 1 Stay Point Detection

INPUT:
1. *UT* = list of user trajectories {<lat,lon,t,seg>, <lat,lon,t,seg>, ...<lat,lon,t,seg>}
2. *eps*, the stay point distance threshold in meters
3. *t*, the stay point duration threshold in millisecond

OUTPUT:
1. SSP = {sp_1, sp_2, ..., sp_m} the list of semantic stay points
2. Clustering of Stay Point

ALGORITHM:
for each user **do**
//Remove inaccurate locations that greater than the average of accuracy
listLocationsPoints = $\{l_p \in UT \mid l_p.a \leq avg(a)\}$

//Get candidate stay points for each day
listCandidateStayPoints = *getCandidateStayPoints (listLocationsPoints, eps, t)*

//Get centroid of stay point by computing mean of stay points
listStayPoints = *computeMean (listCandidateStayPoints)*

//Generate summary of stay point (occurrence, days, duration)
listSummarySP = *generateSummarySP (listStayPoints)*

//Add semantic to the stay points by considering spatial relationship
//with Point of Interest and Postcode
SSP = annotateStayPoint(listSummarySP)

$$\{sspI \in SSP \mid distance(sp, polygon) = 0 \vee distance(sp, polygon) < eps \vee distance(sp, point) < eps\}$$

findClusters(SSP)

Figure 2: Algorithm to extract stay points

In this algorithm, the sequence of locations is retrieved from all user trajectories. Noise points are filtered based on the most frequently occurring (or an average) of location accuracy in the data. The daily stay point candidates are identified based on two parameters, distance and duration threshold (i.e. dist=30 metres and dur=5 minutes). The distance between two location points is calculated by using the Haversine formula. The centroid is calculated to get only one point in each stay point. Regarding spatial and time regularity, we keep the frequency, day, arrival and leaving time features. Finally, the algorithm produces a summary of stay points that consists of the significant places, duration, day and frequency. Furthermore, stay point is enriched with information such as land-use type and postcode.

All user stay point are aggregated and clustered by time, day, or certain period to understand what people tend to do. The changing of stay point patterns identified before the disaster and those recorded after the disaster is critical to know the people go to other places during the crisis/disaster. Figure 3 shows the heatmap of stay points (on weekdays and weekends), with the location's colour intensity determined by the number of times that location is allocated as a stay point.

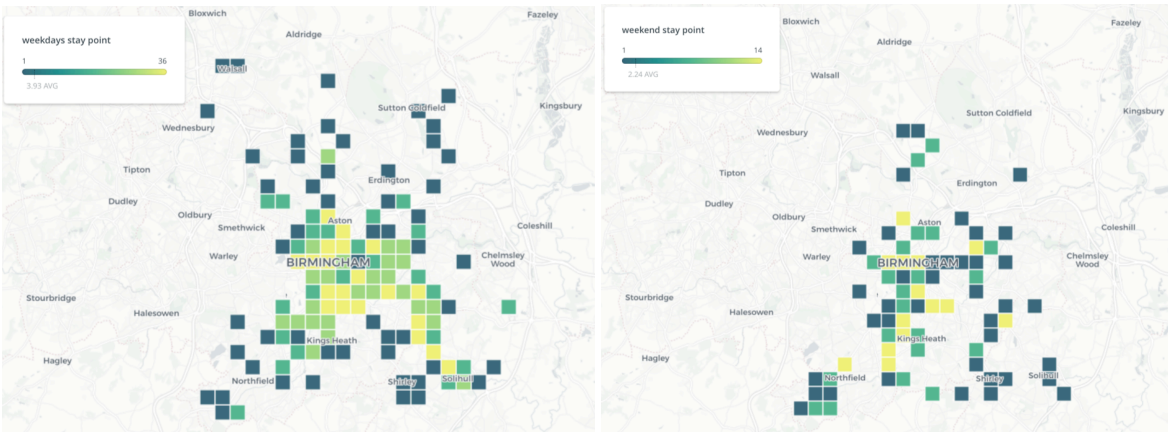

Figure 3: Distribution of Birmingham stay point for weekdays (left) and weekend (right)

Mode detection

Identifying whether, when and where people use the various modes of mobility, i.e. walking, running, cycling or using private of public vehicles is fundamental to understanding how populations can respond to emergency situations. For example, is the population reliant on public transport and the road network; activity modes are slower but less affected by disruption and congestion, as shown by the increasing use of Cycle Response Units in urban areas. The server mode detection using the user's history sensor data (GPS, steps, etc.) and the combined data from all users to determine the most likely mode of travel.

Map Matching

The assigning of the given (inaccurate) GPS location to the most likely path requires considering the mode (i.e. vehicles are largely limited to roadways unlike cyclist or pedestrians) and the most likely route given all the GPS locations allocated to a single journey. The A* graph traversal algorithm is used to find the minimum cost route between the journey start and end points considering all the intermediate locations on the journey. The path does not have to pass directly through the intermediate locations, but instead within the circle around the locations with the radius given by the GPS accuracy (provided by the GPS unit). The mode of travel determines the allowable paths. The cost of traversal is a function of the edge distance (of the path between intersections) and the frequency a path is travelled both by the user in question and the population as a whole.

Visual Analytics

The processed data, described above, is indexed in a high performance cloud-based faceted search engine[9], and visualised via faceted browsing interface, which allows an analyst to constrain and relax filters over the data to explore multiple dimensions of the data. To maintain security the data is stored on a separate server to the, Node.js, interface server. The interface server acts as a secure gateway to the data, and access is regulated by the rights granted to the visual analytics user profiles. For example, some users may only be able to view summary data, whilst other can drill-down to individual users. Figure 4 shows the interface focused on the city of Turin, with the map displaying the frequency of the paths taken, and the facets allowing the filtering of the data according to the journey mode, duration, date, day of week and hour of day. The Origin/Destination matrix can be used to filter the journey to those to/from given areas. The interface also animates the flow of the population, providing an understanding of the movement over time.

The map also provides visualisation of the location data as a heatmap. The locations are indexed using geohashing, which divides the Earth into a hierarchical grid structure, by selecting the appropriate hierarchy level (given the map zoom level) it is possible to efficiently display 100s millions of location points. Figure 5 shows the comparison of common locations in Sheffield during the day versus the night. Such information is useful to know the distribution of the population during an emergency and therefore the number of people affected in each area.

[9] http://lucene.apache.org/solr/

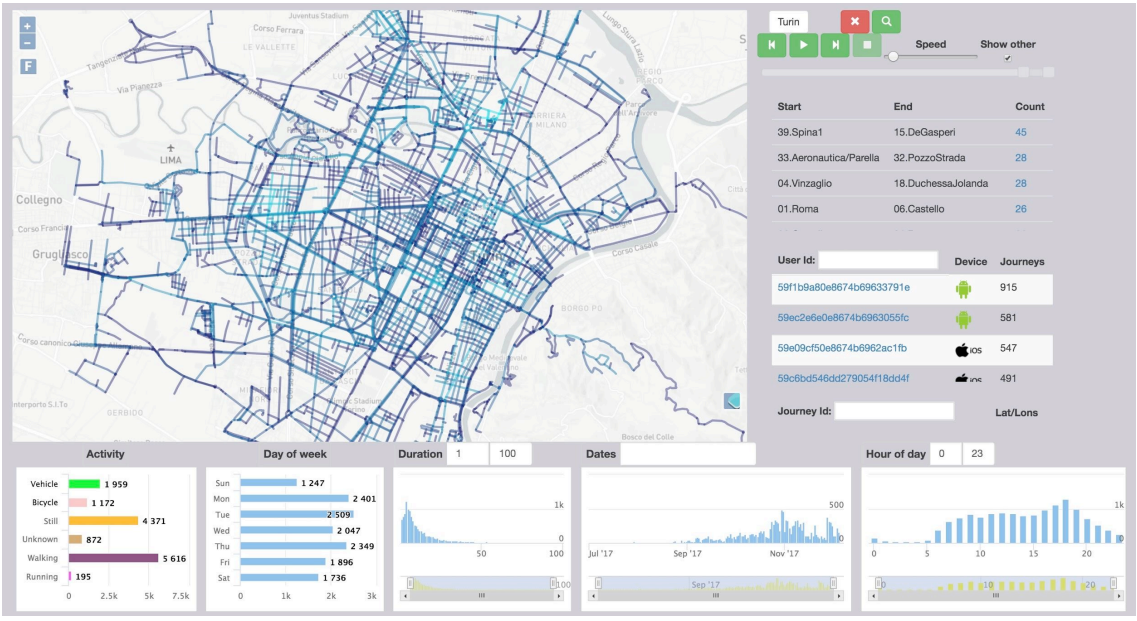

Figure 4: The visual analytics interface

Figure 5: The Birmingham locations heatmap for weekdays (left) and weekend (right)

Evaluation

The framework was evaluated in terms of:

- Usability and user acceptance of tracking application
- Usefulness and potential insights derived from the data collected and processed for emergency managers

The framework was formally tested as part of the EU Project SETA, focusing on assessing the app usability and the activity recognition capabilities. The app was distributed to a group of 59 users in Birmingham for use during October 2017. All the participants were invited to use the app for a prolonged period of time and ask to report any issues using the online reporting tool. The participants were also invited to complete an online questionnaire to report on the usability and precision of activity recognition.

There have been 315 users of the SETA app who have provided data for at least one journey in October 2017. Note that, as users are anonymous, it is possible that a single person can represent multiple users of the app. Of these 315, 59 (18.7%) have provided journey data in the Birmingham area, i.e. within the boundary box (52.38 >= latitude <= 52.61 AND -2.04 >= longitude <= -1.79). Those users produced 7,100 journeys; Figure 6 below shows the distribution of journeys per user (min=1, max=914, mean=120).

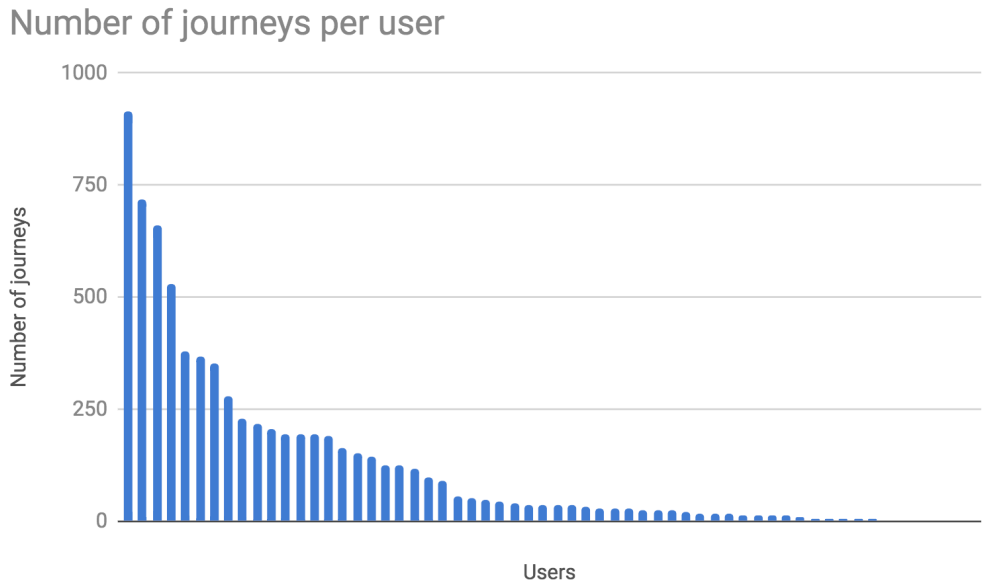

Figure 6: Number of journeys per users

Table 1 below shows the number and type of journeys taken by the 59 users. As can be seen although almost 25% of users had been running, they only had a mean of 4 runs per user, and therefore running was by far the least frequent activity. The most frequent activity was walking, with a mean of over 47 walks per user.

Table 1: Number of users, journeys and journeys per user for each activity type

	Users	Journeys	Journeys / user
Total	59	7100	120.34
IN_VEHICLE	56	1638	29.25
ON_BICYCLE	36	598	16.61
STILL	27	2186	80.96
UNKNOWN	21	253	12.05
WALKING	50	2369	47.38
RUNNING	14	56	4

The visual analytics interface was evaluated by a cohort of 11 stakeholders from specific teams of Birmingham City Council, including Data Analysis, Transport, and Health & Wellbeing teams.

In the following section we will present key findings derived from users' replies to the questionnaire. The questions were based on a Likert Scale from 1 to 5 where 1 = disagree/difficult, 5 = agree/easy. In general the system was well received and seen as "easy to use" and "well integrated". Aside from the general questions concerning the usability of the interface, there was a general agreement that the system provided insight into the understanding of activities in the city (mean=3.3), Figure 7 below.

During the focus groups the users were asked to evaluate the potential for the interface to offer insights on the mobility of the city and to highlight new requirements that would improve the usefulness of the interface. The users particularly focused on the importance of transparency, suggesting that the system should show the degree of accuracy of the map matching, journey segmentation and activity recognition. Whilst the system works by processing and analysing the data over large scale to present a visual interpretation, the users expressed the desire of seeing the "raw" latitude/longitude data. Another requests from the users was to use a different zoning/area systems, e.g. wards and electoral divisions, which requires the provision of area shape data or centroids, this is public data in the UK. This would also enable analysis of mobility data in terms of census ward data, e.g. demographic information. These functionalities have now been added to the interface and will be evaluated in the next phase on the project.

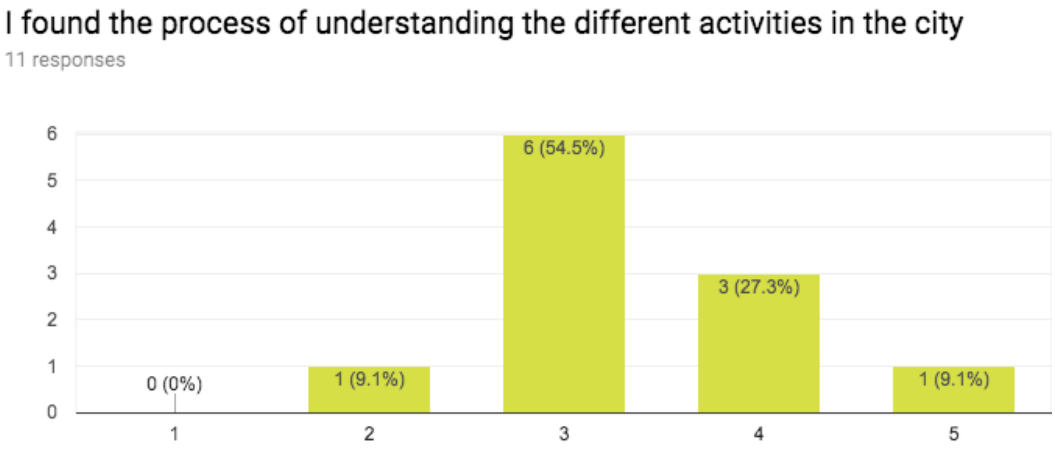

Figure 7: Understanding of different activities in the city

CONCLUSION

In this paper we have described a method and an infrastructure to map mobility patterns at high granularity over large areas. The method is based on a highly efficient tracker running on citizens' mobile phones and a large-scale data collection and analytics platform.

Although the infrastructure has not yet been used during crises, it has been used to track mobility of hundreds of thousands of users, studying their patterns of mobility in terms of Origin/Destination matrices, geolocated patterns, mobility means, etc. This allows decision makers to understand mobility during normal periods and to capture mobility patterns before, during and after crises, so to analyse details of any change in patterns, land use, use of infrastructure, etc. as a proxy to identification of changes in habits, unavailability of resources and infrastructures, road blocks, etc. which are very relevant to decision makers.

The tracker has been released to hundreds of thousands of users and the platform has collected hundreds of millions of data points over the past few months. Different incarnation of the data analytics platform have been used by a public body in England to derive patterns of mobility for health and wellbeing studies using the data of 400,000 users, by MoveMore in Sheffield, UK, to track and model active mobility of thousands of citizens over two months, running city wide competitions, including a workplace competition involving dozens of organisations and a derby between the fans of the two local football clubs. We are currently running a pilot city-wide workplace competition in Turin, Italy, involving hundreds of users where the data is used by planners and decision makers to support modelling of multimodal mobility in the city. Our evaluation with decision makers in three cities has highlighted that the data provided by the infrastructure is considered useful to identify mobility patterns and the framework is usable for planning both short terms and long term.

The infrastructure is very flexible and can be ported to different applications, each of them providing data for understanding mobility.

Future work concerns the improvement of the data analytics capabilities in order to further improve the data analysis and the visual analytics capabilities of the tool. Furthermore, we are planning on integration of the tools with a large infrastructure currently developed in the SETA EU project and that is being released to the mobility control rooms of three cities in Europe,

Finally, we expect to verify the usefulness of the framework for emergency management, by analysing the changing patterns of the mobility within a city caused by large-scale events, both planned (e.g. sporting, entertainment and protest events) and any unplanned (large-scale) events that occur within the study cities.

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Towards Using the Potential of OpenStreetMap History for Disaster Activation Monitoring

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ABSTRACT

Over the last couple of years, the growing *OpenStreetMap* (OSM) database repeatedly proved its potential for various use cases, including disaster management. Disaster mapping activations show increasing numbers of contributions, but oftentimes raise questions related to the quality of the provided *Volunteered Geographic Information*. In order to better monitor and understand OSM mapping and data quality, we developed the *ohsome* software platform that applies big data technology to OSM full history data. OSM full history data monitoring allows detailed analyses of the OSM data evolution and the detection of remarkable patterns over time. This paper illustrates the specific potential of our platform for disaster activations by means of two case studies. Initial results demonstrate that our flexible and scalable platform structure enables fast and easy information extraction and supports mapping processes and data quality assurance.

Keywords

OpenStreetMap, OpenStreetMap History, Disaster management, Street network analyses

INTRODUCTION

Up-to-date geodata is a valuable source of information in the aftermath of a disaster, e.g., to coordinate disaster response and to support routing and navigation in the affected areas. When using proprietary or authoritative map data, it is difficult to provide such up-to-date information. In contrast, openly accessible maps such as *OpenStreetMap* (OSM) enable collaborative and quick mapping of disaster-affected areas, thereby constituting

a valuable source of information. For example, after the Nepal earthquake 2015 more than 7 000 volunteers contributed map data to the OSM database using current satellite imagery (Radford 2015). The *Humanitarian OpenStreetMap Team* (HOT) coordinates such mapping activities through organized mapping tasks using the *HOT Tasking Manager* (HOT Tasking Manager 2018) and communicating the needs of the relief organizations and the affected population on the ground.

Over the last couple of years, OSM data repeatedly proved its potential for disaster applications, in the disaster response as well as the other phases of the disaster cycle (Palen et al. 2015; Dittus et al. 2016b; Eckle et al. 2017). The mapping activations that are supported by many volunteers with various levels of experience oftentimes raise questions related to the quality of the provided *Volunteered Geographic Information* (VGI). Learning about the data quality that can be expected in a disaster activation helps to evaluate the quality and fitness for purpose of the OSM data. For example, in the case of disaster routing, missing or inaccurately represented streets directly affect the routing quality.

Quality assurance mechanisms are directly integrated into the HOT workflow in the form of validations carried out by experienced volunteers. Furthermore, such evaluations can be carried out extrinsically by measuring the data quality of OSM in comparison to other data sets, e.g., proprietary or authoritative data (Haklay 2010; Neis and Zipf 2012; Neis, Zielstra, et al. 2013). While this method proved to be useful in providing measurable results, data to conduct such comparisons are rarely available for the areas of interest (Mooney et al. 2010).

Therefore, data quality assessments need to be conducted intrinsically by making use of the OSM full history data. These data sets contain all edits (being it additions, deletions or modifications of objects) that were made by the OSM community since the beginning of OSM in 2004. While these data sets offer a great variety of crucial information, their analysis is challenging due to the large amount of raw data and the evolving object taxonomy in OSM. In order to address these challenges, we develop the *ohsome* software platform that applies big data technology to the OSM full history data. This paper introduces the platform and illustrates its potential for disaster activation monitoring by means of two case studies.

RELATED WORK

Monitoring disaster activations has already proved to be of great potential for the mapping community itself, and for data users to get a better idea about the data quality. For the Nepal earthquake response in 2015, Anhorn et al. (2016) presented a framework to iteratively validate and update OSM objects. The study focused on the spatio-temporal dynamics of spontaneous shelter camps in OSM. Additionally, the accuracy of the mapping was analyzed using a crowdsourcing approach. Dittus et al. (2016a) also presented a monitoring approach analyzing the different levels of engagement of volunteers and the resulting impact on the data and user activity. As disaster mapping activations are oftentimes criticized for a lack of data maintenance, Quattrone et al. (2016) conducted a long-term monitoring study and assessed OSM data contributions in different countries. Besides monitoring during disaster activations, several post-hoc analyses and evaluations have been conducted, e.g., for Haiti 2010, Typhoon Haiyan 2013 (Zook et al. 2010; Soden and Palen 2014; Palen et al. 2015) and for the more recent activation in Nepal 2015 (Poiani et al. 2016; Soden and Palen 2016).

With the iOSMAnalyzer, Barron et al. (2014) developed a first framework for intrinsic OSM analyses and provided quality indicators for different use cases. Jokar Arsanjani et al. (2013) furthermore evaluated the evolution of OSM data to investigate specific patterns. First comprehensive intrinsic OSM data analyses related to collaborative disaster mapping have been conducted by Dittus et al. (2017), providing insights about mapper behavior, the mapping community and effects on the contributed OSM data.

Openly accessible OSM analysis platforms like OSM Analytics (2018) (a web based interactive visualization of OSM feature density) and EPIC-OSM (a collection of customize-able statistics over raw OSM history data by Anderson et al. (2016)) already provide some quantitative information about data contributions and contribution activity for, e.g., specific HOT projects, but do not provide a full picture of the history of OSM data. Existing software tools to support intrinsic data quality assessments are typically limited by offering only subsets of analysis methods, and/or operate only on small database extracts for a defined number of case study regions.

THE OHSOME OSM HISTORY ANALYTICS PLATFORM

OSM offers a large quantity of data that is also quite diverse in respect of feature variety and scale. One aspect of this is the free taxonomy scheme which is based on tags consisting of key-value pairs that are defined by the community itself. This causes the task of analyzing how the data evolved over time to be rather complex, also explaining the lack of general purpose analysis software until now.

The aim of the *ohsome* platform (Ohsome 2018) that is presented in this paper is to implement a distributed database and computing infrastructure that gives access to OSM history data and allows for fast parallel processing. In order to permit arbitrary spatio-temporal analyses, all information that is present in the original OSM history data set and all available metadata fields are herein considered. The *ohsome* platform is co-developed with the *OSM History Database* (OSHDB). The contained data is divided into spatio-temporal data cubes which may be distributed over a computing cluster infrastructure. In order to meet different user demands, the platform provides an *application programming interface* (API) at each of the following three abstraction levels:

- The *ohsome-API* implements a representational state transfer (REST) web service that permits one to interactively answer and visualize common predefined research questions and analyses. That is, the analyses may be conducted in a standard web browser. This API is most suitable for the general public and for non-programmers.
- The *OSHDB-API* exposes the MapReduce big data programming model (Dean and Ghemawat 2004) in the Java programming language. The Java-API is more flexible than the REST-API but still accessible with basic knowledge of the Java programming language. Most of the more advanced analyses can be realized using it.
- A low level *raw data access* gives even more direct access to the OSM data objects stored in the database and more fine-grained control over the data processing. However, a basic understanding of the internal database structure is required in order to interpret the results of a data request correctly.

Besides the above-mentioned focus on intrinsic data quality metrics, further application of the platform include exploratory data analyses such as visualizing OSM contributor activity and examining individual OSM objects, the analysis of OSM contribution patterns, or general geo-statistics and visual analytics. Possible applications of these functionalities and their potential are presented in the following two case studies. Their purpose is not to provide comprehensive scientific insights, but to illustrate the kind of analyses that may be performed for scientific investigations of OSM history data.

CASE STUDY 1: NEPAL EARTHQUAKE 2015

On April 25 and May 12 of 2015, two major earthquakes with magnitudes of 7.8 (36 km east of Khudi) and 7.2 (19 km southeast of Kodari) and several minor tremors hit the central part of Nepal. In this case study we use the *ohsome* platform to facilitate an exploratory analysis of the evolution of the OSM street network in the aftermath of the Nepal earthquakes 2015 in scope of the disaster mapping activities. Thereby, we focus on the OSM's fitness for use for disaster routing applications.

Common intrinsic quality indicators concerning the street network are completeness of the data set, positional and semantic accuracy and topological correctness (Neis and Zipf 2012; Barron et al. 2014). With respect to routing applications, topological errors in OSM data are described as one of the major challenges (Neis, Singler, et al. 2010; Sehra et al. 2016). For instance, junctions cannot be determined if intersecting OSM ways do not share a common node (Neis and Zipf 2012). Sehra et al. (2017) assess the street navigability of OSM data in Northern India using heuristic indicators and by analyzing road lengths as well as attribute completeness and semantic completeness.

In this case study the evolution of the OSM street network (OSM tag *highway*=*) is investigated for the Nepal earthquake 2015 based on the following quality indicators:

- Completeness: (a) street lengths aggregated for street categories and (b) percentage of streets which include street names (e.g., Sehra et al. (2017)),
- Topological correctness: (c) percentage of intersecting OSM ways that do not share a common node (d) percentage of OSM endpoints close (distance $\leq$ 1 m) but not connected to an OSM way (Jokar Arsanjani et al. 2013; Neis and Zipf 2012; Neis, Zielstra, et al. 2013),
- User activity: (e) Number of users that edited OSM streets (Neis and Zipf 2012).

We examine the topological correctness in monthly time steps for the year 2015, the completeness and user activity is investigated on a daily basis in order to evaluate the direct response phase. The results are presented in Fig. 1.

Volunteers started to map streets in OSM right after the April 2015 earthquake. Within seven days 3 619 OSM users added about 310 000 km to the OSM street network. The maximum number of contributors was reached two days after the event. Thereafter, the number of mappers decreased from more than 1 000 on April 27, to about 100 per

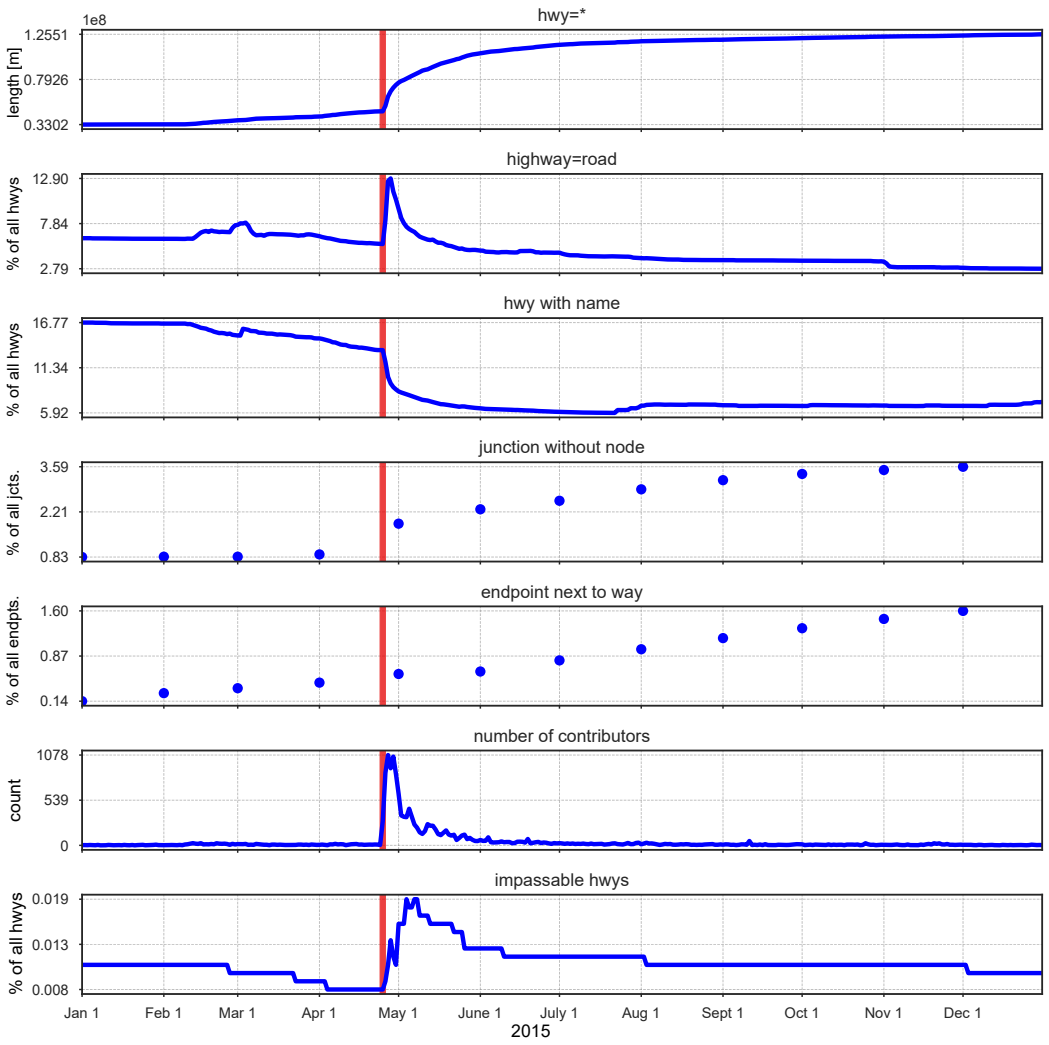


Figure 1. Intrinsic quality indicators, Nepal earthquake response 2015.

day one month later and about 25 contributors per day at the end of June. The Kathmandu district and surrounding regions are the areas with the highest number of contributions. Fig. 2 (left) shows the spatial distribution of the mapping activities and the area for which specific road mapping tasks have been defined via the HOT tasking manager.

Not only did the number of mapped streets increase, but also the number of topological errors (Fig. 2, right). A total of 2 018 intersecting OSM streets without a common node have been detected before the earthquake on April 1, increasing up to 6 332 on May 1. The percentage of such errors was relatively constant before the earthquake. However, topological correctness of the data set has been continually deteriorated after the event. Regarding OSM street categories we focused on the tag *highway=road*. This tag is considered to be temporary and is used for unknown or unverified roads (OSM Wiki: Nepal 2018). During the direct disaster response of the OSM community, the percentage of streets tagged as *roads* doubled from 6% to 12% within three days. This indicates possible semantic inaccuracies in the post-disaster OSM data set. However, the percentage of streets with the tag *highway=road* went back to 6% two weeks after the earthquake, meaning that the streets have been further edited and validated. Furthermore, we assessed the attribute completeness for the OSM key *name*. The percentage of streets with a *name* tag decreased from 13% down to 8% within 10 days after the earthquake on April 25. In contrast to the streets tagged as *highway=road*, not much editing was done in the post-disaster data set and the percentage of streets with a *name* attribute remained low throughout the year 2015.

Disaster relief routing applications rely on up-to-date OSM information. Thus, this information is crucial to effectively support relief organizations. This exploratory analysis shows that the collaborative mapping efforts provided a large amount of street network data after the Nepal earthquake 2015. In the direct-response phase this was achieved at the expense of data quality. However, contributors continued their mapping activities and corrected,

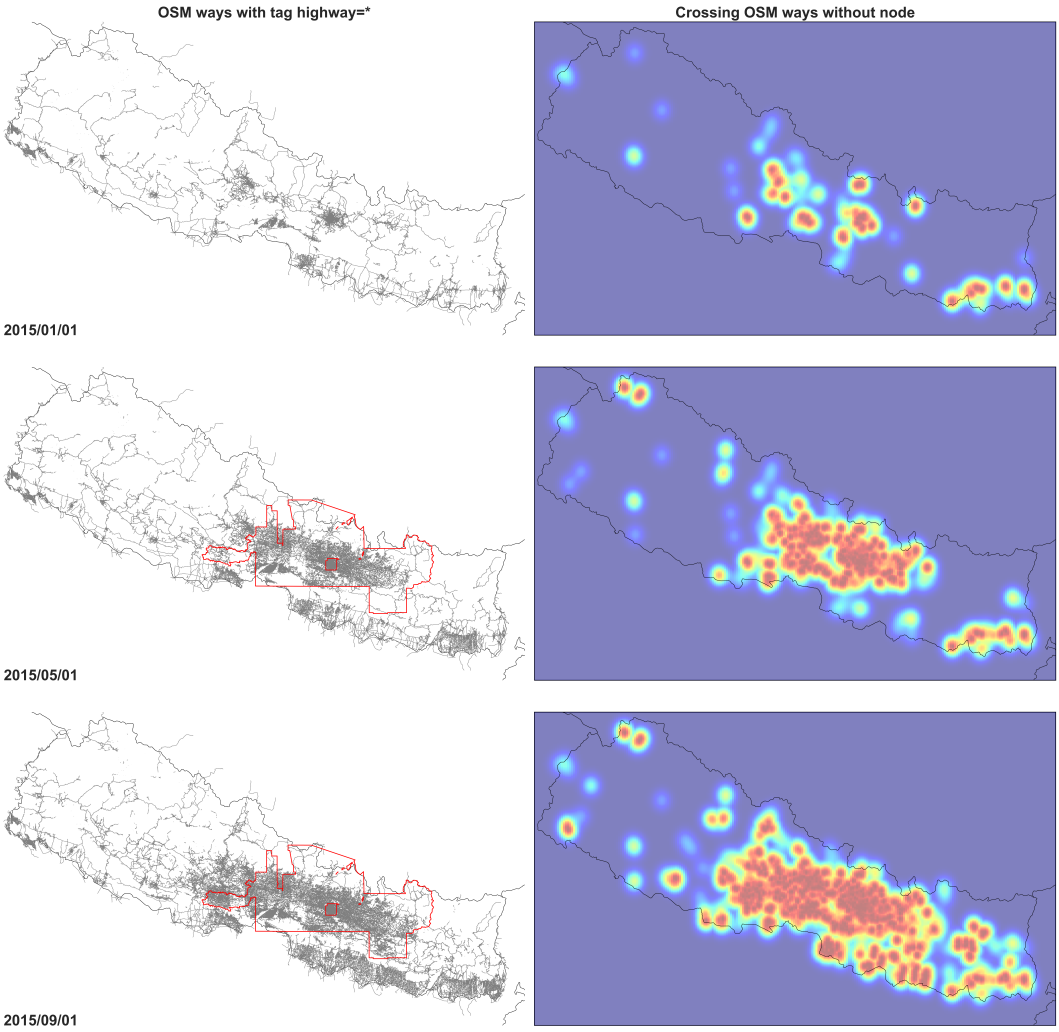


Figure 2. Evolution of the OSM street network in Nepal 2015; the extent of the HOT tasks which focused on street mapping is marked in red (left). Heatmap showing the density of crossing OSM ways without common node (right).

e.g., the possible semantic inaccuracies due to streets tagged as roads to a certain amount. The presented quality indicators were calculated in a few minutes, providing high potential for near-real time quality analyses and, thus, facilitating feedback mechanisms to the OSM mapping community that can help to address issues in a timely manner. This can help to improve data quality and, thus, applications like OSM routing services to support disaster response.

CASE STUDY 2: COMPARATIVE STUDY OF HOT ACTIVATIONS

As described above, HOT was activated for several disasters and provided their support with an increasing number of mapping volunteers over the last years. In each of these activations, main contributions are provided in the response phase of the disasters which generally lasts for more than four weeks after the launch of an activation. While the numerous contributions proved to be of great value for the coordination of disaster management, the VGI character of the data and the different levels of experience of the contributing mappers cause uncertainty regarding the usability of the data in the field.

These kind of questions can be addressed using the *ohsome* platform, e.g., by conducting a follow-up analysis to assess further changes and, therefore, validations that had to be conducted. To achieve this, we extract OSM objects that were added during the direct disaster response period and analyze changes that were applied to the data after the activation period. Because information about buildings and roads are often the most valuable for disaster response, we focus our analyses thereon. The three HOT disaster activations that were selected are the Haiti earthquake activation 2010, the Typhoon Haiyan activation 2013 and the Nepal earthquake activation 2015. While the Typhoon

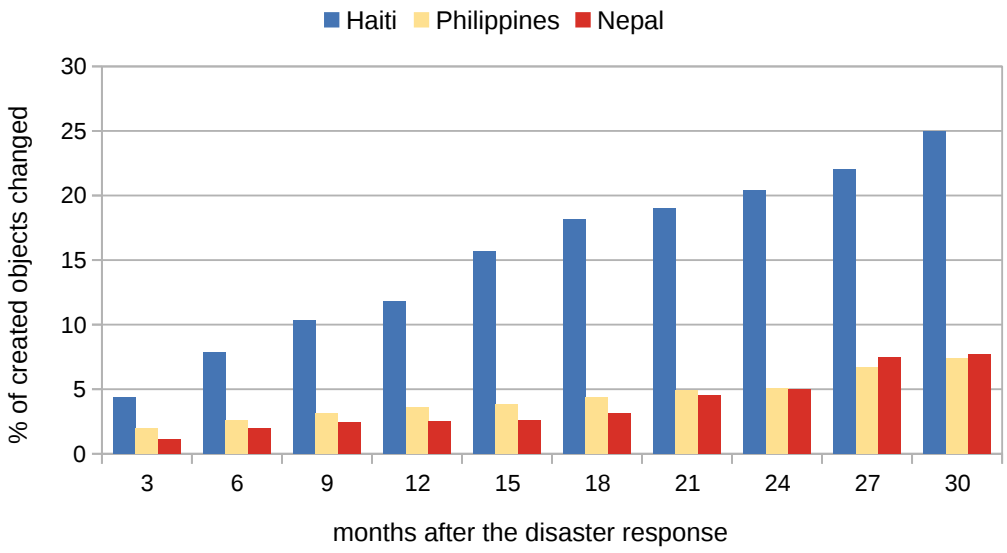


Figure 3. Comparison of changes to data that was created during activations (accumulated).

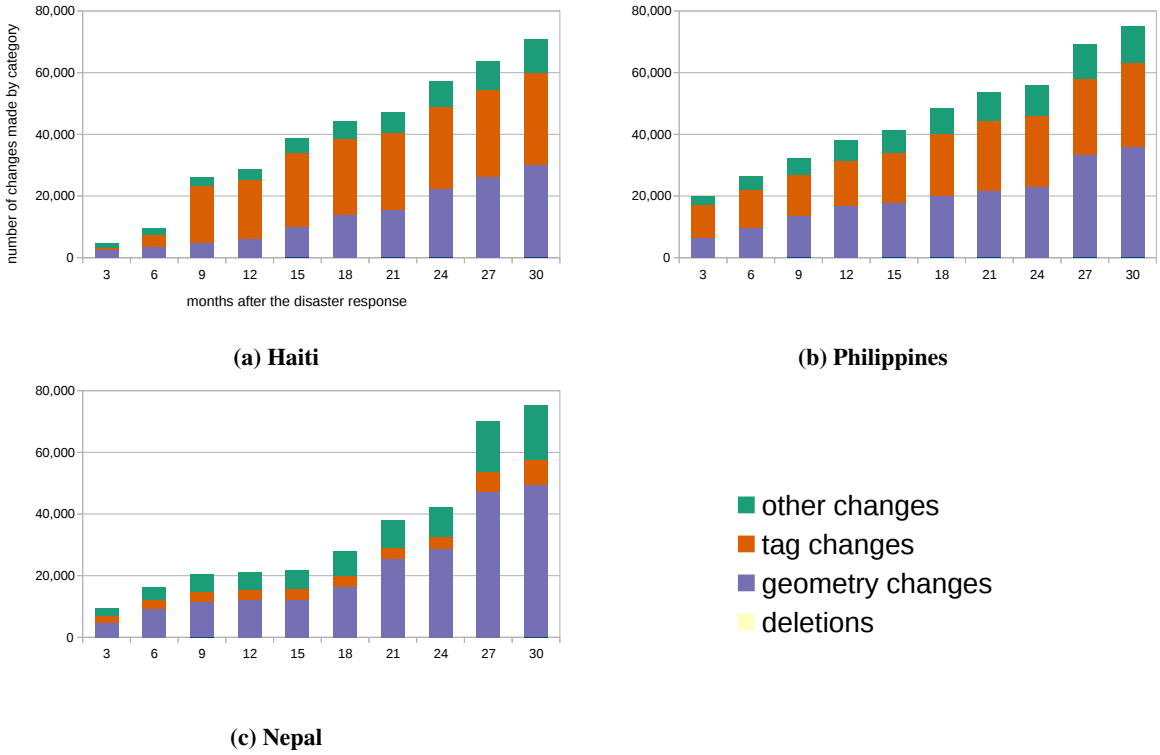
Haiyan and Nepal activation were among the largest in sense of contributors and scope, comparing these activations to the earliest activation in Haiti enables assessing possible developments of the mapping community over time.

Similar to the event-response on the ground, mapping also undergoes different stages of activity: pre-event, event, event-response and post-event. The three events are characterized through some key statistics for the respective periods. While the pre-event period shows average numbers of 0.94 (Haiti), 675.18 (Philippines) and 369.46 (Nepal) total contributions per day, these numbers rise to maxima of 12 156, 76 047 and 186 854, respectively, shortly after the event. However this has to be seen in relation with the total area of the countries (Haiti: 27 750 km^2, Philippines: 300 000 km^2, Nepal: 147 181 km^2 (Central Intelligence Agency 2018) as well as the amount of OSM-Data available at the start of the activation (Haiti: 1 653 elements, Philippines: 460 079, Nepal: 1 357 336). The three events are furthermore characterized through their respective activation outreach with Haiti showing a mean of 33 unique mappers per day during the event-response while the Philippines and Nepal responses both have averages nearly three times as high (Philippines: 96; Nepal: 81).

This exemplary follow-up study, run within minutes and with only little coding effort on the *ohsome* platform, can help to estimate, e.g., the quality of the added objects and the maintenance of the added data. Quality is high if the data does not need to be changed shortly after the event while maintenance increases the number of changes on the long term. Figure 3 shows the percentage of OSM objects created during the event-response period and changed during the post-event period for our three case-studies. This indicates that quality of the added data is high because a maximum of 15% of the objects were changed until one year after the event. The percentages in the more recent Philippines and Nepal activations indicate even higher data quality. At the same time maintenance seems to take place because these numbers still rise two years after the event. Speaking in total numbers 18 185 objects were changed in Haiti (Philippines: 42 747, Nepal: 46 720) within 30 months after the disaster activations. These changes were contributed by 233 unique mappers in Haiti while the Philippines were corrected and maintained by 943 and Nepal by 1 639 unique mappers. Hence while data quality rises, the number of mappers also rises whereby the mean contribution-share of each mapper decreases.

Furthermore, the *ohsome* platform was used to detect the type of edits that have been applied to the OSM data (see Fig. 4). Thereby possible patterns, the evolution of the data and differences between the three events can be investigated. Comparing the activations, variations in type of edits become apparent. Figures 4a and 4c show that most edits after the Haiti earthquake were tag changes, while most edits after the Nepal earthquake consisted in geometry changes. These patterns could represent the ad hoc character of the Haiti activation that caused a lack of coordination and structure, e.g., regarding tagging schemes, that had to be corrected afterwards. Less changes in the later activations could show experience in activation coordination and training, and therefore less need for corrections. On the other hand, frequently updated satellite data, used as mapping-aid can also lead to a high number of geometry changes if the alignment of imagery varies.

While *ohsome* cannot directly provide information about all factors influencing mapping in OSM, it enables detecting patterns that can then be further analyzed through qualitative assessments of the data and the activation



(a) Haiti

(b) Philippines

(c) Nepal

Figure 4. Number of changes by type for the three selected disaster responses (accumulated).

itself. Its combination with other data sets and contextual information can thereby in the future deliver further insights.

CONCLUSION AND OUTLOOK

We presented two case studies which demonstrate the potential of the *ohsome* OSM history analytics platform to extract valuable information from the OSM history data, including mapping processes and data quality related to disaster management. Due to its flexibility and scalability, the platform facilitates these kind of analyses of the OSM data evolution and the detection of contribution patterns in VGI data.

The exploratory analysis of the street network in the aftermath of the Nepal earthquake 2015 shows that the collaborative mapping efforts could provide a large amount of data within a short time. However, this was at first achieved at the expense of data quality. Additionally, the evolution of OSM objects that were added during the very active direct event-response phase was analyzed for Haiti 2010, Haiyan 2013 and Nepal 2015. The results indicate that maintenance of the added OSM data takes places as the total number of follow-up edits increases in the long term. Comparing the three activations reveals a higher percentage of OSM objects changed in the aftermath of the Haiti activation. This could represent the ad hoc character of the first HOT activation, whereas the more recent activations indicate a higher data quality.

The *ohsome* OSM history analytics platform is not limited to post-hoc disaster response analyses but can also be applied to gain deeper insights into OSM data at all four stages of disaster management (mitigation, preparedness, event, response). Likewise to disasters, OSM data itself changes during these phases. Such patterns and changes can be analyzed using our platform and enable addressing further questions related to recovery, preparedness and mitigation: Is the OSM data that was added and/or changed during the response period of an event maintained in and after disaster recovery? What influence does preparedness mapping have for disaster response and data quality?

Further extensions of the database and data analysis framework will make it possible to analyze the OSM data in respect to its metadata such as changeset attributes or user-to-user communication via OSM notes and changeset discussions. While in this study we have shown the potential of the OSM history platform for post-hoc analyses, future work will also facilitate monitoring OSM data contributions during disaster activation in near-real time. Quasi-live OSM data updates (by implementing a mechanism that applies OSM's minutely data updates to our database) will make it possible to create new tools that help to actively improve OSM data quality by providing feedback-loops between data producers and consumers. Timely data quality assessment during disaster response

can help to align training materials, coordination of mapping activities as well OSM-based applications like disaster relief routing.

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Conceptualizing the Role Geographic Information Capacity has on Quantifying Ecosystem Services under the Framework of Ecological Disaster Risk Reduction (EcoDRR)

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ABSTRACT:

The use of ecosystems such as the retention of water in wetlands to absorb storm surge for disaster risk reduction (DRR) is a beneficial and a viable option for community stakeholders. For example, ecosystems can mitigate the effects of hazards experienced in anthropogenic communities. Ecosystem services are the underlying reason for this benefit through their inherent process these services have the potential to significantly reduce the impact of a hazard. In terms of Disaster Risk Reduction, ecosystems can mitigate the effects of hazards experienced in anthropogenic communities. The use of ecosystems with regards to disaster risk reduction has been termed "Ecological Disaster Risk Reduction" or EcoDRR. EcoDRR is the idea of sustainable management, conservation, and restoration of ecosystems to maximize ecosystem services and reduce disaster risks and impacts. The use of geospatial technologies to monitor large scale ecosystems are often subject to Geographic Information Capacity (GIC), or the ability of ecosystem stakeholders to utilize all existing geographic information, resources, and capacities to monitor ecosystem services. For example, there are many geospatial tools that quantify ecosystem services in general, including InVEST, TESSA, and EcoMetrics as a few examples. Though these tools are useful, currently there is not a tool that specifically quantifies ecosystem services in the context of DRR. In this paper, we review current geospatial technologies that quantify ecosystem services. The main contribution of this paper is a conceptual framework intended to quantify ecosystem services in the context of EcoDRR. Ideally, future development of our proposed framework can form a scientific basis for informing communities, society, or organizations the abilities to quantify ecosystem services under the framework of DRR and understand how GIC factors into the efficacy of EcoDRR.

KEYWORDS

Disaster Risk Reduction, Ecosystem Services, Geographic Information Capacity, Hazards.

INTRODUCTION:

Importance of EcoDRR for Disaster Risk Reduction:

The use of ecosystem services in disaster risk reduction has been a viable option in certain cases over traditional engineered approaches. Ecosystems, by nature, carry out ecosystem services which continuously provide benefits to anthropogenic communities. Though definitions are vague, "ecosystem services are the aspects of ecosystems utilized, actively or passively, to produce human well-being" (Fisher et. al. 2009). These services, such as retention of water in wetlands and forests ability to retain soil, have to potential to provide significant hazard risk reduction and have been coined as "Ecological Disaster Risk Reduction (EcoDRR)" (Estrella et. al. 2013). The definition behind Ecological Disaster Risk Reduction is "the sustainable management, conservation, and restoration of ecosystems to reduce disaster risk and adapt to Climate Change with the aim to achieve

sustainable and resilient development" (Sebesvari 2017). It is important for decision makers that utilize EcoDRR to have a clear definition of ecosystem services initially and maintain that definition in order to prevent misconceptions in published literature and government documents (Fisher et. al. 2009). Monitoring these services in general, and in the context of EcoDRR is vital for policy and management, though there is a gap in the understanding of indicators and monitoring approaches for ecosystem services to compare them to other geographic regions (Cord et. al. 2017). The "supply and demand" of ecosystem services are spatially explicit and vastly differ between ecological communities through a variety of means (Krol et. al. 2016). Though, since ecosystem services are spatial in nature, geospatial technologies like Geographic Information Systems (GIS) have proven to be a valuable resource to monitor and quantify these services (Krol et .al. 2016). The use of geospatial technologies to monitor large scale ecosystems are often subject to Geographic Information Capacity (GIC). Which we define as the ability of ecosystem stakeholders to utilize all existing geographic information, resources, and capacities to monitor ecosystem services. The goal of this research reported in this paper was to understand the relationship between Geographic Information Capacity, and current geospatial tools that quantify ecosystem services. Specifically, our goal was to develop a conceptual framework intended to quantify ecosystem services in the context of EcoDRR. Ideally, future development of our proposed framework can from a scientific basis for informing communities, society, or organizations the abilities to quantify ecosystem services under the framework of DRR and understand how GIC factors into the efficacy of EcoDRR.

Importance of Geospatial Technologies:

Risk is spatial in nature, requiring the use of geospatial analysis in order to take both spatial and temporal aspects into consideration (van Western 2010, Krol et. al. 2016). Spatial data can be collected through a variety of means, but the main methods used for environmental analysis are through earth observation satellites, sensors located on drones, and field collection. Earth observation satellites have been proven to provide temporal data over large areas and are a vital tool to monitor natural and anthropogenic variability (Cord et. al. 2017). Data from satellite earth observation tools can be used in all phases of a disaster including monitoring trends prior to a disaster, rapid decision making during a disaster within reason, and damage assessment post disaster. Since the data is already digital and georeferenced, it can be easily integrated into a GIS environment. This data can be rapidly obtained and processed during a disaster, making it a vital tool to make emergency relief decisions and handed to personnel in the field (Montoya 2003). Having a strong GIC will make the process fast and concise which are both vital in disaster response. Through spatial modeling, data from earth observation satellites can be used to monitor changes in ecosystem services and provide stakeholders the opportunity to toggle parameters with the potential to provide optimal outcomes (Cord et. al. 2017). Ecosystem services can be quantified by connecting ecosystem functions to specific services and ultimately human well being (Cord et. al. 20017). Modeling ecosystem services spatially provides the ability to quantify how much an ecosystem will mitigate the impact of a disaster. For example, understanding the relationship between water retention within a wetland and wetland area can significantly help a disaster manager when thinking about potential flood inundation. Knowing a wetland that is a certain number of hectares in area and will hold a certain quantity of water can provide disaster managers a better idea as to where they should build engineered structures to coincide with already active ecosystem services. These geospatial models, like the wetland retention example previously given, are used to estimate where services are produced, where the ecosystem is functioning optimally thus providing the most services, temporal changes in ecosystems, and the impact land use has on surrounding ecosystem services (Krol et. al. 2016). The models take a variety of parameters into consideration thus making them highly customizable to specific locations, and for specific instances. For example, weighted overlay models can examine different risk reducing scenarios for exploring new policies and ideas in turn providing a good understanding regarding potential impacts on ecosystem services (Krol et.al. 2016). All the concepts previously stated are subject to GIC, without proper personnel training, equipment, and available data resources final products will not be able to be created in a manner that is effective in a disaster scenario. A strong GIC will also allow for more precise indicators to be utilized for a specific region. For example, ecosystem service indicators specific for South East United States will drastically differ from indicators for Indonesia. Institutions and communities that have a strong GIC will be able to utilize EcoDRR models created from local indicators and potentially be more resilient than communities that do not have a strong GIC.

Integrating GIS and EcoDRR:

The use of ecosystem services in DRR contributes to sustainable development and have proven to be far more cost effective than traditional engineered approaches for post disaster response and recovery efforts (UN 2005). The combination of EcoDRR and engineered disaster risk reduction can be modeled in a GIS environment giving results that will be the most cost effective and is very useful in areas where land is scarce (Krol et. al. 2016). Having a better understanding of Geographic Information Capacity, as it relates to EcoDRR, will provide

insight on what the risk reducing effect of EcoDRR will be along with how ecosystem services compare with other risk reduction alternatives (Krol et. al. 2016). Thus, ensuring that knowledge, technology, and expertise is transferred will build capacity for disaster risk reduction (UN 2005). The capacity to use GIS can also provide the means to understand and make informed decisions regarding ecosystem services. GIS can be used to analyse consequences, predict impacts, disseminate information, allocate personnel, equipment and resources, along with calculating optimal transportation routes (Montoya 2003). All this information is subject to GIC, and vital to decision makers and helps facilitate decisions regarding which areas are exposed to hazards, areas at greater risk than others, and the occurrence of multiple hazards (Krol et. al. 2016).

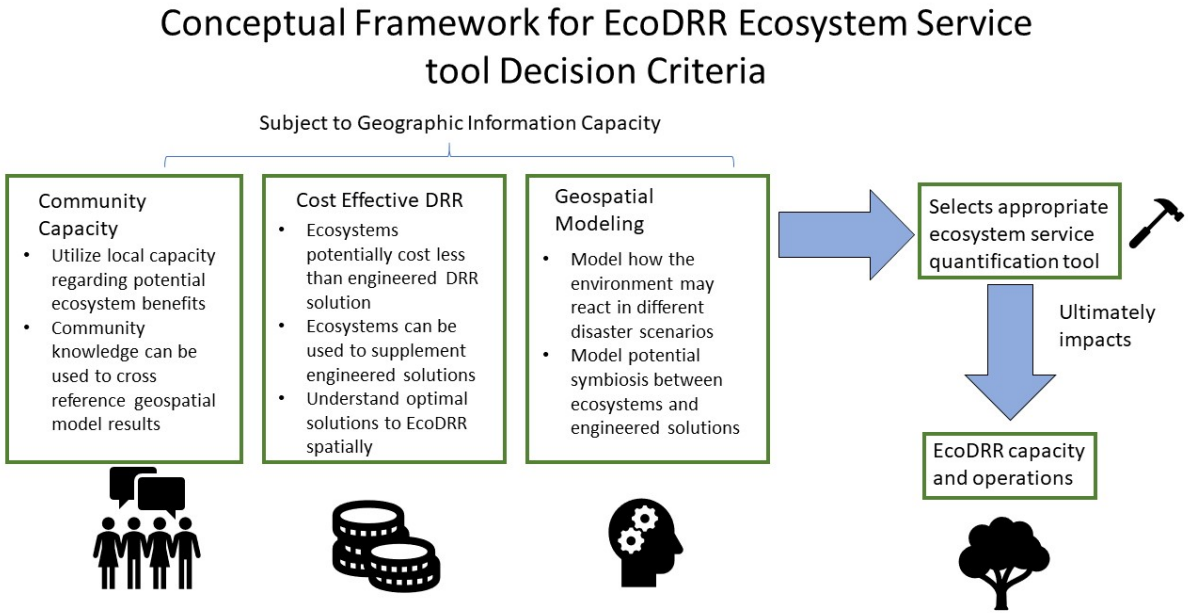

Figure 1: Conceptual model of our research. The focus of the research presented here is looking at how GIC plays a role in identifying a proper ecosystem service quantification tool in the context of EcoDRR.

METHODS:

A desk review was conducted with the specific intention to aggregate publications that were focused on utilizing ecosystem services in the context of EcoDRR. To do this a variety of literature was found in the field of EcoDRR and had some sort of reference to GIC. Although there was no literature that specifically discussed the concept of GIC in the framework of EcoDRR, it was inferred that GIC plays a role in the application of spatial methodology. Once literature was aggregated, it was then analyzed to find trends between works along with differences among publications. Case studies were found that utilized existing ecosystem service quantification tools to gain an understanding on the framework that these tools are being used in. To begin two widely used ecosystem service tools (Integrated Valuation of Ecosystem Services and Tradeoffs - InVEST and Toolkit for Ecosystem Service Site-Based Assessment - TESSA) were searched for to gain an understanding on how professionals are using these tools, and from there search for other tools present, along with how they are being used as well. Many of these publications were not specifically focused on disaster risk reduction and were only focused on other applications of ecosystem service tool software. Based on our review, we determined that there was a lack of framework regarding the use of spatial ecosystem service quantification tools in terms of EcoDRR. This is where concepts from publications focused on DRR was merged with the concept of GIC to develop a conceptual framework on the role GIC plays in EcoDRR (as seen in Figure 1).

QUANTIFYING ECOSYSTEM SERVICES SPATIALLY:

Table 1: Introduction to geospatial tools used in quantifying ecosystem services. (Source: Christin et. al. 2016).

ARIES	This framework is intended to integrate multiple modeling paradigms in spatial modeling and mapping of ecosystem services. Supports artificial intelligence-based data and model selection through semantic modeling to quantify ecosystem service flows from ecosystems to beneficiaries. http://aries.integratedmodelling.org/
Co$ting Nature	Mapping and modeling tool for multiple ecosystem services using global datasets. Quantifying ecosystem services as opportunity costs (IE avoided costs of producing those services from a non-natural capital substitute). http://www.policysupport.org/costingnature
Envision	GIS based tool for scenario based planning and environmental assessment. Enables "multi-agent modeling" to represent human decisions on landscape simulations. http://envision.bioe.orst.edu/
InVEST	Spatial mapping and modeling of multiple ecosystem services. Includes a diverse set of provisioning, regulating, and cultural services from marine and terrestrial environments. The models primarily provide results in biophysical terms to which valuation can be applied. https://www.naturalcapitalproject.org/invest/
MIMES	Modeling platform designed to quantify causal linkages between ecosystems and the economy. MIMES allows an individual to map decisions/ policies, and the output illustrates how those choices affect the economy and ecosystems. http://www.afordablefutures.com/orientation-to-what-we-do/services/mimes
EcoMetrix	Field based tool designed for the use of relatively fine spatial scales. Primarily use is to illustrate the effects of human activities. (Development, or restoration scenarios) on ecosystem services. http://www.ecometrix.ca/
SolVES	Spatial mapping and modeling tool primarily used for quantifying cultural ecosystem services using PPGIS. https://solves.cr.usgs.gov/

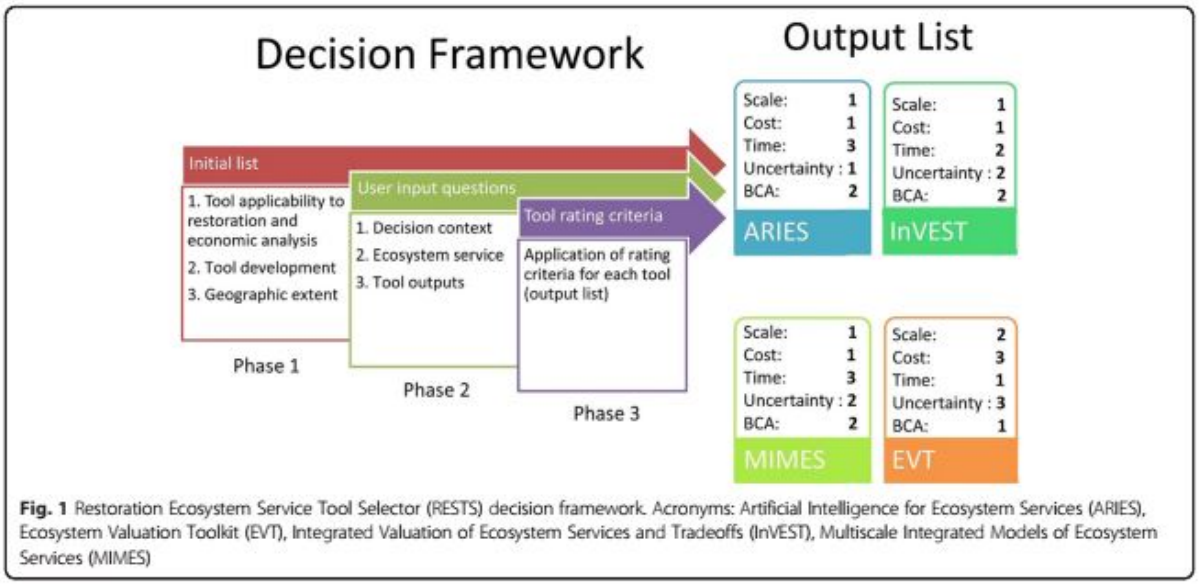

Fig. 1 Restoration Ecosystem Service Tool Selector (RESTS) decision framework. Acronyms: Artificial Intelligence for Ecosystem Services (ARIES), Ecosystem Valuation Toolkit (EVT), Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), Multiscale Integrated Models of Ecosystem Services (MIMES)

Figure 2: RESTS framework Source: Christin et. al. 2016. *BCA stands for Benefit Cost Analysis

Current Ecosystem Service Quantification Framework:

As seen in Table 1 above there are many geospatial tools currently available to use as means of quantifying ecosystem services. Many of these tools have differing end goals as means of measuring ecosystem services creating difficulty in deciding what tool is best for a specific region or instance (as seen in Figure 2). Though the tools presented in Table 1 can be used in DRR efforts, none of them are specifically designed for DRR measures. The Restoration Ecosystem Service Tool Selector (RESTS) is a framework designed to provide decision makers the means to decide what ecosystem service assessment tool is best for their needs (Christin et. al. 2016, Figure 2). The RESTS framework filters tools based on user's criteria outputting tools that are best for the user (Christin et. al. 2016). To do this the framework assigns each tool values based on attributes and evaluates those values based on user input (Chrisin et. al. 2016). Though, the RESTS framework is only for quantifying ecosystem services in general, or for a specific interest of an ecosystem restoration stakeholder. Currently there is no framework that is specifically designed for EcoDRR measures. As seen in Figure 2 the three phases of the RESTS framework provide users outputs with 5 variables that the user may find valuable when deciding what ecosystem service quantification tool is best for them. Creating an EcoDRR framework that performs an analysis that is very similar to the RESTS framework would be very beneficial for disaster risk stakeholders and provide geographic information capacity building. Utilizing such framework would require DRR stakeholders to understand their end goals and understand how they plan to implement EcoDRR measures. Outlined in the following sections are some measures that should be taken into consideration when designing and implementing a framework designed specifically for EcoDRR.

SUGGESTIONS FOR ECODRR FRAMEWORK:

Utilizing Community Capacity:

Utilizing ecosystem services has proven to be a viable option for communities attempting to reduce the impacts of hazards. Many different ecosystems can be utilized for a variety of reasons. For example, coastal wetlands provide protection against flooding, coastal erosion, saltwater intrusion, inland wetlands store rainwater preventing flooding while also postponing the issue of drought by retaining water (Fowler 2017). In many cases spatial information is not enough to obtain a complete picture of the processes going on in the environment. For example, the phenomenon of "Bush Encroachment" is not visible even with some of the best resolution imagery, and the need of local community members who know what is happening is needed to supplement spatial data (Szarzynski 2017). Trained locals who know what they are looking for are vital to supplement spatial data. These locals provide locations where they may have seen areas where "Bush Encroachment" is happening allowing for maps of these areas to be made, and ultimately allowing decision makers to make the most informed decision. Local people can "cross check" remotely sensed data and models, while also providing valuable information on valuable community assets and attitudes towards policies (McCall 2015). Especially in rural communities, the knowledge is present on how to best manage their local ecosystems and resources and should be utilized to

sustainably manage local ecosystems (Karanja 2016). Understanding how local people cope with hazards will also help EcoDRR modelers understand changes in the environment and socio-economic indicators that may not have been picked up in remote sensed data or published data (Peters-Guarin et al. 2011). These local approaches conform to one of the guiding principles in the Sendai Framework. This principle is "Accounting of local and specific characteristics of disaster risks when determining measures to reduce risk" (United Nations 2015).

Utilize Savings:

Utilizing ecosystem services also conforms to another guiding principle in the Sendai Framework. This is "Addressing underlying risk factors cost-effectively through investment versus relying primarily on post disaster response and recovery" (United Nations 2015). By enacting Eco DRR measures the ability for the environment to protect nearby community greatly increases ultimately improving the resilience of the nearby community. Research has shown that every dollar invested in resilience measures equates to seven dollars in savings during the aftermath of a disaster (Karanja et. al. 2016). This is important to consider for regions that may not have significant sums of money but are looking to implement DRR measures. Though, in reality, it has been found that there has been a reluctance to implement Eco DRR measures. According to Levy and colleagues this is because "National and International systems lack 3 main factors when it comes to eco based DRR. These are incentives, few actors have the incentives to carry out high quality assessments and monitoring, the inability to obtain data necessary to assess and monitor measures, and the methods used to understand environmental-political linkages are not sufficient and must be developed through innovation." (Levy et. al. 2004). To make Eco DRR more appealing a standardized framework could be made for each ecosystem type. For example, there could be a wetland framework, a forest framework, grassland framework, etc. Each of these frameworks can then be refined for the specific region at hand. Levy and colleagues propose solutions themselves, "Proposed solutions to the deficiencies mentioned above are to set priorities and identify key assessments and actions, establish clear responsibilities and incentives to produce data, establish a financial basis to create a knowledge grid through data dissemination and bridge cross scale divides." (Levy et. al. 2004). Connecting these proposed solutions to indicators from the Sendai Framework could potentially help create a standardized framework for each ecosystem type.

Utilizing Geospatial Modeling:

Historic environmental maps are seldom referred to in Eco DRR publications. These maps provide a clear logistical visualization as to impacts induced from hazards. Historical maps are generally reference maps throughout time and show how human modification to the land surrounding them ultimately potentially introducing unknown vulnerabilities. Historic maps can be used as hazard maps serving as probability maps for future disasters, signifying that similar events can be predicted in the future based on information in the past (Neussenr 2014). All the essential data for these maps are generally not available. For example, in the United States the United States Geological Survey has quadrangle maps dating back to the 1800's showing locations of settlements, but ecosystems were rarely captured. On top of this dilemma there is a lack of digital elevation data. It may be assumed that the elevation has not changed much, or elevation can be interpolated from what markings are available. These issues are often subject to GIC and plays a vital role in the accuracy and completeness of geospatial models. As stated in the Sendai Framework indicators technical review, one of the critical issues on monitoring global issues is developing a baseline. This includes aggregating, and utilizing historic data between a given time period, though should not impede the development of new indicators (Maskery 2015).

FUTURE WORK AND CONCLUSIONS:

Geographic information capacity plays a valuable role in the understanding on how ecosystem services operate, and the potential to mitigate hazards. The Restoration Ecosystem Service Tool Selector (RESTS) framework is a valuable tool that compares each geospatial ecosystem service quantification tool (Table 1) and provides decision makers costs and benefits of each tool (Christin et. al. 2016). This type of framework significantly helps decision makers with their GIC allowing them to pick specific tools for their needs. These tools then use spatial information and the outputs can then be used in GIS models. Once ecosystem services are quantified a decision maker can use a multicriteria approach to locate where to build ecosystems, and what factors are necessary for a constructed ecosystem to thrive in a given location (Krol et. al. 2016). The multicriteria model is then easily manipulated to give results of optimal location for ecosystems used in DRR (krol et. al. 2016). For example, hydrological models provide valuable information when preparing for flood events.

Moving forward additional data will be collected from DRR experts that have first hand account of utilizing the concept of GIC either directly or indirectly. A variety of interview questions have already been formulated and will be asked to the experts. These questions are (1) What do you perceive the relationship is

between EcoDRR and GIS? (2) Do you see tools like InVEST and TESSA as useful for EcoDRR implementation and projects? (3) Do you see specific regions/ countries obtaining the training and infrastructure necessary to implement EcoDRR measure themselves, or will the help of the UN and other NGO's always be mandatory? (4) Do you see EcoDRR projects improving a region's ability to utilize GIS? (5) The infrastructure needed to successfully use GIS is expensive, do you think regions that decide to implement Eco DRR measures will skip the investment in GIS and just focus their resources in the project? (6) How can the use of GIS be expanded in the field of eco DRR? Should more standardized models be built and then refined for specific regions? (7) How are regions overcoming data problems? Do they go out and record their own data? Are they finding professionals to show them how to create data? (8) How do you perceive the use of historical environmental maps? Are they a necessity, or do they only supplement Eco DRR work? (9) How have you seen the use of local community knowledge assist with Eco DRR projects? Has this knowledge been spatial in nature/ able to represent geographically? If not, how can this information be implemented spatially? (10) How do you see the Hyogo Framework and the Sendai Framework influencing GIS and a country's ability to increase their GIC? From there, it may be possible to work in historical environmental models to the findings of this research paper. The ability of a country/ region to utilize historical environmental models in terms of DRR can greatly improve their GIC due to the ability of these models to clearly indicate regions that will be impacted by specific hazards. It may also be useful to create a specific Environmental Geographic Information Capacity model, where the only indicators would be environmentally related. With critiques from professionals this model may be feasible for regions who are interested in only using ecosystems as means for DRR for any variety of reasons.

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GPS-based solution for tracking and protecting humanitarians in conflict zones

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ABSTRACT

The operational environment in which humanitarians operate is unstable and high-risk; when operating in such environments, time becomes a critical factor. Thus, real-time location systems (RTLS) are often deployed in the operational environment to provide awareness of the location of personnel and assets in real-time that would support an informed decision making in the event of responding to emergency. Whilst standard RTLS are very precise, they are not suitable to outdoor spaces; GPS position technology can be used to identify the location of objects and people and to track them. In this paper, first, we present a description of threat scenarios identified based on information from existing security incidents datasets and from interviews with aid workers and security professionals operating in high-risk regions. Second, we describe the implementation of a GPS-based real-time location tracking and alert system for humanitarians operating in conflict zones that supports the identified scenarios.

Keywords

Humanitarian aid work, Real-time location systems, security threats, threat detections, situational awareness.

INTRODUCTION

The operational environment in which humanitarians operate to deliver aid can be described as unstable and high-risk (Duffield, 2012). Daily missions are carried out in highly dynamic and volatile environments. There is a rapid change in the needs and ability to access to various locations, routes and beneficiary groups. Different humanitarian organizations also access various locations and may use different types of cooperation partners and implementing partners for last mile distribution, making the processes difficult to track. In addition, the deep impact of security risks takes its toll on the daily lives of humanitarians (Schreter & Harmer, 2007).

Managing risks and threats in a timely manner is of fundamental importance (Davis, 2017); thus, there is a growing need of integrated tracking systems for situation awareness (Endlsey, 2004) that can enable better informed decisions related to mission planning, risk assessment and response to emergency situations.

Real-Time Location Systems (RTLS) have been often considered in the past as ideal solutions for the identification and tracking of movements of objects and/or people as they happen. They normally consist of fixed location sensors that receive or read a signal from moving sensors attached to people and/or objects and many techniques and systems are available (Liu et al, 2007). This technology has had applications in many fields, such as healthcare, but they do not support tracking in outdoor spaces (Kamel Boulos & Berry, 2012; Notobartolo et al, 2011; Fisher and Monahan, 2012). When needing to geolocate objects and/or individuals in outdoor spaces, GPS-based solutions tend to be adopted. GPS-based solutions have become increasingly popular in the last few years, with the advent of smartphones and smart devices that integrates motion and location sensors, and they are often integrated in Command and Control systems (C2) to support communication and collaboration between operators in an emergency.

Bakopoulos et al. (2011) have suggested a system based on smartphones and GPS to enhance real-time communication between first responders and control rooms. Wahde et al. (2016) developed a smartphone-based solution to improve ambulance dispatch time using GPS data: users can request ambulances using a mobile app; the nearest ambulance is then dispatched based on the user's current location. A similar solution was proposed by Vasic et al. (2014), focused on dynamic relocation of emergency ambulances and by Balamurugan et al (2015) for automatic routing of ambulances using IoT and GPS-enabled smartphones. Smartphone-based tracking solutions are also utilized for increasing safety: for example Moorty and Joseph (2015) developed a solution to improve women's' safety, based on a mobile app that allows its users to see other users and Police authorities in their nearby vicinity in order to alert them in the eventuality that they are in danger. Police forces and first responders often use GPS-based systems to track their vehicles and resources, integrated in commercial GIS systems[1].

In the humanitarian field, recent work has been done to assess the suitability of smartphone technologies to support humanitarian operations, concluding they can be helpful to support efficiency and effectiveness of missions but intensive evaluation is needed to ensure they support the logistics of humanitarian support (Abushaikha & Schumann-Bölsche, 2016). Sandvik et al (2014) have conducted a critical review of the application of new technologies to humanitarian missions, highlighting how sometimes using new digital technologies could change the process that is used and increase the time required to perform a task, therefore impairing the effectiveness of the mission.

The context in which we have been carrying out this study is a European Project iTrack that aims to deliver an intelligent, integrated tracking and threat identification system for humanitarian missions in conflict zones, mainly in the Middle East. The purpose of the iTrack real-time location system is to provide real-time localization capabilities of staff who are on a mission, to allow a control centre to monitor their location and maintain situation awareness. In order to achieve this, staff will have on them smartphones equipped with a Global Positioning System (GPS) that will allow to track their location. Along with the GPS component the app will monitor the staff movements and allow for real-time communication about threats, by enabling reports submissions, including text, images and videos.

[1] https://esri.ca/sites/default/files/resources/cr/EC2_0039_1201_7B_Public_Safety_1.pdf https://www.indracompany.com/sites/default/files/emergency_management_1.pdf

As part of the project we have conducted user studies to understand which are the main possible scenarios and use cases and we have derived requirements to guide the design and development of the solution, using a hybrid design approach, presented in the next section.

A HYBRID DESIGN APPROACH

A hybrid design approach was chosen to maximise the novel technology advancement with the requirements emerging form desk studies, user interviews and simulation exercises and the requirements and constraints emerging from the ethics and privacy analysis.
A humanitarian mission simulation exercise was run at the beginning of the project iTrack, to derive feedback and requirements. These requirements were crossed with desk research and user interviews to identify a set of highly probable threat scenarios and develop a set of use cases and system users based on the threat scenarios, that were then verified with the original users. In parallel, the technical work packages have been providing details of how the state of the art in tracking and threat identification could be advanced by technical innovation and the Ethics and Privacy work package has been analysing what would be the ethical implications of the innovations. All these contributions were analysed and cross-referenced to ensure the technical innovation would be matching the user requirements and would not be violating any privacy or ethics principles. The outcome of the analysis was a set of uses cases and associated requirements. In the next section we will present the threat scenarios, use cases and requirements.

Threat scenarios and system use cases for humanitarian aid missions in conflict zone

The scenarios and user requirements were based on data was collected from set of interviews with security experts and aid workers from International NGOs operating in the Middle East Region. In addition, we extracted information about security incidents and attacks carried against humanitarian mission from publically available security incidents repositories: 1) Aid Worker Security Database[2], 2) Aid in Danger project[3] , 3) Security in Numbers Database (SiND)[4], and 4) Uppsala Conflict Data Program[5].
The threat scenarios, identified from the information gathered from the field and historic data, are the following:

Scenario 1: Attack on an aid convoy or warehouse

Attacks on humanitarian aid convoys are the most frequent type of incidents. The convoys are either attacked whilst travelling (in transit) or whilst docking and unloading at the warehouse. There are different tactics used by terrorist groups or militias or other groups to carry out those attacks, such as aerial bombardments, or an ambush, or shooting. In Figure 1, we show the event chain of an attack targeting an aid convoy with three possible tactics (i.e. aerial bombardment, militants attack-shooting, and sniper shooting). The convoy scenario can show some of the aspect where technology can support the safety of the convoy: tracking technologies can be employed to maintain awareness of the convoys and individuals; alerts and warning mechanisms should be created to support quick reactions; real-time reporting can be useful to gain situational awareness to help rescue and secure the survivors.

[2] https://aidworkersecurity.org
[3] http://www.insecurityinsight.org/aidindanger/
[4] www.insecurityinsight.org/projectshumanitarian.html
[5] http://www.ucdp.uu.se/#/exploratory

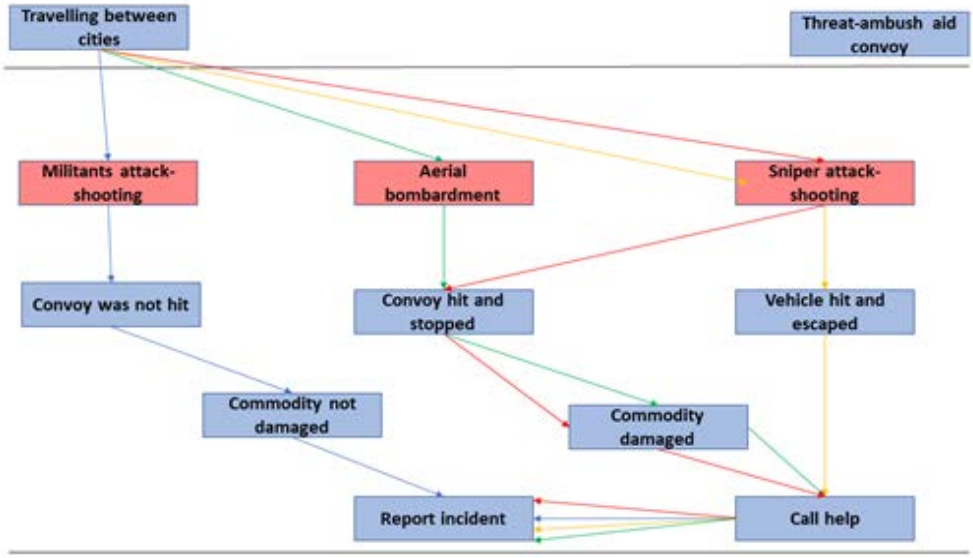

Figure 1 – Three different types of convoy attack: militants attack, aerial bombardment and sniper attack.

Scenario 2: Ambush and kidnapping of aid workers

Kidnapping is the second most prevalent security threat in security incidents targeting humanitarian aid workers. There are different motivations behind kidnapping aid workers, such as political or financial reasons or just being at the wrong place at the wrong time. In Figure 2, we show the events chain of a kidnapping incident and related actions and outcomes. There have been some kidnapping cases where victims lost their lives (Fisk, 2008) and some they were released after some time or after negotiations (Macharia, 2012). Similar to the previous scenario, technology could support such situations by providing a GPS trace of the victim position and also by providing victims the possibly to alert colleagues in real-time of the danger.

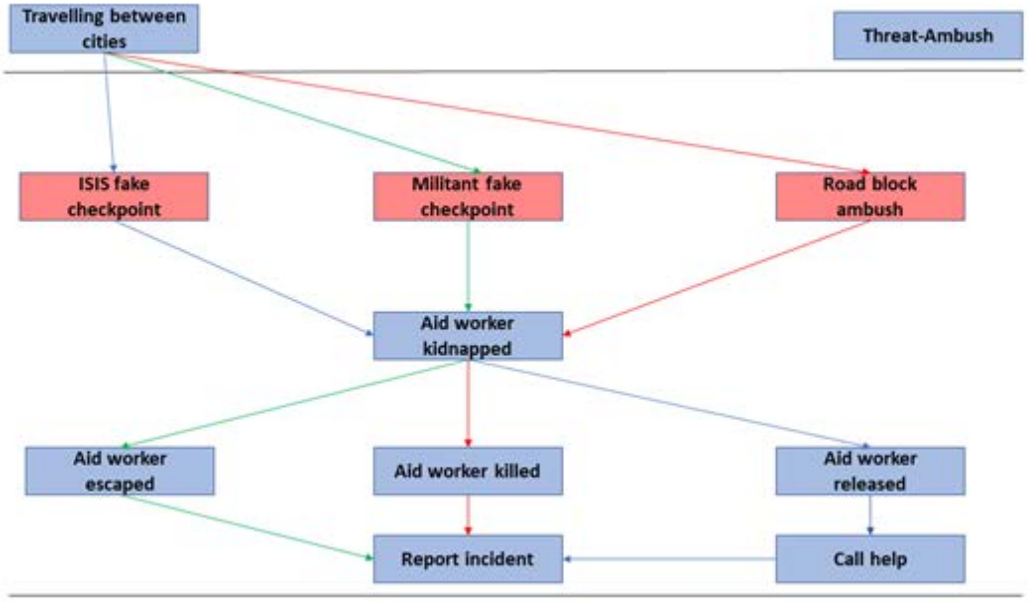

Figure 2 - Ambush and kidnapping of aid workers – events chain

Scenario 3: Shooting aid workers (Individual attacks)

Aid workers coming under crossfire is another type of prevalent incident (see Figure 3). Often assailants are after money or other valuables or after the cargo of the convoy. Similar to the convoy scenario, a tracking mechanism for both the personnel and the assets can help providing information on the location of the event. The ability to send distress signals to security personnel in real-time combined with information about the location, threat and if possible, images can be very valuable for responding rapidly and achieving the best possible outcomes for involved parties.

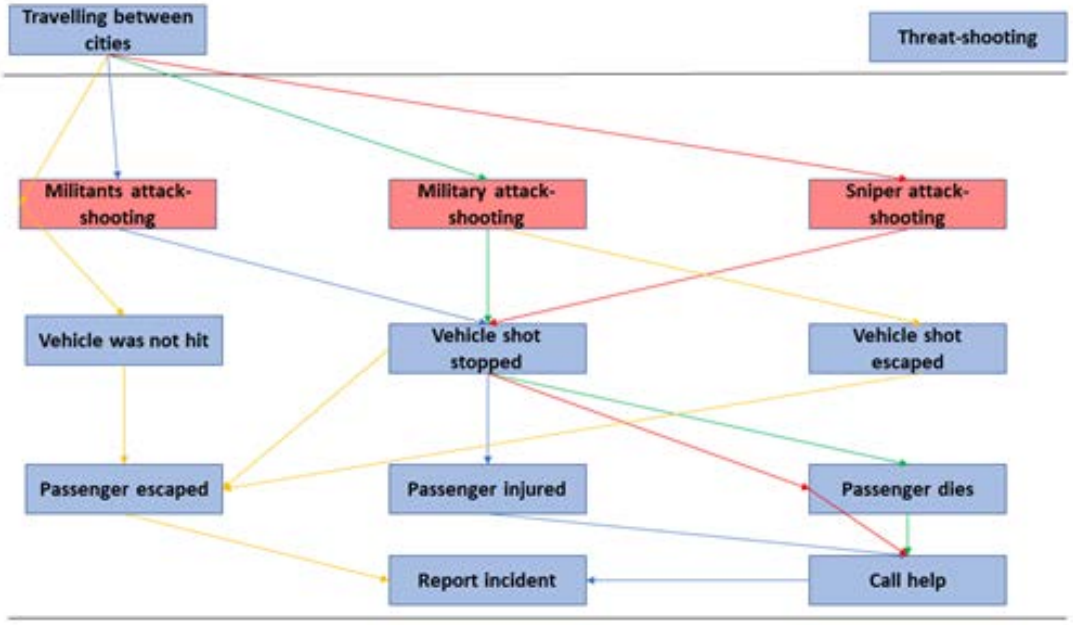

Figure 3 - Individual attacks - events chain

After analyzing the data and the scenarios, we have defined a set of actors involved in the aid delivery process: aid workers, missions' leaders, translators, drivers, and mission coordinators (or officers), warehouse managers, distribution managers. In addition, a person that would be manning a command post (or a control room) to perform information collection, analysis and risk assessments and handle the incident response. Usually those tasks are performed by a security officer or sometimes, an information manager or a control room officer.

From the different threat scenarios, we were able to identify the following use cases:

1. *Use case 1*: Users accompanying the convoy should regularly report their location to the command post or control room. The user *(mission leader, aid worker, driver, translator, security officer*) reports his/her position to the main RTLS-server application via a mobile application by selecting the position on a digital map. The operation can be done manually or set to automatic.
2. *Use case 2*: Mission leader and drivers can send information on status and location of the convoy to the command post or control room, where a security officer or information manager collects and analyze the information and continuously assess the risk situation. The information is sent via a mobile application and can contain geographical coordinates and /or images of the surrounding environment.
3. *Use case 3*: Security officer or information manager in the command post or control room are able to track and locate both the personnel and assets in the convoy in real-time. From information provided in *Use case 1*, the RTLS-server application displays the tracked objects (personnel or assets) as pins on a digital map. Security officer or mission controllers can obtain information of tracked objects by selecting the pins.
4. *Use case 4*: Users accompanying the convoy should be able to report the current status of their safety and/or security incidents in their surrounding to the command port or control room. The user can report his/her status via a status or incident report screen in the mobile application to the RTLS-server application. The status report includes information about the threat type (if any) and location of the incident (either current location or a nearby location selected on a digital map).
5. *Use case 5*: In the case of the attack, users accompanying the convoy (e.g. mission leaders or aid workers) should be able to send an immediate alert to the control room or command post. The command room personnel would issue an alert and forward to all persons operating in the area of the threat. The field workers would activate an *emergency/panic button* either by voice command or by shaking the mobile device. Immediately an alert/notification will be forwarded (including information about the tracked object location) to the RTLS-server application system. Then, the command post operators will receive an alert through the RTLS-dashboard application.
6. *Use case 6*: The command post personnel (security officer, information officer, project officer) should be able to receive and view safety and/or incident reports from the convoy in real-time. The users in the convoy send status report via the mobile application to the RTSL-server application. The command post or control room personnel then will receive a notification of the status update from the field and can retrieve the report and view the information (location, threat status, and /or image) via the RTLS-dashboard application. Incidents will be marked read or unread accordingly.
7. *Use case 7*: Users in the convoy will be able to receive security status updates and threat alerts form the command post. The information will be presented to the convoy personnel via two channels, a mobile application and an onboard-dashboard application. A notification window at the applications will be showing the type of threat, location, a timestamp and it may also come attached with information about its

severity. The threats are also presented according to the prioritization that is predefined and also their effective and expiration time. Additionally, all threats are represented in a different way depending on whether they have been validated or not.

8. *Use case 8*: Convoy users should be able to communicate or message their peers (either in the same convoy or other convoy or back at the office or at the command post or at the warehouse). Similarly, users at the NGO office and command post should be able to communicate or message back the personnel on the convoy(s) or project sites (e.g. warehouse or hospital). The message exchanges will be done via a dedicated messaging screen on the mobile application or the system dashboard.

REQUIREMENTS

In the following section we will highlight the requirements for the location tracking application for humanitarian mission members. Please note not all requirements are reported here, only those that relates to the scenarios above (i.e. more "common" requirements such as the need for user login are not reported here).

Functional Requirements

After analyzing the data and the scenarios, we have defined a set of actors involved in the aid delivery process: aid workers, missions' leaders, translators, drivers, and mission coordinators (or officers), warehouse managers, distribution managers. In addition, a person that would be manning a command post (or a control room) to perform information collection, analyzing and risk assessments and handle the incident response. Usually those tasks are performed by a security officer or sometimes, an information manager or a control room officer.

User login/registration	**Actor**	**Scenario**
To guarantee security, the mobile application shall store a token received by the iTrack platform during the initial login process. All communication between the mobile application and the iTrack platform besides these initial step should include this token and not other information that if intercepted should reveal the identity of the user (first name, last name, email, username, etc.)	Aid worker, mission leader, driver, mission coordinator, translator	All
Personnel tracking		
Automatic and manual tracking must be available	Aid worker, mission leader, driver, mission coordinator, translator	All
The mobile application must acquire the device's current location data through the embedded GPS and sends the user's location to the iTrack platform. The process is executed	Aid worker, mission leader, driver,	All

automatically without need for user interaction	mission coordinator, translator	
The user shall be able to report her/his current location by triggering the location functionality	Aid worker, mission leader, driver, mission coordinator, translator	All
The user shall be able to report her/his current location by selecting her/his position on a map displayed by the application.	Aid worker, mission leader, driver, mission coordinator, translator	All
The control room can request the user to report her/his current location through an app notification.	Security officer, information manager, a control room officer	All
Personnel alerts		
The mobile application displays notifications/alerts received by the iTrack platform. Each notification should be marked according to its severity.	Aid worker, mission leader, driver, mission coordinator, translator	All
The user shall be able to review the notifications/alerts history list. Each notification should be marked also for its current validity (still valid or expired)	Aid worker, mission leader, driver, mission coordinator, translator	All
Messaging		
The control room shall be able to send messages to users on the ground, set up groups of users and choose groups to message.	Security officer, information manager, a control room officer	All

Users shall be able to communicate directly with one another or within groups using the app	Aid worker, mission leader, driver, mission coordinator, translator	All
Threats reporting		
The user must be able to activate a panic button by voice command, automatically reporting geolocation.	Aid worker, mission leader, driver, mission coordinator, translator	All
The user shall be able to report a current or forthcoming threat at her/his current location or at a location selected on a map presented by the application. The threat could affect the current user or others.	Aid worker, mission leader, driver, mission coordinator, translator	All

Table 1 - Functional requirements for real-time location tracking system for humanitarians

Non-Functional Requirements

Category	Consolidated Description
Usability	Users should be encouraged to use the proposed solution. Therefore, the design and development must be responsive to adapt to the user's screen size and orientation. The iTrack solution should be easy to learn, with a small learning curve. The iTrack registration and the login process should be easy, requiring that kind of data from the users that will not discourage them from using the proposed solution. The iTrack solution should be flexible to adapt to different contexts, increasing the social awareness, so that users deployed in different areas where different frameworks should be respected can use it (a context can be a country for example). The iTrack solution should be easily and fast deployable to encourage users to use it. Users tend to prefer a solution that covers their needs and that is easy and quick to deploy.
Security	The solution should support communication between the parts of the system and the users that respects all legal constrains per context. All confidentiality information flow should also be protected.

	Encryption should be used (whenever possible) for transmitting information. The solution should support a role-based authentication and authorization mechanism. Each user will be assigned a role and will be given unique credentials. Only authorized users will be able to use the solution so as to ensure transparency and security. The solution should support data deletion mechanisms to ensure that the data that is no longer required or must be deleted due to restrictions is appropriately destroyed. All ethical and privacy constrains and terms, as well as all individual rights and liberties must be respected by the proposed solution. The solution must have mechanisms to store information securely.
Confidentiality	The solution must protect any information, especially if personal data is included, from loss, misuse and unauthorized access to the data.
Availability/ Accessibility	The solution must be available 24/7. If it is not possible, an offline mode should be considered.
Performance	The solution must optimize performance for what regards battery usage and data transmission.

Table 2 – Non - Functional requirements for real-time location tracking system for humanitarians

DESIGN AND IMPLEMENTATION

The purpose of the iTrack real-time location system is to maintain situation awareness between personnel on a mission and a control center. The system takes the form of a smartphone app (available for Android and iOS) that starts monitoring the user's location once it detects that the subject has started moving.
The main app functionalities are:

- Tracking: automatic or manual location reporting
- Reporting: threat reporting
- Alarm: panic button
- Communication (internal chat)
- Security

Due to the difficult characteristics of the operational environment, the app is designed and implemented to be used in humanitarian missions, attention has been paid to ensure minimal battery consumption and data traffic and ability to cope with network loss. In the following sections we will present the main app functionalities.

Tracking

The app supports automatic and manual location tracking of an individual. When auto-tracking is enabled (enabled by default) the location position is identified through the GPS sensors and other sensors present on the device, is recorded, stored in a secure manner in device's internal memory and sent to the backend immediately, if a network connection is

available, or as soon as a network connection becomes available. To improve battery consumption the location is only monitored when movement is identified – i.e. if the user has been in the same place for the past few hours the location will not change. This reduces drastically the amount of time when the GPS and other sensors are on, reducing the battery impact. As a side effect this also reduces the amount of network data sent as only actual changes in locations are sent to the iTrack platform.
As per the use cases described above, there may be the need for the control room to request the user's position. In this case a pop-up notification is sent through the app asking the user to report their current location by selecting their position on a map (see Figure 4).

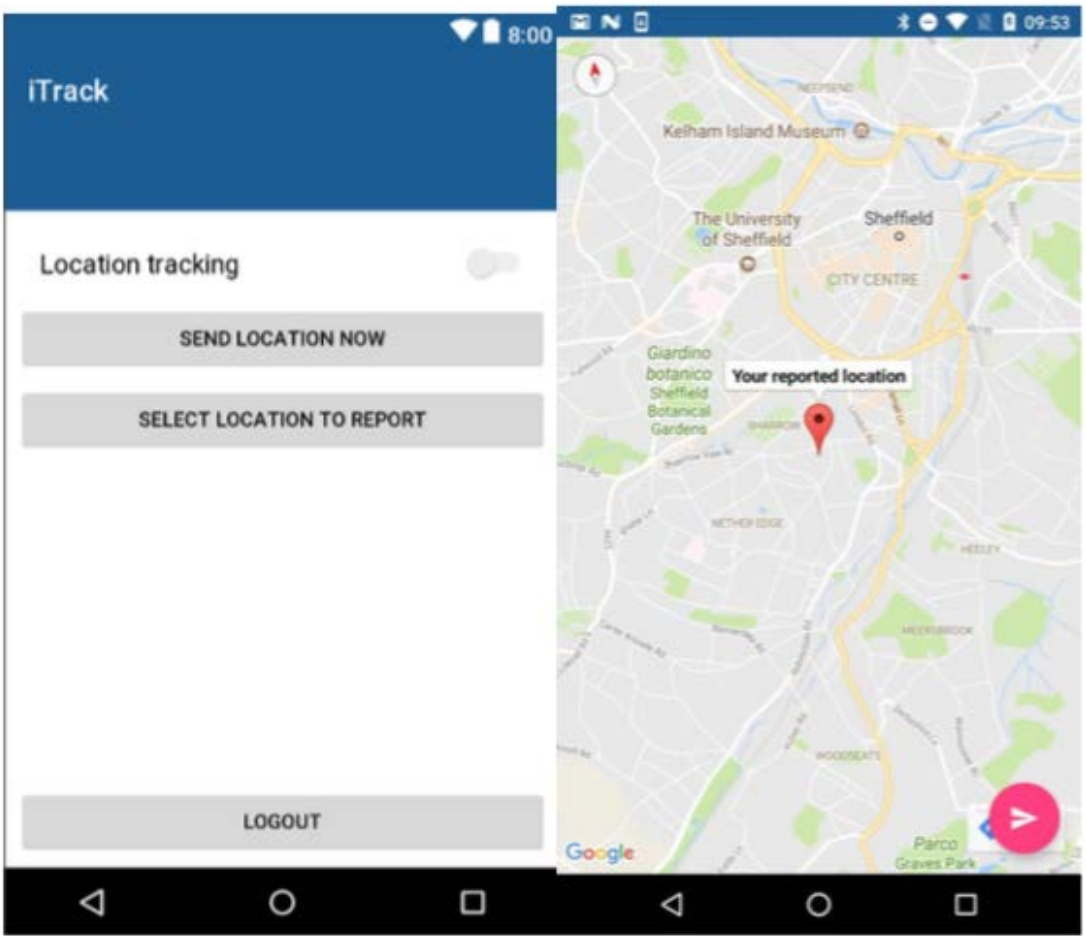

Figure 4 - Location Reporting

Threat reporting

Given the dangerous nature of the operational setting, it is important for the user to be able to report a current or forthcoming threat (either at their location or at in a different one). To make the interaction easier (given the potential risks) and more efficient users just need to select the threat between a pre-existing list (derived from the user studies performed) and either use the location automatically detected or move the pin to a desired location on the provided map (see Figure 5). The interaction can take place through a single interface, again to maximise efficiency and ease of use. Once submitted this report goes automatically and in real-time to the iTrack platform and will be visible to other users.

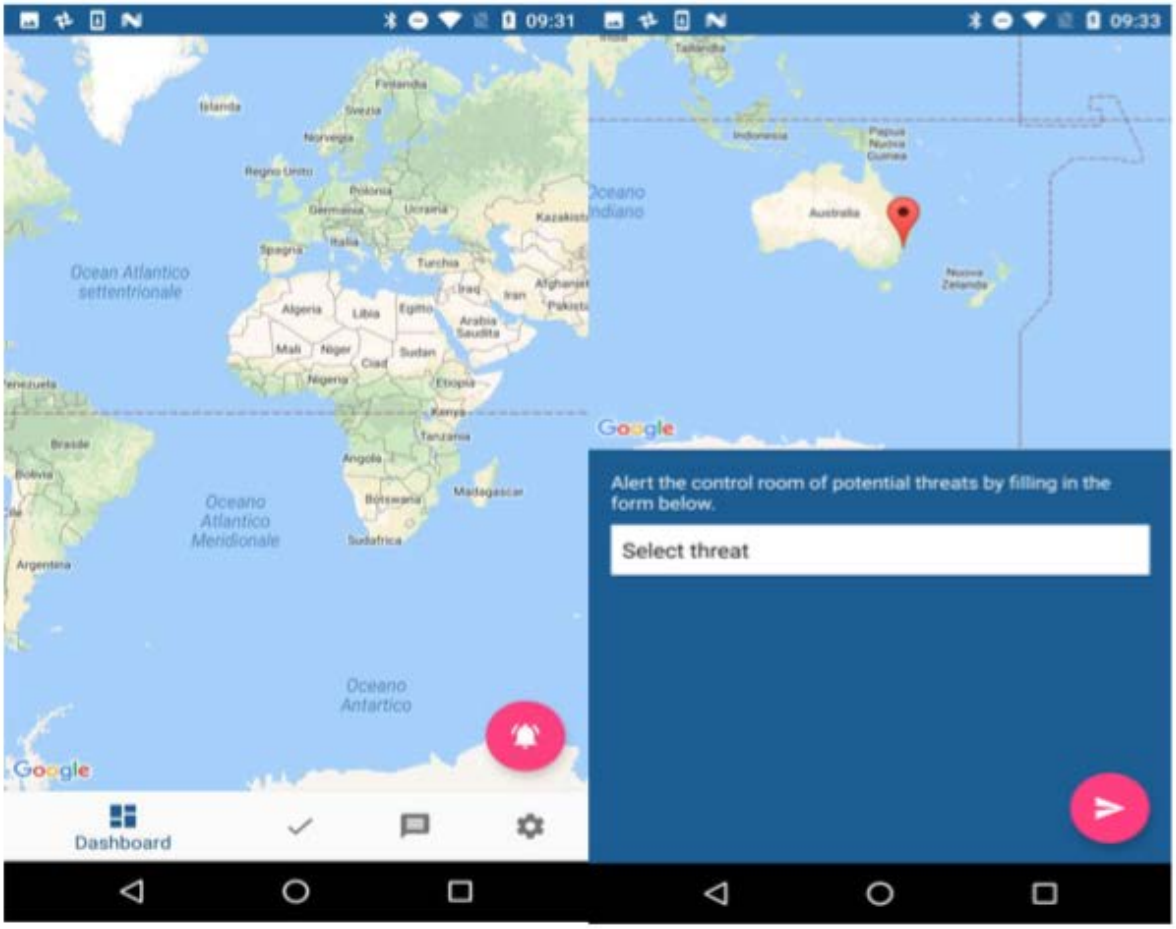

Figure 5 - Threats reporting

Panic button

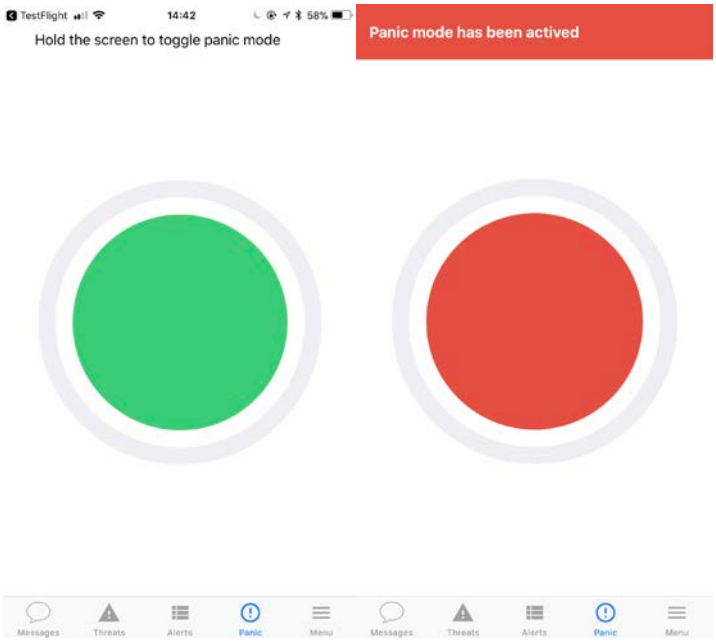

Figure 6 - Panic button alert

A panic button (see Figure 6) has been implemented for situations where the safety of on-field workers is at danger. In order to decrease the number of false alarms the user need to

press and hold the panic button for three seconds and only after that the application goes into panic mode. Once panic mode has been activated, the application alerts the control room and automatically switches on the location tracking in real-time if the user did not have it enabled already. For security reasons, the panic mode cannot be disabled until the user has confirmed with the control room that they are safe.

Communication

The app contains a messaging feature, enabling control room users to message users on the ground, to set up user groups and choose groups to message. The users on the ground are able to communicate directly with one another and with other groups. Using this feature users are able to Send, View and reply to messages and to store messages as evidence. As part of the messaging feature, notifications can be sent to users (see Figure 7).

Figure 7 - Notification feed

Security

In order to protect data and individuals' security (i.e. to avoid that a user's location could be intercepted and used for nefarious actions) the system has been built with the highest security standards. The login process is handled using iTrack Keycloak OAuth API. Upon successful authentication, none of the entered credentials are stored and only the returned authentication tokens are stored for further use in communications with iTrack. All communication between the mobile application and the iTrack platform besides these initial step includes this token and no other information that if intercepted should reveal the identity of the user (first name, last name, email, username, etc.). Each token received has an expiration date. When using the application, the token is refreshed so re-authentication is not required.
The application also supports an extra layer of security through encrypted communication. The control room have the ability to ask all devices to use encrypted communication by

enabling this feature from the iTrack's dashboard. Once enabled all payloads are encrypted on the mobile application's side and decrypted once received by the backend server. Encryption is, however, optional and it is decided on a use case basis due to legal reasons (e.g. in case of usage in countries where encryption techniques are illegal).

Architecture

The application is based on three major sub-systems; server application, client application (on mobile phones) and databases.
The Android application has been developed natively, using JAVA and XML with based on an MVP architecture. This facilitated a better separation of concerns within the application and it also increased the readability of the project should future work be required. Libraries such as Room, for data persistence, and Retrofit for networking have been used. These are used frequently in the industry and are well tested and documented. Similarly, the iOS application has been built using Swift and the MVVM design pattern for separation of concerns, Realm has been used for data storage and Alamofire for networking.
Both applications rely on a Unix server-side backend which facilitates communication between users, which has been built using Ruby on Rails in an MVC pattern. The communication between the client and server is performed using JSON, however, the transport of data is complex, with backend servers sitting in a DMZ. The following diagram (Figure 8) shows a simplified version of the client-server communications layer:

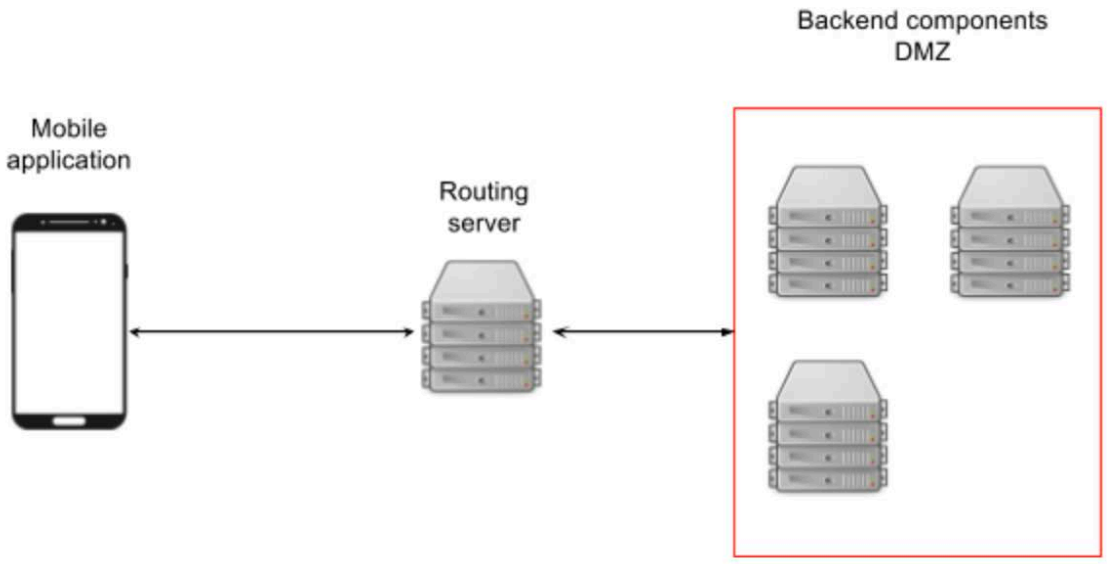

Figure 8 - Architecture diagram

The routing server is responsible for verifying requests and redirecting payloads to the correct component which needs to respond to the client. Responses to the mobile application are provided in an asynchronous manner through push notifications.

CONCLUSIONS AND FUTURE WORK

In this paper we have presented the initial work for designing and implementing a GPS-based system for tracking and protecting humanitarians operating in conflict zones such as the Middle east, Afghanistan, and Africa. The operating settings of such humanitarian missions are high-risk and there is therefore the need to develop new solutions that can support real-time situation awareness both for the humanitarians on the field and for control rooms, in order to: a) protect the humanitarians; b) enable control rooms to use situational awareness to

inform decision-making. Given the complicated settings, the project has carried out an extensive phase of hybrid design, where requirements, threat scenarios and use cases derived from simulations, user interviews and desk research were crossed with technical innovations suggested by the technical partners and with ethics and privacy considerations. A first version of the application has now been implemented and it's in the process of integrating with other components to provide a global situation awareness platform.

In order to test the app in action, the project is running an evaluation of the integrated platform with Ngo users. The evaluation will take place in Delft and will last for one week, during which the different scenarios will be simulated and feedback collected from observers and participants on the suitability of the app to the specific scenarios. Moreover during the week usability tests will be run, to assess interface and features and provide feedback for the next phase.
Future work will concern the implementation of the evaluation feedback plus enhancements to the app usability and functionalities. One example is the current implementation of the panic button: ideally a user should be able to trigger the panic button by voice command. Unfortunately, this functionality is not available in Android therefore its implementation has been postponed for the moment. After the evaluation we will revisit the requirement and, if considered fundamental, it will be implemented for iOS platform. Another future development could be linked to health sensors: at the beginning of the project we investigated the possibility of a mobile application for wearable devices that could detect dangerous situation by looking at users' vital signs during a mission. When discussed with real users, this has raised serious privacy concerns, which rendered the feature impractical and further research and development has not been carried out but future work could consider this.

ACKNOWLEDGMENTS

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3-1-1 Calls Hot Spot Analysis During Hurricane Harvey: Preliminary Results

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ABSTRACT

Hurricane Harvey caused massive damage and necessitated the need for identification of areas under high risk. During Harvey, the city of Houston received more than 77000 3-1-1 calls for assistance. Due to damage caused to the infrastructure, it became difficult to handle and respond to the crisis. Geographic Information Systems (GIS) are a vital technology to assist with real-time disaster monitoring. In this regard, for this work-in-progress paper, we investigated if a correlation could be found between 3-1-1 data calls made during Hurricane Harvey and aerial images captured during the event. Specifically, we were interested to see if 3-1-1 data could be ground-truthed via hot spot analysis. Our preliminary results indicate that visual representation of 3-1-1 call data can aid in analyzing the expected areas of high traffic of calls for assistance and plan an effective way to manage resources. Future work will involve more in-depth analysis of combined 3-1-1 call data with satellite imagery using image classification techniques.

Keywords

Hurricane Harvey, 3-1-1 data calls, hot spot analysis.

INTRODUCTION

Natural disasters affect any geographic area and potentially millions of people residing within it. They are at times difficult to predict or give little to no warning before they turn uncontrollable and fatal. Hurricane Harvey, a natural disaster disguised as a tropical cyclone, caused massive damage mainly due to flooding in the city of Houston, Texas in August 2017. In merely 4 days, the majority of areas within Houston received more than 40 inches of rain, causing alarming levels of flooding which affected thousands of homes, claimed 91 human lives, and over 17,000 people were rescued. During natural disasters, it becomes important to facilitate the identification of risk areas and prioritize the response and mitigation effects involving those areas. 9-1-1 and 3-1-1 services receive massive amount of rescue calls 24/7 in times of mass crisis like Harvey (Harvey's devastating impact by the numbers, n.d.). For example, Houston 9-1-1 received 56,000 calls in first 15 hours and the 3-1-1 department received nearly 77000 calls in those four days of the storm. Loss of power and infrastructure is the most challenging scenario for disaster management as most people are not able to request help using emergency services. Remote sensing can assist in monitoring minute by minute insights of the environmental conditions, providing real-time data estimations which help in disaster response management. During Harvey, this was achieved by government aircrafts capturing aerial images of the flooded and damaged areas, updating every 12 hours. Using the data provided by remote sensors (in this scenario areal images captured by aircrafts), GIS can help in identifying geographic areas which need assistance, thus providing relief to areas most in need. However,

it becomes important to ground truth incidents based on these aerial images and the 3-1-1 call service requests. The reason being that it is important to evaluate which regions did call 3-1-1 but did not receive service due to lack of response. Thus, investigating the spatial relationships between aerial image footage and 3-1-1 calls can become crucial to future response evacuation and plans as well as response management.

We present preliminary results of visually analyzing 3-1-1 calls during Houston Harvey to the 3-1-1 ground truth data. By performing spatial analysis to determine statistically significant hot spot areas of 3-1-1 calls, we can identify from which counties we received the highest flooding calls. Ideally, we can potentially find a correlation which would help analyze where can we expect emergency calls from and efficiently plan resources for response management. In our future work section, we discuss how our analysis can be extended by classifying the images using supervised and unsupervised techniques to distinguish the flooded and damaged areas.

The application of our analysis is not limited to floods or hurricanes like Harvey. The visual correlation between 3-1-1 data (or other citizen-generated data) and real time satellite imagery during any disastrous event can lead to better understanding in identifying areas impacted and improve response management.

RELATED WORK

Our literature review is focused on two sections to ground our research in relevant scientific contexts. The first subsection is about the importance of 3-1-1 call analysis, while the second includes techniques and methods used in classification of satellite images.

Data Analysis

Langenberg (2007) represented the case study of Hurricane Wilma, 3-1-1 and Miami-Dade County which implemented implications for effective emergency management and citizen relationship during disasters. As per the case study, (Langenberg & Schellong, 6 Jan. 2007), Miami-Dade's 3-1-1 Answer Center served as a single point of contact and offered the people an access to government services prior as well as post-emergency situations. On an average 3-1-1 was handling 500 calls per day. During the event of an emergency, the call volume surged from average calls of 2000 per day to 12,737 calls per day. Half of the calls made were initiated from mobile phones. In due course of time, as the hurricane accelerated and impacted the infrastructure, power line and cell towers were no more able to function normally. This created a blind spot for the authorities and disaster management teams as help was not reaching places where the damage to infrastructure was substantial and request for rescue was not reaching the helplines. The Wilma 3-1-1 case demonstrates the importance of 3-1-1 request calls, as it is the only means of information for the relief workers to provide relief and perform a rescue. Any natural disaster has the potential to affect infrastructure in a way that it is rendered useless. It leads to victims not being able to request relief thus resulting in loss of life or injury. This inability for citizens to communicate with disaster responders creates an urgent need for an auxiliary source that can provide relief providers with data that can help them perform rescue operations proactively even when the infrastructure is down, and victims are stuck hoping for a miracle.

Yilong Zha et.al (2014) performed extensive analysis and data-based prediction of 3-1-1 calls in New York City (NYC). They provided statistics on complaint types, geolocation, and temporal patterns and displayed the diversity of the big 3-1-1 data along those dimensions (Zha & Veloso, 2014). For temporal distributions, a visual analysis was created to compare the distribution of request volume over days of the week for the different types of complaints. For understanding geo-correlation to population ratio for the different type of events, they calculated geo-correlation coefficient and used it for future predictions to see which areas receive the highest number of calls and for what kind of event. To predict request volume each day they combined data from U.S. calendar and NYC historical weather data. An experiment was performed using random forest trees considering the importance of features. A prediction table was generated by measuring Mean Squared Error (MSE) for the different types of features. Using this value, they predicted which feature was important to predict the types of complains and volume of calls. Using this method to identify which feature is important can help us understand patterns in the subset and detect events. For example, request volumes of storm debris removal can help us identify which areas are damaged and need amenities. In terms of the work presented by Yilong Zha et.al (2014) it can be

concluded that, how 3-1-1 call data can be used for understanding urban population characteristics and potential 3-1-1 calls that can come during a disaser event. For example, identifying where socially vulnerable populations live and/or what neighborhoods might be expected to generate high volumes of 3-1-1 calls.

Image Classification Techniques

Supervised Technique

In this method, training areas are selected where the user selects the area of interest. Training sets are created for different classes and these classes are merged into a single signature file (Jog & Dixit, 2016). Classification is performed using maximum likelihood, ISO cluster, class probability and principal components methods using this signature file as the input. The output would create an image with classifications that was created in the input.

Unsupervised Technique

In this method the user specifies the number of classes expected and which bands to use (Prasad, Savithri, & Iyyanki, 2015). The software clusters the pixels with similar characteristics and generate corresponding classes. Generally, the iso data and k means clustering techniques are used.

Object Based Technique

Supervised and unsupervised are pixel-based techniques where each pixel belongs to a class. Object based technique groups pixels into shapes and sizes of homogeneous objects. Multiresolution segmentation process which generates different object representation by grouping pixels represent different features in image like square shaped, elevated, using multiple bands (Prasad, Savithri, & Iyyanki, 2015). Nearest Neighbor classification is one of the method use to perform object-based classification in which after multiresolution segmentation, we classify objects on nearest distance and other statistics.

Need for Correlation

As previously discussed, many past researchers have done 3-1-1 call analysis. But to the best of our knowledge, few studies have specifically combined imagery analysis with 3-1-1 calls. The correlation will help to identify the plan for response activities as well as how decision systems and remote sensing technologies can be coordinated. The correlation of the 3-1-1 helpline services and satellite images captured by national imagery departments will help organizations how to make adaptions during emergency services to enhance cost effectively resilience of services during catastrophic events. Satellite imagery, when transformed into raster environment, covers the entire area analyzed and cause of its spatial ubiquity and multitemporal distribution. It is useful in conjunction with other combined data. Data acquisition and integration of remote sensing can help develop new methods for response and recovery operations. Geospatial cross referencing which combines the 3-1-1 data with image analysis helps in spotting damaged sites such as debris and collapsed houses. It also helps in identification of locations with considerable damages which might suffer from power outages as they lack any request for help over 3-1-1 helpline. Further, image classification can be used to categorize debris for planning purposes. The spectral characteristics in different bands of spectrum of the images helps us in classifying images to distinguish between ground surface materials and debris. Combing the 3-1-1 data and images we can produce maps like thermal images showing hot spots. Cross referencing and correlation can help produce maps for seeing transport status, determine level of elevation of debris, and submerged spots. Thus, combing data sets of calls with image analysis results in streamlined rescue management and proactive recue response.

METHODOLOGY AND PRELIMINARY RESULTS

Dataset

The dataset for 3-1-1 calls analysis is taken from the **City of Houston's 3-1-1 department** (City of Houston Department, n.d.). It contains 77,621 call records, while the imagery data set is taken from the (Hurricane Harvery Imagery, n.d.) Hurricane Harvey Aerial Imagery acquired by NOAA Remote Sensing Division. It has flight images captured from an altitude of 2500 to 5000 feet, using a Trimble Digital Sensor System (DSS) for Houston Harvey.

HotSpot Analysis

We first analyzed 3-1-1 calls made during Hurricane Harvey. To analyze the number of calls reported during flooding, we performed preprocessing of the data that included data cleaning, removing missing values, and extracted the calls with flood service requests. Later, using ArcMap GIS, we mapped the x, y coordinates of the places from where calls have been received using the base of Houston street map as shown in Figure 1.

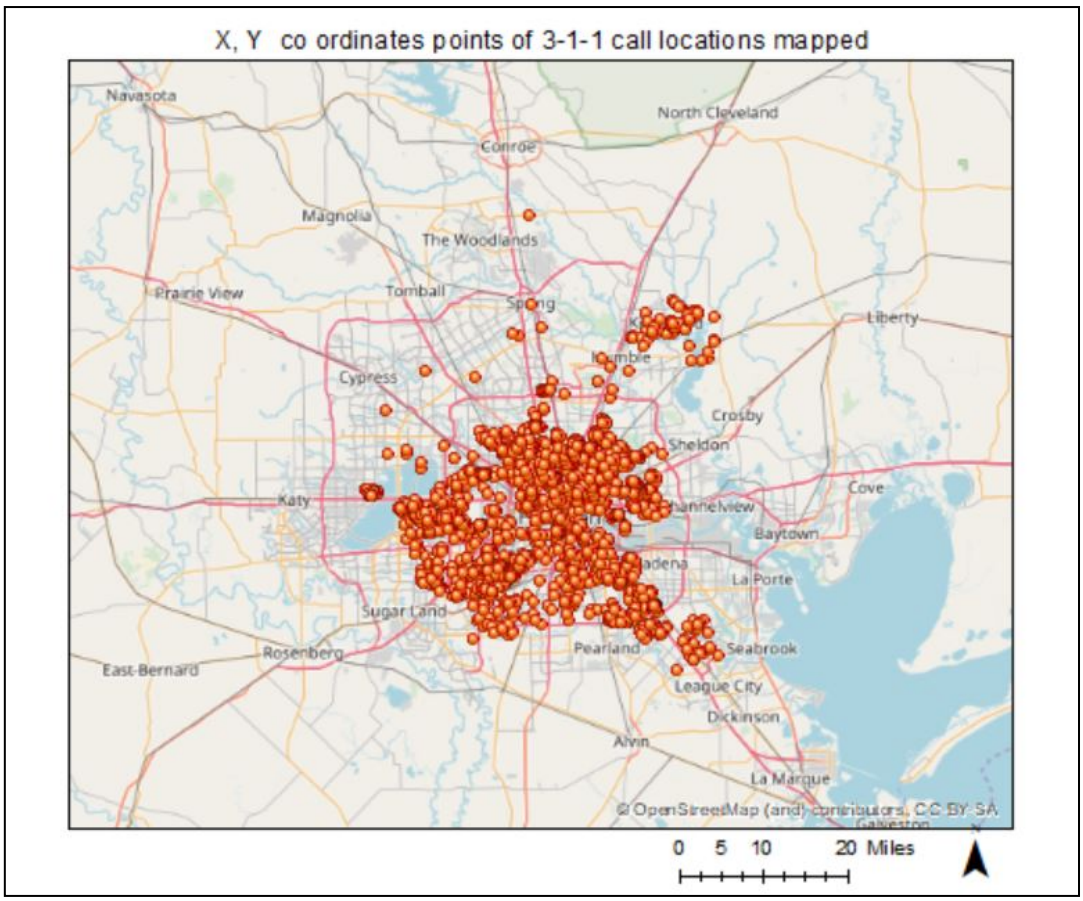

Figure 1. X, Y coordinate points of places with flooding calls

To understand the distribution of calls, their spatial patterns, and to determine resource allocation for emergency response management, we performed hot spot analysis using an industry standard GIS tool. Hot Spot analysis helps understand spatial patterns and determine statistically significant clusters that helps in locating neighborhood optimal locations. For each feature of the input dataset, a Getis-Ord Gi* statistic was calculated that results in z-scores, p-values, and confidence level, i.e the Gi_Bin for respective input feature. Results of this method were used to determine 'cold spots' which are statistically low clustered values and 'hot spots' with statistically high clustered values. Hot Spot analysis uses an input analysis field for determining clustering outputs.

Typically, 3-1-1 calls are highly related to population densities, meaning that populous areas tend to have more calls, which makes the comparison between places with very different population densities unfair. To address this issue, we calculated the density using a count field. A count field is a numerical field that specifies the number of incidents at each location. Using the Esri population census data as the count field and the locations of the received calls as the input, we calculated the density. Using this method, we calculate an appropriate search

distance for determining neighborhood size providing output densities in per square miles. In Figure 2, the low to high color scale range represents low to high range densities. Our intent was just to describe the phenomena and not make inferences or predictions or comparisons, in the future work section we discuss ideas for predictions.

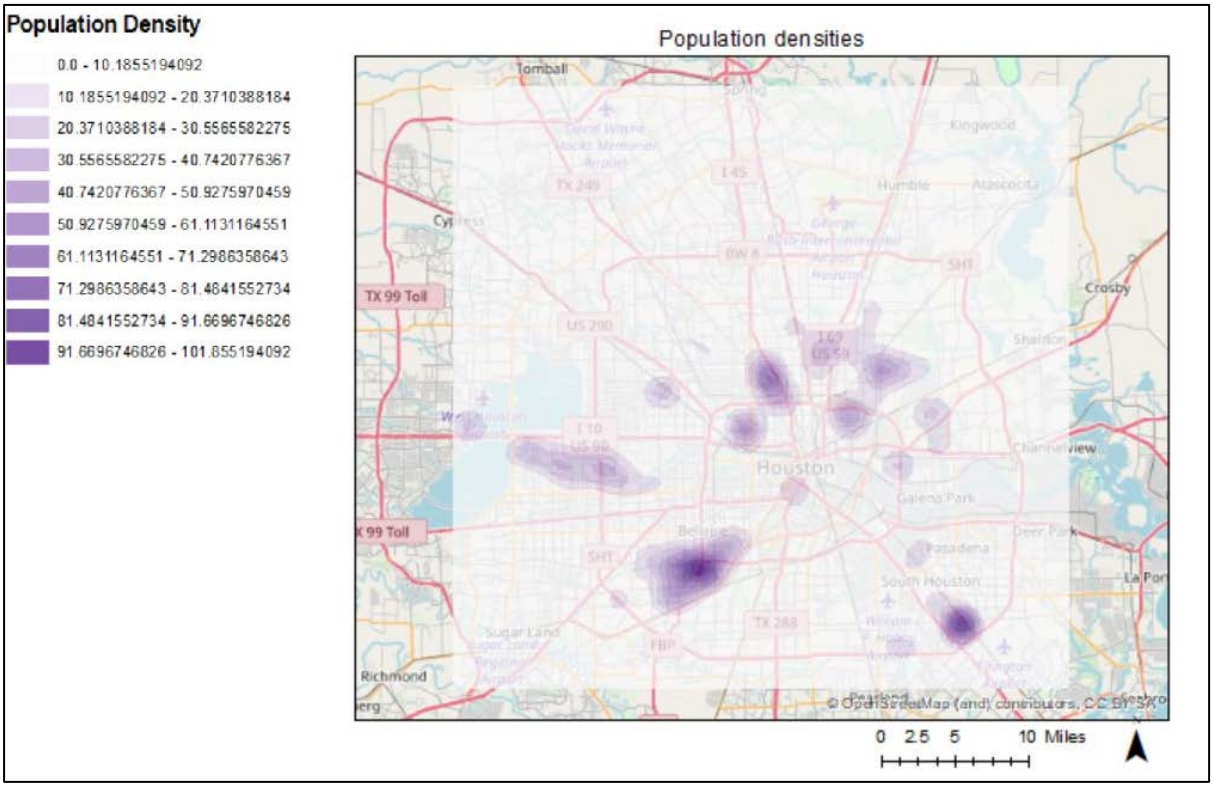

Figure 2. Low to high population density areas

For point data like 3-1-1 call data, which involves spatial clustering associated with incidents, we used several methods to aggregate the data. Since we have x, y coordinate points with short distances between each point, we integrated those points using a neighborhood of 30 feet. The value of neighborhood distance is derived from distance band which is associated to the peak value of incremental spatial correlation which we performed. The output of this spatial aggregation created a new feature called ICOUNT, which represents points with the number of incidents associated at each point. Figure 3 shows the number of incidents at each point where blue points represent locations with more than 4 calls.

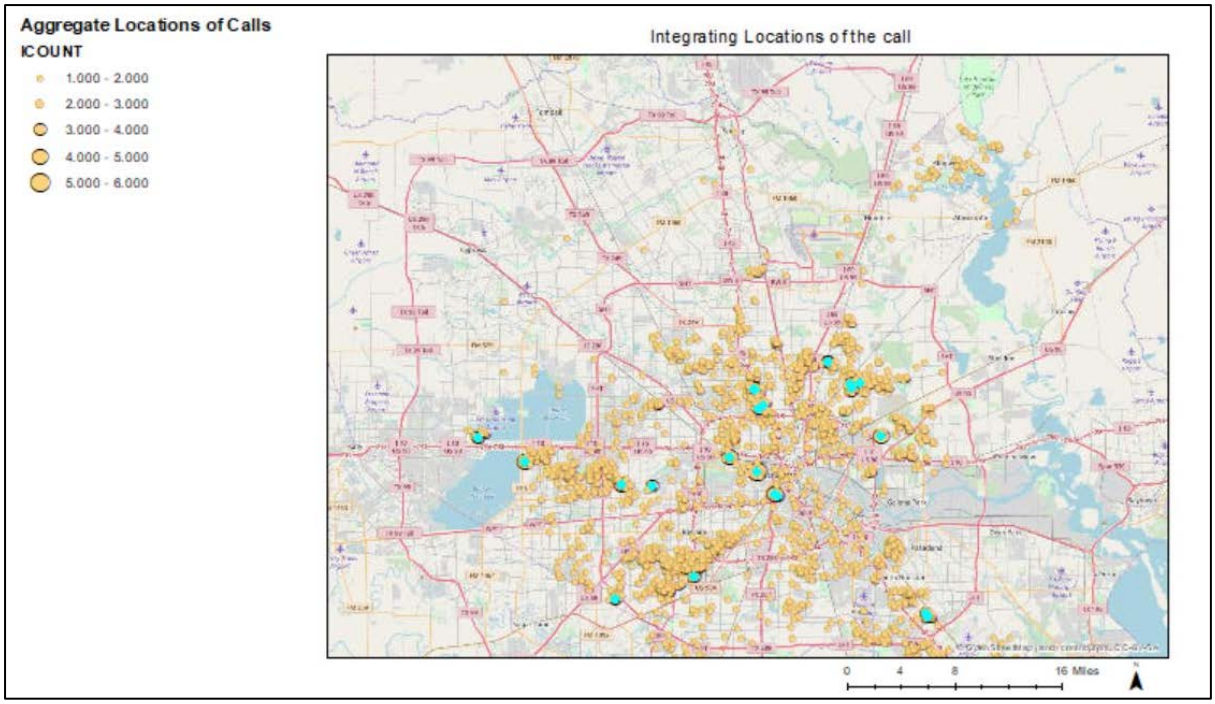

Figure 3. Points in blue represent incidents or number of calls at specific point which have ICOUNT >4

We used the ICOUNT output feature in the hot spot analysis to get the statistics for hot and cold spots. Figure 4 depicts the hot and cold spots with confidence levels. The GI_Bin field depicts the confidence level that helps in identifying low or high clustered points. The confidence level is the proportion of certainty about the true figure (ArcGIS). The proportion can be considered as the confidence coefficient that would be 0.99, 0.95, 0.90. There are different confidence levels for p values and z scores; a p-value represents the probability and z-scores are the standard deviations.

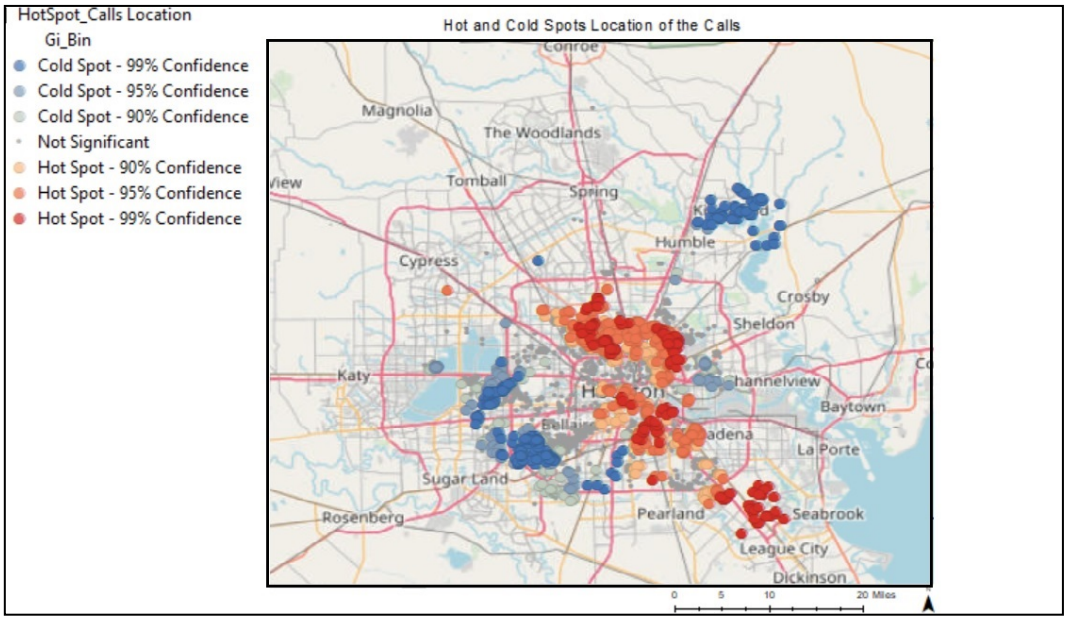

Figure 4. Hot and Cold Spots areas from where flooding calls have been received.

Using the fixed band distance parameter as ICOUNT and Euclidean distance method, we determined the significant spots (as seen in Figure 4) where red areas are the hot spots with high number of calls and blue are cold areas with less number of calls and beige areas are not statistically significant. Hot spots and cold spots are determined by combination of significant z scores and p scores, where a hot spot is an area with the largest number

of flood related calls received, while cold spots are less prominent areas from where the calls have received. The z scores above 1.96 value with 95% confidence level is considered significant hot spot and values below 1.96 are less significant. The 1.96 value is defining that 95% of the area of a normal distribution is within the standard deviations and exhibits a normal pattern (Table 1). From the hot spots, we can determine the likely neighborhood spots for receiving the calls.

Table 1

Gi_Bin	Confidence Level
+/-3	99%
+/-2	95%
+/-1	90%
0	Not significant

For better visualization of the clusters, we created a continuous surface using Inverse Weighted Distance (IDW) based on the GiZ score. Where low to high values based on the weighted distance are stretched or interpolated as shown in Figure 5. The higher values are marked as red and stretched from yellow to blue.

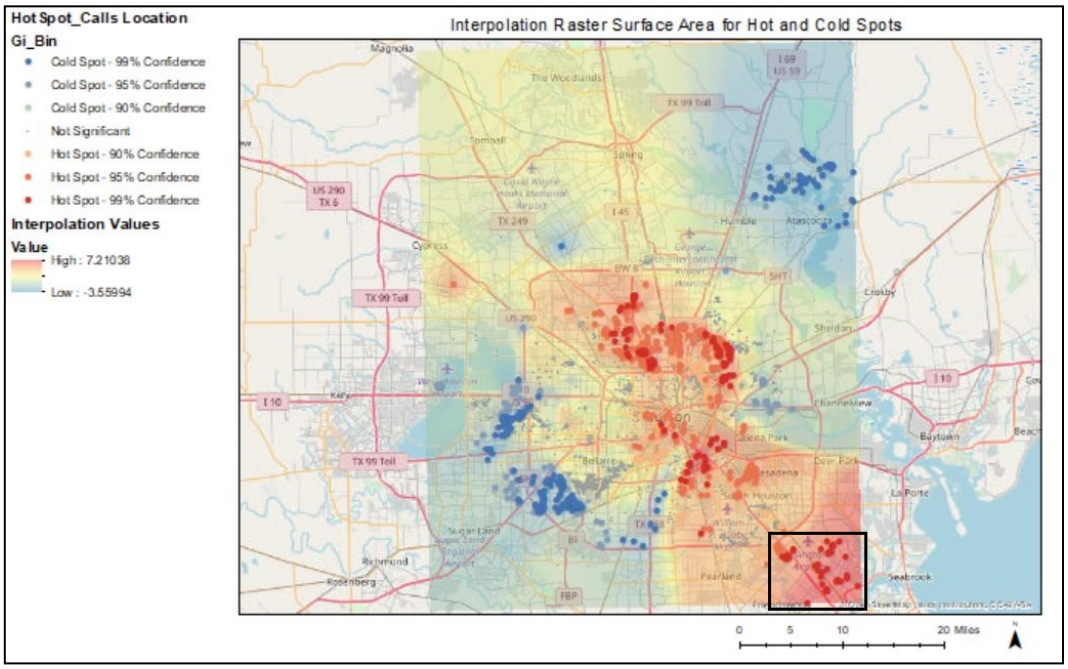

Figure 5. Interpolated raster surface for visualization. The area in the bottom right are the Cities of Dickenson and League City in Galveston County Texas.

Based on the hotspot analysis and IDW surface representation, several interesting patterns in terms of 3-1-1 call volume can be revealed. For example, the bottom right corner of Figure 5 shows a statistically significant area of 3-1-1 calls from the Cities of Dickenson and League City in Galveston County Texas (Burke, 2017). The authors of this paper visited Galveston County Texas in November 2017 and learned from local emergency management officials that Dickenson and League City were particularly inundated by the impacts from Harvey due to low lying elevations. Furthermore, response to this area was hampered by lack of situation awareness in terms of emergency responders having access to real-time data streams to inform response in Galveston County and identify specific areas such as boats for picking up people who were stranded on rooftops. Ideally, methods like the ones we are presenting in this work in-progress paper could be used for real-time analysis of 3-1-1 call data with real time satellite imagery to inform rapid situation awareness and targeted response.

Combined Image Analysis with 3-1-1 Hot Spot Locations

In this section, our aim is to combine satellite images that are geo referenced with the hot and cold spot call locations. Overlaying the significant hot spots and cold spots from where we received the calls over satellite images will enhance the data visualization. The images, associated with the call locations, will give a clear indication of damaged sites. This enables us to determine the ground truth. With the help of overlaying the call locations on imagery, we can pinpoint specific infrastructure locations to locate flooded areas and collapsed structures. With the visualization of damaged sites and correlated calls at that location, we can identify potential areas for evacuation within a ground zero site.

For combined analysis, we need to extract the data from a day flight focusing on specific areas that where depicted as the hot and cold spots. Next, we build a raster dataset of images and convert it the into required band format. These images are then geo referenced and exported in the form tiff to use as a base image.

As shown in Figure 6, we downloaded the image from the NOAA imagery August 30 Flight 1, converted it into a raster dataset, and extracted the University of Houston (UH)downtown area and exported as tiff using image and raster analysis tools in ArcMap. We see significantly hot spot locations near downtown Houston. The UH downtown areas and forest cemetery areas are flooded and damaged. This analysis gives an overview of damaged sites and the neighborhood areas from where calls have received. As per the reports, water-damaged buildings are located primarily in the northern and western areas of downtown. The downtown district was damaged due to increased water levels of Buffalo Bayou.

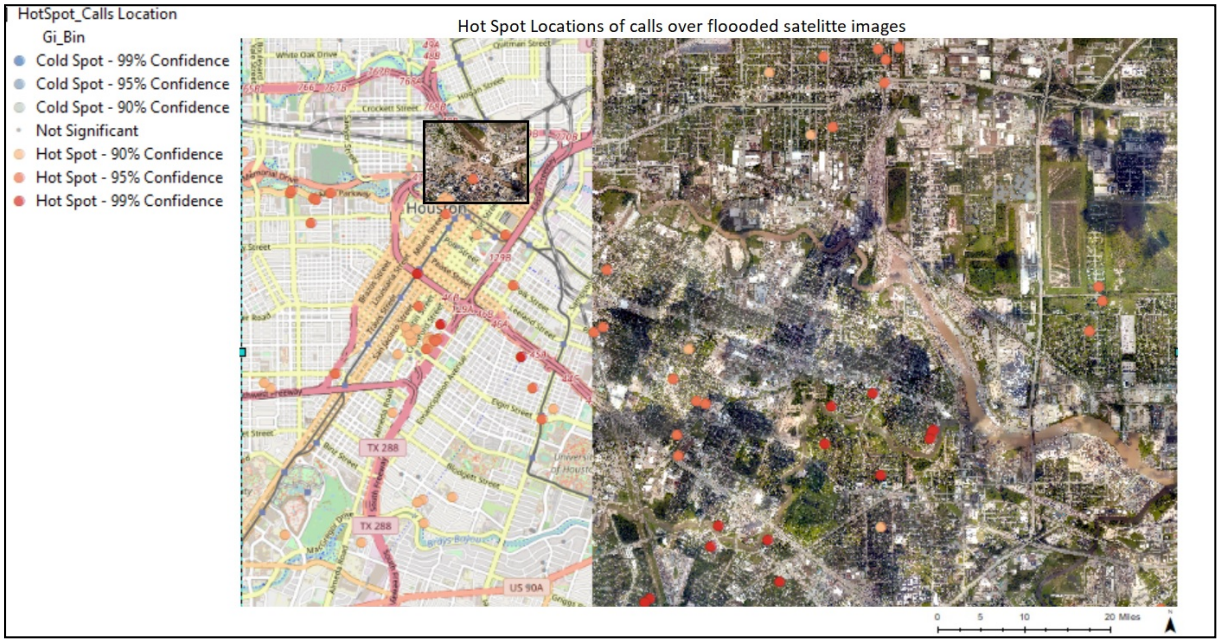

Figure 6. Area in the top left are the hot spots laid over UH downtown imagery and to the right are near Mongolia transit center and Forest cemetery areas

After plotting the referenced images and calls, there were many areas observed as per analysis which were highly damaged, but the locations from where the 3-1-1 had received were significant cold spots. On August 28, the Addicks and Barker reservoirs had filled to the capacity and the infrastructure was shut down (Almukhtar, et al., 2017). A voluntary evacuation was to put to order and the Army Corps of Engineers had to release water from reservoirs to the Gulf (Planas, Satlin, Lohr, & Gordts, 2017).

As reported, the officials did not expect the reservoirs to flood beyond capacity. Before the action was taken, neighborhoods near the dam had already flooded on Sunday night and due to late night help was hardly available. The coast guard rescue boats were sent the next day. The Harris county district emergency services were not available until August 31st. Under such scenarios, the aerial imagery and existing data helps the recovery team to plan evacuation, health and emergency facilities. The Figure 7 below shows the barker reservoir and its neighborhood flooded. But still the number of calls made were less significant due to lack of services available

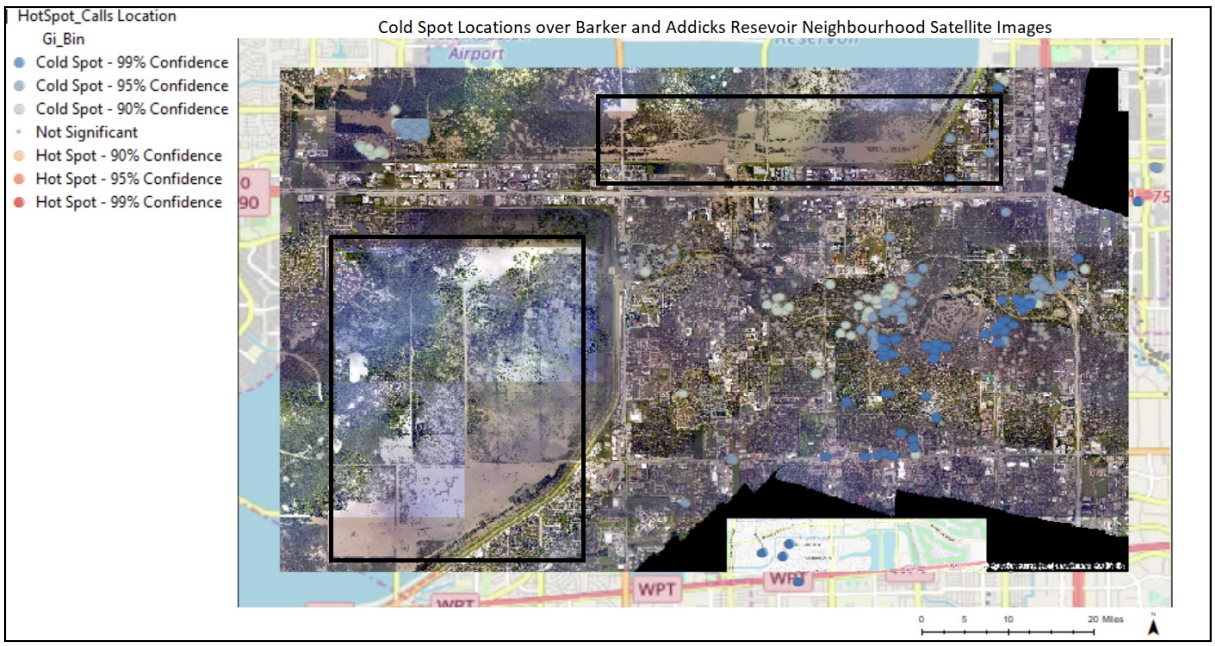

Figure 7. The highlighted areas show the over filled Addick's and Barker reservoir and Cold spots overlaid in their neighborhood areas

Harvey Floods affected Kingwood-Humble areas causing disruption to normal daily life. A lot of houses collapsed and were damaged as the flood gates opened at Lake Conroe, rushing nearly 80,000 cubic feet per second (Kingwood, 2017). A back up was provided for 3-1-1 calls service and a dedicated lime for prompt service was established by the Kingwood Community service and Houston Police. Multiple other online website platforms like nextdoor.com, Kingwood service was used when 3-1-1 dedicated line and other emergency services was not available. In few hours since the storm, the Kingwood areas and communities were stranded without electricity on August 30, 2017 (Kirk, 2017). CenterPoint reported that approximately 100,000 individuals, in its service area across Houston, were without power. The overlaid points of the calls location in the Kingwood areas in the Figure 8. below supports the evidence.

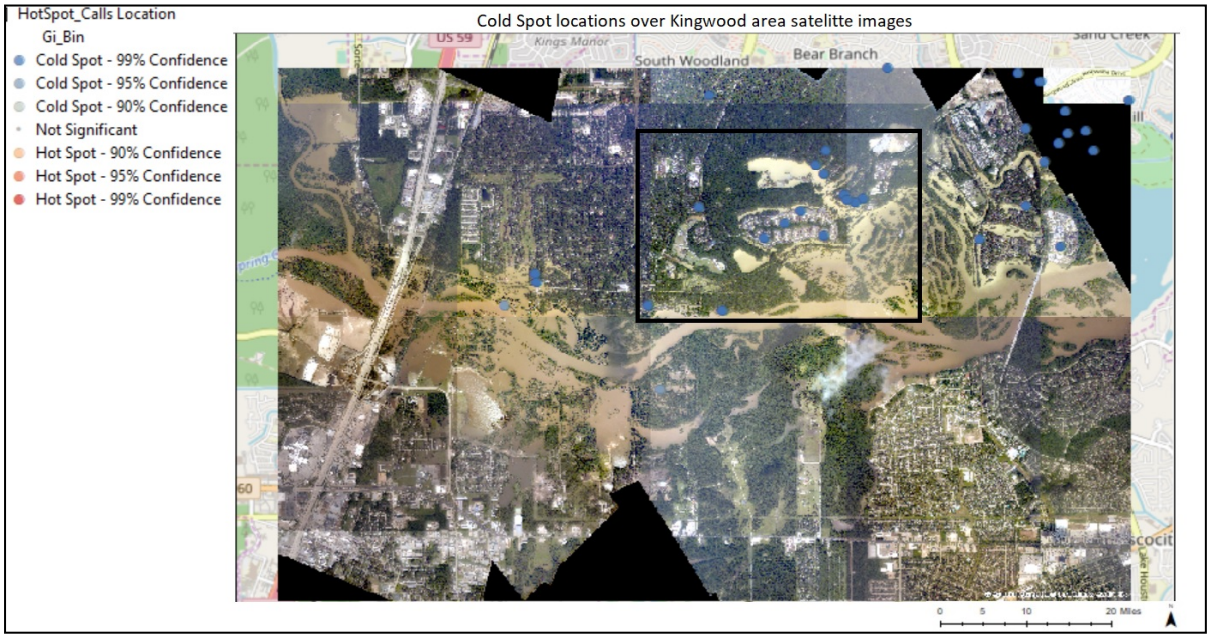

Figure 8. Cold Spots Locations overlaid on satellite images Kingwood areas

FUTURE WORK

Image Analysis

In the work presented here, we have used hot spot analysis to determine clusters of 3-1-1 call data during Hurricane Harvey. We combined statistical hot spots with aerial and remote sensing to have better visual correlation between hot spots and pictorial representation of ground situations. Our future work will involve classification of the images and to use temporal aspect of data to predict hot spot locations from different time slices. In this regard, we present our plan for future work to achieve this research goal.

Classification of images, such as finding patterns and areas of interest is needed for spatial data mining, extracting information for applications, thematic map creation, image interpretation, disaster and emergency response management, effective decision making and field surveys (Prasad, Savithri, & Iyyanki, 2015). In a paper review about the classification methods and techniques, the methods were classified into two categories supervised and unsupervised. The supervised training involves creating training sites based on ground truth samples and prepare images from raw data. Next, create signatures from training samples and apply to the whole image and then transform to create a suitable map (Jog & Dixit, 2016). The most widely used techniques or algorithms for supervised classification are Maximum Likelihood classifier, Minimum distance, and Image Segmentation. The steps involved in unsupervised classification techniques is to create clusters by grouping pixels and later assign labels to meaningful pixels. The most common algorithms used are ISO data and k-means. The methods are reviewed based on classification accuracy and kappa coefficient (Abburu & Babu Golla, June 2015). Based on this measures for multispectral satellite images object-based classification technique is better

ArcMap based texture analysis program for extraction of flooded areas from TerraSAR-X satellite image conducted by Biswajeet Pradhan where they analyzed imagery using pixel-based and object-based classification schemes also concluded that thematic map produced by pixel-based classification did not result in high accuracy results as compared to the object-based approach (Pradhan, Hagemann, Tehrany, & Prechtel, 2013).

This is the second phase where we would analyze the satellite imagery. For Harvey, NOAA collected imagery has from August 27, 2017, to September 3, 2017.We need to extract the data from a day flight focusing on specific areas which where depicted as the hot spots. Later will build raster dataset of images and convert into required band format. To perform classification will use various remote sensing techniques which include supervised, unsupervised and object-based classification.

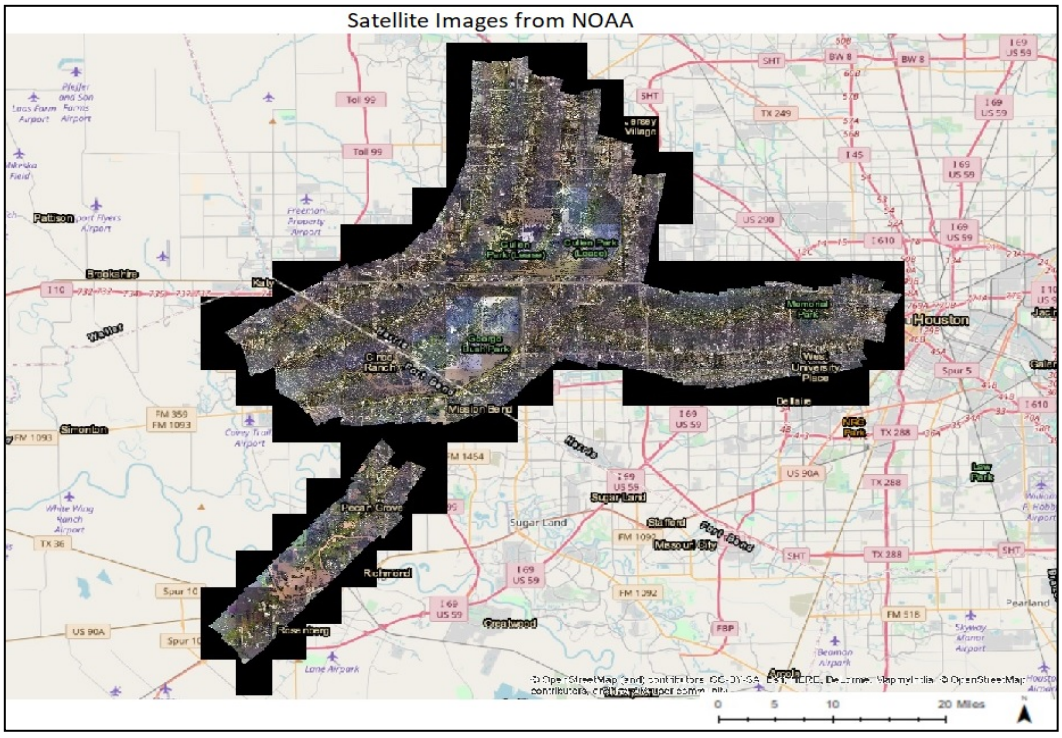

Figure 9. Satellite images from NOAA imported as raster datasets in ArcMap

As shown in Figure 9, we would import satellite images from NOAA Hurricane Imagery as raster datasets. These raster datasets are converted into mosaic dataset for performing different classification technique. To perform supervised classification, we would generate training samples by drawing polygons for different classes (ArcGIS Image Classification, n.d.). The classes would be the flooded water areas, damaged area, roads. After generating training samples, we would run the algorithms to produce classified images. In our case study object- based approach is the best suitable for high spatial resolution images. Multi resolution segmentation uses both spectral and contextual information thus rendering objects with better quality.

Evaluation and Comparison of Analysis.

After analyzing the hot spots, we would investigate the maximum calls where received and then determine the neighborhoods which are at potential risks and need a response. Next, we would do a comparison of these data points with the classified images of damage as per geographical area to find the correlation of the ground truth. We would try plotting and layer this data into an interactive map. To find the ground truth would match the results with Harvey by numbers and FEMA data.

CONCLUSION AND SUMMARY

In this paper we study the 3-1-1 calls Hot Spot analysis during Hurricane Harvey. Thomas Langenberg's case study suggests the need of an axuilarry source of information apart from 3-1-1 calls to effectively manage the rescue operations. Our approach takes into consideration that aspect of diaster management and introduces the correlation of sattlelite imagery with 3-1-1 call data. Our analysis provides detailed information about the situation during the event which can be used by the disaster management to plan effectively. With the combination of spatial and image analysis we can evaluate data closer to ground truth that can facilitate timely and well-informed management decisions. We propose that this analysis can be further applied to any natural disaster with same efficiency.

ACKNOWLEDGEMENTS

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Flood Hazard, Vulnerability and Risk Assessments for Uttarakhand State in India

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ABSTRACT

The Indian state of Uttarakhand, located in the valleys of the Himalayan Mountains, is severely prone to flash floods. High intense rainfall, river channels and slope are some of the significant factors responsible for flash floods. In this work-in-progress paper, we addressed these challenges via flood risk analysis in a geoprocessing framework that utilized hazard and vulnerability assessments, computed using hydrologic and demographic data by employing Analytical Hierarchy Process (AHP). The resulting maps indicated that flood risk regions have significant correspondence with regions that are highly hazardous and vulnerable. These maps could help develop better disaster management measures for Uttarakhand. Flash floods still being a globally challenging problem, these methods could be used to expand research to improve flash flood predictions and warning systems in many countries.

Keywords

Flood risk, DEM, GIS, India, Uttarakhand.

INTRODUCTION

Floods are the most catastrophic and the most frequently occurring natural disaster across the world. Floods are responsible for 47% of all weather-related disasters (UNISDR, 2015). About 6.8 million people died of floods in the 20th century. Statistically, 2.8 billion people have been affected (Doocy S, et al., 2013) with an average of more than 80 million affected each year across the globe in the last 30 years (Bhatt, et al., 2014). The repercussions include 4.5 million homeless, 540,000 deaths, 360,000 injuries and millions unrecorded (Doocy, et al., 2013). Economic loss for the last thirty years amounts to more than $11 billion. Between 1994 and 2004, Asia has seen approximately 1,500 flood disasters (Bhatt, et al., 2014).

The Indian sub-continent is highly vulnerable to natural disasters like floods, earthquakes and landslides. The state of Uttarakhand, which is located at the foothills of Himalayas, with China and Nepal as its neighboring countries (see Figure 1), is severely prone to floods and flash floods. Furthermore, flash floods often trigger landslides, and mudslides in regions that are geologically unstable. Some of the major events that have occurred in the last 30 years are Malpa flood and landslide of 1998 in Pithiragarh, Rudraprayag flood in 2001, Tehri flood of 2002 and Varunavat flood of 2003 (Pande, 2010).

In June 2013, people of Uttarakhand witnessed one of the worst flash floods seen in over a century. More than 6,000 people died, which is the highest for that year (Wake, Bronwyn, 2013), and thousands more were affected (Cho, et al., 2016). According to the Indian Meteorological Department (IMD), most regions received between 300mm and 400mm of rainfall within a span of four days, 14 – 18 June 2013. This torrential rain, caused by a cloudburst, ravaged the state that had already been subjected to high intense rainfall a few days before, 10 -11 June 2013, which had completely saturated the soil (Rao, et al., 2014; Martha, et al., 2015). The significant run-off that soon ensued was not only because of pre-saturated soil, but also from rapid snowmelt (Cho, et al., 2016).

Figure 1. Geographic Map of the Study Area

Consequently, the cumulative effect was two catastrophic flash flood events that led to land and mudslides, Mandakini river flooding, channel shifts, Lake Chorabari breach, destroying multiple settlements and thousands of lives. Kedarnath settlement, located along the banks of river Mandakini and a few hundred meters below Lake Chorabari, was completely wiped out by the disaster (Dobhal, et al., 2013, Rao, et al., 2014). The panchromatic satellite images of the settlement before and after the flash floods are shown in figure 2.

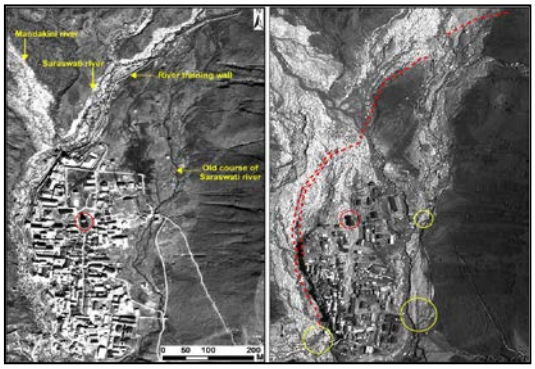

Figure 2. Left image is the pre-disaster 2.5 m resolution panchromatic image from GeoEye, and the right image is the post-disaster 2.5 m resolution CARTOSAT panchromatic image (Martha et al., 2015)

Even though, we have made significant advances in flood forecasting and early warning systems, flash floods are still a challenge because they occur due to intense short bursts of rainfall and measuring the intensity and duration of high intense rainfall is extremely difficult (National Research council, 2005; Rao, et al., 2014). Flash floods mostly occur in complex mountainous regions (National Research Council, 2005). Historically, heavy rainfall and cloudburst have been the main factors for floods in this region. (Bhambri, et al., 2016). High elevations, dense river network and the soil type have augmented the severity of flash floods. (Danumah, 2016; Hill, Firoz, 2010). Furthermore, state-wide hydro-electric power plants have been claimed to have intensified the impacts of floods (Sati and Gahalaut, 2013). This is because, these projects involve deforestation, blasting and tunneling and constructions in regions without proper inspection of the layout. Projects without proper inspection are geologically hazardous, as a significant portion of the state is situated on highly active seismic plates and disturbances could trigger floods and landslides (Ray, et al., 2016; Martha, et al., 2015; Sati and Gahalaut, 2013). Lack of significant information regarding the topographical and meteorological factors, rugged terrain and dense vegetation are major obstacles for having better disaster management relief.

June 2013 flash floods drew the attention of the scientific community, and an increasing number of research has been carried out ever since. Rao, 2014 carried out a comprehensive hydrological and hydraulic simulation study for Kedarnath town that quantified the causes of the flash floods. An extensive study about the devastation in terms of property damage for the regions of Garhwal and Kedarnath was carried out by Bhambri, et al., 2016. Number of landslides triggered by the flash floods were studied by Martha, et al., 2015. Cho, et al., 2016 took a different approach and carried out a comprehensive research on anthropogenic causes for climate change that caused the flash floods using Coupled Model Intercomparison Project Phase 5. Despite the wide variety of research, there are not many studies performed regarding flood risk management. Although, Bhatt, et al., 2014 carried out flood hazard and risk assessment for Chamoli district, a thorough research for flood risk analysis for the whole state is yet to be performed.

Multi-Criteria Analysis (MCA) has been popularly used by many researchers across the world to carry out flood risk analysis. Danumah, et al., 2016 used MCA to perform flood hazard and risk analysis for Abidjan district in Cote d'Ivoire. MCA was used for studying the flood hazard zones in Rhodope-Evros region in Greece by

Kazakis, et al., 2015. Matori, et al., 2014 used MCA methodology to identify flood prone zones in Perlis, Malayesia. Most of the research is limited either to a small region and /or for hazard or risk analysis. There are not many works on flood hazard, vulnerability and risk analyses for a whole state, which is data demanding and complicated. This is the issue addressed in this research.

This paper describes an extensive investigation of a variety of topographical and hydrological factors responsible for flash flood events in Uttarakhand state that are then applied to a geoprocessing framework using MCA. A series of maps were generated based on each factor, which were used to create hazard, vulnerability and risk index maps for the entire state. These maps provide a wealth of information that could prove to be useful across departments and organizations that are collectively responsible for decision making processes during flood disasters. The rest of the paper is divided into the following sections – study area, data sets, methods, results, discussions, summary, conclusion and future work.

STUDY AREA

Uttarakhand is a state in the Northern part of India, which shares international border with Tibet in the North and Nepal in the East. To the South and the West are two Indian states, Uttar Pradesh and Himachal Pradesh respectively, as shown in figure 1. The geographic extent of the state is 31.469° N, 79.062° E in the North, 30.25° N, 81.02° E in the East, 29.56° N, 77.99° E in the South and 31.06° N, 77.806° E in the West, with a total area of 20,650 sq. miles. The diverse topography includes glaciers, large number of perennial rivers, rugged mountainous terrain and dense forests. The elevation of the region varies greatly between 300 and 8,000 meters. About 68.4% of the state is covered by evergreen forests and 85% by mountains (Bhambri, et al., 2016; Bhatt, et al., 2014; Shresthta and Zinck, 2001). The topographical map is shown in figure 3.

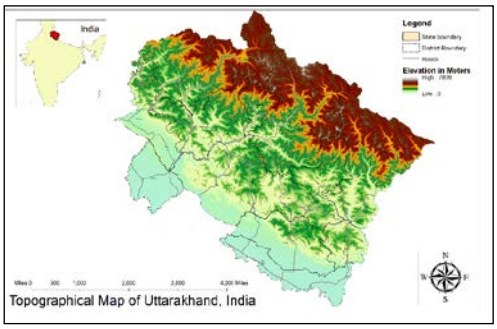

Figure 3. Topographic map of Uttarakhand state depicting elevation range from 0 to 7,809 m, river network, highways, state and district boundaries. An inset of a map of India shows the geographical location of the state.

DATA SETS

Conceptually, hazard, related to flood events, is characterized by the law of probability that considers factors related to natural phenomena, like hydrological and meteorological, and anthropogenic activities for a region. Vulnerability determines the damage sustained by the socioeconomic factors like demography for the region due to the disaster caused by the above factors. Risk, for a region, is determined as a product of hazard and vulnerability (Gilard,2016). Therefore, to compute flood risk, flood hazard and vulnerability assessments must be first carried out. The datasets used for hazard and vulnerability assessments are described below:

For hazard assessment precipitation, drainage density, soil moisture and slope datasets were used. Tropical Rainfall Measuring Mission (TRMM) precipitation raster dataset from 1998 – 2013 was obtained from NASA's Giovanni website. (Acker and Leptoukh, 2007). Shuttle Radar Topography Mission (SRTM) 30 m resolution Digital Elevation Model (DEM) data was obtained from USGS's EarthData website (NASA LP DAAC, 2000; Kobrick and Crippen). A total of 16 DEM raster tiles were obtained to cover the entire study area. Soil Moisture Index (SMI) data from National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL) (Dool, et al., 2003). Hydrography (river network) was obtained from MapCruzin website (MapCruzin). Population, settlements, places and road network vector datasets required for vulnerability assessment were all obtained from MapCruzin (MapCruzin).

METHOD

There are a lot of methods for flood risk analysis – quantitative, semi-quantitative and qualitative like indicator-based approach – of which quantitative is the more comprehensive method that not only identifies the potentially flood-risk areas, but also helps in cost benefit analysis, important for recovery stage. The method

involves quantifying all the components considering a variety of aspects of flood events – temporal probability of hazards with intensity and frequency, spatial probability of vulnerabilities and intensity of exposure at risk elements. The downside of such quantitative methods is that they are data demanding and difficult to apply for larger study area and/or regions that sufficiently lack data (Van Westen, 2016). Event-tree approach, a semi-quantitative method is used for flood risk analysis, which mainly focuses on multi-hazard or multi-disaster events and their frequency, which is not the focus of this research. For a large region like Uttarakhand, that is challenged by its terrain, remoteness, and lack of sufficient data, a more qualitative approach is appropriate, like the indicator-based approach. This method utilizes the indicators of hazard and vulnerabilities to assess the risk of the study area (Van Westen, 2016). Multi-Criteria analysis is a popular indicator-based approach that is used to carry out a holistic assessment of the indicators or variables to compute risk analysis by using remotely sensed data where quantitative ground data is lacking. The MCA method and algorithm used in this research is explained in detail in the following paragraphs.

Multi-Criteria Analysis (MCA) is a decision-making method for solving complex problems that involve multiple variables, high degree of uncertainty, many alternatives and scientific and socioeconomic challenges. Analytical Hierarchy Process (AHP) is the algorithm used as a part of MCA for hazard and vulnerability assessments. The entire analysis is carried out in a geoprocessing workflow using ArcGIS. The steps taken are describes as follows:

1. Set the final goal for the problem - Flood Risk Index Map is the final goal.
2. Consider the factors influencing the problem and collect data accordingly - Hydrologic, topographic and demographic factors.
3. Divide the problem into different levels - Level 1: Variables – Datasets. Level 2: Criteria – Hazard and vulnerability assessments. Level 3: Goal – Flood Risk Map
4. Solve each criterion using AHP.
5. Combine the intermediate results (from level 2) to obtain the final goal.

Data Preparation

The entire data preprocessing workflow for hazard and vulnerability assessments are presented below in the figures 4 and 5.

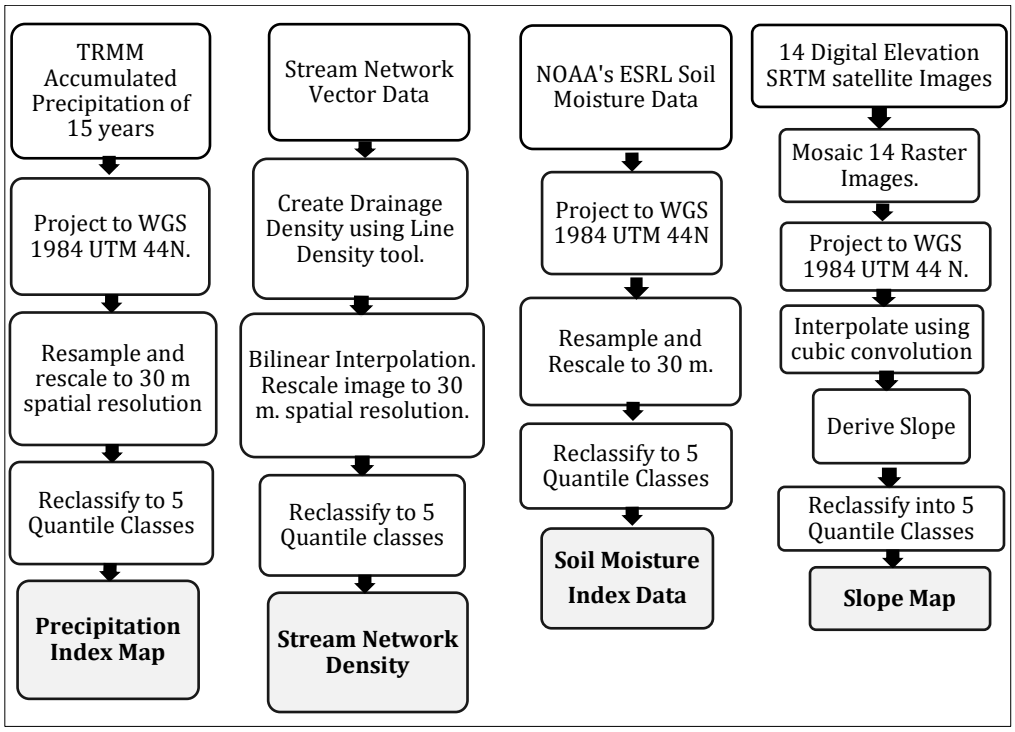

Figure 4. Data Preprocessing Workflow for creating Variables to be used in AHP for Hazard Assessment

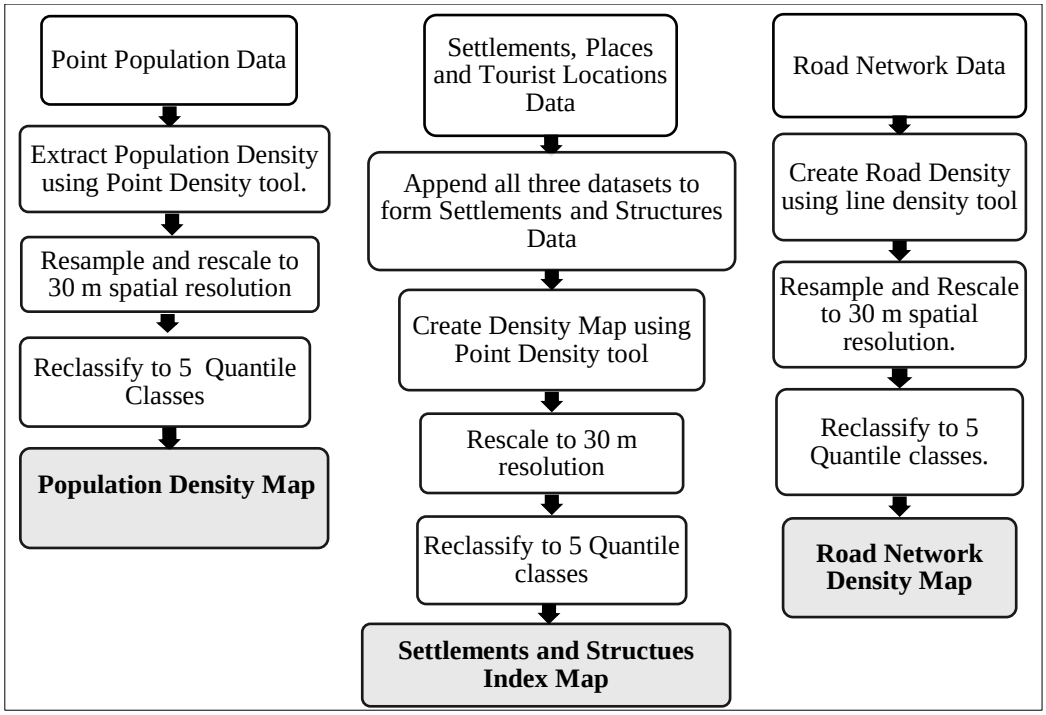

Figure 5. Data Preprocessing Workflow for creating Variables to be used in AHP for Vulnerability Assessment

Analytical Hierarchy Process (AHP):

AHP is most widely used for solving complex problems in which pairwise comparison is carried out between two variables by assigning weights according to Saaty scale, which is explained in table 1 (Danumah, et al., 2016; Kazakis, et al., 2015, Saaty, 1980).

Table 1. Saaty Scale used in AHP

Weights	Priority of the weights	Description
1	Equally Important	When both variables are equally significant to the criteria.
3	Slightly Important	One variable is mildly significant than the other.
5	Moderately Important	One variable is moderately significant than the other.
7	Strongly Important	One variable has higher significance than the other
9	Extremely Important	The variable has the highest significance to the objective.
2, 4, 6, 8	Intermediate preference between the weights	When compromise is needed between the two variables.

In AHP table, the variables are listed as attributes of comparison in the same order as row and column headers. Each row variable is compared with each column variable and input weights are assigned from the Saaty table based on the priority of the row variable. For instance, a value of 1 is entered as input if either a variable is compared with itself or the two variables have equal importance. When a value is entered for a row variable, then the reciprocal of the weight is assigned to the corresponding column variable that is listed along the row. The AHP tables for hazard and vulnerability assessments are shown in tables 2 and 3, which consist of input weights from the Saaty table, their normalized values (designated by their variable names with Nr as subscript), Priority Vector (PV) and Weighted Sum (WS). Weighted Sum is calculated by creating a matrix of elements obtained by each column of the input weights with corresponding priority weights. Then, the sum of each row gives the Weighted Sum (WS) for the matrix. To get consistent results, Consistency Ratio (CR) must be less than 0.1, which is calculated using Consistency Index (CI), Random Index (RI) and maximum eigenvalue (λ_{max}). Random Index (RI) (see Table 4) is selected from the Random Index Table based on the number of variables (Danumah, et al., 2016; Kazakis, et al., 2015; Saaty, 1980). The input weights for the AHP are based on

extensive literature review, which is explained in detail after the AHP tables and calculations.

Table 2. Flood Hazard Assessment AHP Table.

Variables	PRP	DD	SOIL	SLP	PRP_{Nr}	DD_{Nr}	$SOIL_{Nr}$	SLP_{Nr}	PV	WS
PRP	1	3	5	7	0.5966	0.6618	0.5357	0.4375	0.5579	2.3541
DD	0.333	1	3	5	0.1986	0.2206	0.3214	0.3125	0.2632	1.0983
SOIL	0.2	0.333	1	3	0.1193	0.0734	0.1071	0.1875	0.1218	0.49142
SLP	0.143	0.2	0.333	1	0.0853	0.0441	0.0356	0.0625	0.0568	0.22971
Total	1.676	4.533	9.333	16						

PRP = Precipitation, DD = Drainage Density, SLP = Slope

$$\lambda_{maxH} = Average\left(\frac{WS}{PV}\right) \quad (1)$$

Where, λ_{maxH} is the maximum eigenvalue for hazard variables.

$$\lambda_{maxH} = \left(\frac{2.3541}{0.5579} + \frac{1.0983}{0.2632} + \frac{0.49142}{0.1218} + \frac{0.22971}{0.0568}\right)/4$$

$$\lambda_{maxH} = 4.1177 \quad (2)$$

$$CI = \frac{\lambda_{maxH} - n}{n-1} \quad (3)$$

$$CI = 0.0392 \quad (4)$$

$$CR = \frac{CI}{RI} \quad (5)$$

$$CR = 0.043 \quad (6)$$

In equation (5), RI = 0.9 for 4 variables (See Table 4).

Table 3. Flood Vulnerability Assessment AHP Table.

Variables	POP	SS	RD	POP_{Nr}	SS_{Nr}	RD_{Nr}	PV	WS
POP	1	3	5	0.6523	0.6923	0.5555	0.6333	1.945
SS	0.333	1	3	0.2172	0.2307	0.3333	0.2604	0.78958
RD	0.2	0.333	1	0.1304	0.0768	0.1111	0.1061	0.31946
Total	1.533	4.333	9					

POP = Population, SS = Settlements and Structures and RD = Road.

$$\lambda_{maxV} = Average\left(\frac{WS}{PV}\right) \quad (7)$$

Where, λ_{maxV} is the maximum eigenvalue for vulnerability variables.

$$\lambda_{maxV} = \left(\frac{1.945}{0.6333} + \frac{0.78958}{0.2604} + \frac{0.31946}{0.1061}\right)/3$$

$$\lambda_{maxV} = 3.0381 \quad (8)$$

$$CI = \frac{\lambda_{maxV} - n}{n-1} \quad (9)$$

$$CI = 0.01905 \quad (10)$$

$$CR = \frac{CI}{RI} \quad (11)$$

$$CR = 0.032 \quad (12)$$

In equation (11), RI = 0.58 for 3 variables (See Table 4).

Table 4. Random Index Table

Number of Variables	RI
2	0.00
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Flash floods mostly occurs in complex terrain by orographic precipitation, which occurs by the influence of mountains or sometimes by hurricanes and tropical systems (Azmeri, et al., 2016; Hill and Firoz, 2010; Nation Research Council, 2005). Most flash floods are mainly triggered by high intense rainfall. However, there are other hydrological factors that also contribute to the cause. River channels, terrain slope, soil type and moisture, vegetation, landuse, snow melt and lake breach are some of them (Azmiri, etal., 2016; Bhambri, et al., 2016, Hill and Firoz, 2010; Martha, et al., 2015, National Research Council, 2005; Ray, et al., 2016). Azmeri, et al, 2016, Bonacci, O., et al, 2006, Kazakis, et al, 2015, Matori, et al, 2014, Strudevant-Rees, et al., 2001 have all considered intense rainfall as the main cause for floods in their research. Cloudburst and high intense rainfall were also the main causes for flash floods in Uttarakhand (Bhambri, et al., 2016; Cho, et al., 2016; Rao, et al., 2014; Sati and Gahalaut, 2013). Therefore, precipitation was given a higher weight in comparison to drainage density, soil and slope in the AHP table.

Large number of river channels near settlements is hazardous because greater drainage density causes channels to overwhelm with additional run-offs, thereby flooding the region (Hill and Firoz, 2010). Kedarnath is the perfect example for this situation, as it is situated on the banks of river Mandakini, which completely devastated the town (Bhambri, et al., 2016; Martha, et al., Rao, et al., 2014). Danumah, et al., 2016 and Kazakis, et al., 2015 considered drainage density as second hazardous factor in their research as well. For the number of perennial rivers that flow close to the settlements, and the close hydrological connection between intense rainfall and river flooding, drainage density was a more hazardous factor compared to slope and soil.

Soil moisture index is crucial for the run-offs. During monsoon seasons, due to normal antecedent rains soil gets saturated, which leads to increasing run-offs during intense rainfall. However, it was considered relatively less crucial compared to the former factors for causing flood hazards because it relatively less hazardous if there are no pre-saturation conditions.

Slope influences the run-off factor during intense rainfall. Steeper terrain causes lesser water to be absorbed leading to significant run-offs both ono surface and in channels. However, it is more hazardous when steepness is low as water floods in low elevated regions (Kazakis, et al., 2015). Since most of Uttarakhand has higher elevations slope was assigned the least weight in pair-wise comparison in AHP.

Finally, flood risk map is generated as product of flood hazard and vulnerability assessment results. The entire workflow is shown in figure 6, which represents all three levels – variables, criteria and goal.

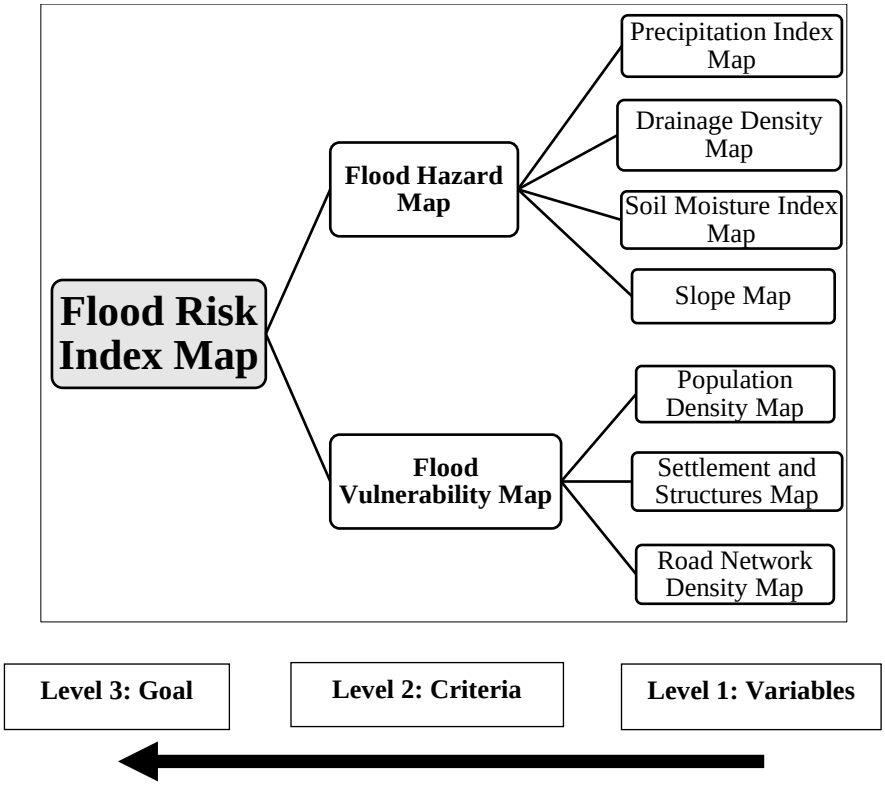

Figure 6. Multi-Criteria Analysis Workflow for Flood Risk Analysis

RESULTS

A total of 13 maps were generated from all the workflows in ArcGIS and were classified in 5 classes that are tabulated below:

Table 5. Map Classes

Index	Class	Color
1	Very Low	Dark Green
2	Low	Green
3	Medium	Yellow
4	High	Orange
5	Very High	Red

The results of preprocessing workflow for hazard assessment are thematic maps of precipitation, drainage density, soil moisture and slope. These are displayed in figures 7 and 8. Figure 9 is the Flood Hazard Map which was obtained by using the above maps as input variables to AHP hazard assessment table.

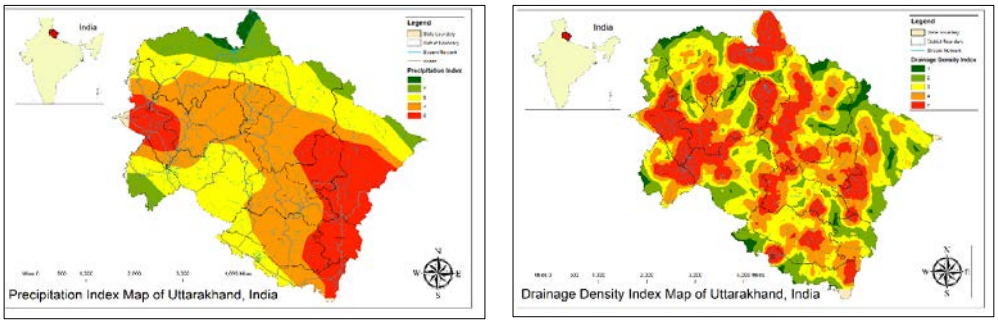

Figure 7. Precipitation and Drainage Density maps obtained from flood hazard preprocessing steps

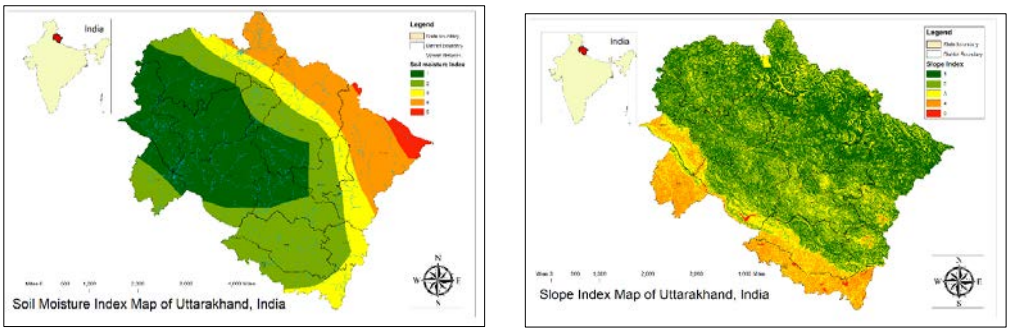

Figure 8. Soil Moisture and Slope Maps of Uttarakhand State, India

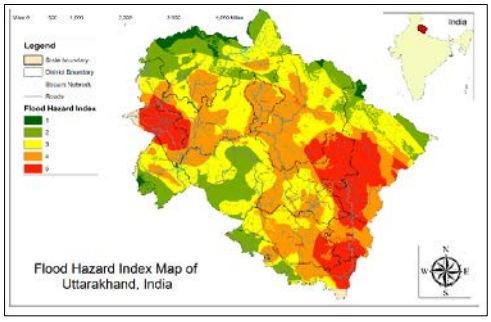

Figure 9. Flood Hazard Index Map. Classes 4 and 5 hazard regions correspond with that of Precipitation and Drainage Density regions

Data preprocessing results for vulnerability assessment were population density, settlements and structures, and road density maps. These are displayed in figure 10. Using these as inputs to vulnerability AHP table, flood vulnerability index map was created that is shown in figure 11.

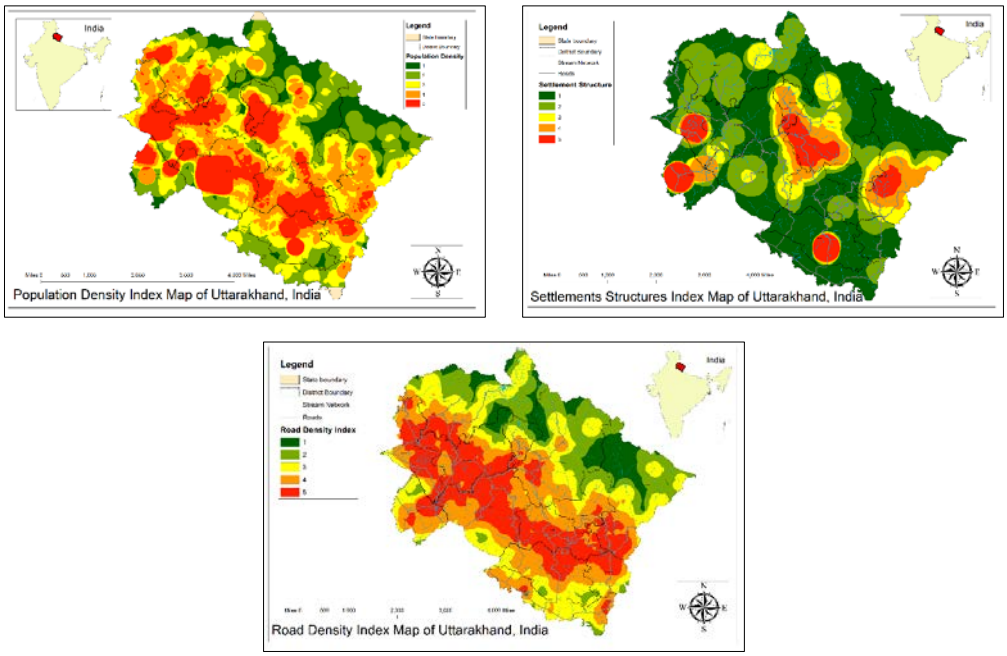

Figure 10. From top left clockwise: Maps of Population Density, Settlements and Structures, and Road Density

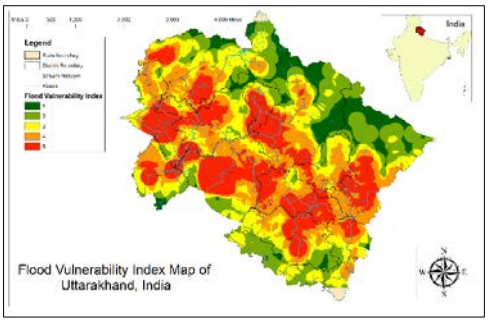

Figure 11. Flood Vulnerability Index Map. Evidently, highly vulnerable regions correspond with areas of high population density and settlements and even road network despite assigning lower weights.

The product of flood hazard index and vulnerability index maps is the flood risk map that is shown in figure 12. Figure 13 shows two overlay maps of flood risk – one with major hydro power plant locations and the other with locations of historical flood events that evaluates the results of the analysis.

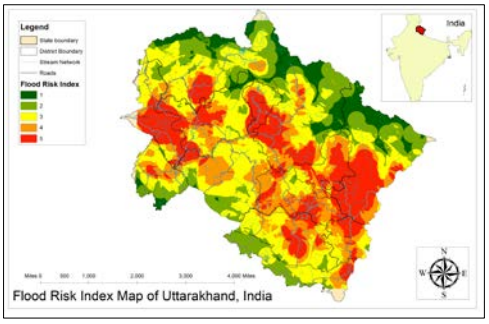

Figure 12. Flood Risk Index Map of Uttarakhand

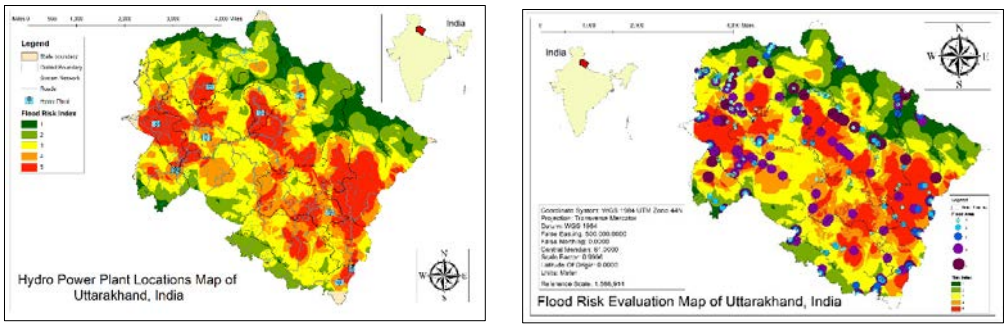

Figure 13. On the Left is a map of Flood Risk overlaid with Hydro Power Plant Locations, many of which are in high risk zones. On the Right is Flood Risk Map overlaied with locations of historical flood events. These events are represented by graduated dot density. So the large purple dots represent greater number of flood events that mostly coincide with classes 4 and 5 of the risk index.

Analytical results of multi-criteria analysis using AHP for flood hazard and vulnerability assessments in geoprocessing framework using ArcGIS are tabulated below.

Table 5. Flood Hazard Assessment Analytical Results. CR = 0.043

Variables	Eigenvalues	Eigenvectors	Criteria Weights
Precipitation	4.117	0.888	56.5009
Drainage Density	-0.0037	0.4121	26.2201
Soil	-0.0037	0.1847	11.7504
Slope	-0.1095	0.0869	5.5285

Table 6. Flood Vulnerability Assessment Analytical Results. CR = 0.036

Variables	Eigenvalues	Eigenvectors	Criteria Weights
Population	3.0385	0.9161	63.6986
Land Use	-0.0193	0.3715	25.8285
Road	-0.0193	0.1506	10.4729

DISCUSSION

Variable Classification

The classification of each variable is based on the degree of influence a variable has on hazard or vulnerability and the type of relation it has with the index factor: direct or inverse. For instance, precipitation has a direct relation with the index factor. Lower precipitation regions are assigned classes 1 and 2, while higher precipitation regions are classified 4 and 5 indicating that they are highly prone to flood hazards. Similarly, low population density regions are classified as 1 and 2 because they are less vulnerable to flood disasters, whereas high population density regions are assigned classes 4 and 5 as they are more vulnerable.

Soil moisture index and slope are the only two variables that are inversely related to the index factor. Soil moisture data obtained from NOAA's ESR Laboratory is created using water heights in soil (Dool, et al., 2003). Therefore, regions with low moisture index have low water heights indicating lesser moisture absorption capability and therefore are more prone to flood hazards. However, regions with high soil moisture index have better moisture absorption capability and are therefore less susceptible to flood events. Hence, in the reclassification step, low soil moisture regions were assigned classes 4 and 5, and high soil moisture regions were classified as 1 and 2.

Extending the same concept to slope, regions with higher steepness or slope are assigned classes 1 and 2, and regions with low slope are classified as 4 and 5. This is because, during heavy rainfall, water flows down quickly in steeper regions, which decreases stagnation. On the other hand, in less steep regions, water flows slowly, which overwhelms the river channels and cause flooding. Therefore, flat lands are more prone to flood hazard than steeper regions (Danumah, et al., 2016, Kazakis, et al.,2015).

Flood Hazard Assessments:

According to the analytical results of hazard assessment shown in table 4, 56.5% of the flood hazard is caused by precipitation and 26.2% by drainage density. This result is consistent with the studies Azmiri, etal., 2016; Bhambri, et al., 2016, Hill and Firoz, 2010; Martha, et al., Rao, et al., Sati and Gahalaut, 2013 that indicated that high intensity rainfalls, runoff and lake breaches frequently cause devastating floods. Even though, the slope in the central region of the state was less steep, it did not have much influence in the hazard map as it was awarded the lowest weight. Therefore, its overall contribution to causing hazard is just 5.5%, which is preceded by soil moisture index with 11.7% contribution. The values of maximum eigenvalue (λ_{maxH}) and CR, 4.1177 and 0.043 respectively, from equations (2) and (6) match the values from the analytical results of AHP. (see Table 5).

Flood Vulnerability Assessment:

Population, settlements and structures and road network are the most vulnerable to flood hazard. The population map is denser than the settlements, because the population map has considered the population at the tourist attractions as well. Millions of tourists visit many of the popular destinations, making some of the regions more

populated than they are. According to table 5, 65% of the vulnerability factors is population, which is followed by 25% of settlements and structures. Only 10% of the total vulnerability factors is attributed to road network. The values of maximum eigenvalue (λ_{maxV}) and CR, 3.0381 and 0.032 respectively, from equations (8) and (12) closely match the values from the analytical results of AHP (see Table 6).

Flood Risk Assessment:

The higher flood risk regions are the areas that are not only highly populated, with larger settlements, more buildings and tourist attractions, but also receive high precipitation and have large number of drainage networks. These areas are also mostly valleys surrounded by steep mountains. The hydroelectric power plant locations map (Figure 13) was created using the data from NRSC's (National Remote Sensing Center of India) WRIS (Water Resources Information System of India) portal (WRIS NRSC). As seen in some of the literature, Hydroelectric power plants are now being considered as a potential cause for increasing the effects of flood, thereby increasing the hazard. From the power plant map (Figure 13), it is evident that most of these plants are situated in very high-risk regions.

The flood risk evaluation map (Figure 13) has historical flood events data overlaid on the risk map. The dot densities represented by small blue dots indicate small number of flood events, where as the large purple ones indicate large number of major flood events. From the map, it is evident that majority of the purple dots coincide with red high-risk regions. This shows that the method and the data sets used in this research produced verifiable results in relation to historically recorded flood events. These results could definitely be improved with better data, inputs and applying qualitative methods.

SUMMARY, CONCLUSION AND FUTURE WORK

Uttarakhand is a land of steep Himalayan mountains, dense perennial river networks, home to a host of pilgrim and tourist places, attracting thousands of people from across the world. The region is situated in a seismic active zone, and the recent urbanization has made the state more unstable. The state is also known for adverse weather conditions, which receives high intense rainfall and frequent cloudbursts. All these factors are responsible for the state being prone to flood disasters. Recent devastating flash floods have raised concerns regarding disaster management methods.

In this research, we identified regions highly prone to flood events and recognized precipitation and drainage networks as the main causes. Many historical flood events took place in the high-risk zones. Using the flood risk maps, several measures could be taken to improve the disaster management methods in the future. For instance, distance from the river networks could be considered to develop better strategies to protect the settlements in case of a disaster. Road network and drainage network maps could be used to plan evacuation routes. Anthropogenic factors like deforestation, constructions projects and hydro power plant projects have increased the frequency and intensity of floods. Power plant projects involve digging and blasting of vast land areas, and since Uttarakhand is in a seismically active zone, these activities make the region more unstable, and lead to multiple disasters like floods, landslides and mudslides. There is a lot of scope for further analysis in this regard. For instance, Geostatistical analysis could shed more light on the correlation between power plants and flood hazard. More comprehensive hydroelectric power plant data with geological and vegetation data could also be considered in the future works.

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Track 7

Planning, Foresight and Risk Analysis

Study on the Utility of Emergency Map in Emergency Response

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ABSTRACT

As modern cities expand rapidly, the loss of emergency has been more serious. To reduce or even avoid losses caused by disasters, using emergency maps to collect, aggregate, analyze, and communicate information is a prerequisite for efficient response. In this paper, we analyzed the impact factors of information transfer efficiency, and constructed the communication model provided by Emergency Map. By comparing the difference with case deduction between the traditional communication mode in emergency response and the new communication mode based on Emergency Map, which is called Group Communication Mode. We proved the Group Communication Mode had the advantages to improve information transfer efficiency in emergency response. Emergency Map can be an effective tool for the timely transfer of information among departments, which put forward a novel communication mode in emergency decision-making process.

Keywords

Emergency Map, communication model, Group Communication Mode, order degree, information transfer efficiency.

INTRODUCTION

On account of the unexpectedness, tremendous conflict and social influence of the emergency, emergency become the focus of the public concern and need timely response to decrease loss once emergency occur. As cities expands rapidly with great human and resource aggregation, the loss of disasters would have been more serious, and how to reduce life and property loss is the primary issue for decision-makers. The information delay and distortion in emergency response process caused the more serious loss. In 2003, the SARS broke out. Because of the poor information communication, it was difficult to integrate varieties of emergency resource, and the diffusion of epidemic situation lost control (Fan, 2007). The Indonesia tsunami in 2004 was predicted by the Pacific Tsunami Warning Center located in Hawaii, but the failed communication with Indonesia delayed the tsunami early emergency seriously (Hu&Wang, 2008). The WenChuan earthquake in 2008, the poor information communication caused the confusion rescue command and there were the problems of insufficient or excess rescue force at the rescue scene (Ministry of Civil Affairs Chinese National Disaster Reduction Center, 2009).

Grasping the emergency information timely is the premise of making appropriate decision. The emergency information transfer restricted the betimes and effectiveness of emergency response directly, which affected the returns to scale of emergency management. (Sheng&Guo, 2013). Since the events such as 9·11 that underscored the failure of prior governmental information sharing, public organizations had shifted from a model that emphasized information protection to one where cross-organization information sharing was the new goal (Yang&Maxwell, 2010). There are usually many difficulties perplex the emergency management around information, such as difficult to obtain, organize, share and apply. In the process of emergency response

cooperated by multiple participants, the information was the tie to implement the communication and cooperation effectively. So the information sharing became an indispensable link in the emergency response process, and even bottleneck problem (Chen & Zeng, 2017).

In China, the functional department as a basic unit constituted the emergency management system (Liu et al.,2013), and intra-departmental information transfer was timely and effective (Ruan&Yang et al., 2010). However, when significant emergency occurred, emergency management required multiple departments to share information and make decision together (Zhang et al.,2016). Then the development of the situation can be effectively controlled, which can avoid a wider range of losses. So Chinese emergency management still need some effective means of information communication to handle significant emergencies (Jing et al., 2010). As a multi-party cooperative consultation system, Emergency Map can be an important aid in emergency decision-making process (Beijing GSAFETY Technology Co., Ltd., 2011). The consultation participants plotted on the same map to share their own information, so other participants could get information by the plotted map at the same time.

In this paper, we provide a novel communication mode based on the Emergency Map, which is called Group Communication Mode. On the basis of the impact factors analysis of information transfer, we clarify the process of Group Communication Mode and the traditional communication mode of emergency response in China. We introduce the timeline of emergency response and the order degree of the information transfer system in methodology section. Finally, we compared the Group Communication Mode and the traditional communication mode of emergency response in China by a case study, including time consuming and order degree of information transfer.

THEORETICAL ANALYSIS AND HYPOTHESES

Based on the analysis of impact factors of information transfer efficiency, we sort out three impact factors. And among them, we can improve the information transfer efficiency by improve the connection relation. We compare the main characters of the information transfer models and clarify the processes of traditional communication mode and the Group Communication Mode in emergency response.

Analysis of Impact Factors of Information Transfer Efficiency

Defined by informatics, the information transfer process includes the information coding of senders, information transfer between senders and receivers and the grasping information of receivers (Hwang&Kim, 2007; Kimmerle et al., 2011). As for emergency management, the senders should choose and describe the information, and the information should be passed to the receivers through specific channel and tools (Li et al., 2013). The factors that influence the information transfer efficiency in the process of information transfer are shown in Table 1. They are divided into three aspects: information itself, information subject and connection relation. It is undoubtedly that the prime factor which can affect the information transfer efficiency is the information itself. The information characteristics affect not only the coding efficiency of senders but also the decoding efficiency of receivers. The complexity of information is one of the impact factors, and the bigger the information complexity is, the lower the information transfer efficiency is. The standardization degree of information is the other impact factor, the higher the standardization degree is, the higher the information transfer efficiency is. And the information subject is another factor that affects the information transfer efficiency, which depends on both senders and receivers' information literacy. As for senders, the capability of sending message determines the coding distortion. While for receivers, the information demand is the impact factor of the transfer efficiency, including current demand and potential demand. The current demand is the standardized demand of emergency information, for instance, the prescriptive information in emergency response plan. And the potential demand is the non-standardized demand of emergency information, which is still in subconscious and described inaccuracy, for instance, the information demand for an unprecedented emergency. However, due to the uncertainty and diversity of the emergency, the potential demand of the information is the primary stage of the current demand, and the amount of it is also far more than current demand. There are many characteristics of the potential demand, such as potential, massive, fuzziness and conversion property. The connection relation of the information subject is also a main impact factor of the information transfer efficiency. When various parties in the information chain communicate by different connect methods, the information transfer efficiency is affected by out-degree, incoming degree, diversity, centrality degree, and so on (Pfeiffer&Velthuis, 2009).

How to improve the efficiency of information transfer in emergency management process is the main issue, and it needs to be solved by emergency management participants. We assume that the emergency response participants have the professional ability. It means that the information subjects do their best to avoid coding distortion and clear current demands. As mentioned above, we should start with the information itself and the connection relation to improve the information transfer efficiency. On the one hand is reducing complexity

degree and promoting standardization simultaneously degree of emergency information. The Emergency Map provides a platform of emergency deliberation and the plotted map figurative emergency information from the abstract text. On the other hand is adopting a more reasonable communication connection mode of nodes, which can both reduce the time cost of information transfer and approach the effect of communication sufficiently.

Table 1. the impact factors of information transfer efficiency

Impact factors	**Impact mode**	
Information	Information complexity	
	Standardization degree of information	
	Capability of send massage	Coding distortion
Information subject	Information demand of receivers	Current demand (Standardization)
		Potential demand (non-standardization)
Connection relation	Node connection pattern	

The Communication Mode

American psychologist Levitt divided the information transfer process into five models, including Chain Model, Ring Model, Wheel Model, Complete Channel Model and Y Model (Huang, 2000; Levitt, 1986). Figure 1 shows the characteristics of the five communication models in information transfer process. The information flow in Chain Model transfers one by one, and the information distortion is the main problem of this model. The Ring Model is a closed information transfer mode, so the information flow constitutes a closed loop. And the information transfer velocity of Ring Model is much slower than other transfer models. There is an information center in Wheel Model, which is responsible for the distribution and collection of the information. The information centralization degree of the Wheel Model is the highest, but the communication channels are indirect among group members. All information subjects can participate in the communication by Complete Channel Model, so that they can share information or get information from the specific object directly. However, the rapid growth of time consuming will become an unavoidable problem. The information subjects are divided into multiple levels, so the information transfer processes are only between two adjacent levels to maintain information order degree. But the higher information centralization degree and stronger property of organization are sources of both advantages and disadvantages. The higher efficiency of information transfer coexists with the information distortion, due to the deletion of the transverse communication and arrogation. Based on Emergency Map, we define a new communication model which is called Group Model. The information plotted on the map transfer by the Emergency Map, so the other participants can grasp the information directly.

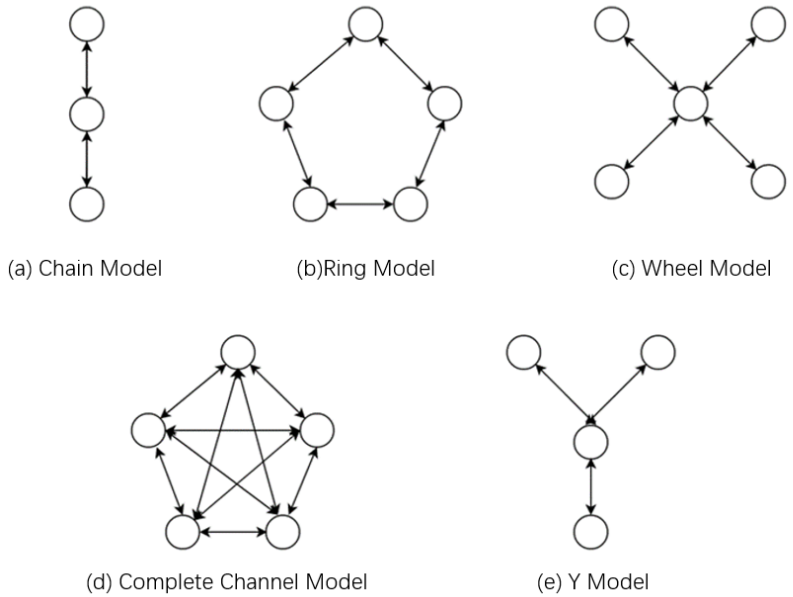

Figure 1. characteristics of the five communication models in information transfer process

Table 2. the main characters of the information transfer models

Information transfer model	Main character
Chain Model	The most probability of causing information distortion
Ring Model	Closed information transfer mode
	Slow transfer velocity
Wheel Model	Highest centralization degree
	Lack of communication paths
Complete Channel Model	The most sufficient communication
	The most time consuming
Y Model	High centralization degree
	Information distortion caused by deletion of the transverse communication
	Arrogation
Group Model	High centralization degree
	Straightforward information transfer paths
	High information fidelity
	Communicate sufficiently by adequate communication channels

Traditional Communication Mode of Emergency Response in China

In traditional communication mode, the emergency management process of Chinese government is shown as Figure 2. After emergency, the local government clears the emergency object on the basis of the emergency response plan pre-established by China State Council firstly. Then the local government divides the relevant functional departments into several decision-making groups, and each group has its own emergency object. Secondly, after the establishment of decision-making groups, every group member shares information with others and takes the Wheel Model way of communication within groups. Then every group generates a group decision and own concession baseline, and reports them to the local government. Thirdly, the government discriminates and gathers disputes in the received reports. Then the disputes feed back to the groups, and they resolve the dispute between groups. Finally, if the decision is accepted by others, the government summary and generate the overall decision. In emergency management process, with the situation evolving, the communication process is repeated until the emergency response finished.

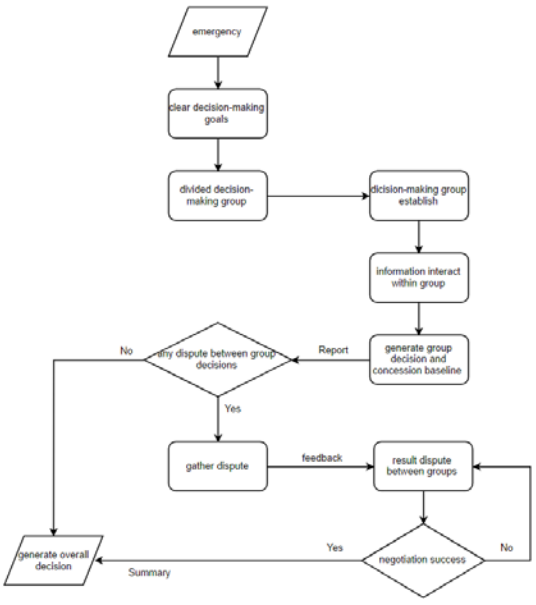

Figure 2. The traditional communication mode of emergency response in China

Group Communication Mode Based on Emergency Map

Based on Emergency Map, a new communication model is defined in information transfer of emergency management process, which is designed as "Group Model" in table 2. The information holder can plot his emergency information on the Emergency Map provided by a shared GIS server, with which the plotted map is distributed to other emergency decision makers simultaneously, and there is no need to transfer information to each decision maker one by one. It can be considered as a Wheel Model with a virtual and alterable center, which distribute information to others at the same time. But better than the Wheel Model, there is ample communication channels in Group Model and the communication between each two is realizable. Therefore, the time consuming can be greatly reduced to the equal level of Wheel Model information transfer mode, and the participants of emergency management can make sufficient communication. The Group Model inherits the high centralization degree and straightforward transfer path derived from Wheel Model, so the information fidelity can be maintained at a high level. Meanwhile, it discards the disadvantages of Wheel Model and achieves the communication effects of Complete Channels Models.

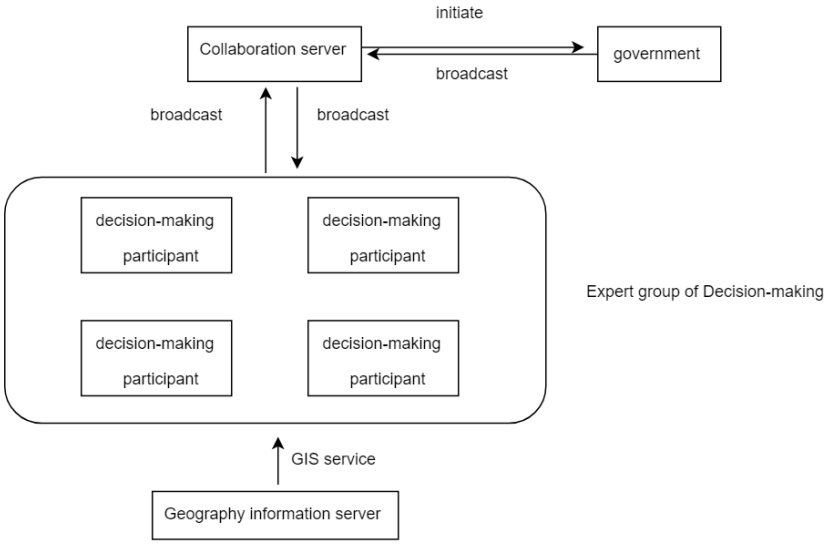

Figure 3. The Group Communication Mode of emergency response

METHODOLOGY

We clarify the timeline of emergency response process, from the emergency occurrence as the initial point to the successful response as the terminal point. And we introduce the order degree of the information transfer system, which is used to measure the comprehensive ability, including the ageing entropy and the quality entropy of information transfer.

Timeline of Emergency Response

Figure 4 shows the timeline of emergency response. The initial point is the occurrence time point of emergency. Then the information finders describe the collection information and send information to the others by specific mode. The time of describing information is T_1, which is called information pretreatment time. On the basis of modern network communication technique, the transfer speed of network data remains high speed in the normal condition. So we can ignore the time consumption of data transfer under unobstructed communication condition. After receiving the emergency information, other decision-making administrations decode and accept the information. The time between the information receiving to obtaining is T_2, which is called relaxing time of information obtaining. The time for the members of emergency management to make deliberation and generate an emergency decision is called decision-making time, which is shown as T_3 in Figure 4. The time between emergency decision generation and successful response is called decision-implement time, which is shown as T_4 in Figure 4. Therefore, when emergency occur, there is limited time for emergency management administrations to response, which is shown in function (1) as W_t. To decrease loss as much as possible, the emergency administration should make optimal decision under current conditions and carry out it. Therefore, T_1 and T_2 should be shorten as much as possible to guarantee enough time for decision making and implementation. We

consider that the decision-making participants communicate by group mode can significantly increase the efficiency of information transfer, which also shortens T_1. And the plotted map should be much more acceptable than traditional abstract text information, which shorten T_2 for participants in emergency response process.

$$\max(T_3 + T_4) = \max[W_t - (T_1 + T_2)] \quad (1)$$

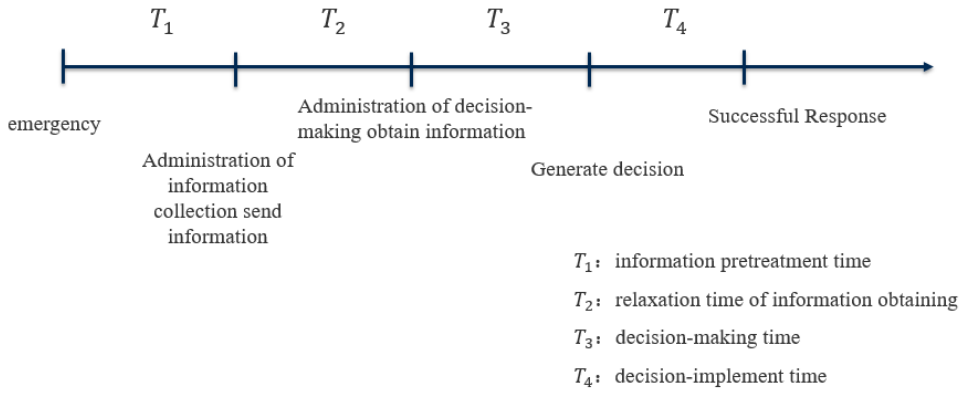

Figure 4. Timeline of emergency response

We combine the information pretreatment time (T_1) and relaxation time of information obtaining (T_2) together to be taken into consideration, which includes time consuming within groups T_i and time consuming between groups T_o.

$$\mathrm{T} = T_1 + T_2 = T_i + T_o \quad (2)$$

We obtain the irrelative function of T_i.

$$T_i = \sum_{i=1}^{m} A_{n_i}^2 t_1 \quad (3)$$

t_1 is the time consuming of communication between two group members. n_i is the participates member of decision-making group. m is the groups member that divided by emergency objects. Therefore, we obtaine the function of T_o.

$$T_o = A_m^2 t_2 + m t_3 \quad (4)$$

t_2 is the time consuming of communication between two groups. t_3 is the time consuming of communication between the government and groups.

The Order Degree of the Information Transfer System

To measure the comprehensive ability of information transfer in emergency response, we introduce the concepts of the system order degree (Qiu, 2011; Yan et al., 1997). The order degree of the information transfer system depended on two aspect of factors, which are quality and ageing of the information transfer. To quantify the two index, we introduce the concept of ageing entropy and quality entropy, like information entropy. The information entropy theory was put forward by Claude Elwood Shannon in 1948 (Shannon, 1948), what was used to describe the uncertainty of the information system, just like the thermal entropy was used to describe the confusion degree of the molecularity in Thermodynamics. The calculation formula of information entropy is $\mathrm{H} = -\sum_{i=1}^{n} P_i \log_2 P_i$. And the entropy is a measure of the disorder of the entropy, and the order degree of system can be measured by the function, $\mathrm{R} = 1 - \mathrm{H}/H_m$. H_m represents the maximum entropy of the system, which is the most confusing system of the system. The probability of symbol in the information entropy theory is used to describe the number of microstate of the information transfer in ageing and quality entropy. Moreover, we consider that, the information ageing and the information quality have the equal status for emergency response. Therefore, the function of order degree of the information transfer system is obtained.

$$\mathrm{E} = (E_1 + E_2)/2 \quad (5)$$

E_1 is the information transfer ageing, and E_2 is the information transfer quality.

Ageing Entropy of Information Transfer

Ageing entropy of information transfer represents the ageing uncertainty of the information transfer, and it used to measure the swift degree of information transfer. According to the function of information transfer determination from Qiu (Qiu, 2011), we obtain the interrelated calculation function based on the principle of information transfer ageing improvement by increased direct connection.

$$M_1 = \sum_{i=1}^{N}\sum_{j=1}^{N} L_{ij} \tag{6}$$

Among them, M_1 is the total number of microstate of the information transfer ageing. The microstate means the node state observed through one angle, and there are several states of one node usually. The realizable probability is the ratio of the node microstates number and all nodes microstates number. L_{ij} is the shortest path between the two nodes in the information transfer system, which is called as connection length of two nodes. If the two administrations connect directly, the connection length is 1. If the two administration connect through other administrations, the connection length should (be added 1 to) add 1 after each administration. To determine the ageing microstates of each administration, we should calculate the shortest connection lengths of every administration L_{ij} according to the characteristics of information transfer system. Among them, i and j are the number of the administrations, i,j=1,2,…,n.

$$A_{1m} = log_2 M_1 \tag{7}$$

A_{1m} is the maximum ageing entropy of the information transfer.

$$P_1(ij) = L_{ij}/M_1 \tag{8}$$

$P_1(ij)$ is the realizable probability of ageing microstates of information transfer between administration i and administration j.

$$A_1(ij) = -P_1(ij)\, log_2\, P_1(ij) \tag{9}$$

$A_1(ij)$ is the ageing entropy of two arbitrary information transfer. Therefore, we obtained the determination function of total ageing entropy of information transfer.

$$A_1 = \sum_{i=1}^{N}\sum_{j=1}^{N} A_1(ij) \tag{10}$$

Then we obtain the determination function of the information transfer ageing.

$$E_1 = 1 - A_1/A_{1m} \tag{11}$$

Quality Entropy of Information Transfer

The quality of information transfer is the measure index of information transfer accuracy between administrations. The quality entropy reflects the quality uncertainty of the information transfer, which is used to measure the distortion degree of information transfer. According to the function of information transfer determination (Ping et al., 2013), we obtain the interrelated calculation function based on the principle of information transfer quality improvement by decreasing direct connection.

$$M_2 = \sum_{i=1}^{N} K_i \tag{12}$$

Among them, M_2 is the total number of microstate of the information transfer quality. K_i is the number of administrations which have direct connection with the administration, and it is called amplitude of administrations connection. To determine the amplitude of administrations connection, we should calculate quality microstates of each administration K_i according to the characteristics of information transfer system. Among them, i is the number of the administrations, i =1,2,…,n.

$$Q_{2m} = log_2 M_2 \tag{13}$$

Q_{2m} is the maximum quality entropy of the information transfer.

$$P_2(i) = K_i/M_2 \tag{14}$$

$P_2(i)$ is the realizable probability of quality microstates of information transfer, which belong to the administration i.

$$Q_2(i) = P_1(i)\, log_2\, P_2(i) \tag{15}$$

$Q_2(i)$ is the quality entropy of the administration i, which is used to measure the uncertainty of the information distortion in the information transfer process. Therefore, we obtained the function of total quality entropy of information transfer.

$$Q_2 = \sum_{i=1}^{N} Q_2(i) + \log_2 M_2 \tag{16}$$

Then we obtain the determination function of the information transfer quality.

$$E_2 = 1 - Q_2/Q_{2m} \tag{17}$$

CASE STUDY

A maneuver in Guangxi Zhuang Autonomous Region for nuclear accident was utilized as a case study. There were 12 administrations which participated in the emergency response according to the National Nuclear Emergency Plan established by China State Council for traditional communication mode. These administrations are shown in Table 3, including Environmental Protection Department (EP), Health and Family Planning Commission (HF), Transportation Department (TD), Development and Reform Commission (DR), Public Security Department (PSD), Civil Affairs Department (CA), Information Office (IO), Headquarter of Military Area Command (HM), Weather Bureau (WB), Power Supply Bureau (PSB), Maritime Bureau (MB), and Telecommunications Administration (TA) directly. In traditional communication mode, they should be divided into several groups by decision-making goals in order to make the appropriate decision. According to the maneuver scripts and the emergency objects perspective in the National Nuclear Emergency Plan, the 12 participates were divided into 9 groups. They are also shown in Table 3, including mitigation and control of radiation accident, radiation monitoring and consequences assessment, personnel radioactive protection, covert and evacuation placement, decontamination and medical treatment, access and port control, market regulation, social order maintenance, and information report directly. The summary of group results is shown in Table 3. Moreover, the other mode was Group Communication Mode. In this mode, all 12 participates from a large group were involved in decision-making based on the Emergency Map. Then, we compared the result calculated by traditional communication mode and Group Communication Mode.

Table 3. the summary of group results

No.	Decision-making object	Group participants
1	Mitigation and control of radiation accident	EP, HM, TA, PSD
2	Radiation monitoring and consequences assessment	EP, HM, MB, WB
3	Personnel radioactive protection	DR, HF, EP, WB, PSD
4	Covert and evacuation placement	HF, TD, PSD, CA, IO, HM, PSB, TA
5	Decontamination and medical treatment	HF, HM
6	Access and port control	PSD, MB, IO
7	Market regulation	DR, IO, TD, EP
8	Social order maintenance	PSD, MB, IO
9	Information report	IO, EP, TA, PSB, WB, PSD

Time Consuming of Information Transfer

In this maneuver process, we used two communication modes, including the traditional communication mode and the Group Communication Mode, to determine the information transfer time consuming in emergency response. The time consuming is shown in Table 4, which is coming from the experiments carried out in the course of the maneuver. Therefore, the time consuming decrease greatly by using the communication mode, which can reach 94%.

In the maneuver process, we used two coding methods, including text information and plotted map information to code the emergency information. The time consuming of information transfer is shown in figure 5, and the time consuming decrease greatly by using plotted map information. The decrease of time consuming is different in each group, which depends on the amount and complexity of information. In this maneuver, the maximum decrease ratio is 71.3% in group 8, and the minimum decrease ratio is 47.8% in group 6.

Table 4. the time consuming of two communication modes

	Plotted map information	Text information
Traditional communication mode	57372	151242
Group Communication Mode	3418	8413
The ratio of time consuming decrease	94.1%	94.4%

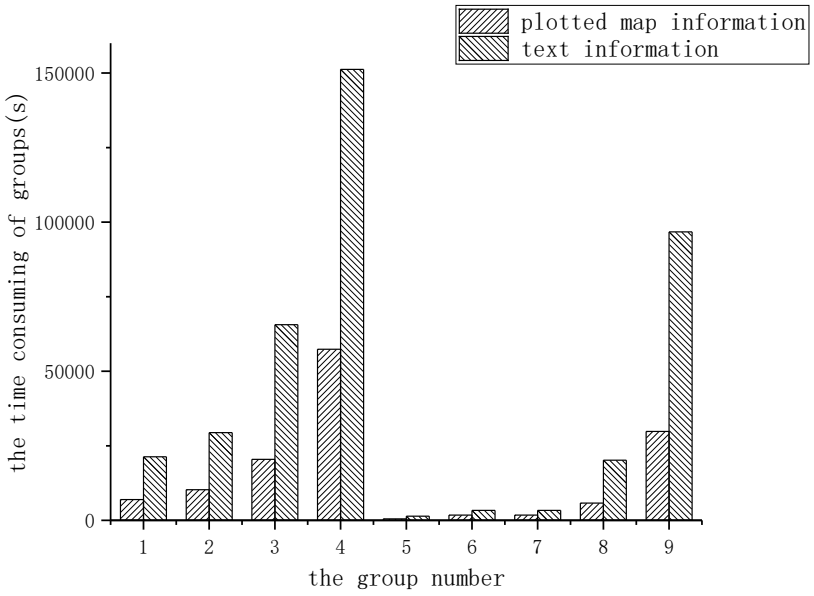

Figure 5. the time consuming of information transfer by two coding methods

The Order Degree

The order degree of two communication modes and the compared results are shown in Table 5. Every participant in Group Communication Model has equal position, so their own state observed through one angle is completely identical, which means there is one microstate of each participants. So the total ageing entropy and total quality entropy are both zero. The information transfer ageing of traditional communication mode is 0.348, and the Group Communication Mode is 1, which is increased by 1.87 time. The information transfer quality of traditional communication mode is 0.528, and that of the Group Communication Mode is also 1, which is increased by 89.4%. Therefore, the order degree of the traditional communication mode is 0.428, and the Group Communication Mode is 1. The order degree of information transfer system can be increased by 1.28 times with Emergency Map.

Table 5. the order degree of two communication modes

	Traditional communication mode	Group Communication Mode
Microstates number $\boldsymbol{M_1}$	39	12
Total ageing entropy $\mathbf{A_1}$	3.446	0
Maximum ageing entropy $\mathbf{A_{1m}}$	5.285	3.585
Information transfer ageing $\mathbf{E_1}$	0.348	1
Microstates number $\boldsymbol{M_2}$	106	12
Total quality entropy $\mathbf{Q_2}$	3.176	0
Maximum quality entropy $\mathbf{Q_{2m}}$	6.728	3.585
Information transfer quality $\mathbf{E_2}$	0.528	1
Order degree $\boldsymbol{E}$	0.438	1

CONCLUSION

At last the conclusion and future work are proposed. When extensive emergency occurs, there are urgent needs about information sharing (among departments) and the collaborative treatment, which can control the situation timely and avoid the wider range of losses. Based on the analysis of the impact factors of information transfer efficiency, the Emergency Map is a consultation platform to solve these problems in emergency response. We provide a novel communication model based on emergency map that is different from traditional five communication models. The communication model is called Group Model. Compared with other communication models, it has high centralization degree and information fidelity by straightforward information transfer paths, and communication sufficiently by adequate communication channels. And the emergency map provides a novel communication mode for multi-party collaborative in emergency response, which has great advantages compared with the traditional communication mode in China. The Group Communication Mode can decrease the time consuming of information transfer in emergency response process greatly, which helps to gain much more time for decision-making and implementation. The order degree of the Group Communication Mode is better than that of the traditional communication mode. The participants can plot their information on the map, and the plotted map information can further decrease the time consuming of information transfer in emergency response, which can also enhance the realistic and immersion of participants. Moreover, we determine the time consuming decrease by a case of maneuver in Guangxi, China, and compare the order degree of traditional communicational mode and Group Communication Mode in this case.

The following research will be focused on the discussion of the mechanism of decoding methods impact the time consuming of the information transfer, and the analysis if there are any other ways to decrease time consuming of information transfer in emergency response, such as convert the information potential demands to current demands.

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Approaching the criticality of information for emergency response and control center operations

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ABSTRACT

Successful emergency response and control center operations rely on a great number of information sources. The importance of said information becomes immediately obvious if it is not available when required during an emergency situation. This can be described as the criticality of information, signifying a potential need for action to prepare for functional failures. The concept described in this paper approaches the criticality via an analysis that examines various combinations of information sources and situations in order to identify weaknesses and improve existing procedures. The proposed semi-quantitative assessment was developed taking several attributes and characteristics of criticality into account and afterwards conducted in close cooperation with emergency response institutions.

Keywords

Criticality analysis, information management, emergency services and procedures

INTRODUCTION

During a violent storm in the late summer, heavy rain and gale-force winds struck the city of Calau in Eastern Germany. Every available fire brigade in the area was activated to respond to a multitude of emergency calls. The local department in Calau deployed a temporary control center in order to deal with all the problems at hand and coordinate mission orders as well as the involved units. Between closing a big access road due to a broken down power line, shutting down train traffic because of a number of trees on the tracks as well as several other locations that had to be cleared of trees, fallen power lines and other debris operations continued until the early morning hours (Volunteer Fire Brigade City of Calau 2013). While firefighters were eventually able to deal with the overwhelming events of that night, the difficulty of receiving, processing and distributing or utilizing all available and necessary information was made apparent. Handling emergency situations of such high and luckily irregular magnitude poses a problem for emergency control centers, dispatchers and first responders alike. With a multitude of incidents likely occurring at the same time, the actors involved are faced with numerous problems including information overload and availability. Modern technology can offer at least partial solutions to these problems, for example through the use of decision support systems and automated data processing. In order to accomplish that however, relevant information and processes have to be identified pertaining to different types of missions or events.

Here, “criticality of information” attempts to distinguish between different corresponding aspects for the purpose of improving workflow. Commonly used terms related to this concept such as “vulnerability” or “risk” will be assessed to define the criticality of information sources that are required for certain emergency response procedures and to develop a comprehensive and coherent approach that can aid with fire brigade and control center operations by further examining the corresponding findings as well as putting them in context with existing procedures (or lack thereof) that can be encountered during everyday events.

This paper attempts to create a baseline for such an approach. Working closely with various emergency response institutions, a concept was implemented that enables users to identify the significant processes at hand and take action accordingly, e.g. by improving specific communication chains or determine a given system's weak points. Therefore, the following section analyzes related work and defines the terms that are needed to approach the criticality of information in the third section, where a process will be outlined that allows for further analysis through use of a scorecard. Afterwards, this concept will be discussed together with the first results and feedback received by the aforementioned institutions. The final section will then draw conclusions from this first approach and provide an outlook comprised of possible changes.

RELATED WORK AND TERMS

Critical infrastructures have long been the subject of diverse research. They are often subdivided into network or basic critical infrastructures (such as power supply) and socio-economic service critical infrastructures such as emergency and rescue services or disaster protection (Federal Ministry of the Interior of Germany 2009). The latter are the focus of this work. The examination of these complex systems, especially from a socio-technical point of view, has for a long time focused on the concepts of preparedness and prevention as well as vulnerability and resilience. However, criticality has established itself as a term in the context of risk research and is gaining increasing influence (Bijker et al. 2014; De Bruijne and Van Eeten 2007; Hémond and Robert 2012; Theoharidou et al. 2009).

According to the Federal Office of Civil Protection and Disaster Assistance in Germany (2017) criticality is defined as a relative measure of the importance of an infrastructure in relation to the consequences of a disruption or malfunction for society's security of supply with essential goods and services. The concept is commonly described through special characteristics or properties that vary between different authors and scenarios or specific critical infrastructures in the case of infrastructure research. Theoharidou et al. (2009) outline three characteristics of criticality to analyze the impact of a disruptive event on different sectors: Firstly, the "scope or spatial distribution", secondly the "severity or intensity or magnitude" and thirdly the "effects of time or temporal distribution" (Theoharidou et al. 2009 p. 36). By comparing criticality and risk analysis for critical infrastructures they identified that risk analysis is rather organization-centric with regard to aim and impact type and the scope focusses on internal assets and systems. Criticality analysis on the other hand is rather society-centric and its scope does not only include internal assets but also interdependencies.

In comparison to the characteristics presented by Theoharidou et al., Katina and Hester (2013) also identify four generalized criticality factors in regard to critical infrastructures. They build their argumentation strongly on the fact that resources like funding, human workforce or available technologies among others are limited and a criticality assessment is needed in order to prioritize infrastructures and efforts. The criticality factors are based on a synthesis of factors from literature to create a generalized baseline for all infrastructures. They distinguish between the 'level of resiliency' with respect to the defensive properties of a system, the 'level of interdependency' where they refer to the connectedness of a system or its external relations, the 'level of dependency' posing the question of how much people's daily activities relate to a system and the more traditional 'level of infrastructure risk' which includes threats, vulnerabilities and their likelihood.

A different characterization was made by Fekete (2011). He argues that the criticality, in his context of infrastructural services, is most present in cases of failure and consequent loss of services or resources. He continues to point out that from an etymological perspective criticality relates to the concept of crisis and implies a "turning point or an impending change" (Fekete 2011 p. 16). In relation to time the criticality of an infrastructure system is constructed by reflecting on the 'normal' and the 'crisis' mode of operation. For a better criticality assessment Fekete introduces three general criticality properties based on the use of criticality in nuclear science: critical proportion, critical time and critical quality. In doing so, the proportion expresses aspects of extent, such as spatial range and scope or number of elements and services. Additionally, the number of redundancies is a crucial point in this context. Critical time is described by the author via duration and the mean times to repair, recovery and functionality but also the robustness or resilience of a system. Lastly, critical quality can be exemplified by quality of services or loss of trust.

As part of the described methodology to filter and prioritize critical assets of large organizations such as the US Army, Anderson et al. (2008) connect vulnerability and criticality. They introduce four properties of vulnerability that have an implied notion of criticality: redundancy, robustness, resilience and security. The filtering and prioritization approach presented by the authors contains seven steps ranging from scenario identification to a multi-criteria risk, criticality and vulnerability evaluation and finally operational feedback. To balance their multiple perspectives for measurements and management they use a scorecard model with a normalized score so that every characteristic of a system is equally accounted for.

As illustrated before, the characteristics of criticality contain aspects of risk and vulnerability and may connect these two concepts by adding a public interest or social pressure (especially regarding the function of a system) to the assessment. As Theoharidou et al. (2009) state, criticality can be used as a synonym for 'risk' and 'vitality'. The attributes of criticality impart a sense of urgency on the general association with "importance" that can be found within the analysis of risks and vulnerabilities of a system. Its notation thus expresses a relevance of a system or a system component and might entail an obligation to act. Based on that understanding, the criticality of information that can be found in the context of emergency and rescue services as well as disaster control and management describes the importance or relevance of an information source for a situation and the potential need for action to prepare for functional failures. As a consequence, information and its availability or lack thereof can have a direct impact on the security of society since the function of a given critical socio-economic service infrastructure may no longer be (fully) guaranteed.

APPROACHING CRITICALITY OF INFORMATION

While the last section gave an overview of the attributes of criticality and introduced the criticality of information as a relative measure in the context of emergency and rescue services, this section will introduce an approach for the assessment concerning the criticality of information. Due to the similarities to risk and vulnerability the assessment of the criticality of information is similar to the analysis of the aforementioned. First of all, the system and its boundaries need to be defined in order to create a frame of reference. Since the criticality of a system or its components can only be determined in relation to another system, a function or an attribute of a system, the criticality of information in the context of this work refers to the criticality of an information source in relation to emergency situations or processes it is associated with. The identification of all relevant processes or emergency situations as well as the information sources has to be made by the end-user. They define the depth of the analysis and filter emergency situations as well as information sources based on scope. Examples of emergency situations among others may include mass casualty incidents, ambulance transports or fire-fighting operations. Optionally, the identified processes can be grouped (e.g. according to organizations such as rescue service and fire brigade or alternatively according to frequency). Examples of information sources range from basic information, e.g. alarm data or regulations and laws, to emergency call support systems and more extensive data such as weather forecasts, information from social networks or operators of critical infrastructures. It is also interesting to receive input from commanding officers or other emergency personnel, as long as a clear flow of information can be established. To visualize the relations between information and the emergency situations and later on display the criticality of information, a situation-information-matrix is created. These matrices are somewhat comparable to threat-system-matrices which are used for vulnerability analyses as presented by Baker (2005) or Anderson et al. (2008).

After the initial identification the criticality assessment can be carried out. By understanding the criticality of information, processes and sources can be identified that are particularly relevant to the function of the system or in this case critical service infrastructure. Based on the analysis short-, medium- or long-term strategies for strengthening and optimizing the individual system components can be made. The analysis can be divided into four steps: (1) identification of the process relevance; (2) criticality scoring; (3) considerations of usage and prioritization; (4) criticality evaluation. Figure 1 provides a graphical overview of the analysis. In order to obtain the most accurate estimate possible, each source of information must be considered for each emergency situation. To this end, all sources of information relating to a situation are first examined one after the other and then repeated for all other situations.

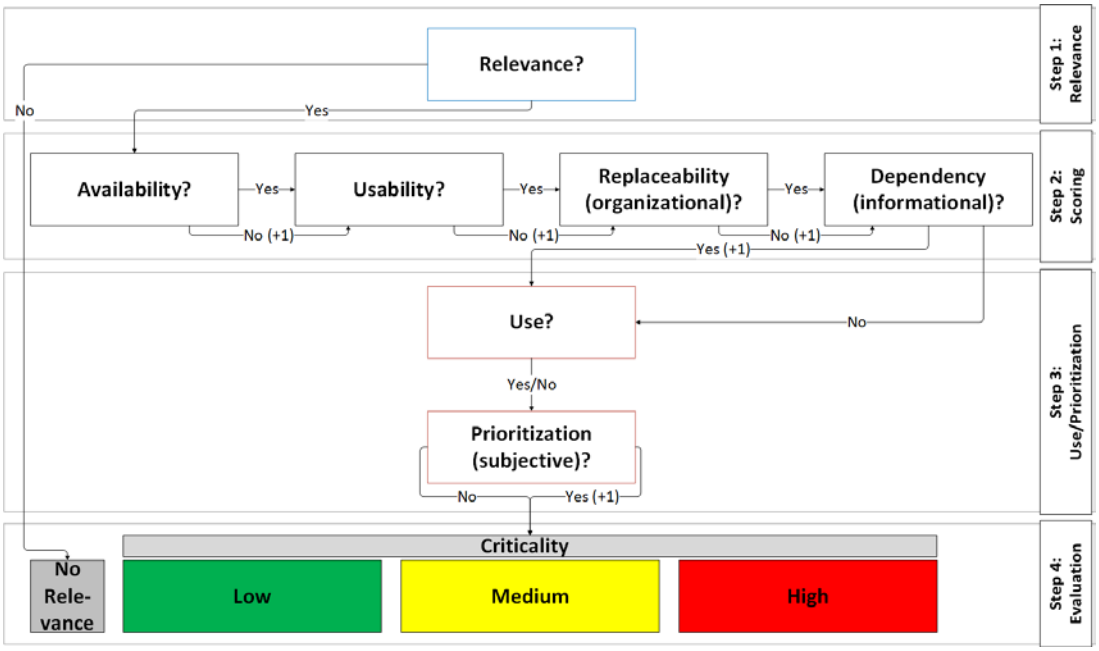


Figure 1. Overview of the criticality assessment

Step 1: Relevance

The first step of the analysis is concerned with the question of relevance. Before individual classification may begin, it has to be determined whether or not an information source is relevant to a certain process or mission type. At this point, the attributes or characteristics mentioned above may mostly be neglected as they become important at a later stage, for example definitions relating to vulnerability. The first step is much more basic and can be interpreted similar to the notion of "exposure" regarding the vulnerability assessment of critical infrastructure (Wienand and Hasch 2016) that examines whether or not a given system is actually exposed to a certain risk or danger. Propagating this idea to information processing or analysis results in the very first question one should ask before going into detail: Is the source of information even relevant to the process (s. Figure 2)? Only then could an information source or knowledge related to it yield additional benefit for the observed situation, making further analysis worthwhile. In case the source of information is beyond the effective system boundaries it may be dismissed entirely.

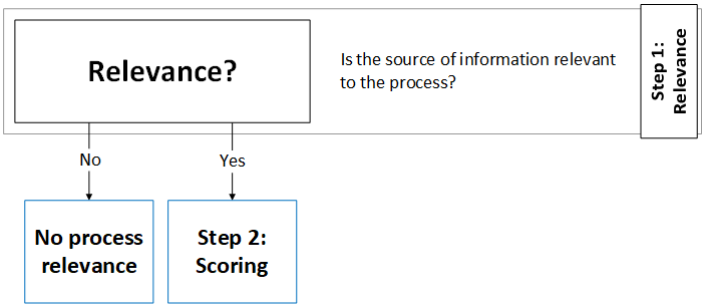


Figure 2. Detailed view of the first step (relevance)

Consider the following examples:

a) Does the information on available emergency capacities of the regional power network offer added value regarding regular ambulance transport situations? No, as a general rule of thumb this source of information will most likely not be relevant for the situation in question. As such, no further analysis is needed for this pairing of information source and situation, concluding the considerations right away.

b) Are the available emergency power capacities of interest for emergency procedures during heavy storms? Yes, as exemplified in the first section this information is required when dealing with power line disruptions as well managing the infrastructure that is still up and running, e.g. restoring power to hospitals and other important buildings or parts of a city first while making sure that backup power bridges gaps where needed. Such events may occur during a storm situation. Thus, the analysis is continued in step 2: Scoring.

Step 2: Scoring

In the second step of the analysis, the criticality is rationally assessed. For that purpose, different criteria are defined in order to assess the criticality of an information source for a given process. Based on the related work and terms outlined in the second section, availability, usability, (organizational) replaceability as well as (informational) dependency will be utilized for scoring. Each category will be further explained below, increasing the criticality score depending on the answer (s. Figure 3). As it can be very difficult to justify a certain ordering or emphasis, the approach of a scorecard was chosen to determine the criticality via the four criteria. Here, all parts of a scoring step or algorithm are viewed as equally important (Kaplan and Norton 2007) and thus can equally increase the criticality score. This is done when it is otherwise not possible to answer questions regarding the hierarchical structuring: Is having an old and possibly outdated version of an information source better or worse than having none at all? How would this rank in comparison to eligible substitutions where one might have to accept certain restrictions? From a researcher's standpoint this is especially difficult when dealing with terms and concepts that are at times open to interpretation or personal opinion as will be explained in step 3. This results in the scorecard approach presenting itself as an apt procedure to consolidate the relevant criteria. In regards to criticality, the idea of utilizing a scorecard as described by Kaplan and Norton has for example been applied in relation to the criticality analysis of the US Army in Anderson et al. (2008). While the ordering of the criteria mentioned above is not of significance, it is very important that all four are always checked during this step in order to obtain a criticality score. Using the attributes and characteristics identified in the previous section the line of reasoning with regard to terms like quality, redundancy and similar can be put to use concerning the criticality of information (sources). There is however no single correct way to accomplish this step as a lot of the terms are used interchangeably, for example in Katina and Hester (2013 p. 221) where the level of dependency is measured via usability and categorized through the associated scope while other authors use the same terminology to describe different concepts. Additionally, most if not all of those concepts intersect in multiple ways. This shows that finding a cohesive unified approach is rather complicated. However, applying the aforementioned attributes and characteristics to the criticality of information might still help to understand those ideas and make drawing conclusions easier. The criteria of the scoring procedure were defined via potential associations and are explained in the following paragraph.

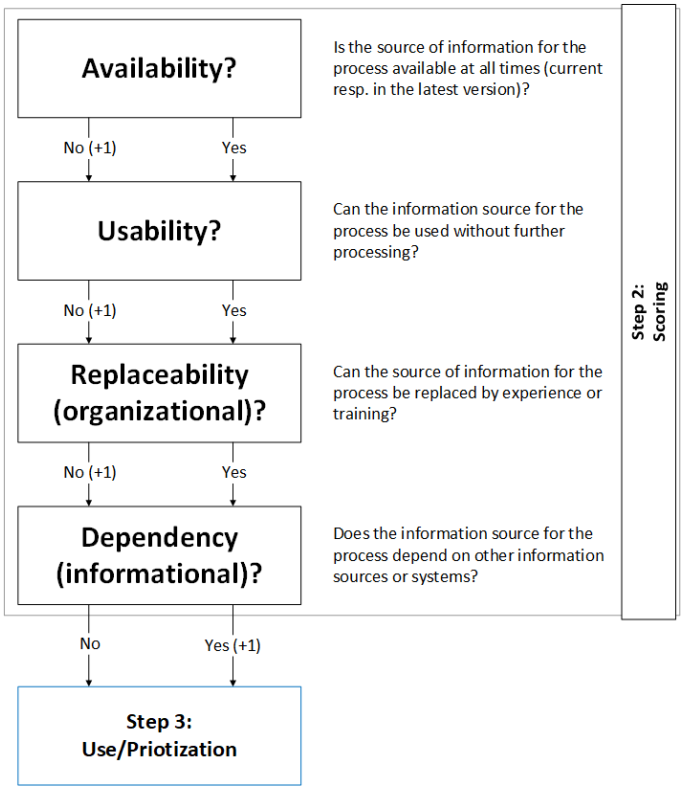


Figure 3. Detailed view of the second step (scoring)

Availability

The notion of availability is often mentioned when critical infrastructures are assessed, for example in Fekete (2011) who describes the critical time availability together with resiliency, i.e. a system's ability to resist a

disruption or recover afterwards. It is also related to the concept of redundancy (Anderson et al. 2008) since having adequate backups available for when a source of information cannot be accessed due to unforeseen circumstances. Availability thus retains the meaning it is regularly associated with and in regards to criticality of information simply poses the question of whether or not an information is available for the situation in question at all times. This is further exemplified with the following scenarios:

a) Information on the current temperature and climate conditions for the location of a rescue operation can always be attained, e.g. through the German Weather Service. As such, the score is not increased before moving on to *Usability*.

b) The information on the designated use of man power and other resources for disaster management exercises, e.g. a mass casualty incident, is always available in the currently valid version of the action plan as a PDF file or printed out documents. Unless this information is lost, the score is not increased.

c) The information on the available emergency power capacities for a storm situation cannot be retrieved at any time in most cases but must be provided by the network operator. Using an external source also increases the chance of receiving incorrect, incomplete or outdated information. Since the availability cannot be ensured, the criticality score is increased by 1 before continuing to *Usability*.

Usability

The scope of the term usability is very broad. Due to that it is difficult to associate it with a specific attribute. In regard to critical infrastructures, Fekete (2011) puts the factor of critical quality into context, determining under what circumstances and how an infrastructure deals with a situation. For the criticality of information this leads to the interpretation of whether or not the source can be used without further processing or if the quality is insufficient, thus having to adjust the information to the situation at hand. Continuing the first two examples from before, this could result in the following scenarios:

a) The German Weather Service provides information on the current temperature for the location of a rescue operation in an easily interpretable number format. It can be made available, e.g. to a dispatcher, by practically every software system in control center operations. It is thus not deemed critical and *Replaceability* can be evaluated without increasing the score beforehand.

b) The information on the tasks of the administrative staff for a mass casualty incident is described in the civil protection concept (several pages of full text). This text document is classified as an unstructured piece of information and requires further action such as filtering depending on situational specifics for efficient use. Therefore, the information source has to be processed and the criticality score is increased by 1 before continuing.

Replaceability (organizational)

The connotation of replaceability, both in the technical and organizational sense, is mentioned in association with critical infrastructures in several ways, for example in a risk analysis on systems based vulnerability carried out on behalf of the Federal Office of Civil Protection and Disaster Assistance (Wienand and Hasch 2016). Applied to the concept of criticality of information it is considered if a source of information could be entirely replaced by experience or training of the employees for the situation in question. This is exemplified as follows:

a) The instruction manual on the advised steps to perform cardiopulmonary resuscitation (CPR) from the emergency call support system can be replaced by knowledge gained through regular first aid courses. The score is not increased.

b) The information about a building's wall or insulation materials often depends on various factors such as year of construction, regional differences and whether or not it was actually built according to plan. In the event of a fire personal knowledge is too unreliable and thus dismissed. The criticality score is increased by 1.

Dependency (informational)

Katina and Hester (2013) explain (inter-)dependencies in the context of infrastructures where for example a system's connectedness is measured in order to assess the criticality. With regard to information it should therefore be evaluated whether a source for the situation at hand depends on other sources of information or systems and if it can be obtained directly. Consider the following scenarios:

a) Information on the current temperature for the location of a rescue operation can be retrieved directly from the German Weather service as described above, there are no dependencies and the score is not increased.

b) The information on the individual steps for performing CPR is stored in a given emergency call support system,

e. g. NOAS, and can only be called up via this system which in turn might depend on other aspects. Thus, the criticality score is increased by 1 and the analysis is continued in step 3.

Step 3: Use/Prioritization

In the third step, the actual use of an information source for a given situation is considered. This takes into account the subjective perception of its importance by prioritizing various aspects. Through records of usage it is possible to distinguish between new sources of information and existing ones that are already in use. Since the former were not included in the processes up until this point it can be assumed that the criticality assessment is more influenced by subjective perception rather than practical experience. For instance, if a person or an institution only recently integrated a dataset into their processes the assertions made by them is likely to differ from those that have been using the data for a long time. Even if the drawn conclusions are similar, the adequacy has to be carefully evaluated depending on whether or not they stem from a gut feeling or longtime experience. However, this step can still yield useful results when the relevant aspects are taken into consideration and rated accordingly. This includes the optional prioritization that follows the usage (s. Figure 4), increasing the criticality score when the information source is deemed particularly important, no matter if old or new. This way, information that is personally perceived as essential is assigned a higher criticality. In an effort to maintain continuity and user-friendliness, prioritization is also carried out with a simple Yes/No response scheme and a potential increase of the criticality score by 1. Handling prioritization in such a way is sufficient for the vast majority of cases. However, there may be situations for which a specific source of information is subjectively irreplaceable, so the score increase would have to be adjusted. For these individual instances, an appropriate prioritization score could be defined in consultation with the end user on a case-by-case basis.

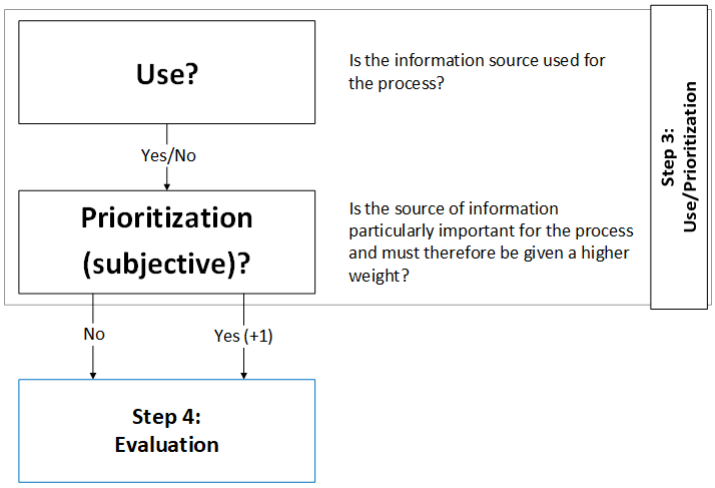


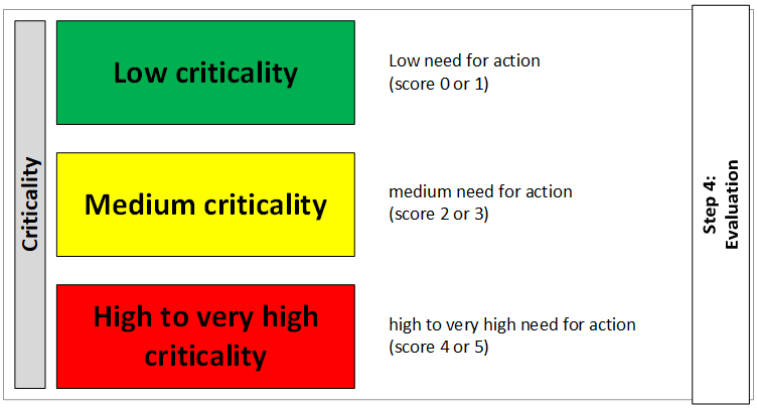
Figure 4. Detailed view of the third step (use/prioritization)

An apt example for this is described as follows:

The data generated by social networks is a source that few have utilized so far, at least for the purposes discussed in this paper. Therefore, the scoring is likely to be influenced by ones like or dislike for those platforms as well as personal social media usage. Those proficient in dealing with social networks will likely exhibit a different attitude towards the newly established information sources than those that have little to no experience at all. Additionally, some might only associate the term “social media” with specific platforms like *Twitter*, *Facebook* or *Instagram* while others might evaluate social networks altogether. This could lead to results that are potentially skewed due to misunderstanding or over- or underrating certain implications when having to assess lesser known processes and information sources.

Step 4: Evaluation

During the fourth and final step of the criticality analysis the evaluation and visualization takes place. A distinction is made between the mostly objective part (results from step 2) and the extended part of the evaluation which is subjectively prioritized. Afterwards, the results are categorized visualized by means of a comparison of inputs and information as shown in Figure 5. The developed matrix can also be expanded upon by optional additions, e. g. frequency of use or data type of an information source. In addition to that, certain groupings or conditions can be employed that allow for further refinement of the results.



(a)

Information	Emergency Situation: Situation 1	Situation 2	Situation 3	Situation 4	Situation 5
Information 1	1	1	1	0	1
Information 2		3		2	1
Information 3		4		3	2
Information 4	2	1	2	1	2
Information 5	0	1	1	1	0

(b)

Figure 5. (a) Detailed view of the fourth step (evaluation) and (b) exemplary matrix

German fire brigades use a specific database that holds all relevant information regarding hazardous materials. While it is a very important source of information in itself, it is not necessarily critical for all considered processes. This can be exemplified through the following scenarios:

a) When called to the scene of a disaster such as a shipwreck, the database will only be relevant if the vessel was carrying hazardous goods. As such, the information could be relevant to the process, but since it is available, usable and independent the criticality remains low. Due to only needing this specific information source in some cases it is not prioritized, however, the database is irreplaceable, leading to a total score of 1. As long as the circumstances remain unchanged, no further action has to be taken.

b) Changing the situation to an emergency relating to hazardous materials such as spillage of a dangerous chemical also leads to a different outcome of the criticality analysis. Since the database will likely always be consulted in a case like this, prioritizing it leads to an increased score and medium criticality. This does not necessarily imply the need for further action but rather signifies an important source of information for the given conditions. The associated aspects such as availability should always be watched with due process.

c) This can be demonstrated by further altering the scenario. If the database is not available, for example due to an error with the server it is stored on, and can thus not be used for its intended purpose the score changes result in high criticality. During an evaluation, this would indicate the need for immediate rectification like making sure the server is restored to normal operation or having a backup solution available.

The example described above is based on first feedback received from fire brigades. At first glance, few situations were identified as highly critical which is plausible when taking into account that available information sources for a given mission, i.e. the obvious answers, are considered first and foremost. The following section focuses on putting these preliminary results into context and discussing them further.

FIRST RESULTS AND DISCUSSION

The approach presented here was handed out to a number of professional fire brigades in Germany including a short definition of the terms and concepts of ‘criticality’ and ‘criticality of information’ based on the scientific discussion. Also, some examples for potential emergency situations and sources of information were mentioned in order to put the concept in a more feasible context. Although the responses have not all arrived, important conclusions can already be drawn from initial oral and written feedback. First of all, the notion of criticality: even though first responders were not familiar with the concept itself and the notion was, if at all, only known from terms like ‘critical infrastructure’ or ‘critical component’, the general feedback for using criticality or criticality of information as well as the chosen characteristics in the context of emergency services was very positive. It was stated that the approach supports the creation of priorities for example by visualizing the relation between information sources and situations. By defining corresponding criticalities, it is furthermore acknowledged that some system components or some information are simply not replaceable. This can be shown via the emergency call data: If no one makes an emergency call and thus there is no call information for the dispatcher, no intervention will be initiated and no resources are deployed. In order to establish an even greater account of such systems and information, some practitioners have suggested adding further classification of importance to the approach that supplements prioritization.

It appears there are differences between fire brigades regarding the depth of the analysis conducted. Where information sources and emergency situations were chosen rather general, fewer combinations had a high or very

high criticality score. In these cases, it was emphasized further that a lot of the success of emergency response was due to education and training of emergency personnel. The information that is needed in that case is rather specific such as knowledge about chemical reactions. Here, the presented approach may also be used for educational purposes or in combination with trainings to sensitize the people. When the analysis was carried out in a very in-depth manner, including all technical systems and information flow in order to identify specific possibilities to improve the systems at hand, the criticality score was more diverse. Here, the approach was utilized to improve technical systems and help identifying so far unknown relations between different processes or sources of information.

Summing up, the analysis of the criticality of information helps evaluating information sources and their dependencies. Questions like 'What is the most critical information or situation?' can now be answered. By further analyzing relevant information and processes with regard to e.g. the information type or the frequency of the process, strategies for an improved information management can be devised. The consideration of potentially new and/or prioritized information sources also appears to be of great feasibility. One could also contemplate the need for effective provision of said critical information in the given context and whether it is critical because it needs to be handled with urgency, because it affects the area of functional failures mentioned above or a combination of these factors. Additionally, by engaging multiple end-users in the discussion on what information sources are of personal importance or might help dealing with a situation, alternative ways for future emergency response operations can be created while incorporating new technologies and information sources. Even though the approach was designed focusing on fire brigades and control center operations and so far was evaluated by different fire brigades only, it is applicable to other emergency and rescue services or disaster relief organizations. This could also include disaster management teams and operations in networked critical infrastructures such as power supply or communication lines. Here, analyzing the criticality of information can help in comparing and understanding difficulties of different organizations and hierarchies.

CONCLUSION AND OUTLOOK

By transposing the characteristics and attributes mostly used in the context of critical infrastructure research, this paper introduced the notion of criticality of information for emergency and rescue services as well as disaster control and management. It further presented an approach for assessing the aforementioned in relation to specific emergency situations. The concept with its four-step criticality analysis procedure was conducted in coordination with a number of German fire brigades. First results and preliminary process evaluation already showed the usefulness of the approach and the applicability of the selected attributes and characteristics. In order to ensure smooth existing practices as well as identify constellations regarding certain situations and their relevant information that are being dealt with either insufficiently or incorrectly, the concept also accounts for proper interpretation and emphasis, for example through visualization for the semi-quantitative analysis via a scorecard. Furthermore, the outlined approach offers the potential to uncover new information sources and incorporate them for the purpose of rectifying current shortcomings and improve emergency response and control center operations.

While the preliminary feedback received from the fire brigades showed promising results, there were also some uncertainties regarding a few aspects of the concept. As such, once the full results of the analysis are obtained all answers will be evaluated further in order to achieve a more unified and representative survey. This will allow for proper quantitative analysis and empirical research. In order to support the partners in practice, an information concept based on the theoretical approach presented here is planned, which is to serve as the basis for a semi-automatic or fully automatic software tool and to support the acquisition, analysis and visualization of the data. Results of the analysis could then for example be reviewed for similar pairings of information sources and situations found throughout different scorecards or grouped by region as well as characteristics such as organization size or type. The same could be done for various mission types for the purpose of identifying comparable approaches and gain added value for the institutions involved. Altering the approach this way would also enable the aforementioned incorporation of new information sources. Similarly, an in-depth view at properties like data type or spatial allocation might aid with overcoming problems by composing an improved overall system and giving recommendations for training. One example could be combining different results regarding related processes to identify corresponding information sources and create redundancies that will help with critical attributes such as availability. If this can be achieved the proposed approach for the criticality analysis of information sources can help prepare emergency response and control center institutions as a critical socio-economic service infrastructure for upcoming challenges and ensure appropriate functionality.

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Accident Analysis Methods and Models — a Systematic Review

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ABSTRACT

After a risk has manifested itself and has led to an accident, valuable lessons can be learned that can be taken into account to reduce the risk of a similar accident occurring again. This calls for accident analysis methods. In the past 20 years a large number of accident analysis methods have been proposed and it is difficult to find the right method to apply in a specific circumstance. We conducted a review of the state of the art of accident analysis methods and models across domains. We classify the models using the well-known categorization into sequential, epidemiological and systemic methods. We find that these classes have their own characteristics in terms of speed of application versus pay-off. For optimum risk reduction, methods that take organizational issues into account can add valuable information to the risk management process in an organization.

Keywords

Accident Analysis, Incident Analysis, Telecommunications

INTRODUCTION

The research reported in this paper was motivated by the goal of defining a risk analysis method for telecommunication service failure. Failure of telecommunication services can both cause crises (*e.g.* loss of signaling along railroads) and aggravate crises due to the inability to effectively communicate during the crisis resolution stage. In previous research, we have defined the RASTER method for risk analysis of telecommunication service failure, which is now used by the Dutch telecommunications regulator (Vriezekolk *et al.*, 2011; Vriezekolk *et al.*, 2015). Our current research aims to strengthen risk analysis by including lessons learned from past accidents. As part of the LINC (learning from incidents) project started by the Dutch telecom regulator, we conducted a comprehensive literature review of accident analysis methods, that we report here.

Methods to investigate accidents have been proposed and investigated at least since the early 1970s, but the number of methods proposed has increased steeply since the late 1990s. Different methods have been proposed for different domains, and they may use different accident models. For quite a few methods, there is little published evidence that they have been used more than once or twice. On the other hand, a few methods are cited frequently, and some techniques, such as fault tree analysis, are widely used in practice. Some methods are easy to use but lead to a potentially incomplete analysis, while others are expensive to use while allowing more thorough analysis. This raises the question whether from all of the published methods, a generic method can be distilled, using the useful elements of all published methods, and whether we can provide guidelines for choosing an appropriate accident model depending on the context of the accident.

In this paper we present a systematic literature review of accident analysis methods published since the early 1970s across many domains. After a discussion of related work, we state our research questions, we introduce the three classes in which accident analysis methods are generally categorized, and describe some statistics of the corpus of literature we found. We provide qualitative analytics for the different classes of analysis models. We conclude with the answers to our research questions. We present a generic accident analysis method, that can be applied in

a lightweight to heavyweight manner, depending on the context of the accident. We also provide generic accident models for two of the major classes of analysis methods: sequential and epidemiological. A full account of our literature review, including selection method, databases under investigation, the full corpus under consideration and an overview of all methods found has been reported in (Wienen *et al.*, 2017).[1]

Related work

For the purpose of this review, Accident Analysis is the analysis of an accident that has actually happened. The analysis is done with the benefit of hindsight and it works back from the actual event towards its causes and enablers. Note that there are accident analysis methods that are prospective — most notably methods used in the Nuclear Industry. These methods simulate extreme conditions inside a nuclear facility to estimate the impact of nuclear accidents (Eggen and Banal, 1976). These methods are out of scope for this review.

Risk analysis is the *a priori* assessment of what *can* go wrong and what its impact may be. Risk analysis therefore works with possible paths towards possible outcomes. Accident analysis and risk analysis are each other's complement, as a fully analyzed accident may give new insights that can be added to an already existing risk analysis.There have been other reviews of accident methods (*cf. e. g.* (Bosse and Mogles, 2013; Herrera and Woltjer, 2010; Mohammadfam *et al.*, 2014; Strömgren *et al.*, 2013; Underwood and Waterson, 2014; Wagenaar and Schrier, 1997)), but we found none that have the breadth of this review. They single out specific methods, sometimes describing the classes mentioned in this article, sometimes applying them to real world problems. But they do not give an overview of the breadth of the subject as comprehensively as our research. Note however, that for risk analysis, this type of research has been done before (*e.g.* (Tixier *et al.*, 2002)).

For the purpose of this article, we use the following definition of an accident:

An Accident is an undesired and unplanned event that results in a loss, damage or injury.

This term is generally used in the industry, but some fields (such as Medicine and Telecommunications) prefer to use the term *incident* for an accident as meant in this definition.

RESEARCH QUESTIONS

The questions we pose ourselves for this research are the following:

1) What is the state of the art in accident analysis methods?
   a) Which accident analysis methods are in use today?
   b) Which accident models are in use today?
   c) What are the comparative strengths and weaknesses of these methods?
2) Can we draw up a generic model encompassing all current accident methods and models?
   a) What are domain-specific entities, attributes and relationships in accident models?
   b) Can we formulate a generic analysis method and model

We chose to cast our net as wide as possible. That meant that the scope for this investigation covers domains as varied as nuclear industry, aviation, space flight, chemical industry, traffic, outdoor activities and emergency services. We did this with two aims: first, to learn as much from different domains as we could, and second to improve our chances of finding specific methods used for telecommunications.

We ended up selecting 216 articles. In those articles 63 methods were described. Of these methods, 23 were mentioned at least three times. This included PRISMA (Van der Schaaf, 1996) and HFACS (Shappell and Wiegmann, 1997), which are not analysis methods. The remaining 21 methods (henceforth the "Top 21") have been subjected to further, quantitative analysis. Due to the sheer number of methods found, we only discuss the Top 21.

RESULTS

Introduction

In order to provide some structure, we have divided the analysis methods into four categories. Three of these have been identified by Hollnagel (Hollnagel, 2002; Hollnagel and Goteman, 2004) and they form three classes of methods, based on the accident model that they employ. The fourth is a rest category ('Other').

[1] This work is part of the research programme Cyber Security research with project number 628.001.020, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Sequential accident models describe the accident as the end point of a string of causes.

Epidemiological accident models describe the accident as the product of the interaction between a set of entities and actors, some of which may be visible, and others invisible. In effect it is a sequence of causes that are inhibited or enabled by environmental factors that also have a place in the model. This model is similar to models of how diseases develop, hence the name. Key factor in epidemiological types of analysis is the description of latent factors that contribute to the development of an unsafe act into an accident.

Systemic accident models describe the accident as the result of the interaction within a tightly coupled system and between a system and its context. Feedback loops may play an important role in these models.

Other These methods and models are either defined very superficially, rendering them impossible to categorize, or are not analysis methods *per se*.

Descriptive statistics

From Figure 1, we conclude that there is a clear distinction between the number 1 (STAMP) and the rest of the field. This is partially because it is a popular subject for theses: four Master's and six PhD theses. No other method has been the subject of so many academic theses.

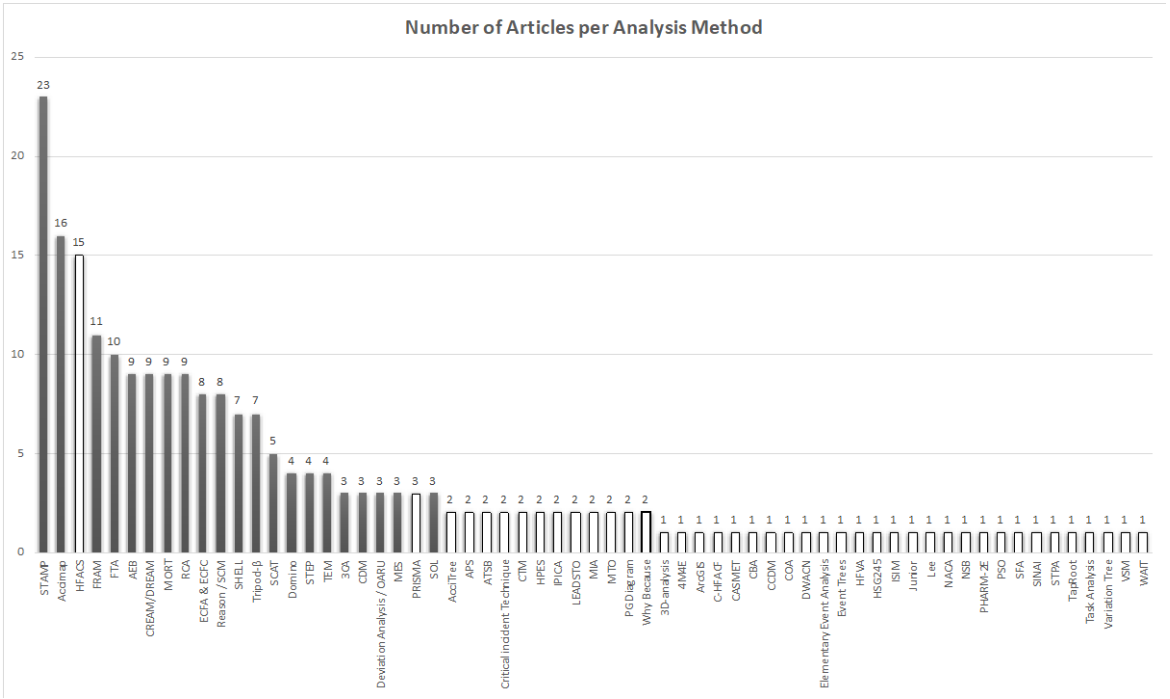

Figure 1. The number of times a method was mentioned in the articles researched. Note: only when actually defined, applied or used in a comparison — not mere mentions. The methods we discuss in this article are in black, the others in white

Domains in the corpus

Figure 2 shows that some domains mostly use methods that are more often discussed in the literature (*e.g.* mining, maritime), while others mostly use methods that we encountered only once or twice in the literature (*e.g.* medical and traffic). This may be due to the maturity of the practice of accident investigation in the former domains as compared to the latter domains. One counter example for this hypothesis is the low number of Top 21 methods for aviation accidents — a field for which we would expect some maturity. For nuclear accidents, the number of methods is zero, as we only found *a priori* analysis methods in this domain.

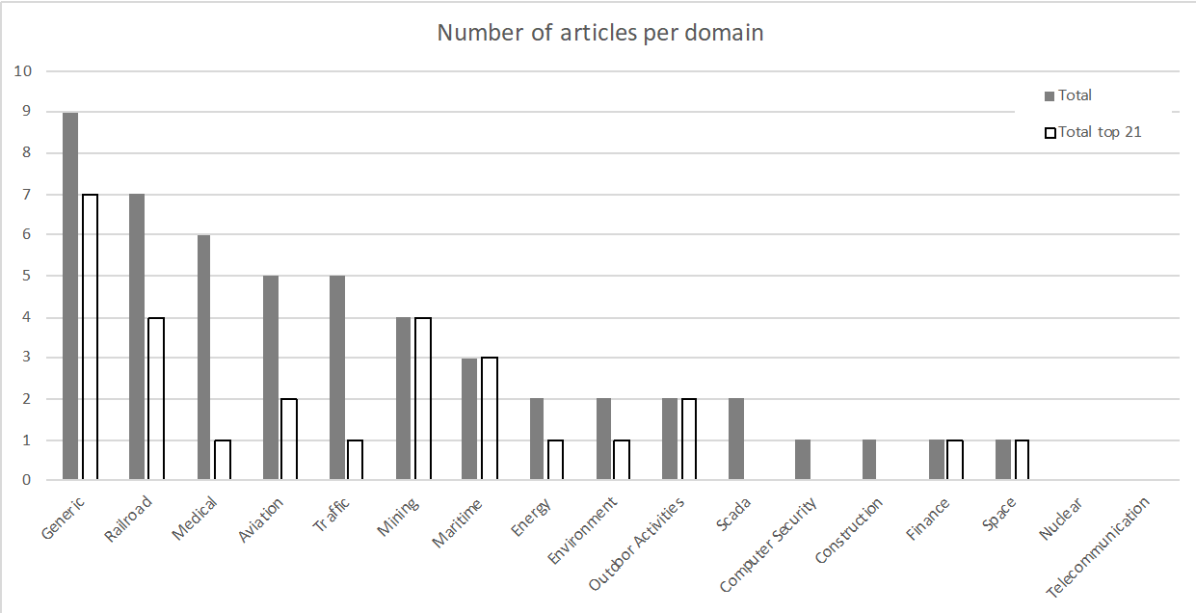

Figure 2. The number of analysis methods per domain. As can be seen from the graph, the number of more accepted methods (those that are in the top 21) differ strongly per domain.

Articles per class and per year

Figure 3 describes the distribution of articles in the corpus over time. This suggests that accident analysis methods are growing as a field of research. Note that the queries were executed in May, June and July 2015, hence the lower number of articles in 2015.

The general trend is that interest in accident methods is growing over time (*see* Figure 3), with the sequential methods starting early, followed by epidemiological and systemic, in that order. Furthermore, the interest in individual systemic methods is relatively high, with 33 articles about only 2 methods (on average 16.5), while that for individual epidemiological methods is lower, with 62 articles about 9 methods (on average 6.9). The average for individual sequential methods is comparable to the epidemiological (40 articles about 6 methods, averaging at 6.7). This is quite remarkable, as these methods have been around far longer (from 1941 for epidemiological models and from 1973 for sequential models) than the systemic (from 2004). This is indicative for the academic interest in the systemic accident models.

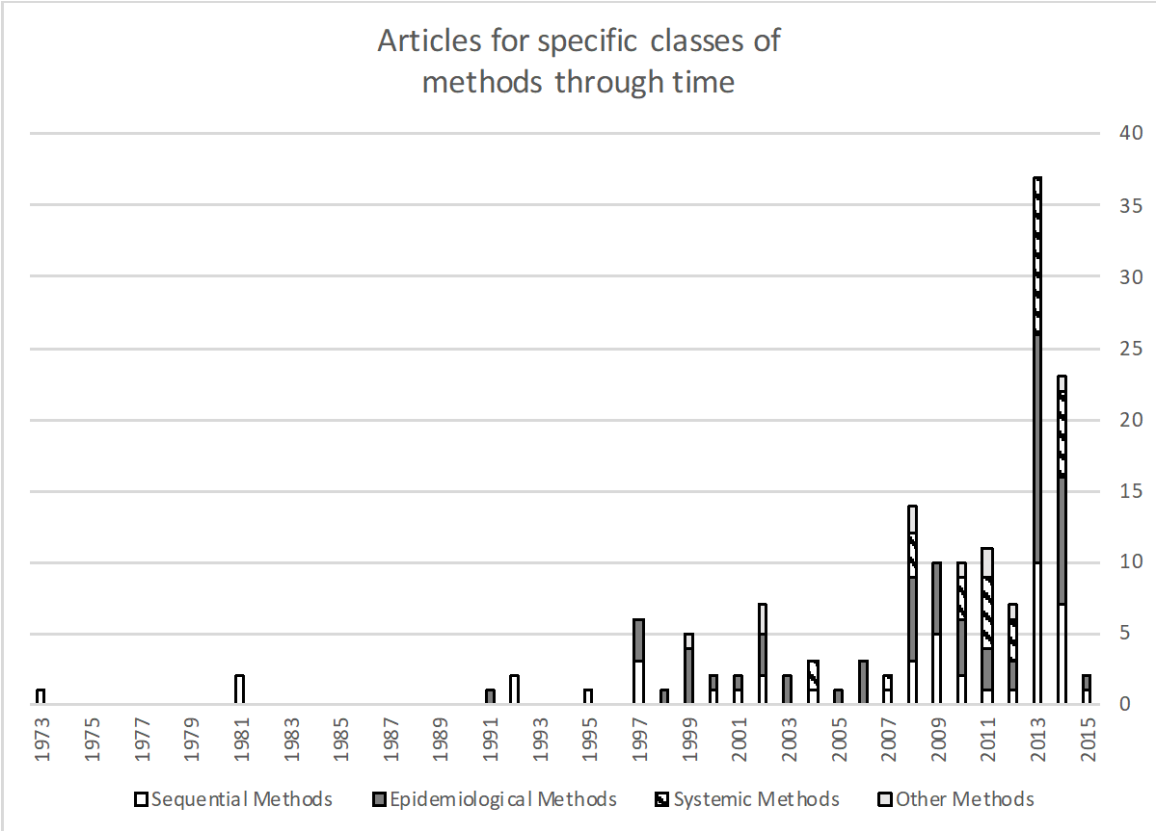

Figure 3. The number of articles per model class through the years. The median for sequential methods is 1992, for epidemiological methods is 2003 and for systemic methods is 2012

Qualitative Analysis

Table 1 shows that the top 21 contain representatives of all three classes along with a few other methods.

Table 1. Methods per Class

Class	Methods
Sequential	Deviation Analysis, ECFA/C, FTA, MES, MORT, RCA, STEP
Epidemiological	3CA, Accimap, AEB, CREAM, Domino Accident Model, Reason/SCM, SCT, SOL, TEM, Tripod-β
Systemic	FRAM, STAMP
Other	CDM, SHELL

Sequential Methods

Sequential methods describe sequences of *events*, connected through cause-consequence links. Events constitute the main entities of the models describing accidents in a sequential method. The accident itself is an event as well. Other methods use *conditions* that enable the event.

The term "sequential" refers to the cause-effect sequences that have actually led up to the undesirable event. A well-known sequential method, used both in accident analysis and in risk analysis, is the Fault Tree Analysis (FTA) method (figure 4.) Note that in contrast to the accident analysis method, in sequential *risk analysis* all possible causes that can lead to an undesirable effect are taken into account.

The most notable strength of the sequential methods is that they have been around for a long time, giving them time to mature. They are easily understood as they paint a picture of sequences of events leading up to the accident. As a result of this clarity, they can be persuasive when trying to convince management to allocate budget to preventing accidents from happening. One weakness is that these methods do not take the socio-technical context into account. They can only lead to improvements that are clear from the chain of events leading to the accident and the barriers

preventing those. Please note that this is a weakness of the methods, and not of the models *per se*, as the models do provide means to model socio-technical factors.

We have created narratives for all sequential models that are used in the methods investigated, identifying entities and relations and we have combined these into the following narrative describing an overarching model:

> A sequential model can be represented by a causal network (with branches and merges, but without loops) of events and states leading up to an accident, which causes damage; branches may be AND or OR branches (and merges too), and edges can be inhibiting. A causal network does not contain feedback loops. Some events are failures, incidental factors, or deviations from a norm. Some are determining factors of the accident. Some are the result of unsafe acts or errors of people. So the network may include events in the social environment.

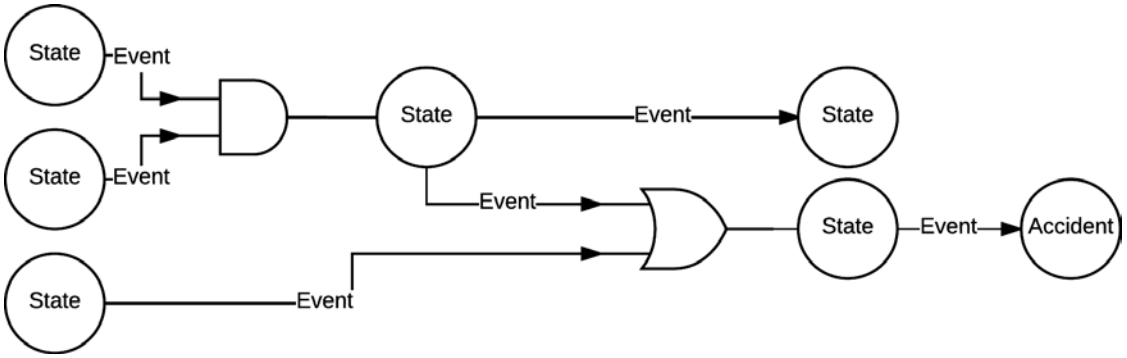

Figure 4. A sequential model for an otherwise unspecified accident. In contrast to a risk analysis this describes an actual series of events resulting in a past accident.

Epidemiological Methods

Epidemiological methods are also modeled around *events*, but they add a layer of *latent conditions* to the model. *Latent conditions* are conditions that are present in the system well before the onset of an accident (Hollnagel, 1999), but are not recognized as such by management before the actual accident occurs. *E. g.* bad maintenance may cause a sprinkler installation to stop functioning. This condition may be present for a long time, but will only be evident when a fire starts and the sprinkler installation malfunctions. Events are generally described as consequences of *actions* by *actors*. These actors are influenced by their *environment* (organizational goals, safety culture, pressure on scarce resources, more or less adequate management and legislation and so forth). Furthermore, some form of risk control is active through the use of *barriers* which may function more or less effectively due to similar environmental factors. One of the more prominent methods the AcciMap method (Rasmussen, 1997; Branford *et al.*, 2009).

The main benefit of this class of methods is that they not only take a serious look at the socio-technical context, but they also have attention for latent conditions present in the system. They can therefore uncover shortcomings in company culture, safety procedures, legislation et cetera that the sequential methods cannot. They will generally take more time to complete as the scope of the investigation is larger. And they may take more effort to convince management to accept the lessons learned as they will sometimes disclose managerial shortcomings. Furthermore, they can be more convoluted, as the context is harder to incorporate into comprehensive and clear pictures that paint the narrative of the accident.

The overarching narrative for Epidemiological models is (*see* Figure 5):

> Actions have (direct or indirect) consequences due to the behavioral variability always present in a socio-technical system. These consequences are events that can be critical. If there is no functioning barrier in place, a critical event has an accident as a result.
>
> In epidemiological methods, actions are triggered by tasks, orders, plans, production goals, and decisions on different system levels. Organizational influences, such as management and the allocation of resources (personnel and equipment), create local conditions that can trigger accidents. These local conditions can both be latent and overt threats.

Events can be characterized by time, location, action and actor.

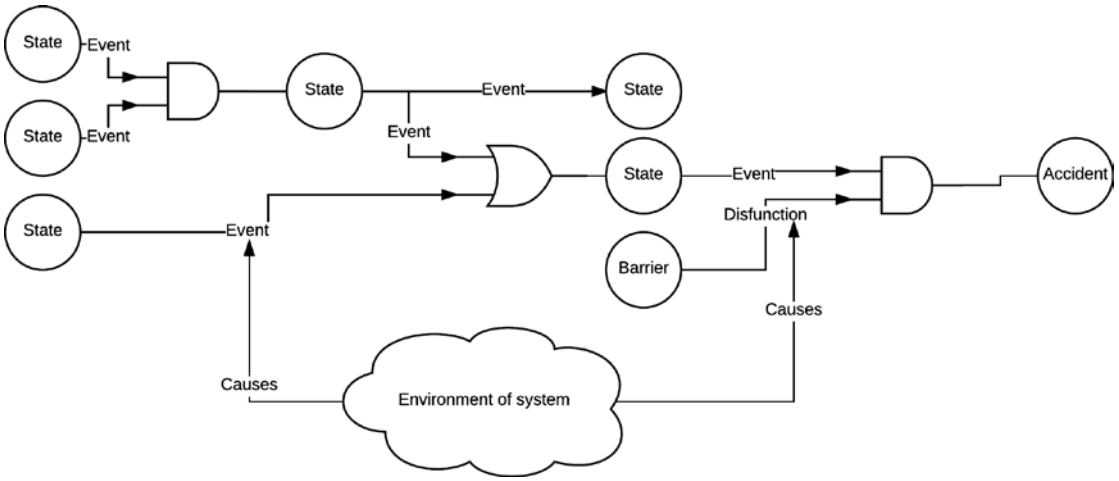

Figure 5. An epidemiological model for an otherwise unspecified accident

Systemic Methods

The two most quoted and well-known methods are STAMP by Nancy Leveson (Leveson, 2011) and FRAM by Eric Hollnagel (Hollnagel and Goteman, 2004; Hollnagel *et al.*, 2014). The systemic methods are characterized by strong links between the different components of the system that directly influence each other. This is mirrored by their ontologies. As FRAM and STAMP use a different paradigm for analyzing the environment, there is little correspondence between the main entities in the methods. STAMP uses a system-theoretical control cycle model, containing the process under control, sensors, actuators, controllers and conceptual models governing the decision taken to control the process. FRAM on the other hand only knows *functions* with several parameters that influence the output of the functions and with interactions between the functions leading to events. Due to the disparate descriptions of these two methods and the fact that we did not find any more systemic methods, we did not succeed in creating an overarching narrative.

The systemic methods take more effort to apply than the other classes of methods as they necessitate a deeper analysis of the regular processes and organization in order to either map them on system-theoretical feedback-control loops (STAMP) or functions (FRAM). This extra effort is in many cases not justifiable considering the benefits of such an analysis. Especially in situations where the consequences of incidents are relatively minor (no lethal victims, no major financial consequences), these methods are too heavy. The literature seems to support this, as the only applications of FRAM and STAMP are as part of the analysis (mostly as an academic exercise) of aviation accidents (Carvalho, 2011) and incidents (Herrera and Woltjer, 2010) and naval accidents (Herald of Free Enterprise (Praetorius *et al*., 2011)) for FRAM and Master's and PhD research projects for STAMP (Dong, 2012; Helferich, 2011; Kawakami, 2014; Li, 2013; Spencer, 2012).

Comparing the three models

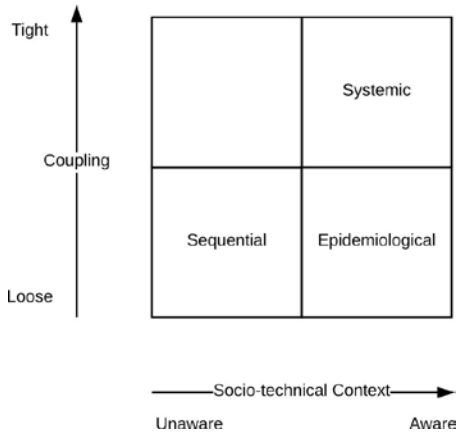

Figure 6. Comparing the three classes of models along two distinguishing axes

In figure 6, we compare the three methods and their underlying accident models. In the historical development of these methods (from the lower left quarter through the lower right quarter up to the upper right quarter), we see the following: the earliest, Sequential models only looked at the system itself, without taking the socio-technical context into account. The Epidemiological models added the socio-technical context. The Systemic models were developed for tightly linked systems and after the Epidemiological methods introduced the socio-technical context, the developers of the Systemic methods made the socio-technical context an integral part of their methods.

Generic Accident Analysis Method

The reviewed methods share a common approach, that we view as a generic, domain-independent accident analysis method, which contains two steps which the analyst can choose to skip, depending on the circumstances of the analysis:

1. Find all events that have a causal relationship with the accident.
2. Describe the history of the accident by linking these events.
3. Find all conditions that enabled these events, including events that lead to those conditions (only in Epidemiological and Systemic methods)
4. Identify components, feedback mechanisms and control mechanisms that played a role during the development of the accident (only in Systemic methods)
5. Identify at which points the accident could have been prevented and analyze if this can be generalized
6. Draw conclusions and propose improvement actions

DISCUSSIONS AND CONCLUSIONS

Answers to research questions

1a) Which incident analysis methods are in use today?

We have identified 63 methods for accident analysis in the corpus we researched. The methods and their frequencies are listed in Figure 1. Most methods that are mentioned only once or twice, but a few methods have a stronger presence in the literature.

1b) Which incident models are in use today?

The literature recognizes three different classes of analysis models: the Sequential, the Epidemiological, and the Systemic. They differ in if and how they include socio-technical context and in how they handle the internal links in the system under consideration. The most often quoted methods per model class are: FTA for the Sequential

methods, AcciMap for the Epidemiological methods and STAMP for the Systemic methods.

1c) What are the comparative strengths and weaknesses of the methods?

The strengths and weaknesses are linked to the class of models the methods employ. Sequential methods have been around for a long time and have been able to mature. They paint a picture that is relatively easy to understand and can be quite persuasive. Their main weakness is that they do not take the socio-technical context into account.

The strength of the Epidemiological methods is that they *do* take the socio-context into account. They also give insights in latent conditions that have enabled the chain of events to unroll into an accident. Their weakness is that it takes more time to perform an analysis using an Epidemiological method, and it may be harder to present the results as the different visual methods are more complex than the average Sequential method.

Systemic methods are more appropriate for systems that have tight couplings where a change in one part of the system has a direct consequence in another part of the system that may be hard to predict. They are more appropriate for Perrow's 'normal accidents' (Perrow, 1984) and are basically in a class of their own. They are more expensive to execute as they take more time and resources.

2a) What are domain-specific entities, attributes and relationships in incident models?

We found that the individual models do not contain domain specific entities, attributes or relations. But we did find that the entities, attributes and relations are class specific. We did not find any methods that have been applied to telecommunications networks. Given the domain independence of the models, the different models should all be applicable to accidents in the Telecommunications domain.

2b) Can we formulate a generic analysis method and model?

We have been able to formulate generic accident models for two of the three classes of models (Sequential and Epidemiological). We have given graphical representations of these models as well. The Systemic models (notably FRAM and STAMP) differ in so many respects that formulating a generic accident model was not feasible.

Furthermore, we have been able to formulate a generic method for accident analysis. This method covered all three classes of models.

Conclusions

The research in accident analysis methods is growing, as evidenced by the number of articles per year (*cf.* Figure 3). Furthermore, the attention has shifted over time from sequential methods and epidemiological to systemic methods. Especially, the high volume of articles for the latter (even though it only involves two methods) is an indication of its relative popularity in academic circles.

We find that many of the methods (40 out of 63) are only mentioned once or twice in the corpus of literature we studied. This implies that those methods did not receive much scrutiny from the scientific community and have not been applied very often. The quality of these methods cannot be determined from the literature, but the absence of discussion is in stark contrast with the 13 most discussed and applied methods (starting from 7 times up to 23 for the method that was most discussed).

Furthermore, we see a clear distinction in the classifications between the groups: if we disregard the methods that we did not classify (due to too little information or no specific class), we find for the Top 21 methods that 10% falls outside the three main classes, while for the remaining 27 methods (40 minus 13 unclassifiable methods), 48% falls outside the three main classes. This may be an indication that the authors of many of the less mentioned methods are unfamiliar with the subject and were trying to re-invent the wheel. The great number of methods in the Sequential and Epidemiological classes may indicate an evolution of methods within those classes. We did not analyze this any further.

When balancing strengths and weaknesses of the different analysis methods, we are considering the classes instead of the individual methods. There is a difference between 1) methods that quickly resolve the incident and restart the interrupted service and 2) methods that from a service continuity point of view, make sure that a similar incident does not happen again. This will give us information about which class of methods to choose.

The Sequential methods paint very clear pictures that can assist in resolving incidents quickly after they developed. For troubleshooting purposes, these methods can be lightweight enough to quickly find the cause of an incident and repair the issue. However, these methods will miss deeper, structural causes, often present in the socio-technical

system. Too few resources for maintenance or a broken safety culture will not be identified by these methods.

The Epidemiological methods however, although taking more time, will tend to find the latent factors that — after resolution — may strongly help reduce incidents of the type investigated in the future. We can even imagine that they may uncover a fundamental flaw in the organization the resolution of which can help prevent a larger class of incidents. The concept of barriers gives a clear reference point where to apply corrective measures, giving management a clear means to improve the safety of the system.

In many domains, from a business point of view, the Systemic methods are too expensive to use for the analysis of accidents and incidents: the costs would seldom outweigh the benefits and these methods are therefore not efficient enough for regular business activities and accidents or incidents with relatively light damage. Furthermore, safety is an emergent property in systemic methods. That makes it harder to formulate corrective measures that can be implemented by management.

To sum up, a sequential method may be appropriate during the resolution phase of an incident, while an epidemiological method is more fitting for a deeper analysis after the incident has been resolved in order to find latent factors that can be neutralized to prevent incidents from happening again. Systemic methods will not add enough value to this process to justify the considerable effort and consequently considerable costs.

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A Conceptual Double Scenario Model for Predicting Medical Service Needs in the International Disaster Relief Action

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ABSTRACT

Man-made and natural disasters have affected people worldwide. Mass casualty incidents would create a surge in demand for medical services. **Medical service needs** are the basis of medical strategic readiness plan. In recent years, international actions have been criticized for being ill-adapted to dominating health needs of the affected region. The "**Scenario-Response**" modeling is an important method in disaster prediction. This research established **a medical service needs conceptual scenario model** with two different levels of ambition: a disaster scenario, in which casualty figure, composition of injuries are constrained by the types of the disaster as well as the degree of the damage, and a country scenario, in which the healthcare needs are constrained by the health coverage and the health condition of local people. In this research, Armed conflicts in Yemen and Syria Arab Republic was selected as research target where the model is applied to conduct the relevant analysis. The results proves that the outcome earned by using this model could fit the reality to a great extent..

Keywords

Disaster Relief; Medical Service Needs; Scenario Model.

INTRODUCTION

Over the past years, man-made and natural disasters have affected large numbers of people worldwide. Some of the disasters were sudden-onset disasters (SOD), such as earthquake outbreaks and terrorism attacks, while the others would exist for a long period of time, such as humanitarian crisis or armed conflicts.(Leaning and Guha-Sapir, 2013) Once these disasters happen, mass casualty incidents will create a surge in demand for emergency medical services. In some countries, especially low and middle income countries, international actions are needed. (Reinhardt et al., 2011)

The basis of international action is medical resources preparedness, such as staffing, requisite equipment, and needed medical supplies. (Guha-Sapir, 1991)Medical resource preparedness is based on determining the likely composition of injury or patient streams during the action. (Zouris et al., 2001) "Scenario-Response" model is the main method for disaster relief study. This model has been applied in making Readiness Strategic Plan, simulating exercising, predicting and early warning and so on. (Wei et al., 2017) Some medical relief "Scenario-Response" models focus on establishing the disaster scenario which could determine the likely amount and composition of injury or patient stream after disaster outbursts. Then the medical resources readiness plan could be made based on them. (Zouris et al., 2001) Other scenario models are optimization models which focus on optimizing the medical evacuation decision making, the priority for receiving care, the medical resource effective allocating, etc.(M. and K., 2017; PP. et al., 2016) All these models tend to focus on providing life-saving trauma care in the early disaster relief period.

But in recent years, foreign medical rescue teams deployed to sudden-onset disasters (SOD) have been found to arrive too late to provide life-saving trauma care. They have also been criticized for over focusing on trauma care and for being ill-adapted to dominating health needs of the affected region(Gerdin et al. 2013). During the disasters, local health services may be disrupted so that international help is necessary and urgent needed, not only in dealing with the effects of the disaster but also to maintain routine health facilities for unrelated conditions (Motamedi et al., 2012; Reinhardt et al., 2011).In some experience summary articles, the influences of the local health service coverage, the local people health condition, the health condition of children, and professional health service for children and other special population are instantly mentioned. For example, some articles focus on the children and maternal in the armed conflicting region. (Zeid, 2015)Who are more vulnerable and easy to be injured when facing the disaster. (Yonekura et al., 2013) Without local professional service to specific person, the humanize crisis is more likely to occur. Some other articles also evidenced that people with chronic diseases (PCDs) are easy to get hurt in the disaster.(Chan and Sondorp, 2007) Some research mentioned the neglect of PCDs in the disaster relief. The lack of medicine for PCDs in the relief results in non-sustainable treatment for PCDs which could lead to series of consequences even life loss. (Miller and Arquilla, 2008))

So when we consider establishing the Scenario model for international medical relief, we should not only take emergent medical needs into consideration, but the local health service coverage and population health condition also.

BACKGROUND

Up to recently, no research is found to establish a model consider both the disaster characteristics and the characteristics of local health coverage and the basic health condition of local population.

The main concern of World Health Organization (WHO) is the potential risk of pandemic after the disaster, even that was unconfirmed yet. WHO also published a general guideline for international medical rescue team to follow when executing an international action. But according to some research, this guideline was not fully followed due to several reasons. One reason is that this guideline is not associated with the local reality. (Gowing et al., 2017)

Since 2010, six "Mission Harmony" humanism medical assistant actions have been executed world-wide based on the "Ark Peace" hospital-ship, PLA, China. Medical resource preparedness plan have been made before setting out according to the composition of patients offered by the local health department. But when the hospital-ship arrived the destination, the situation is different to what had been estimated. The patients were mainly children, women and the elders and the composition of disease is different from what is offered. Some of the medical resources, such as medicines for children and some sort of acesodyne were used up while the intravenous (IV) fluids and some sort of antibiotic were wasted. (Sun et al., 2016)

In order to enhance the efficiency and reasonability of medical resource preparedness during international medical relief action, more factors related to local health service and health condition should be taken into concern when establishing the scenario model.

METHODS

We modeled a scenario model with two different levels of ambition: a disaster scenario, in which mortality, casualty figure, composition of injuries are constrained by the types of the disaster as well as the degree of the damage, and a country scenario, in which the healthcare needs are constrained by the health coverage, the health condition, the communicable disease and non-communicable disease contribution and the service availability towards the special population such as maternal and children. We estimated the associated medical needs are both effected by the two scenarios.

The outcome of this model is the medical service needs which are the basis of medical resource preparedness plan. The model could provide the likely composition of injury or patients which determines the composition of staffing, requisite equipment, medicine and other needed medical supplies.

An abridged general view of the model is shown in Figure1. The characteristic indexes of the medical service needs are approximate injury or patient amount , composition of injury or disease condition and composition of injury or disease type. The disaster-level model is related to the characteristic factors of the disaster such as the type and degree of the disaster, the area struck by the disaster, the time when the disaster happened, etc. This model have a great effect on the medical needs greatly at the first period of time (T1) during which most survivors are discovered.

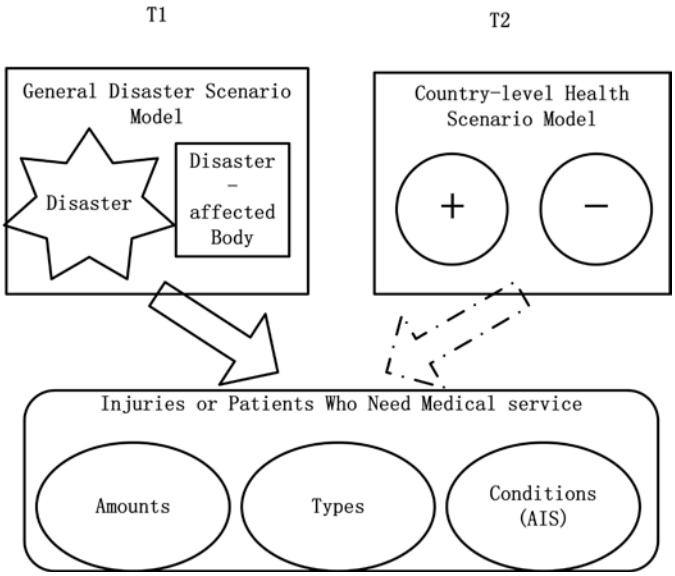

Figure 1. Abridged General View of the Double-level Scenario Model

But with the expansion of time, especially close to the end of golden rescue time, the country-level model have a gradually increasing influence on the medical needs in the second period of disaster relief time (T2). (Lulu et al., 2012) The country-level model is related to the characteristic factors of the country's health condition and health service coverage.

Further description of the double-level scenario model are as follows.

Level 1-- General Disaster Level Scenario Model for Medical Service Needs Prediction

There are lots of researches on the models of emergent medical service needs constrained by the disaster characteristics. But these researches didn't reach a common consensus on the definite model. But reviewing these researches, the relationship between the disaster characteristic factors and the medical service needs are certain. The indexes to describe the emergent medical service needs have high correlation with the disaster characteristic factors such as its time, area, type, degree and the fragility of disaster-affected body or region. Generally speaking, if the disaster hit wide range of area and took place at a severe degree, large amount of injury and more severe hurt injuries would occur. If the disaster outburst during night, injury amount would be larger. If the region hit by the disaster had high fragility such as poor quality of construction, disadvantage landforms and so on, the injury amount and severe hurt injuries would also increase. Certain types of injury would increase in certain disasters, for example, crush injuries would increase in earthquake, burn injuries and airway damage would increase in fire hazards, explosive injury and bullet wounds would increase in the armed conflicts, etc.

Based on these researches, we established a conceptual model of disaster level medical service needs. We use Injury Amount (IA)、Composition of Injury Condition (CIC) and Composition of Injury Type (CIT) as outcome indexes to describe the medical service needs. The model's income indexes are Disaster Type(DTy), Disaster-affected-area Fragility (DF), Disaster-affected Population (DP)、Disaster Degree (DD)、Disaster Time (DTi). The abridged general view of the model is shown in Figure2.

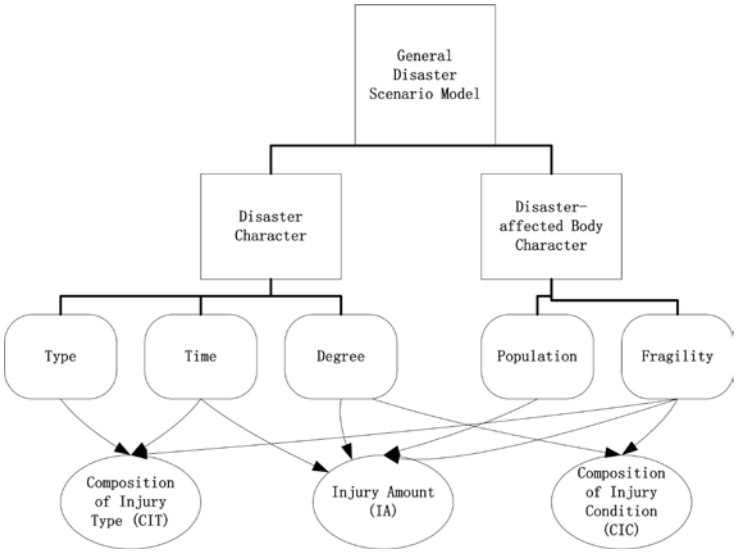

Figure 2. Abridged general view of the disaster level model

The mathematical expression of the conceptual model is as follow.

{IA, CIC, CIT}-f{DTy, DC, DP, DD, DTi}

This expression could decomposed into 3 sub-expressions.

(1) IA=f'(DP, DD, DF, DTi) (when DTi≦7, value DTi the actual day number; when DTi>7, value DTi =7)

In this sub-expression, DP is the base number of the injury amount which has positive correlation with DD and DF. According to some earthquake relief researches, the injury amount would increase rapidly during T1 period which generally last from the 1st day to 3rd or 7th day after disaster outburst. Then, with the end of golden survivor searching time, the injury amount would increase slightly. So in the expression, we use the actual number of day when DTi<7 and value DTi with 7 when DTi>7.

(2) CIC=f''(DD, DF)

This sub-expression expresses the relationship of CIC and DD, DF. CIC indicate the composition of critical injury, severe injury and walking wounded. The classification of injury is according to the Abbreviated Injury Scale (AIS) which is commonly used in emergency triage. When the DD and DF are higher, the composition of critical injury and severe injury would be higher, vice versa.

(3) CIT=f'''(DTy, DD, DF)

This sub-expression expresses the relationship between CIT and DTy, DD, DF. What injury type would occur in the disaster is determined by the DP while the composition of different injury types are determined by DD and DF.

Level 2-- Country Level Scenario Model for Medical Service Needs Prediction

According to existing researches, with the expansion of time, the amount of injuries caused by the disaster always increasing steadily,, while patients due to the poor coverage of health service, poor sanitary condition, poor immunization and other local health problems gradually increase rapidly that occur in the disaster-stricken population. (Leaning and Guha-Sapir, 2013) This condition could be described in two aspects. One is the new occurrence of patients and diseases, the other is the changes of injury amount and composition of injury condition.

If the local health condition, health coverage and infectious disease control are in good condition, the medical

treatments could decrease the amount of injuries especially the critical or severe injuries. Also, children, maternal women and elderly people with chronic diseases would be taken good care, preventable infectious diseases would under strict control and the health of the disaster-stricken population would be controllable. If the situation is less optimistic or still go towards a bad way, the severe injuries could turn to critical injuries and the critical injuries could lost their life due to the lack of timely medical treatments. The local people especially children, women and the elders could suffer huge humanitarian crisis while infectious diseases could become pandemic.

So we established a country level medical service needs after disaster based on over 1,000 health related indexes monitored by WHO in 194 countries. These indexes are monitored constantly to see if the country could reach the Sustainable Development Goals (SDG) in 2030. We selected 6 types of these indexes to reflect the influence to the medical service needs after disaster.

The outcome indexes of this model are mainly two types. One type reflect the treatment of injuries, such as Injury Amount Adjust(IA-A) and Composition of Injury Condition Adjust(CIC-A). The other type reflect the disease treatment or control condition in period T2, such as Patient Amount (PA)、Disease Composition (DC) and Infectious Disease Epidemic (IDE). When we want use the first type of outcome index, we should use them multiply by the outcome indexes of the level-1 model. Thus, we could get the final injury amount and likely composition of injury condition in period T2.

The income indexes of this model contain two aspects with 6 types of indexes. One aspect of the indexes reflect the resistant capability of the local health service system when facing disaster struck. If these indexes are high, injuries especially severe and critical injuries would be treated quickly and the health service system would soon recover to the normal order. The other aspect of indexes reflects the fragility of the local population health condition. If these indexes are high, new patients and new types of disease would increase rapidly even new infectious disease pandemic would occur. Injuries condition suffered by the disaster would be getting worse due to poor basic health condition. So we call the first aspect of indexes positive indexes which could release the health damage caused by disaster and we mark these indexes with a "+". We mark the second aspect of indexes with a "-" because they have negative effects on disaster medical relief and would worsen the health damage caused by disaster.

The first aspect of indexes include 3 types of indexes which are Health Coverage (HC), Professional Service for Special Population (PSSP) and Infectious Disease Control (IDC). The second aspect of indexes include 3 types of indexes which are General Health (GH), Special Population Health (SPH) and Infectious Disease Composition (IDC).

The abridged general view of the model is shown in Figure3.

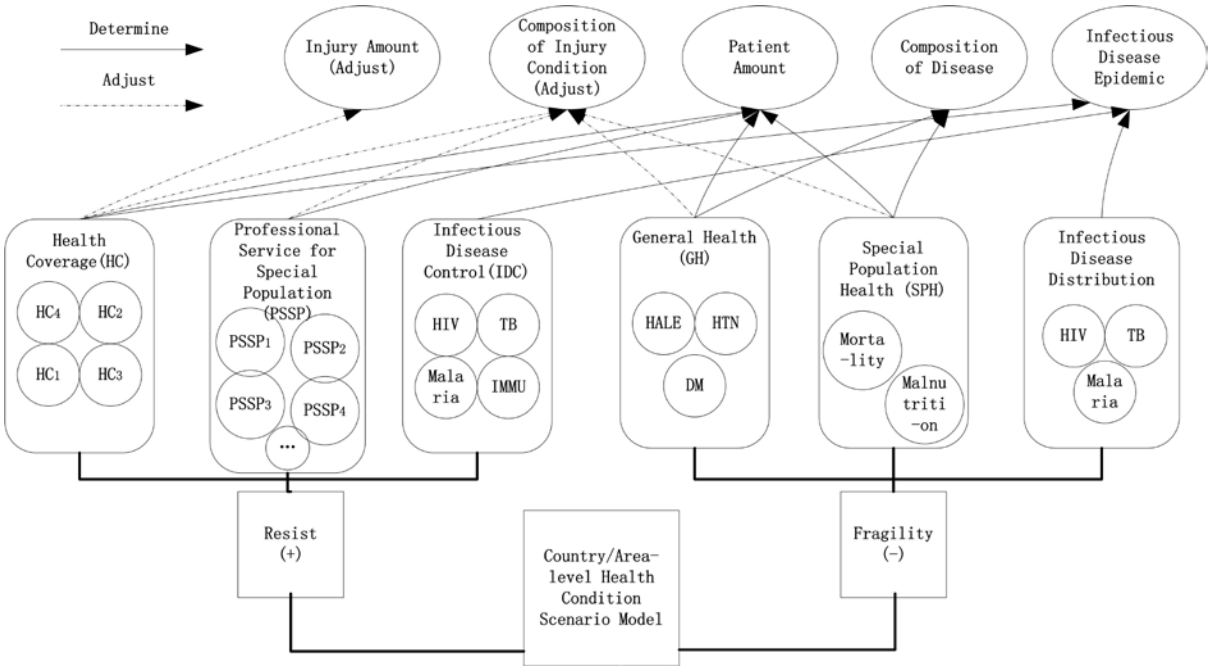

Figure 3. Abridged general view of the country health level model

The mathematical expression of the conceptual model is as follow.

{IA-A, CIC-A, PA, CD, IDE}-g{HC, PSSP, IDC, GH, SPH, IDD}

This mathematical expression could decomposed into 5 sub-expressions.

(1) IA-A= -g'(HC, PSSP)；(2) CIC-A=-g''(HC, PSSP)+g''(GH)

-g' and -g'' indicates negative correlation. When HC, PSSP is high which means local health service is good or above the global average level, IN-A and RIC-A is low which means the amount of injury and the ratio of critical or severe injuries decreases. g'' indicates positive correlation. When GH is high, RIC-A is high which means the ratio of critical or severe injuries increases.

(3) PA=P*[g'''(GH)-g'''(HC)]+SP*[g'''(SPH)-g'''(SPS)]; (4) DD=-g''''(HC, PSSP)+g''''(GH, SPH)

P stands for the total population affected by the disaster. SP stands for the special population affected by the disaster including children, women and the elderly. g''' and g'''' indicates positive correlation while -g''' and -g'''' indicates negative correlation. So these two expressions means the higher value the GH and SPH is, the larger amount of patients and patients with severe diseases would occur. Vice versa.

(5) IDE=-g''''(IDC, HC)+g''''(IDD)

This expression means if the IDC and HC are acceptable in the local area, the possibility of IDE is low. If the area's infectious disease condition is poor which means one or more infectious disease is out breaking, the possibility of new infectious disease pandemic is high. Meanwhile, the members of international medical relief team should take measures in advance such as injecting vaccine or taking precaution measures to prevent infection.

The 6 types of indexes included 20 specific indexes. Table 1 shows the data type presentation, indicators, whether could be graded (e.g. the index of "Basic Hospital Access" could be divided into 4 levels, <10, 10-19, 20-30, >30), global average level and the effectiveness of these indexes.

Table 1. General view of the 20 specific indexes of the country-level model

Factor	Name	abbreviation	Index	Data Type Presentation	Indicator	Whether Graded	Grade No.	Globle Average	Effectiveness
Resist (+)	Health Coverage	HC1	Basic Hospital Access	Ratio	Hospital beds (per 10 000 population)	Yes	4		The higher percentage or ratio could help the country or area to reduce the injury number, release severe wounded and reduce patient number after disaster
		HC2	Health-worker Density	Ratio	Density of physicians (per 1 000 population)	Yes	6		
		HC3	Access to Essential Medicines	Statistic	Median availability of selected generic medicines (%)	No		Public: 37.7/46	
		HC4	Compliance with the International Health Regulations	Percent	International Health Regulations (IHR) core capacity index	Yes	4		
		Other	Mobilization of resources; Sanitation and hygiene	Percent	General government expenditure on health as a percentage of total government expenditure; Population using at least basic sanitation services(%)	Yes	7;4		
	Proffessional Service to Special Population	PSSP1	Family planning	Percent	Married or in-union women of reproductive age who have their need for family planning satisfied with modern methods	No		76	The higher percentage could help reduce child or women injury, release severe child wounded and reduce child or women patient number;
		PSSP2	Antenatal delivery and care	Percent	Antenatal care coverage - at least four visits (%)	Yes	4		
		PSSP3	Health-seeking behavior for child illness	Percent	Children with suspected pneumonia taken to an appropriate health provider (%)	Yes	5		
	Infectious Disease Control	HIV	HIV Therapy	Percent	Estimated antiretroviral therapy coverage among people living with HIV (%)	Yes	5		The higher percentage indicates the country or area could prevent new infectious disease outbreaking at a higher level after disaster.
		TB	Tuberculosis Therapy	Percent	Tuberculosis treatment coverage for all forms of tuberculosis	Yes	4		
		IMMU	Immunization Coverage	Percent	Diphtheria tetanus toxoid and pertussis (DTP3) immunization coverage among 1-year-olds(%)	Yes	4		
fragility(-)	General Health Condition	HALE	Health Adjusted Life Expectancy	Age	life expectancy weighted oradjusted for the level of health-related quality of life	No		59	Lower age and higher percentage indicate poorer health condition which would aggravate the severity of injury and patients as well as the number of patients
		HTN	Prevalence of raised blood pressure	Percent	Percent of defined population with raised blood pressure (SBP≥140 OR DBP≥90)	Yes	5		
		DM	Prevalence of raised blood glucose	Percent	Prevalence of raised fasting blood glucose	Yes	5		
	Special Population Health	Motality	Maternal mortality; Under-five mortality	Ratio	Maternal mortality ratio (by 100,000 live birth); Probability of dying by 5 per 1000 live birth.	Yes	6	216; 40.8	Higher ratio or percentage indicate poorer health condition among children and women which would aggravate the severity of injury and increase special patients.
		Malnutrition	stunting among children under 5 years of age	Percent	Prevalence of stunting among children under 5 years of age	No		22.9	
	Infectious Disease Distribution	HIV	HIV/AIDS	Number	Number of people (all ages) living with HIV Estimates	No		190,155	Higher number indicate higher probability of occuring new infectious disease patients after the disaster
		TB	Tuberculosis	Number	Number of new Tuberculosis cases (per 100 000 population)	No		142	
		Malaria	Malaria	Number	Number of new malaria cases (per 1000 population at risk)	No		94	

We use spider diagram to schematize the country level scenario model. The six directions represent six types of indexes. The left part of the spider diagram indicates positive indexes that present the local resistant capability. The right part of the diagram indicates negative indexes that present the local population's health fragility. Every point on the coordinate presents a value. The middle area of the coordinate indicates the global average level. The further to the center, the higher value it presented. If we connect every point on the each different coordinate, a image would be formed to indicate the combined effectiveness to the medical service needs. If the image's left proportion is larger than the right, the local resistant capability prevails and that would decrease the medical service needs. If the image's right proportion is larger, it is more likely that local people would fall ill or get hurt. If the image's right proportion is larger than the global average level image, international actions are necessary. (Figure 4)

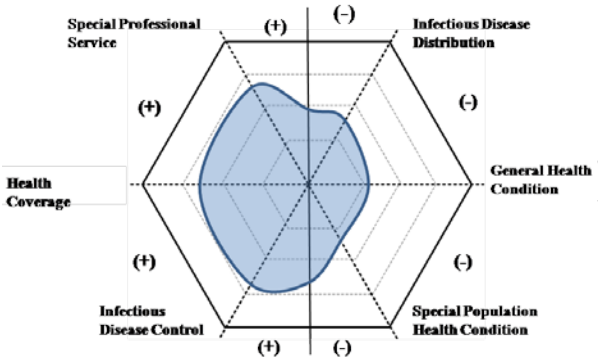

Figure 4-1. Positive Country Level Spider Diagram

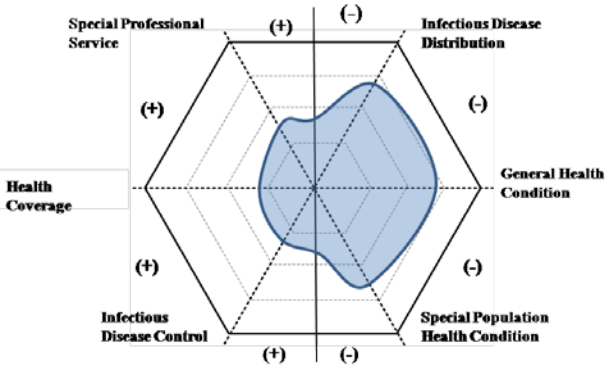

Figure 4-2. Negative Country Level Spider Diagram

RESULT AND DISSCUSSION

Use the double level scenario to analyze the international medical service needs in Yemen and Syrian Arab Republic, both of which out broke armed conflicts.

As shown in table 1, the input indexes' value of the two countries are similar. Both conflicts come of "Arab Spring" which started from 2011. Both conflicts affected the whole country. Both countries have similar location and population. So the outcomes of the 1st level model are similar. As far as this result is considered, which most international medical relief team has done at first, a similar medical strategic readiness plan should be made.

Table 2. Input Indexes of Disaster Level Scenario Model in Yemen and Syria Arab Republic

Nation	Population	Conflict Source	Start Time	Hit Area	Degree of the Conflict
Yemen	25,235,000	Arab Spring	2011	Whole country	Severe
Syria	22,712,000	Arab Spring	2011	Whole country	Severe

We established the second level scenario model for Yemen and Syrian Arab Republic. The value of the input indexes are shown in table 3. We could see from the table, the health condition and health coverage of the two countries are different. From a rough comparison, health related situation in Syrian Arab Republic is better than Yemen.

Table 3. Input Indexes of Country Level Scenario Model in Yemen and Syria Arab Republic

Factor	Name	abbrevi at-ion	Index	Yemen	Syrian Arab Republic	Globle Average
Resist (+)	Health Coverage	HC1	Basic Hospital Access	7 grade:1	15 grade:2	grade:2
		HC2	Health-worker Density	0.311 grade:1	1.546 grade:3	grade:3
		HC4	Compliance with the International Health Regulations	46 grade:2	63 grade:3	grade:2
		Other	Mobilization of resources; Sanitation and hygiene	3.93/60 grade:1/2	4.8/93 grade:1/4	grade:4/2
	Professional Service to Special Population	PSSP1	Family planning	69.6	87.5	76
		PSSP2	Antenatal delivery and care	49.1 grade:2	91.1 grade:4	grade:2
		PSSP3	Health-seeking behavior for child illness	34 grade:2	76.8 grade:4	grade:3
	Infectious Disease Control	HIV	HIV Therapy	No data	18 grade:1	grade:3
		TB	Tuberculosis Therapy	59 grade:2	80 grade:3	grade:2
		IMMU	Immunization Coverage	DTP3:84 grade:3	DTP3:70 grade:2	grade:2
Fragility (-)	General Health Condition	HALE	Health Adjusted Life Expectancy	54	63	59
		HTN	Prevalence of raised blood pressure	30.7 grade:4	24.5 grade:2	grade:3
		DM	Prevalence of raised blood glucose	11.3 grade:4	14.6 grade:5	grade:3
	Special Population Health	Motality	Maternal mortality; Under-five mortality	385;47	68;17.4	216; 40.8
	Infectious Disease Distribution	HIV	HIV/AIDS	No data	9,900	190,155
		TB	Tuberculosis	48	21	142
		Malaria	Malaria	22.2	0	94

Data source: WHO's The Global Health Observatory theme pages. (http://www.who.int/gho/en/)

Schematizing the model inputs with spider graphic, we could see the difference between the two countries from Figure 5. In figure 5-1, the area which indicates health coverage is smaller than global average level and while the area indicates population health condition is larger. This indicates the same degree armed conflict could cause lager health damage as well as a higher possibility of humanitarian crisis to the people in Yemen. Lower health coverage also indicate a possibility of pandemic infectious disease that are transmitted through water or air. Comparing figure 5-1 and 5-2, the value of IDC in Syria is lower than in Yemen, especially the vaccination level. This indicate it is more likely that a infectious disease which has immunoprophylaxis method would pandemic in Syria. But the IDC capability index implies that the epidemic situation in Syria would be better in Yemen. When we multiple the level-2 model outcome with level-1 model, the medical service needs prediction are mainly the outcome of level-2 model which indicate that we should make a more urgent and plentiful international medical relief readiness plan and mobilize more sufficient international medical resource support for Yemen than Syria.

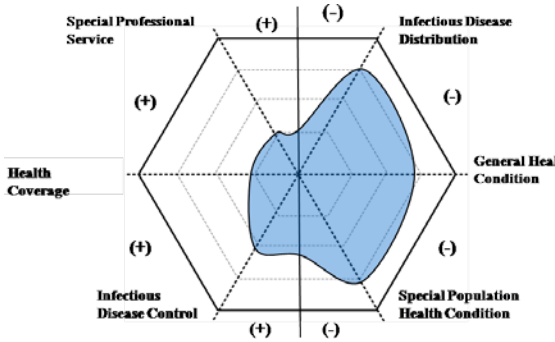

Figure 5-1. Country Level Spider Diagram of Yemen

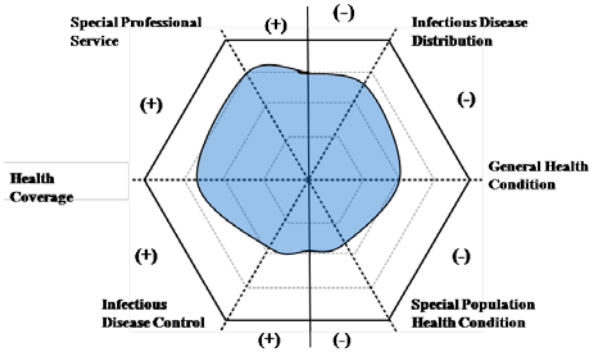

Figure 5-2. Country Level Spider Diagram of Syria

From the WHO reports, the two countries had different medical needs. According to reports, the number of people in need of humanitarian assistance is 20.7 million in Yemen while the number in Syria is 13.1 million. The number of people in acute need of humanitarian assistance is 9.8 million in Yemen while the number in Syria is 5.6 million. In Yemen, 1.8 million children acutely malnourished. In Syria, the situation is better, 19,000 children acutely malnourished. Cholera out broke in Yemen and the cumulative total from 27 April 2017 to 14 Jan 2018 is 1,035,676 suspected cholera cases and 2,244 associated deaths. Polio out broke in Syria and the total number of cVDPV2 cases from Jan 2017 to Jan 2018 is 78.

From these facts, it can be concluded that the medical service needs in Yemen are more urgent and complex than in Syria. More international actions are needed in Yemen. From the WHO's new response plan for these two countries, we could see that the main points in Yemen's plan are more emergent medical resources delivery and life-saving medical services supports and trainings. Syria's plan focuses mainly on helping the local health service system to recover and supporting polio vaccination.

The outcomes and indications of the double-level scenario model fit this reality.

If only the disaster-level model is considered, international medical relief team tends to make similar readiness plan for Yemen and Syria. When the country-level model were also considered, it becomes clear to see the difference of medical service needs and different readiness plan suggestions gradually form.

CONCLUSION AND NEXT RESEARCH PLAN

When predicting the medical needs in international disaster relief actions, research should pay equal attention to the disaster scenario and the local medical and health scenario. In order to establish a more fit-to-reality medical readiness plan could be made. This research aims to establish a double scenario model for medical service need prediction. This research established the frame of the model (as shown in Figure 6) and two conceptual expressions of the model.

The model can be consummate by some improvement, such as: relationship between the inputs and outcomes should be more clear and calculable. Each index might have different weight in the model and the weight might change with time. The sensitivity analysis of the model is also needed. More case studies are needed to check the effectiveness of the model as well. Further research plans are making and more research measures are taking.

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A coordination lattice model for building urban resilience

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ABSTRACT

Common denominators emerge difficultly in projects bridging science and society or/and across disciplines. Managing crises require inter-organizational learning and citizen involvement, but, often such undertakings lead to bargain resulting in sub-optimal decisions. Building resilience into human communities demands complex projects, which further require good problem definition, starting with agreements on values and knowledge, as basis for further agreements on goals and methods. This paper spreads the Data-Information-Knowledge-Action-Result frame over a 4-level process to generate a *DIKAR_process* matrix and lattice that allows optimal orientation and coordination towards achieving a set of common denominators and coordinated action protocols. This framework allows sequences and cycles that can be formulated and pursued simultaneously, comparatively and iteratively, within any large, heterogeneous constituency of actors involved in building resilience in local communities. The model is illustrated and discussed in relation to urban sustainability issues and complementary methods like knowledge maps, mental models, social learning and scenarios.

Keywords

Resilient communities, Social learning, Data-Information-Knowledge-Action-Result, Foresight, Planning

INTRODUCTION

Dealing with crises requires inter-organizational learning and effective citizen involvement, but, in the absence of common denominators, these easily lead to bargaining resulting in sub-optimal decisions (Moynihan, 2008; Turoff et al., 2013). Resilience of human communities can only be built through complex projects, which in turn require good problem definition. This starts with agreements on values and knowledge, as a necessary condition for further agreements on goals and methods (Castle & Culver, 2013). However, developing a set of common denominators is a long-term activity that never stops, because it takes projects bridging science and society or/and involving different disciplines (Brand et al., 2013; Mauser et al., 2013; Polk, 2014; Janssen et al., 2015; Schimel et al., 2015). Getting partners on the same page requires a lot of uncertainty, investment of resources and experimentation, learning, conflict management and institutional building. Such projects and programs include a broad range of disciplines, social actors and contexts, each with its own issues, terminology and worldview. They are triggered by convergences of interests matching public demands or other types of opportunity, but most of the initial coordination efforts are dedicated to alignment of formal requirements. Essential contextual and conceptual mismatches are postponed to later stages, presumably to be addressed 'as per normal' or/and "one problem at a time". However, resilience can only be treated effectively as part of a holistic endeavor about sustainability, whereby disciplinary experts can't "just do one thing", but have to work together, learn from each other and make expert-decisions as a group, and engage in stakeholder collaboration and social learning (Clark et al., 2016). This starts with project preparation. Very often, and especially in the case of megaprojects, not the best projects are being funded, but those who look best on paper (Flyvbjerg, 2014). Especially when they haven't worked together before, intended partners can easily overestimate both their common grounds and their individual adaptability, at which point crisis becomes inevitable.

MODEL

To overcome inertia or project setbacks a group of actors and stakeholders (scientists, citizens, etc.) must recognize that they must avoid a situation of poorly-structured problem, i.e., one with latent disagreements on

values (general rules of operation) and knowledge (general terminology, theories and models). If they don't, they have no realistic basis for meaningful and effective coordination on goals, and further on methods. This situation is particularly frequent in the case of pioneering, large and transformational projects connecting science and society (Mingers, 2004; Mauser et al., 2013; Midgley et al., 2013; Janssen et al., 2015, Schimel et al., 2015). Nonetheless, common denominators are difficult to come by in projects and programs covering the relations between science and society, but also between different disciplines or professions (Figure 1).

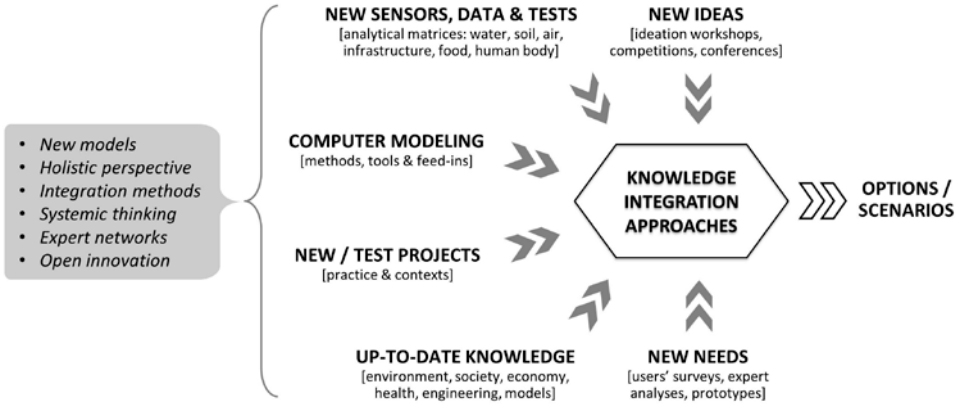

Figure 1. General representation of knowledge integration in communities – principles required (bullets of the left-hand side, on the small grey background) and practice (convergent categories on the right-hand side)

In the absence of a basis of common denominators, such a constituency is a group of agents locked in a situation of Prisoner's dilemma whereby, in order to avoid being duped, it is rational for each agent to make non-cooperative choices that will yield lower individual payoffs and the lowest payoff for the group as a whole. Drawing on practical experience and literature, this paper proposes for trials in different contexts a co-work simplifier design for developing common denominators in complex endeavors, i.e., for planning collaborative work in projects and programs aiming at building resilience in local communities (Figure 2).

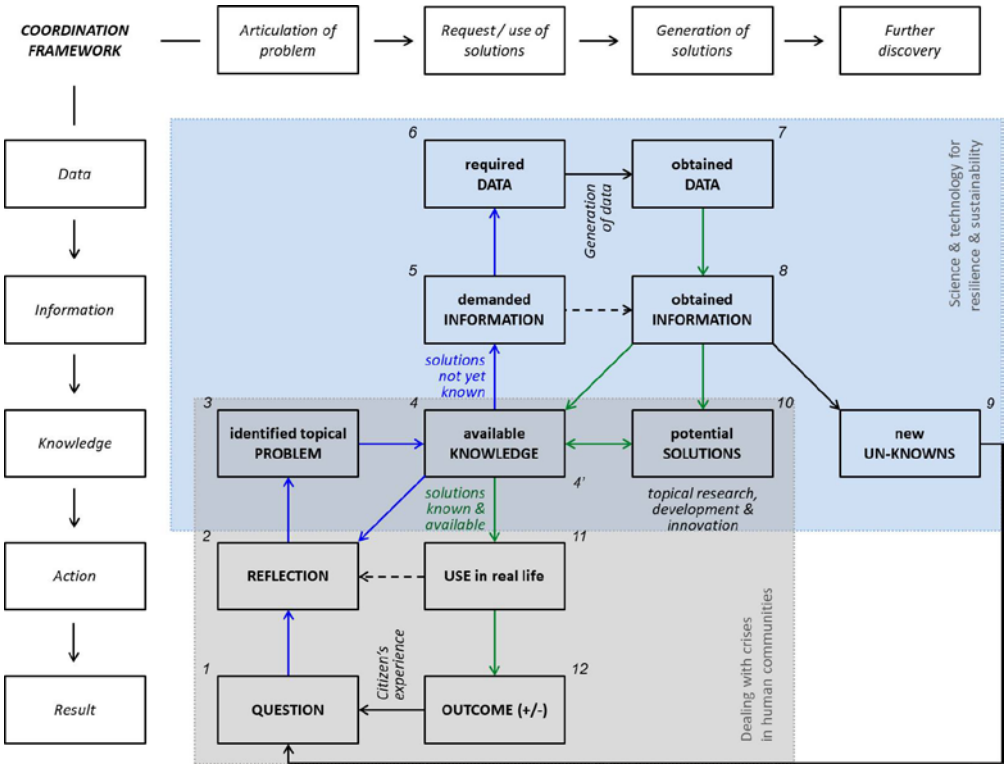

Figure 2. *DIKAR_process* matrix for structuring collaborative work in a project and between work packages for building resilience in human communities. Numbered cases show co-work steps understood as "coordination rooms". Arrow indicates the the transformations taking place between steps, e.g., interpretation of new data results in new information. Arrow colors indicate sequences aiming at Strategic data acquisition and at Outcomes respectively.

The model starts from a set of core definitions (Table 1): scientific but simple, inspired by practice and the basic principles of agent-based modeling (ABM) approaches, as applied to organization studies (e.g., Miller 2015).

Table 1. Basic (start) definitions used in the DIKAR_process model

DIKAR	Definitions	Example with urban (river) water pollution	Agent
Data	A measured or estimated value, i.e., a number *	A measured or estimated concentration of 2.5 μg l^{-1} of atrazine, a common herbicide and endocrine disruptor (i.e., it can alter the human / natural hormonal system) in a river sample (water or/and sediments).	Scientists and supervised lab personnel.
Information	A result of the scientific / professional interpretation of Data items **	Telling whether the measured concentration of the target analyte (i.e. in analytical chemistry, the targeted substance) is above / below a certain threshold. From our Data item, three Info items can result: 1. It is above 0.1 μg l^{-1} (0.1 microgram per liter), the legal threshold in the European Union (EU); 2. It is above 2.0 μg l^{-1}, the recommended threshold by the World Health Organization (WHO) 3. It is below 3.0 μg l^{-1}, the legal threshold in the United States of America (USA).	Usually scientists; depending on the context, relevant professionals.
Knowledge	The ability to 'connect the dots' in the Big Picture as described by theories and related models (i.e., every Information item is being combined and corroborated with other Information items), so as to:	(i) Identify options for action, (ii) Improve current models and theories, (iii) Renew the step of Reflection to update Problem co-definition within the agreed common set of social values, as needed, (iv) Request new Information items, or (v) Generate new Solutions. e.g., if similar loads of the analyte have been confirmed with alternative methods, in multiple samples (as described in a protocol), a studied water body <u>can</u> be identified as polluted (in the EU), not polluted (in the USA), or alarming (in countries using WHO standards). This identifies option (iii) above, then (i) per jurisdiction, e.g., (if in the EU) pursue protocol for polluted water; (if in a country using WHO standards); (if in the USA) do nothing until the next sampling as normally scheduled. If none of the five resolutions is possible, the result is a New Unknown, which in practice may (or may not) lead to a new topical Question, e.g., "Is the collected data item a result of a measurement error or signaling a one-off pollution event or a single point-source that easy to remove or a situation of diffuse pollution caused by atmospheric circulation or the effect of a decontamination treatment that diminished some previous concentrations until they arrived below the threshold of relevance in the USA?".	Those experts who are capable of generating and/or using relevant theories and models.
Action	Choices and proceedings on possible paths (i.e., scenarios and procedures)	The studied water body <u>is</u> identified as polluted (in the EU), not polluted (in the USA). This means path (iii) above <u>has been taken</u> and the Problem has been clearly identified and Knowledge has been updated. Further, a second round of action is as such: (i) per jurisdiction, e.g., (if in the EU) the protocol in place for polluted water is being applied (pursued); (if in the USA) nothing will be done until the next sampling as normally scheduled.	All entities that are undertaking action ***
Result	Any situation that is a basis for new experiences; evaluations; Questions	For example, the legal pollution thresholds at a given location / in a given country tend to correspond to up-to-date toxicological thresholds based on indicators of pollution impacts on human and/or ecosystem health. This means that the likely result of polluted water will be a number of cases of intoxications in the human population; also disturbances in the ecosystems.	All entities that are experiencing a situation; the stakeholders ****

* This means scientific data; but it can be adapted to include other types as needed, e.g., in informatics all digital records.
** The difference it makes (so it roughly corresponds to Shannon information) but it can be adapted to also include other types as needed, e.g. algorithmic information.
*** Citizens, companies, any institution pursuing their interests and obligations. Actions can be divergent or convergent, coherent or not, friendly or not, and coordinated or not. Agents have various degrees of freedom and can engage in competition, in cooperation or in both.
**** These entities may have participated or not to Action.

A basic user template is shown in Table 2. It can be extended as text, spreadsheets or/and diagrams, as needed.

Table 2. DIKAR_process user template for joint resilience-building endeavors that are bridging domains, disciplines and professions. Work steps take the form of coordination rooms, here illustrated with a would-be project and two work packages. Each complete cycle starts with a chosen topical question.

Step no.	COORDINATION ROOMS	***e.g., Would-be project: machine learning (ML) for building resilience in cities***	**e.g., WP1: building alternative paths for clean water in cities**	**e.g., WP2: developing platforms for dialogues between citizens & experts**
1	**QUESTION**	***Q1. How to use ML for catalyzing a high level of resilience in cities?***	**Q1.1. How to improve water safety, cost & accessibility?**	**Q1.2. How to improve the dialogue between experts & citizens?**
2	**REFLECTION**	*Resilience: key aspects in transitions to sustainability; urban adaptation to climate changes (Ciumasu 2013; another one, find review on resilience or/and climate).* *AI/ML multiplier effects in development of solutions*	Water management divided in separate sectors: supply, waste water, sanitation and storm water (Bach *et al*. 2014; Ntanou *et al*. 2014; Pahl-Wostl 2017) ML+ parameters can help create new, unified options.	Project co-involvement of can elicit convergence of perspectives (Van der Wal *et al.*, 2014; Clark *et al.*, 2016). Health, safety is holistic, i.e., in dealing with crisis, sectors must co-work
3	**PROBLEM** (to be co-defined by project partners)	*The risks and opportunities of ML/AI are currently not well charted, which creates all kinds of hypes and fears*	Water governance failure, lacking tools, e.g., sensor architectures for unified water quality control	Science-society co-working failure due to lacking good tools for effective experts-citizens dialogues
4	**KNOWLEDGE** (if solutions known & available, jump to step 11. Else, continue to step 5.)	*EXPERT TEAM: with rules, theories, models; thematic networks & topical clusters; non-governmental bodies; relevant industries; etc.*	SCIENCE TEAM: ecology, water, analytical chemistry, toxicology, engineering, etc., with holistic & specialized models	SOCIETY TEAM: design, business, communication, sociology, informatics, law, arts, etc., with their holistic & special interface tools
5	**NEW INFORMATION demanded** (as coordinated across WPs)	*E.g., lists of needed info items; expert parameters;* *E.g., Lists of ML tools & utilizations in real life* *E.g., Details on evolving public perception of ML*	E.g., chemical, biological, eco-toxicological tests E.g., analyte loads & related toxic effects; E.g., ML-based techniques for sampling & analysis	E.g., lists of info items about water, with risks, etc. E.g., visual demo items with science / ML methods E.g., all cultural references & the public perceptions
6	**NEW DATA demanded**	*- Lists of raw data to be generated by a protocol* *- Lists of all potential ML options on all city topics*	- Lists of raw pollution data to be generated by protocol - Lists of all issues and ML options in water analytics	- Survey on public opinion about urban water pollution - Lists of all ML options on citizen-expert interaction
7	**NEW DATA obtained**	*- Lists of data items generated as per protocol*	- Lists of data items generated as per protocol	- Lists of data items generated as per protocol
8	**NEW INFORMATION obtained**	*- Lists of all new info items obtained from all new data*	- Lists of all new info items obtained from all new data	- Lists of all new info items obtained from all new data
9	**Potential SOLUTIONS**	*E.g., city model mapping topics, ML risks & benefits*	E.g., testing new sensor architectures by water uses	E.g., online interface with options, alerts & services
10	**NEW UNKNOWNS**	*E.g., new issues & topics as resulted from works*	E.g., costs of additional tools for city-scale uses	E.g., collateral risks; costs of technological choices
4'	**KNOWLEDGE (updated)**	*E.g., constant learning; updated models & toolbox*	E.g., new models: transport -energy-land-water nexus	E.g., new dialogue models, priorities & scenarios
11	**USE in real-life** (chosen solutions)	*E.g., clearer set of options involving AI/ML*	E.g., a best tools and infrastructure designs	E.g., web tool for citizen-expert interactions; projects
12	**OUTCOME**	*E.g., risks being +/-charted, ML/AI is explored (or not)*	E.g., ML-based, city-scale water quality monitoring	E.g., ML-based/-enhanced science-society activities.
NQ 1	**NEW QUESTION** (starting a new full-cycle iteration)	E.g., What long-term roles of ML in society/cities?	E.g., What best tools for promoting science?	E.g., What impacts of ML on education?

Intended to be applicable to all types of collaboration and workflows, this basic framework explicates the Data-Information-Knowledge-Action-Result (DIKAR) frame (Venkatamaran 2002; Bytheway 2014) along a work process that is carried out by explicit agents, e.g., the participants to a project, or agents participating in broader social transitions (Miller, 2015; De Haan & Rotmans, 2018). This results in a basic, bi-dimensional matrix within which one can identify a stream of work steps, i.e., "coordination rooms" for developing and managing common denominators. In those, a set of definitions (values and knowledge) are co-defined and agreed by a group of experts (or experts and citizens; all needed participants) through a set of commonly agreed qualitative and quantitative methods that end with various forms of collective expert decisions (e.g., Ciumasu 2013, Van der Wal et al., 2014; Pahl-Wostl, 2017). These are then recorded, used in a project as such and to insure alignment and coordination between its work packages and updated when needed, as needed.

In the general model, work begins with a chosen topical question and continues with a series of steps, paths and cycles which can be tested and iterated (2-n times) until the optimal routine is found for the intended use. There is no prescript number of iterations. The model allows optimal orientation and coordination towards achieving a commonly agreed set of action protocols, i.e., sequences and cycles that can be formulated and pursued simultaneously, comparatively and iteratively, within any large, heterogeneous constituency of actors involved in building resilience in cities.

By means of iterations, the described bi-dimensional matrix can add variations. Collectively, all these variations can be understood as conferring a depth dimension to the bi-dimensional matrix described in Figure 1, making it a de facto three-dimensional lattice that is charting all paths. Depending how we classify the depth variations, the three-dimensional lattice can be also generalized as multi-dimensional lattice. Once iterations started to happen, the lattice model describes a space of options that can be explicated in the sense of implicate/explicate order of David Bohm (2002), i.e., it can unfold to display practical details, so as to reflect priorities and any specific demand, e.g., as spreadsheets. The confirmed space of options growths with any variation of criteria or types (definitions) of data (e.g., various types of scientific data, informatics data) or/and types of information (e.g., Shannon's or/and algorithmic).

DISCUSSION

Essentially, DIKAR_process, it is a lattice model of the type used in both natural and social sciences to make realistic approximations of various processes and various interactions between agents, and between agents (or groups of agents) and their environment. In terms of potential applications, DIKAR_process is a basic, start design for planning work and managing complexity in heterogeneous constituencies. This general model gives a large team constant visibility on the whole project: what matters, status of the project and status of the work packages, at any moment in time; how they got there (logical or/and process, ontological description), why, and what are the next coherent steps that are possible between the applied topical question (which is normally formulated holistically, as reflecting real-life concerns) and the detailed requirements of the technology and the protocol employed in data generation. For these reasons, the model is suitable for strategic data acquisition, as well as data-based scenario building, during the preparation phases of crisis management.

Urban resilience requires the development of common denominators (a) between different types of actors and (b) between professionals from different disciplines having different meanings for different notions. By preventing the development of common denominators, social dilemmas like the Prisoner's dilemma undermine resilience building. DIKAR process helps solve such dilemma, thence it helps build the fundaments for co-development of a common understanding, which is a necessary condition for further development of scenarios and tools that can be used in situations of crisis. More often typically recognized, endeavors of human collaboration, notable those toward responses to crises and in general for the transition of cities to sustainability, are hampered by the fact that partners presume they mean the same thing when using a key term while in fact they assign different meanings that may overlap a bit or not at all; and they discover the mismatch later, often when it is too late, which results in very significant losses of project resources, of assets intended to protect or of both. The common understanding and common denominators in terms of notions, methods and tools must be developed before crises strike, as part of preparation of options for response.

The general model applies for all types of projects, with any question, it is adaptable to any context, and can be used with tools (software and hardware) of choice. This makes it useful for scaling-up collaboration in organizations of any size. This also allows optimization of planning and work processes at separate phases, e.g. during preparation, implementation and evaluation.

This paper is meant to be a concise introduction to the concept that will be further developed in a stream of subsequent papers. As key observation, there is a great deal of confusion in the literature on what constitutes Knowledge, Information and Data, and the terms are often used interchangeably or/and with different meanings

in different disciplines or contexts. The idea of the model presented here is to start with a simple set of definitions that allow clear distinctions (and relations) between the three, and then adapt the definitions as needed in different context, provided – and this is a fundamental condition – that those definitions are negotiated and agreed by the participants to that particular project. As they have to start with something, the paper hereby can serve as starting platform if they choose so.

In brief, Knowledge ultimately means people - with their capacity to connect the dots using theories and models. For example, sustainability is now understood systemically. According to this, any economic system is a subsystem of a social system, itself a sub-system of a natural system (Giddings et al., 2002; Gowdy & Erickson, 2005). This nested inclusion relationship can be made operational in terms of sustainability filters that can be used to plan or assess risk management projects (Ciumasu et al., 2012), each filter being a list of items, as indicated in the user template (Table 2). There is no true resilience outside sustainability or a human community, but this means an amount of complexity that is overwhelming and this usually results in nothing significantly being done until crisis strikes. The DIKAR_process framework is a holistic model that can play the role of start platform for meaningful and fruitful collaborations in projects organized as clusters or networks (or both) and covering all disciplines and professions. To take the example of water, there is a need for large programs in water research, and partnerships with other societal actors; a need for more knowledge-to-action work in water under climate changes (Pahl-Wostl et al., 2013). A combination of structural and non-structural measures can be very effective in reducing flood risks, but they depend on socio-economic aspects and governance arrangements which requires participation of many stakeholders, e.g., building resilience by combining flood-related measures with land use, insurance and urban revitalization projects, e.g., with Rotterdam in the Rhine-Meuse-Scheldt delta (De Graaf & Van der Brugge, 2010) and London in the Thames estuary (Dawson et al., 2011).

In context, the model seeks to help articulate efforts to develop new roles of science in society and to help interaction between science and society, notably in the largely uncharted space that is widening between current scientific and technological advances and new societal needs (Lubchenco 1998; Scholz 2017). Progress follows big societal questions. For instance, the so-called "artificial intelligence" (AI) is omnipresent in major technology forecasts by Gardner, Deloitte, Accenture or governmental agencies. In terms of impacts in society, AI compares with electricity a century ago or steam engines three centuries ago, and is expected to generate transformations that equal a new industrial revolution. There are catchy but largely misleading commercial metaphors like "Data is the new oil" (The Economist, 2017) which are wrongly painting Data (rather digital records, not necessarily scientific data) as a commodity. In fact, useful data is a limited product, as generated through purposeful efforts under pre-defined requirements, e.g., as outlined in Fig. 2 with blue (ascending) arrows. Also, AI still only involves a small number of data types: the digital records that are being used for a narrow set of task automations that are currently feasible. But the role of data in science and society is quite broader.

By anchoring itself in all science, AI could widen its relevance and deepen its potential beyond this initial hypes and distrust, and achieve a more balanced discussion between qualitative and quantitative aspects. This can provide useful avenues for discussions about the connections between smart cities, urban metabolism models and sustainable cities / eco-cities (Ciumasu, 2013; Ntanou et al., 2014), and how AI can play a catalytic role in managing risks, crises and transitions in human communities. AI has the potential to have transformative impacts – provided that it manages to anchor itself in the whole of science. AI-aided holistic models can enable solutions to problems that have been impossible or excessively hard to address. One such example is the common-pool resources (CPR) dilemmas, also known as 'tragedy of the commons', that is, long-term collective destructions of shared natural resources (e.g., air, water, ecosystems) or products of civilization (e.g., common urban spaces and infrastructure) by self-interested short-term exploitations. DIKAR_process combined with AI can help partners in complex contexts and endeavors engage with each other in spite of the complexity of the situations (which usually pushes toward non-cooperative choice in the prisoner's dilemma). This model, when applied, can help participants understand each other and develop a common understanding and representation (mental model) of their shared resource, and how it evolves and operates, so as to distill optimal rules and to sustain reciprocity in a community of users (Ostrom et al., 1999; see also Pahl-Wostl, 2007). Often such overexploitations of ecosystems lead to disequilibria, and ultimately disasters (Gurjar et al., 2006). The main advantage of the general model is that it allows clear formulation (and therefore automation) of routine searches (of solutions) and activities. This can bring down coordination costs and thus free resources for qualitative interaction. This can make possible solutions to the tragedy of the commons type of situations which otherwise would not be possible due to overwhelming complexity and resource-intensity of coordination (making self-interested decisions more economically logical). This increased capacity to cooperate is what allows building solutions and paths and protocols into human and technological systems.

The paper hereby provides a structured state-of-the art review and a synthetic model for the managers of contributions to complex projects aiming at solving current problems (Ahern et al., 2014) and/or increasing

urban resilience (Godschalk, 2003; Meerow et al., 2016) as component of the wider urban sustainability (e.g., Alberti & Marzluff, 2004; Ernstson et al., 2010; Ciumasu, 2013; Sellberg & Wilkinson, 2015; Meerow & Newell, 2016; Eakin et al., 2017). In-depth modeling and testing would go beyond the scope and space limitations of this paper but will be presented in further oral and written communications, using order theory (e.g., Monjardet 2003; Fu et al., 2010), category theory (e.g., Philips & Wilson 2010; Tsuchiya et al., 2016) and graph theory (e.g., Otte & Rousseau, 2002; Stell, 2014), Agent-Based Modeling (ABM) and the related Multi-Agent Systems (MAS) (Miller, 2015; Bloembergen et al., 2015). In brief, the DIKAR_process model is the core of a strongly connected direct graph (e.g., Otte and Rousseau, 2002) whereby a set of vertices (nodes; categories) are connected by directed edges (morphisms; transformations) that have a direction (arrows), so that every vertex (category) is reachable from every other vertex. It allows the formulation as steps, sequences of steps and loops that describe all possible interactions inside a group of agents. The model is issued from the synthetic formalization of the feedbacks from all the partners of Econoving project (a university-industry-government cluster) hosted at the University of Versailles (2008-2013) and focused on eco-innovation (i.e., innovation for sustainability, meaning it integrates environmental, social and economic aspects) and is currently used in the project ACE-ICSEN, a trans-disciplinary university cluster at the University Paris Saclay. The User Template (Table 2) was made at the request of the participants and managers of the ACE-ICSEN project, as part of the Author's role in the work package focused on trans-disciplinary integration of different thematic modules focused on cities, climate changes and health.

In practice, DIKAR_process is complementary to other models and approaches, e.g., problem structuring (Scholz et al., 2009; Ciumasu et al. 2012); comparisons of mental models to monitor shared understanding of a problem (Scholz et al, 2014); issue mapping (Cronin et al 2014); measures of social learning by different actors (Van der Wal, 2014); Delphi-based streamlining of priorities into scenarios (Ciumasu, 2013); technological revolutions and new techno-economic paradigms (Perez 2010). In addition, DIKAR_process is focused on coordination for systematic and consistent production of common denominators as a precondition for further success with methods such as those mentioned above. As illustrated in Table 2, negotiation rooms can host an unlimited range of views. Dealing with disagreements in various contexts is a theme *per se*. Because of the wide differences in terminology and methodologies, one cannot realistically hope to bridge semantic differences quickly. Instead, discussions should use available methods and aim at reaching collective expert decision; e.g., Delphi-based methods (Ciumasu, 2013), whereby views are collected and debated in rounds, until a common understanding is reached through informed voting resulting in an aggregated decision. This does not force a perfect common theory conciliating theories or/and preferences but to identify what is best "what to do next" as accepted by all participants, e.g., be it a definition, a list of priorities or/and scenarios. Another approach uses measures of social learning (Wal et al., 2014), whereby participants' world views (e.g., hierarchist, individualist and egalitarian) converge or diverge during a project.

Taking into account these examples and the rest of the literature, the paper is also an invitation to use the template and provide feedbacks about its applicability.

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Analyzing Cascading Effects among Critical Infrastructures: The CERBERUS Approach

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ABSTRACT

In this article, we present a novel approach, which allows not only to identify potential cascading effects within a network of interrelated critical infrastructures but also supports the assessment of these cascading effects. Based on percolation theory and Markov chains, our method models the interdependencies among various infrastructures and evaluates the possible consequences if an infrastructure has to reduce its capacity or is failing completely, by simulating the effects over time. Additionally, our approach is designed to take the intrinsic uncertainty into account, which resides in the description of potential consequences a failing critical infrastructure might cause, by using probabilistic state transitions. In this way, not only the critical infrastructure's risk and security managers are able to evaluate the consequences of an incident anywhere in the network but also the emergency services can use this information to improve their operation in case of a crisis and anticipate potential trouble spots.

Keywords

Cascading effects, interdependent critical infrastructures, Markov chains, simulation.

INTRODUCTION

Critical infrastructures are assets or systems (or parts thereof) which are essential for the maintenance of vital societal functions. Any failure of a critical infrastructure, either in part or as a whole, will have considerable impact not only on the infrastructure itself but also on the social well-being of people (European Commission 2008). Therefore, critical infrastructures are of significant importance for the maintenance of key processes in society such as the supply of essential goods and services. Such critical infrastructures can be found in different areas, including the basic supply chain networks (electricity, gas, water) as well as information and communication (ICT) networks and ranging to complex systems with severe social impact when not working properly, such as medical care or transportation networks.

In the last decade, critical infrastructures became more and more interconnected with each other, resulting in a highly complex and sensitive network with a variety of interdependencies. Not only do many infrastructures depend on the resources other infrastructures provide but they also exchange a vast amount of information or use each other's services. Thus, incidents within one critical infrastructure can have far-reaching consequences, affecting multiple other infrastructures as well as society as a whole. For example, the disruption of the electric power supply in California in 2001 affected several other critical infrastructures, like the production of oil and natural gas as well as the transportation of gasoline through pipelines (Fletcher 2001). In 2003, a major electricity blackout in Italy lasting for twelve hours resulted in a financial damage in the order of 1182 million Euros (Schmidthaler and Reichl 2014). Furthermore, the hacking of the Ukrainian power grid in 2015 and 2016 (E-ISAC 2016; Condliffe 2016) and the resulting outages for large parts of the country underline that the increased interrelation between communication and operational networks can have severe consequences. Hence, identifying, analyzing and assessing the possible cascading effects that might stem from such incidents has become a core duty in critical infrastructures' risk and resilience management.

In this contribution, we present a novel approach for identifying and assessing potential cascading effects within a network of interrelated critical infrastructures. Our method applies concepts from the fields of percolation theory and Markov chains to describe the interdependencies among various infrastructures. Hence, if an infrastructure has to reduce its capacity or is failing completely, these concepts facilitate the evaluation of the possible consequences by simulating the effects over time. Furthermore, our approach uses probabilistic state transitions to account for the intrinsic uncertainty and randomness which resides in the description of potential consequences a failing critical infrastructure might cause. In this way, not only the critical infrastructure operator's risk and security managers are able to estimate the possible consequences of an incident anywhere in the network but also the emergency services can use this information to improve their operation in case of a crisis and anticipate potential trouble spots.

The approach we present here has been developed in the research project CERBERUS (Cross Sectoral Risk Management for Object Protection of Critical Infrastructures) funded by the Austrian Research Promotion Agency (FFG) and therefore is referred to as CERBERUS approach. The main idea behind this project is to collect and represent security-relevant information of critical infrastructures with a core focus on the interdependencies among them. This information is integrated into a risk model, which specifically considers the propagation of threats in as well as their cascading effects on the network of critical infrastructures. Since two public agencies (i.e., the Ministry of the Interior and the Ministry of Defense) are directly involved in the project, one major goal is to establish an appropriate protection level for critical infrastructures from the federal perspective and to apply novel theoretical models for risk management to ensure the infrastructure objects' security.

The remainder of the article is structured as follows: in the subsequent section, we will give a short overview on current research activities related to our methodology. Then, we will provide a detailed overview on the CERBERUS approach, indicating how we build up to our model, how we describe stochastic interdependencies and how we simulate cascading effects. Afterwards, we illustrate the integration of the approach into the larger CERBERUS system and discuss the benefits and limitations of this system, concluding with some final remarks.

RELATED WORK

Dependencies between interacting critical infrastructures (CIs) or parts thereof can be manifold and have been extensively studied in recent years. Hence, various approaches to categorize these dependencies can be found in the literature (cf. (Rinaldi et al. 2001; Dudenhoeffer et al. 2006a; b; Pederson et al. 2006; US Government 1996)). There are basically five distinct categories which have been suggested in the above approaches, covering physical, informational, geospatial, procedural and societal dependencies (Rinaldi et al. 2001; Dudenhoeffer et al. 2006a; b). These categories can help to better understand the interplay between the infrastructures, e.g., by visualizing them using an interdependency graph, and support the assessment of the likelihood for an incident to affect related infrastructures. However, in real-life scenarios the dependencies are much more complex and the definition of these categories as provided in the literature is often too generic to be directly applied in practice.

Therefore, more sophisticated approaches to categorize and describe the interrelations between CIs are the Hierarchical Holographic Model (HHMs), the Input-output Interoperability Model (IIM) as well as the Hierarchical Coordinated Bayesian Model (HCBM) (cf. (Haimes et al. 2007) for further details on these models). In this context, the HHM (Haimes 1981) provides a taxonomy, which describes the various possible interdependencies between CIs in further detail than, for example, given in (Rinaldi et al. 2001). This allows to get a more precise and properly defined notion of the existing interdependencies. IIM (Haimes and Pu 2001; Santos and Haimes 2004; Setola and Porcellinis 2009) also provides a detailed view on the interdependencies between CIs (or, more generally, economy sectors) and describes the effects of incidents based on linear equations. However, it is strongly focused on economic aspects, which might not always be the appropriate context when looking at CIs. Rather, extreme events of low likelihood but with a severe impact are of particular interest but, in general, only sparse data is available on such events. Therefore, HCBMs (Yan et al. 2006) allow to combine data on extreme events coming from multiple sources to enhance the accuracy and variance when estimating the consequences.

Interdependency graphs are also frequently used as a basis for methodologies simulating (and also forecasting) the propagation of failures and describing cascading effects. A first approach in this direction was the Cross Impact Analysis (CIA) introduced in (Gordon and Hayward 1968) with an alternative approach described in (Turoff 1971). The CIA allows to describe how the relations between events would affect resulting events in the future. An extension to CIA, called CIA-ISM (Cross Impact Analysis and Interpretative Structural Model) (Bañuls and Turoff 2011), is extensively used in emergency management to analyze the interaction between critical events and obtain a reasonable view on potential future consequences (for a more detailed review on CIA and CIA-ISM for cascading effects, we refer to (Turoff et al. 2016) and the references cited therein).

Another effective way to model (sometimes unknown) dynamics and relations between events, stochastic processes can be applied. By using randomness, these models can account for the intrinsic randomness and uncertainty, which resides in the relations and the interplay between critical infrastructures. A prominent example for this is percolation theory, a methodology commonly used for the analysis of epidemics spreading (Sander et al. 2002; Newman 2002; Kenah and Robins 2007; Salathé and Jones 2010) but only rarely used in the fields of security and risk management so far. For example, an extension of percolation theory has been applied in (König et al. 2016) to model the propagation of malware spreading within a utility provider's network. Additionally, techniques based on Bayesian networks are also used to describe interdependencies between critical infrastructures, as, for example, described in (Schaberreiter et al. 2013). In a more general approach, Interdependent Markov Chains (IDMCs) are used to describe the propagation of cascading effects within an infrastructure (Wang et al. 2012; Rahnamay-Naeini et al. 2014; Rahnamay-Naeini and Hayat 2016). Initially, IDMCs have been applied in the energy sector to describe the system's dynamics in order to analyze overload scenarios and to consider the probability for a blackout (Wang et al. 2012; Rahnamay-Naeini et al. 2014). This work has been further extended to be applied between critical infrastructures as well (Rahnamay-Naeini and Hayat 2016). However, Bayesian models as well as Markov chains are more challenging to apply compared to percolation theory due to the huge amount of data required for analyzing the system and understanding the interplay. Further, the effects of random failures on critical infrastructures can be described with multi-graph models (Svendsen and Wolthusen 2007) or models that take into account higher order dependencies (Kotzanikolaou et al. 2013; Theoharidou et al. 2011).

CERBERUS APPROACH

Defining the Model

A crucial requirement for modelling interdependencies between any type of objects or components is the amount of available information about the dynamics of the overall system. In some domains like the energy sector, the dynamics of specific systems are well known and accurate physical models are available that allow an analytic estimate of the effects implied by an incident. Applying such models, the effects of a short power outage or temporary peak loads on other components can be modeled precisely. On the opposite end of the spectrum lie complex technical or social systems. In these systems, various individual objects or components are interacting with each other based on relations that are not fully known and each system reacts differently on incidents. In this context, the underlying dynamics are typically too complex to admit a concise mathematical description. When trying to understand these systems, we can only rely on observations or historical data to learn the behavior of the system. In case a lot of observations are at hand, Bayesian networks can be used to model the system; otherwise if only scarce data is available, percolation theory can be applied (cf. also Figure 1 below). Given the description of a specific system (either based on observations or the knowledge about internal dynamics), the evolution of the system in the future can then be illustrated using simulations.

The network of interdependent CIs ranks among the second area: although the dependencies might be known or can be described, the details of the dynamics (i.e., how an infrastructure reacts to an incident within another infrastructure) cannot be specified in full detail. Hence, the CERBERUS model lies "in between" the two extreme characteristics of perfectly known dynamics, where the system's behavior can be described by a deterministic flow chart, and entirely stochastic behavior, where effects are captured by conditional probability distributions, e.g., a Bayesian network. The CERBERUS model – as visualized in Figure 1 – unifies the two positions by sacrificing parts of the expressiveness of both models for the sake of a model that can simulate both a deterministic and stochastic behavior (at least in restricted form), is easy and efficient to parameterize, and is fast to simulate.

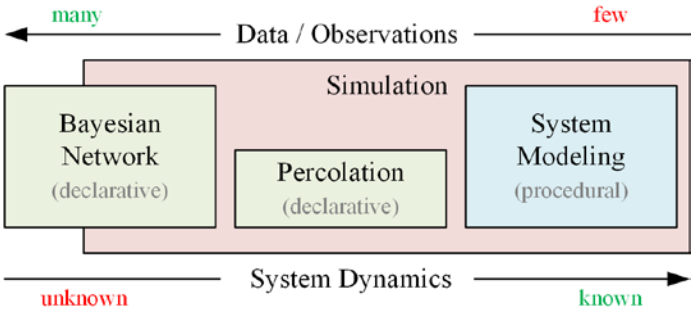

Figure 1. Illustration of the tradeoff between different approaches to model the network of interdependent CIs

Describing Stochastic Interdependencies

The CERBERUS model describes each CI as a node in a directed graph, where the edges indicate the dependencies between these CIs (and in this way adapting the idea of an interdependency graph). In this graph, an edge from CI *X* to CI *Y* indicates that CI *Y* depends on an input from CI *X* to work properly (cf. Figure 2 below). In other words, CI *X* is a "supplier" for CI *Y* (or CI *Y* is a "customer" of CI *X*). Although this representation illustrates the general interdependencies between a certain number of CIs (e.g., the infrastructures located within a specific region or province), it does not provide any detailed information on how much the individual infrastructures influence each other.

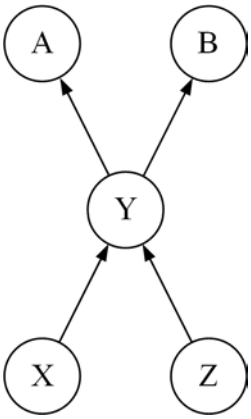

Figure 2. Simple example of a CI interdependency graph

In general, an impairment in the functionality of CI *X* could have a small or large effect on the operational state of CI *Y*, depending on how dependent CI *Y* is on the resource or service provided by CI *X*. Hence, in the CERBERUS model each CI is described by a finite number of different states *k* representing its operational condition. This operational state of an CI may or may not change according to the operational states of its suppliers, based on the individual interdependencies between them. In order to model this state change, each edge between two CIs is extended by a multinomial distributed random variable (König and Rass 2017). This variable then describes the probability that the CI *Y* goes from state k_i to k_j based on the current state of its supplier CI *X*. We assume that all CIs are in one of the *k* states so the change of state of CI Y due to the current state of CI X can be understood as a (generalized) Markov chain, similarly to the approach described in (Rahnamay-Naeini and Hayat 2016) and others (see related work above). As a visual representation, these states can be illustrated using different colors (e.g., ranging from green to red) to reflect the severity of each state, as shown in Figure 3.

Giving a simplified example, we assume that both CI *X* and CI *Y* can be in one of five different states of operation. These states range from "1" describing the normal operation up to "5" describing a complete failure of the infrastructure. Further, the probability of CI *Y* switching from one state to another is given by the state *k* its supplier CI *X* is currently in. Hence, if CI *X* notifies CI *Y* about an impairment in its operation (e.g., CI *X* switches to state "3", corresponding to medium troubles with its service provisioning), CI *Y* switches from state "1" to a state of reduced operation with a certain probability as a reaction to CI *X*'s current condition.

Furthermore, if multiple suppliers notify about their states, a CI may internally undergo transitions into multiple states at the same time. Though paradoxical at first glance, this may indeed happen in reality: if several suppliers report problems or shortages, a CI may encounter multiple issues at the same time. For example, in case a power outage is the main problem, this can imply a shortage of water supply due to pump failures as a secondary (implied) problem later on. A CI depending on both power and water supply will be affected by both incidents. According to the *maximum principle*, such different conditions may be aggregated into the most severe condition for the CI to determine the overall operational state of the CI. That is, if a CI has multiple problems of different severity, its overall operational state is determined by the most severe incident that it currently has to deal with, shown in Figure 3.

Simulating Cascading Effects

One possibility to simulate the CERBERUS model is to use a discrete event-driven system like OMNeT++. This allows to implement the information flow between nodes in a straightforward manner and to reflect a wide range of different dynamics in the CERBERUS model, with the most important being:

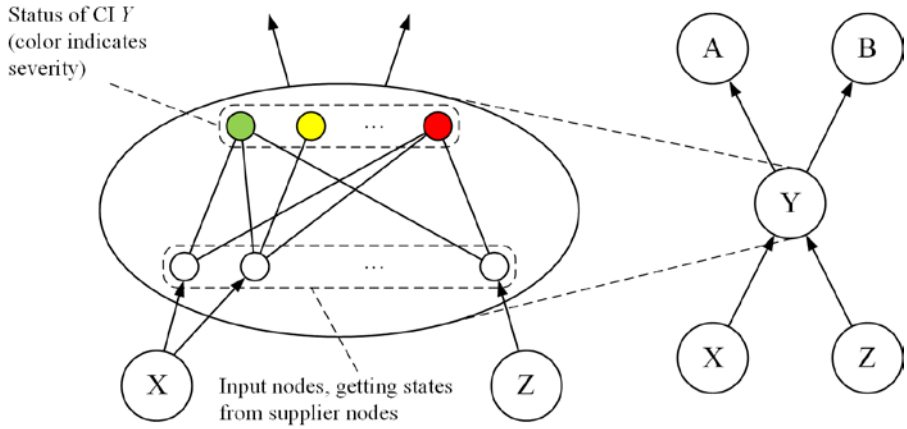

Figure 3. Illustration of the CERBERUS Model (König and Rass 2017)

- *Deterministic effects*: if CI *Y* functionally depends on CI *X*, then the chances for CI *Y* to switch to a problematic state can be set to 1, implying that whenever *X* has a problem, *Y* will have a problem, too (for sure).
- *Random effects*: an incident affecting CI *X* may not immediately trigger a problem for CI *Y*, but only do so with a certain likelihood (as in the case of stochastic models like Bayesian networks) or after a specified period of time. In this way, the model accounts for the intrinsic uncertainty which resides in the interplay between the respective CIs

The number of parameters to be specified in this kind of model is quadratic in the number of states, since the transitions between any two distinct operational states specified in the model need to be specified. For example, for $k = 3$ operational states ("OK" / "problems" / "outage"), a total number of four transitions have to be defined, typically specified in matrix form (cf. Table 1 for an example).

state of supplier *X*↓ \ follow-up state of CI *Y*→	**OK**	**Problems**	**Outage**
OK	1	0	0
Problems	0	0.33	0.33
Outage	0	0.01	0.66

Table 1. Example for a transition matrix in the CERBERUS model

The simulation starts with a specific incident (selected by the user), which affects a certain set of CIs. The CIs depending on them switch from their initial state "OK" to a problem state with a certain probability specified in the *transition matrix* for the respective edge in the dependency graph (cf. Table 1). Further, the transition is specified for three time periods; "short-term", "medium-term" and "long-term". Their meaning can be defined individually for each CI, since the timeframe considered as "short-term" is different for a power provider than for a food provider. Hence, the values of the transition matrix are related to the severity of the dependency between CIs X and Y and the duration of a problem/outage. Additionally, redundancies like emergency power generators or other contingency measures can also be directly modeled in the simulation.

The CERBERUS model can also cope with time-dependent effects, i.e., if a CI can cover short-term outages of a supplier but will eventually stop working itself if the supplier does not continue its service within a certain period of time. In this case, each transition in the matrix above can be made time-dependent, i.e., the probability to switch from "OK" to "Problems" is zero for CI *Y* between $t = 0$ and $t < T_0$, where T_0 is the time window that can be covered from backup resources at CI *X*. After that time, CI *Y* will either require CI *X*'s service or it will itself run into problems. In the above matrix, the transition probability for "OK → Problems" can then be set to $p_{\text{OK}\to\text{Problems}}(t) = 0$ for $0 \le t < T_0$ and $p_{\text{OK}\to\text{Problems}}(t) = 1$ for $t \ge T_0$.

Figure 4 displays the simulation frontend, showing the interdependency graph in the right area of the window in

a simplified form. The configuration of the simulation, specifically the setting and fine-tuning of the transition matrix, is done in the left part of the window, showing some switches and controls to trigger incidents or recoveries at the desired instants of time. The aforementioned transition matrix is highlighted in different colors, using yellow for transitions within short terms, orange for medium term transitions and red for transitions in the long(er) run. Upon starting the simulation, a script is compiled and sent to OMNeT++ simulation backend.

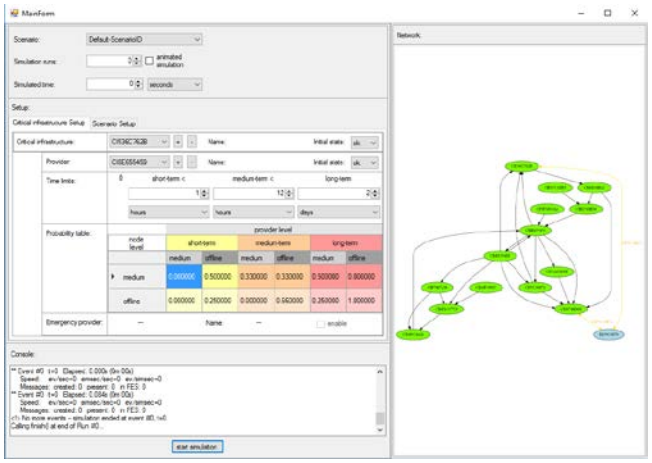

Figure 4 Screenshot of the Simulation Configuration Frontend

CERBERUS SYSTEM OVERVIEW

Our approach to model and simulate cascading effects described in the previous section represents the core of the CERBERUS system (cf. Figure 5 below) developed in the research project of the same name. The approach is the basis for the Dynamic Risk Analysis component as well as the Simulation component of the proposed system, which are illustrated on the right-hand side of Figure 5.

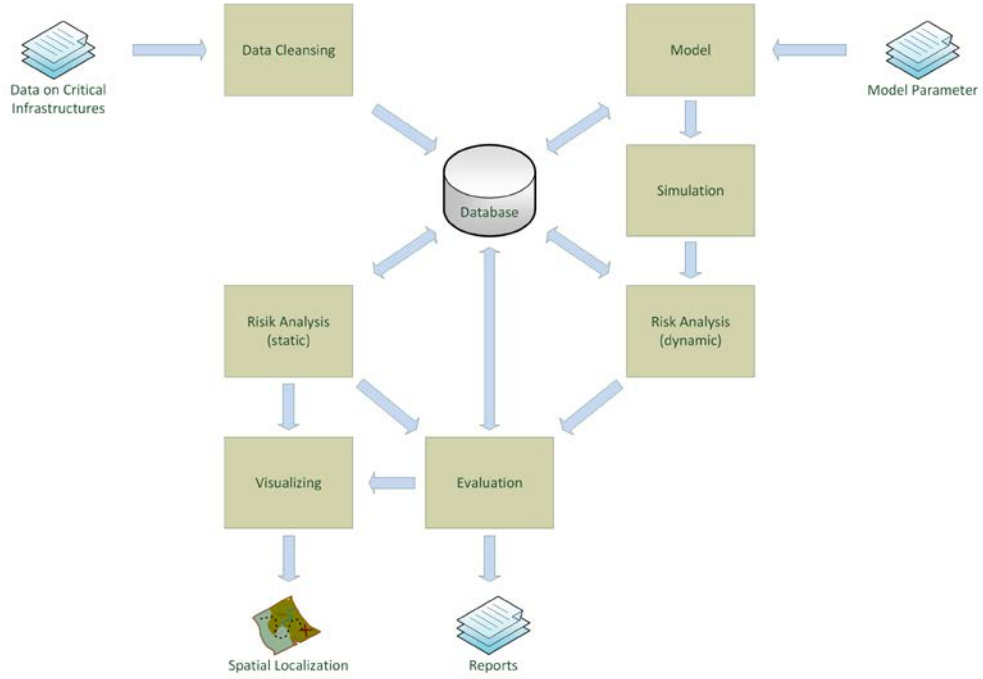

Figure 5. Schematic illustration of the CERBERUS system architecture

More precisely, the CERBEURS system builds upon information about the CIs coming from existing data gathered by the user. In the CERBERUS project, this is done by governmental bodies (cf. the next section for details), which are in close contact to the CIs and support them on security-related issues. This data includes general information on the infrastructures, e.g., its location, responsible contact persons, etc., as well as details on the security measures implemented by the infrastructure, if available. Additionally, for each CI a list of suppliers and customers is given as defined in the CERBERUS model (cf. also Figure 2 above).

Besides the data on the CIs, the parameters of the model have to be defined, e.g., the number of different operational states or how they are visualized. Based on this information, the CERBERUS model is instantiated in the Model component using the collected data on the CIs. Further, the interdependency graph of all infrastructures is created, representing each CI as a node with several "suppliers" and "customers" (as given in the collected data), and the predefined number of operational states, as well as the transition probabilities for each supplier that affects a customer. The graph is then passed on to the Simulation component, where the cascading effects of a specific incident (specified in a scenario) happening at one infrastructure (causing it to reduce its operation or fail completely according to the model) are simulated and assessed. The evolution of the overall interdependency graph, i.e., the state transition of all CIs, throughout the simulation are stored and passed on to the Dynamic Risk Analysis component. Therein, the information is evaluated, inspecting how often a CI is affected by an incident, which operational state it will be in on average and which will be the most severe operational state due to an incident. The results are used on the one hand to form the dynamic risk level but are further used to make estimations about the resilience level of each infrastructure. As mentioned above, the Simulation component together with the Dynamic Risk Analysis represent the dynamic risk model of the CERBERUS system.

Along with the dynamic risk model, the CERBERUS system also evaluates a static risk model, implemented in the Static Risk Analysis component (illustrated on the left-hand side of Figure 5). The static risk model mainly builds upon information related to the security measures which are put into action in each CI. In detail, best practice guidelines on security like the ISO 27001 (International Organization for Standardization 2013a), ISO 27002 (International Organization for Standardization 2013b), the German IT Baseline Security (Bundesamt für Sicherheit in der Informationstechnik 2016) or others defined a catalog of security measures, which should be implemented to be prepared against specific threats. Although CIs are, in general, aware of these frameworks and implement many of the suggested security measures, it is not possible to do so for all of them. Hence, the static risk level for the CI is computed based on the resulting gap.

As it is shown at the bottom of Figure 5, the CERBERUS system aims at providing different outputs to the user: on the one hand, reports are combining the information coming from the static and the dynamic risk analysis. These reports will be prepared to fit the needs of different addressees, for example, technical experts, crisis response teams or managers. On the other hand, a visualization component supports a geospatial overview on the potential effects of a specific incident. Since the GPS information for all CIs is at hand, they can be located in a GIS tool and the infrastructures affected by an incident can be highlighted according to their current state throughout the simulation. Therefore, the users of the system will obtain all the available information for an overview on the potential cascading effects of an incident, which will support them in making the right decision to counter these effects.

APPLICATIONS AND LIMITATIONS OF THE CERBERUS SYSTEM

Outputs

The CERBERUS approach aims at studying resilience of a system of interdependent CIs against externally triggered incidents. This assumes that every CI can handle internal incidents as part of the daily business, hence these events are not modeled or discussed here further. First and foremost, the CERBERUS system (implementing the CERBERUS approach) provides a detailed overview on the dependencies between the considered CIs in the form of the interdependency graph. This graph is built from the relations between individual infrastructures, which links all the infrastructures together based on their suppliers and customers, as described above. The simulation component of the CERBERUS system uses this graph to discover cascading effects that an incident occurring at one infrastructure can have on downstream (dependent) infrastructures and the whole network as such. In this way, the CERBERUS approach extends the direct dependencies among CIs (visible in the interdependency graph) by making indirect dependencies of higher-order visible, i.e., indicating how dependent a CI is on the seamless operation of the suppliers of its suppliers (and so forth).

Furthermore, the data retrieved from the static and the dynamic risk model are combined and integrated into a general risk level for each infrastructure. This risk level is essentially the CI's expected "robustness" (cf. Figure 3) in the light of different incidents. This value is averaged from multiple simulations, based on the various security measures that an infrastructure has implemented to prevent specific threats and on its interdependence with other infrastructures. In other words, the more security measures a CI has implemented, the lower its risk level will be, meaning an expectedly better operational status. In addition to the risk level, a resilience level is defined based on this degree of dependence of one infrastructure upon others. More precisely, the less affected an infrastructure is by a failure of one of its suppliers, e.g., due to redundancy, the higher is its resilience level. Essentially, the resilience level is computed in a similar way compared to the risk level, but the

underlying hypothesis between the two levels is different: risk levels are conditional expectations in light of certain incidents. Resilience is the respective unconditionally expected operational status. Both, the risk level and the resilience level are designed on abstract qualitative scales, e.g., ranging from “low” to “high” or from “1” to “5”. The scales and the different levels can be defined by the user and thus are fully tailored to his or her needs.

Finally, all output information can be used to increase the preparedness of each individual CI but also of the emergency response teams, which should assist the infrastructures in case of an incident. In detail, if a CI’s risk or resilience level is above a certain threshold this indicates that the infrastructure needs to implement additional security measures to be better prepared for an emergency. The risk and resilience level, together with customized simulations, also indicate which infrastructures might need special attention in case of a specific incident happening somewhere in the network. This information can later be used to optimize the preparation and operation of emergency response teams.

Application Fields

We foresee two different fields of application for the CERBERUS system. On the one hand, the system is designed to be used by governmental bodies, which have an overview on the different types of CIs in a specific region (e.g., a city, county or province). The assumption is that the governmental body either has explicit information about the interdependencies between the CIs already at hand, e.g. from previous studies, or gets in contact with experts from the CIs to obtain the relevant information. If this information can be used as an input, the CERBERUS system can model an incident and simulate its consequences for the CI network. The resulting risk and resilience level identify current weak spots among the infrastructures, e.g., if a specific CI encounters severe problems in many simulations due to its dependencies on other CIs, the governmental body might approach the CI operator suggesting additional security measures to be implemented.

Furthermore, the results from the simulations also support the governmental body in optimizing the preparation and operation of emergency response teams in disaster management. Simulated scenarios may help allocating resources and setting up emergency plans. The CERBERUS system allows to identify which CIs might need special assistance by providing an overview on the potential effects of an incident on the overall CI network. Hence, emergency response teams plan their support actions (i.e., where to send their people first) by learning from the simulation results. Moreover, simulations can be automatically generated from the infrastructure model, e.g., simply by iterating over all combinationally possible outage scenarios. In this way, conceivable but yet unknown worst-case scenarios can be identified and the existing disaster management plans can be adapted and extended based on these simulation results.

On the other hand, the CERBERUS system can also be applied by the operators of large CIs, which want to get an overview on the interrelations between different parts of their organization (e.g., subsidiaries, production lines, internal services, etc.) and on the dependencies on their suppliers. In this context, more details on the internal processes, system dynamics and the resulting dependencies will be available, providing much more data for the CERBERUS model. Accordingly, the simulations can be more fine-grained, e.g., with a higher number of operational states. Here again, the results coming out of the CERBERUS system can be used to identify weak spots, indicating crucial processes and services within the CI.

We stress that in both cases the human factor can be modeled quite explicitly with the CERBERUS approach, since human actors with strong influence on certain parts of the system can simply be assigned their own node in the interdependency graph. It is conceptually no problem to treat a human entity as a CI on its own, on which other parts of the system depend (e.g., requiring the person’s skills) and who itself depends on other systems (e.g., information sources, telecommunication, etc.). Incidents influencing a human actor would then primarily relate to social engineering (externally triggered incidents), treating human failure as an internal incident whose treatment is (or should be) part of the internal risk management maintained by a CI.

Limitations

Since the CERBERUS approach is designed towards a tradeoff between flexibility (expressive power) and usability (simple to parameterize), it is necessarily a compromise between different models and as such limited, relative to other models (as shown in Figure 1). The approach is very much data driven, requiring detailed information on the individual CIs and on the interdependencies between them as well as on the consequences of certain events (cf. Figure 5 and the description of the CERBERUS system above). Furthermore, the probability matrix describing the state transitions for a CI also needs to be estimated, which can be a lengthy and complex process.

All the required information usually has to be gathered from experts within the CI. Due to the sensitivity of this

information, the CI operators might be particularly reluctant to provide it to externals (e.g., governmental bodies, as mentioned above). A crucial aspect in this context is the question of authority and jurisdiction regarding who is allowed to collect this sensitive information. In Austria, the Ministry of the Interior and the Ministry of Defense have the joint duty to protect the Austrian CIs and thus they are gathering information from CI operators. However, there is no legal obligation for the CIs to provide the information to the ministries, which leads to more complex situations. In other countries, there is often no central agency entrusted with the task of protecting all the CIs within the country. Rather, different agencies and governmental bodies are in charge of different sectors like electric power, gas or water, as for example in the United States, which makes the communication and mutual information exchange very difficult as well as raises issues on the jurisdiction.

Additionally, the experts providing the information within the CIs might not have enough experience on a specific matter such that not all or incorrect information is fed into the system. This could be due to the fact that the person responsible for carrying out the risk analysis does not have a full overview on the field (e.g., because the person is supervising several organization units) or is not qualified enough (e.g., because the person is working on risk analysis as an add-on due to budget constraints). Consequently, this might lead to less accurate results from the model. However, we have seen that the direct contact with experts might also reveal latent information, e.g., about implicit dependencies between CIs.

CONCLUSION

In this article, we presented the CERBERUS approach to model and assess the consequences of cascading effects in a network of critical infrastructures. It allows to represent a critical infrastructure in different operational states directly depending on the corresponding state of the infrastructure's suppliers. We showed how the propagation of cascading effects among these critical infrastructures can be described and simulated using stochastic processes to account for the intrinsic randomness and uncertainty which resides in the interplay of critical infrastructures. As an output, the approach provides a certain risk level (based on static and dynamic aspects) and a resilience level (based on the interdependencies) for each infrastructure. We are currently implementing the CERBERUS approach as a software solution, which will support operators and governmental bodies in ensuring a high degree for security and preparedness of critical infrastructures.

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Towards Disaster e-Health Support Systems

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ABSTRACT

Disaster management and the health sector ought to be natural allies, but their different origins, culture, and priorities of the various agencies tasked with disaster response mean that communication and coordination between them is often lacking, leading to delayed, sub-standard, or inappropriate care for disaster victims. The potential of the new e-health technologies, such as the electronic health record, telehealth and mobile health, that are revolutionizing non-disaster healthcare, is also not being realised. These circumstances have led to an international project to develop a disaster e-health framework for the objectives of intelligent adaption to changing scenarios, presentation and management of information, and communication and collaboration. In this paper, we describe characteristics of disaster e-health support systems to achieve such set of objectives.

Keywords

Disaster e-health, disaster response, disaster e-health support system

MOTIVATION

In a major disaster[1], there are inevitably human casualties who need rapid treatment for trauma, and the specialised field of *disaster medicine* has evolved for this purpose (Hogan and Burstein, 2016). Essentially, disaster medicine applies public health and specialist tools to define clinical protocols in a disaster response. Other stages of the disaster management lifecycle are also in the scope of disaster medicine. On the one hand, within the preparedness stage, there is a need to teach the competencies required by clinical personnel to act under high pressure in an adverse work environment (Subbarao et al., 2008). On the other hand, disaster medicine is present also in the recovery stage since, as stated in (Galea, 2007), the health consequences of disasters, initially exhibited as fatalities and injuries, often appear years later as chronic and mental illnesses.

Modern medicine has changed dramatically with the advent of numerous information and communication technology (ICT) enabled tools, globally known as *e-health* applications or systems (Coiera, 2015). However, whilst disaster management has rapidly adopted and deployed ICTs to change for good the way the different stages of the disaster lifecycle are dealt with (Hristidis et al., 2010; Rao et al., 2007), there is little systematic use of modern e-health tools in disaster medicine (James and Walsh, 2011; Sakanushi et al., 2013). It is well known

[1] We use "disaster" as a generic term covering a range of disastrous events, from mild emergencies to catastrophes. We will use more specific terms when dealing with particular cases.

that e-health technologies like the electronic health record, tele-health systems, decision support systems, data analytics, RFID tagging, the Internet of things, cloud computing, social media, etc., are revolutionizing the planning and delivery of mainstream healthcare (Coiera, 2015). All of them can make health information and health-related services available anytime, anywhere, automate workflows, and provide seamless care for immediate intervention or longer-term treatment. They also *democratize* healthcare by encouraging the active participation of the citizen in the care process. Crucially, however, beyond the application of electronic triage and telemedicine, disaster medicine clinicians are seldom trained to be aware of these technologies, let alone to acquire competency in their use (Sakanushi, K et al. 2013; Doarn and Merrell, 2014).

The different origins, development, and priorities of disaster management and disaster medicine have led to a lack of communication and coordination across these disciplines during disasters, leading to delayed, sub-standard, inappropriate, or even unavailable care. This concern has prompted Bissell (2007) to write *"Emergency management and the health sector are natural allies that have, seemingly, only recently begun to recognize each other"*.

Since little progress had occurred in such respect, an international project was established to develop a new paradigm, called *Disaster e-health,* to fill the gap between disaster management and disaster medicine. Disaster e-health aims at promoting the application of e-health technologies to assist the prognosis and treatment of the sick and injured in a disaster, and to support appropriate care in the post-disaster situation. It can be thought of as a domain at the intersection of three constituent fields, namely disaster management, disaster medicine, and e-health.

The ISCRAM community and ISCRAM's annual international conferences created bonds between Auckland University of Technology, New Zealand, and the University of Agder, Norway. Both institutions conduct research on health, e-health and disaster management. The collaboration between research teams from both institutions to advance disaster e-health acted as a lever to improve disaster healthcare. The research group expanded quickly to incorporate expertise in information systems from the University of Nebraska, Omaha, USA, and has grown further to embrace researchers from universities in Canada, Bulgaria, Sweden, and France.

The DEH project has received grants that have led to the appointment of two PhD students at AUT. The research has succeeded in scoping the disaster e-health domain (Norris and Althwab, 2013; Norris et al., 2015) and developing key topics such as inter-agency communication, scenarios for disaster e-health applications, and education (Abbas et al., 2016). The grants have also served to run international workshops in Norway, the USA, and New Zealand as well as at the recent ISCRAM 2017 conference in France. The goal of these workshops has been to develop a roadmap for disaster e-health that accelerates its development and sets the domain on a path to becoming a vital and sustainable component of mainstream disaster healthcare.

Running in parallel with the DEH project, a European (EU) Horizon 2020 research project, with nine different countries involving cities and universities throughout Europe, has been looking at crisis and disaster resilience with a view to developing a holistic approach to resilience that integrates the many perspectives, including healthcare, that need to be considered when a disaster occurs (Smart Mature Resilience, 2018).

Arguably, to achieve a marriage of disaster management, disaster medicine and e-health, an integrated support system should be developed. In this paper, we report our work in progress towards the development of *disaster e-health support systems (*DEHSSs). We analyse the multidimensional nature of disaster e-health, founded on coordination, information and knowledge management, visualization, collaboration and communication, and describe the characteristics DEHSSs should have to support the definition and enactment of medical disaster response plans, both at training level and in actual incidents. Our goal is to define a roadmap for the development of tools that add value to current software infrastructures in different aspects like augmenting the situational awareness of responders, providing advanced diagnosis and triage utilities, covering the informational needs of medical responders, and eventually helping victims to keep calm and safe while helpers arrive to their place.

We first describe the landscape of disaster e-health in the context of knowledge management. Next, we sketch the requirements for embedding e-health applications in disaster preparation plans and outline the main topics to deal with on the way to DEHSSs. Some conclusions close the paper.

A MULTIDIMENSIONAL VIEW OF DISASTER E-HEALTH

Disaster e-health was defined in (Norris et al., 2016) as *"the application of information and e-health technologies in a disaster situation to restore and maintain the health of individuals to their pre-disaster levels"*. The "e-"prefix is key in the definition since it denotes extensive use of ICTs to build solutions aiming at improving the speed and quality of response as well as victim access and safety. These responses are performed by medical response teams, often in cooperation with other responders such as firefighters or police forces. Hence, disaster e-health must be based on tools supporting the different stakeholders –including the victims themselves. Different authors have

proposed multidimensional approaches to crises response (Canós et al., 2004; Comfort, 2007; Wolbers et al., 2017), and the use of specific technologies to support each dimension. Figure 1 shows the main dimensions that, in our view, disaster e-health tools should deal with. The principal support relates to the specification and monitoring of the intra- and inter- force *coordination* mechanisms that allows dispatching the right orders to the right actors at the right time, keeping process awareness to ensure full process coverage and avoid redundancy.

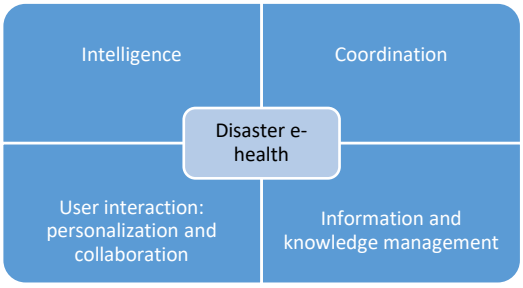

Figure 1. Dimensions of disaster e-health

The orders must be accompanied by the information required to perform each task to improve the e-health awareness and skills of disaster responders. The improvement must come from the inclusion of e-health knowledge in the disaster preparedness knowledge set. As pointed out by (Diniz et al., 2008), three basic types of knowledge affect disaster responses. First, tacit knowledge is in the minds of responders and is the result of years of experience in their work. Second, formal knowledge is the type of knowledge collected into a disaster plan, technical manuals, etc. Its sources are primarily the tacit knowledge that has been gathered in planning sessions, training exercises, etc., plus the result of engineering tasks, and other cross-disciplinary sources (e.g. maps and phone directories). Finally, the contextual knowledge emerges as first-responders (medical emergency services, public health authorities, law enforcement team, civil protection professionals, and others) respond to the disaster and provides "fresh" information about the situation of victims, properties, weather conditions, etc., constituting the so-called *context* of the situation.

The information provided to responders must be carefully selected to avoid overload and/or lack of information, which makes *customization* become another important issue. Moreover, in particularly complex cases, *collaborative decision making* can be also a requirement, as well as some type of decision support system. Last not least, the collection of high amounts of data from different types of sensors, especially those that monitor vital variables of persons, will require different types of intelligent (big) data processing tools.

EMBEDDING E-HEALTH APPLICATIONS IN DISASTER PREPARATION PLANS

Disaster response plans are the *cookbooks* where organizations of any type and size describe the procedures to respond to different types of adverse events. Plans include all the actions to perform in case of incidents, along with the information required by the actors involved in them. The plans serve also to define formal training exercises, as defined in (Taber et al., 2008), within the scope of the preparedness stage of the classical disaster management lifecycle. Depending on the size and type of organization, plans can be large textual documents whose elaboration spans for months or longer; moreover, they are difficult to disseminate among the different stakeholders since personalization is not one of the priorities of their designers. As a consequence, the command and control staff process the plan and generate the different instructions to the different responders.

Some authors have claimed that a broader view of disaster preparedness and response plans is required (Canós et al., 2004). Specifically, a shift towards interactive systems should significantly enhance the usability of disaster plans. Such an approach should take advantage of the numerous advances in software technology like process modelling and execution environments to cover the coordination dimension, data and application integration models to deal with the different types of knowledge, new interaction paradigms to provide customized interfaces, and so on. From this perspective, disaster plans would be a kind of processes or "*megaprograms*" (Wiederhold et al., 1990) that define the coordination of high-level modules to solve the complex problems presented by disaster response. Coordination would be specified as a process using some process modelling language, preferably with improvisation-supporting constructs (Dirr and Borges, 2016).

Disaster response plans aim primarily at avoiding life losses, so their procedures tend to prioritize the evacuation of people, paying little attention to the health status of victims and the interventions they require. In these cases, the speed, accessibility, and cost-effectiveness of e-health systems would be of great help for medical responders. Hence, e-health systems should be incorporated as additional modules of the megaprogram a disaster response plan is. Syntactic interoperability would allow the connection of e-health systems with the disaster management systems by defining the necessary interaction protocols. Additionally, the integration of heterogeneous e-health data into the context of the disaster will require semantic integration mechanisms based on ontologies. Last, but not least, privacy issues require special attention. In this regard, work in the so-called Hippocratic Databases (Agrawal et al., 2002) can be very relevant.

It is well-known that poor inter-agency communication, particularly between emergency managers and clinicians,

is a significant cause of sub-standard healthcare in disasters. One of the co-authors of this paper is developing a classification as a basis for a systematic approach to the development of systems that will re-engineer critical communication processes using information and e-health technologies (Abbas et al. In press). The objective of this approach is to specify and design a knowledge-based telehealth system based on the timely exchange of information contained in *minimum data sets* (MDSs) defined by inter-agency needs. The MDSs draw on data captured by sensors in real time and also contained in dynamic databases constructed from environmental, demographic, and clinical sources. The MDSs are assemblies of database records updated in real time and maintained by appropriate document management systems. Knowledge exchange by MDSs shares similar design characteristics - intelligent adaption to changing scenarios, presentation and management of information, and communication and collaboration- with research on multimedia emergency plans by another co-author of this paper (Canós et al., 2004). These two studies have the same overall goal, personnel safety, with complementary perspectives – the multimedia emergency plans are concerned with preventing injury, and the research on MSA focuses on providing rapid and appropriate healthcare when injury has occurred.

TOWARDS DISASTER E-HEALTH SUPPORT SYSTEMS

To make the benefits of disaster e-health tangible, DEHSSs should be designed and developed. In terms of global disaster response, a DEHSS would be the *view* of a larger disaster support system generated specifically for medical responders. Such a view would necessarily include editing facilities to allow disaster e-health experts to add as much formal knowledge as possible and define the coordination mechanisms that prescribe the right response to a particular incident. From all the formal knowledge, and possibly incorporating context, the system should be able to generate personalized action plans depending on the particular skills of each responder. In addition, self-care instructions and even psychological attention could be provided to victims waiting for their support to arrive. Finally, logging all the actions performed would be of great help during the *post-disaster* analysis of the responses.

Besides actual disasters, which would provide the *situated training* mentioned in (Taber et al., 2008), the functionality of DEHSSs would allow more formal training experiences. The possibility of defining disaster scenarios and enacting the corresponding responses, with their corresponding further evaluation, would certainly increase the capabilities of the medical response teams. Efforts are required in a number of research and development lines, where new solutions can be created from scratch or adapted from similar solutions in closely related fields, like:

- Document engineering tools for the efficient generation of personalized training and/or response plans.
- Process support technology to model and enact response procedures; support for improvisation must be among its main requirements.
- Library and information science principles to organize information in digital libraries accessible to the different components of DEHSSs.
- Big data analytics suites to process all the data received by wearable devices and sensors that help to improve situational awareness.
- Mapping and navigation software to generate safe evacuation paths to people affected by a disaster, as well as to help responders access to disabled victims. The development of map-driven mashups showing geo-tagged pieces of knowledge is undoubtedly convenient.
- Augmented reality interfaces that complement the aforementioned mashups, bringing e-health related information relative to victims like the electronic health record, vital signs, and so on.

The infrastructure supporting DEHSSs must principally be cloud-based since *flexibility* to support hundreds or thousands of requests per time unit is the key to make any solution viable. Therefore, the creation of government-owned private clouds raises new architectural challenges that are worth study.

CONCLUSION

In a disaster, the potential victims are the weakest link in the chain of assistance. In most cases, the lack of good training programs at schools and municipalities makes people to *"run towards where they see others run"*[2] as their primary reaction. In other cases, the willingness to support other victims can lack a clear objective sometimes leading to counter-indicated care. Additionally, when rescue forces get to where victims are, little information is provided about their health history, risking the application of wrong treatments. So far, the emergency management research community has been much more focused on rescue tasks than in providing enhanced attention to the people.

Disaster e-health aims at filling the gap between people's needs and rescuers capacity of action in several ways.

[2] In words of J. M. Gil, a psychologist expert in disasters; informal talk.

First, providing better situational awareness about the state and medical history of citizens affected by a disaster. Second, by increasing the knowledge available for medical responders. Third, by improving preparedness of both responders and citizens to drive first-minute responses which can save lives. And fourth, making disaster response go one step further by leading the medical dimension to the same level than others. The challenges are numerous, both at the conceptual and technological level. We expect that the development of DEHSSs will make real the potential that disaster e-health shows in the mid-term.

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Track 8

Social Media Studies

ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017

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ABSTRACT

In 2004, Information Systems for Crisis Response and Management (ISCRAM) was a new area of research. Pioneering researchers from different continents and disciplines found fellowship at the first ISCRAM workshop. Around the same time, the use of social media in crises was first recognized in academia. In 2018, the 15th ISCRAM conference will take place, which gives us the possibility to look back on what has already been achieved with regard to IT support in crises using social media. With this article, we examine trends and developments with a specific focus on social media. We analyzed all papers published at previous ISCRAMs (*n*=1339). Our analysis shows that various platforms, the use of language and coverage of different types of disasters follow certain trends – most noticeably a dominance of Twitter, English and crises with large impacts such as hurricanes or earthquakes can be seen.

Keywords

ISCRAM, Social Media, Trend Analysis, Systematic Literature Review, Vocabulary Analysis

1. INTRODUCTION

While social media have recently become natural elements in many people's everyday lives, their origins date back further than one might tend to think. These networks emerged from knowledge management and collaboration ideas such as Memex by Vannevar Bush, a first hypothetical hypertext system from 1945, and the concept of Computer-Supported Cooperative Work (Allen, 2004). The so-called Web 2.0 was the interactive implementation of a specific type of platform where users could contribute and share content as well as interact with each other – in contrast to the business-focused Web 1.0, which primarily enabled one-sided communication. Such interaction can be subsumed under 'computer-mediated communication', as described in many examples in "The Network Nation" by Hiltz and Turoff (1978), a hypernym for what is today called 'social media'. Usage of these platforms has increased dramatically over the past ten years and made social media indispensable (Statista, 2017), with the social network Facebook having the largest world-wide group of users (over 2 billion), closely followed by the video-sharing platform YouTube (1.5 billion) and instant messenger WhatsApp (1.3 billion). The image-sharing platform Instagram is used by more than half a billion people, the business network LinkedIn by over 100 million, while the microblogging service Twitter has more than 328 million users[1].

Crisis scenarios have become an important field of application for social media, which, under the term of 'crisis informatics' (Palen & Anderson, 2016), has been an extensive area of research since 2006 (Palen & Hughes, 2018; Reuter & Kaufhold, 2018). During this time, crisis situations have been quite common: Between 2005 and 2015, an average of 631 disasters occurred worldwide each year, causing over 80,000 casualties and affecting almost 200,000 people, while causing monetary damage of the equivalent of over 160 billion US$ (IFRC, 2015). When talking about crises and disasters, we'd like to distinguish between natural and human-induced events. The related terms convey slightly diverse meanings: *crisis* generally implies a situation that cannot be overcome by an organization without taking particular measures, while *emergency* includes the characteristic of *unpreparedness*,

[1] It should be stated that these numbers are snapshots only. The social media realm is a very dynamic one where todays's hot platform might be out of operation within a short period of time.

and possible impact that has to be kept under control (DHA, 2000). For a thorough discussion of terminology involved also see Coombs and Holladay (2012).

While a lot of research has been carried out on crises, emergencies or disasters with regard to social media use, there are only a few studies systematically analyzing recent developments – particularly none with a special focus on ISCRAM. By examining related work (section 2) on the history of social media in crisis management and the history of ISCRAM, we point out existing research gaps. Based on these we describe our method (section 3), which includes a quantitative study on the development of the vocabulary used in all ISCRAM papers. Finally, we present the results of our investigation (section 4), draw conclusions and discuss our findings (section 5).

2. BACKGROUND AND RELATED WORK

2.1 History of Social Media in Crisis Management

The role of social media in emergencies is gaining relevance. First examples of the use of wikis (Palen & Liu, 2007), photo repository sites (Liu et al., 2008), the microblogging service Twitter (Hughes & Palen, 2009) and other platforms in emergency situations date back to the beginning of this millenium. Early cases are the terrorist attacks of September 11th, 2001, the Indian Ocean tsunami in 2004, and the Southern California wildfires in 2007. The first event provoked the development of emergency management as a research field, which had previously been marginally treated in unrelated disciplines. As an important tool for engagement and for unofficial citizen communication, social media have since been used to share and obtain information in crisis situations and make sense of an evolving dynamic environment (Bruns et al., 2012). Ever since their inception in the early 2000s, there exists almost no large emergency[2] where the use of social media has not been studied (Reuter & Kaufhold, 2018).

Reuter et al. (2018b) summarized cases of social media in emergencies between 2001 and 2017 and observed a wide range of events covered in scientific studies, which allows for the easier detection of patterns and trends in the different social behaviors. Moreover, Olteanu et al. (2015) identify types of content and information across crises. Several limitations in the research corpora and technologies can be discerned: Twitter, although only used by relatively few citizens compared to other sites like Facebook, has been analyzed by a majority of studies (Kaufhold & Reuter, 2016; Reuter et al., 2018b). One reason might be that Twitter's open API, terms of use and the simplicity of 140/280-character messages allow for a convenient way of gathering data and establishing substantial data samples (Imran et al., 2015). Further reasons for the focus on particular platforms might be related to the location of the researchers themselves, of funding bodies and programs, and to a host of socio-economic factors influencing the platform use and distribution within affected populations.

Another limitation concerns the location of events and language of social media content. While the analysis of social media in crises has become commonplace in the US since about 2006 (Palen & Hughes, 2018), there is still relatively little research on this topic in Europe (Backfried et al., 2015) and elsewhere as well as on non-English speaking communities (Reuter & Kaufhold, 2018). Related studies, mainly on automatic information extraction from social media that can help disaster prevention and management, have been conducted in Japan as a country prone to earthquakes (Sakaki et al., 2010), and similarly in Qatar (Imran et al., 2014).

Natural Language Processing (NLP) tools used to analyze data are generally much more advanced for English language content. This mirrors the situation in several related areas such as Automatic Speech Recognition (ASR), Named-Entity Recognition (NER) or Topic Detection (TD) which have all received a lot of attention in the US, driven by DARPA sponsored evaluations such as the HUB, TDT or MUC evaluations (Fiscus & Doddington, 2002; Grishman & Sundheim, 1996; Przybocki et al., 1999). Extensions to other languages and groups of languages - each one exhibiting particularities in structure and use on several linguistic levels - often require substantial amounts of time and up to this date remain a significant challenge. Languages with scarce resources, so-called *low-resource languages* more recently have also become the focus of attention at conferences such as LREC[3] and Interspeech[4], leading to gradual improvements on corpora and language specific technologies. Advances in deep-learning paired with the availability of data further aid in the extension to such languages.

As social media have become indispensable for the public and private sector in crisis situations, their scientific analysis in this context has been advancing, although still bound to limitations and bias in location, language and technology. The most influential venue for this research area is the international ISCRAM conference. Therefore, besides the trends mentioned above, we are interested in how the papers developed at this specific conference.

[2] *large* primarily in a humanitarian sense rather than from an economic point of view
[3] http://www.lrec-conf.org/
[4] http://www.isca-speech.org/iscaweb/index.php/conferences/interspeech

2.2 History and Topics of ISCRAM

The history of Information Systems for Crisis Response and Management (ISCRAM) began in 2004, when interdisciplinary researchers, who felt their work had not received appropriate acknowledgement, gathered in Brussels, Belgium, for the first ISCRAM workshop (Table 1). Their central research question was how information technologies, especially decision support systems, could help manage crises (Comes et al., 2013). This first, successful and well-visited meeting, already brought together experts from various fields to develop a framework of a 'dynamic emergency response management information system' for stakeholders from different areas (Turoff et al., 2004). Their diverse needs and desires should be addressed by using elements of computer-mediated communication, all directed towards a more efficient emergency management (Campbell et al., 2004).

Year	Location	Program and conference chairs	Social Media-related Track(s) and Track Chairs
2004, 2005	Brussels, Belgium	*Bartel Van de Walle and Benny Carlé*	-
2006	Newark, New Jersey	*Bartel Van de Walle and Murray Turoff*	Communication Challenges in Emergency Response / Workshop on Future Communication Requirements for Emergency Response *(B.S. Manoj and Alexandra Hubenko Baker)*
2007	Delft, the Netherlands	*Bartel Van de Walle, Paul Burghardt, and Kees Nieuwenhuis*	Virtual Teams and Virtual Communities in Emergency Preparedness and Response *(Starr Roxanne Hiltz and Leysia Palen)*
2008	Washington, D.C.	*Bartel Van de Walle, Frank Fiedrich, Jack Harrald, and Theresa Jefferson*	Social Networking, Web Collaboration and e Participation in Crisis and Risk Managements *(Simon French and Clare Bayley)*
2009	Gothenburg, Sweden	*Jonas Landgren, Bartel Van de Walle, and Susanne Jul*	Collaboration and Social Networking *(Linda Plotnick and Connie White)*
2010	Seattle, Washington	*Mark Haselkorn, Simon French, and Brian Tomaszewski*	Collaboration and/or Social Networking *(Starr Roxanne Hiltz, Leysia Palen, and Paloma Diaz)*
2011	Lisbon, Portugal	*Maria A. Santos, Julie Dugdale, and David Mendonça*	Social Media and Collaborative Systems *(Starr Roxanne Hiltz, Paloma Diaz and Linda Plotnick)*
2012	Vancouver, Canada	*Brian Fisher, Richard Arias-Hernandez, Leon Rothkrantz, Jozef Ristvej, and Zeno Franco*	Social Media and Collaborative Systems *(Starr Roxanne Hiltz, Paloma Diaz, Leysia Palen, and Linda Plotnick)*
2013	Baden-Baden, Germany	*Jürgen Beyerer, Thomas Usländer, and Tina Comes*	Social Media and Collaborative Systems *(Starr Roxanne Hiltz, Volkmar Pipek, Linda Plotnick, and Kate Starbird)*; Community Engagement in Crisis Informatics Research *(Christine Adler, Zeno Franco, Paul Bledzycki, Tracey O'Sullivan, and Syed Ahmed)*
2014	State College, Pennsylvania	*Andrea Tapia, Starr Roxanne Hiltz, Mark S. Pfaff, Linda Plotnick, and Patrick C. Shih*	Social Media in Crisis Response and Management *(Linda Plotnick, Starr Roxanne Hiltz, Volkmar Pipek, Kate Starbird, and Amanda Hughes)*
2015	Kristiansand, Norway	*Monika Buscher, Leysia Palen, Amanda Hughes, and Tina Comes*	Social Media Studies *(Starr Roxanne Hiltz, Amanda Hughes, Imran Muhammad, Linda Plotnick, Christian Reuter, Kate Starbird)*
2016	Rio de Janeiro, Brazil	*Marcos R. S. Borges, Paulo Victor de Carvalho, and Andrea Tapia*	Social Media Studies *(Amanda Lee Hughes, Muhammad Imran)*
2017	Albi, France	*Tina Comes, Frédérick Bénaben, Matthieu Lauras, Chihab Hanachi, and Aurélie Montarnal*	Social Media Studies *(Amanda Lee Hughes, Starr Roxanne Hiltz, Muhammad Imran, Linda Plotnick, Christian Reuter)*
2018	Rochester, USA	*Brian Tomaszewski and Kees Boersma*	Social Media Studies *(Starr Roxanne Hiltz, Amanda Lee Hughes, Imran Muhammad, Christian Reuter)*

Table 1. Locations and chairs of the past ISCRAM conferences from 2004 to 2017.

Five years later, in 2009, the field was still emerging, but already receiving more recognition (Jul, 2017). Three of the people responsible for the early creation of ISCRAM produced a very successful text book on Information Systems for emergency management (van de Walle et al., 2010). A Belgium-based non-profit ISCRAM Association was founded, whose goal is to promote community, research and knowledge exchange, as well as to develop systems for emergency management. The association, its activities, standards and legal matters are managed by the Board of Directors consisting of ten members, who are elected for a period of two years directly by its members at the annual conference.

The ISCRAM conference has been held at different institutions worldwide and monitored by changing program and conference chairs. A specific social media track was established as early as 2006. Prior to the major conferences, ISCRAM offers a meeting for PhD students. A standardized academic curriculum dedicated to the cooperation between emergency management and information systems has been proposed (Turoff, 2014). To date, ISCRAM has been established as a legitimate research area, where work is regularly published in influential

journals (Hiltz et al., 2011; Pipek et al., 2014; Reuter et al., 2018a) and presented at conferences, workshops and meetings dedicated to crisis topics.

2.3 ISCRAM and Social Media

Social media play a central role in ISCRAM research. As a general overview of topics dealt with by ISCRAM, we analyzed the ten best-cited papers published in the conference proceedings, based on the 2017 Google Scholar rating. Most of the studies deal with social media used in crisis situations, primarily Twitter, presenting the main subject of four of the ten works (Ashktorab et al., 2014; Caragea et al., 2014; Hiltz, Kushma, & Plotnick, 2014; Imran et al., 2013). Another remarkable commonality is that many studies adopt the example of natural disasters such as floods and hurricanes, as well as dealing with events and affected parties located in the US.

A number of limitations and problems with the analysis of social media in crises have been detected. In the vast number of messages on social media, a diversity of topics and levels of relevance were found (Imran et al., 2013) and low quality and trustworthiness identified (Tapia et al., 2013). The sheer number of posts makes efficient processing and timely reaction by humanitarian organizations and emergency managers difficult if not impossible. For three contributions, the goal was therefore to develop a system to automatically filter, classify and extract information in order to raise awareness and generate practical information for crisis managers and volunteers (Chowdhury et al., 2013; Hiltz et al., 2014a; Imran et al., 2013). However, automatic classification is not yet adapted to and reusable for short texts that are characteristic for microblogging services (Imran et al., 2014). Also, there is a lack of connection between the location of the disaster event and those tweeting about the disaster (Caragea et al., 2014; Hiltz et al., 2014b). Caragea et al. (2014) therefore carried out sentiment analysis and mapping of Twitter posts.

Some of the studies relied on quantitative data analysis, while others also conducted qualitative interviews with stakeholders like emergency managers and intervention teams, to investigate communication practices and how these could be enhanced by social media (St. Denis et al., 2014; Tapia et al., 2013). One paper took up a topic on the meta level, examining the interoperability of crisis-term-ontologies that support communication between different organizations during an emergency (Liu et al., 2013). Another work focused on enhancing communication, particularly between volunteers (Reuter et al., 2013). Here, the lack of a contact point between real and virtual volunteers and a decrease in active volunteering were targeted by using a variety of systems, enhancing collaborative resilience. The aims are to develop and enhance prototypes, frameworks and systems for stakeholders in various kinds of natural or human-induced crises. At the same time, they display a variety of methodological and technological approaches to this topic, as well as a diversity regarding their specific goal.

2.4 Research Gap

While we acknowledge the summarized research on social media in crisis management (section 2.1) and the history and topics of ISCRAM (section 2.2), emphasizing the central role of social media (section 2.3), we are aware that these data present just an excerpt of the reality. The social media landscape is a very dynamic and fluid one, with platforms appearing and disappearing continuously, morphing into new incarnations and online populations migrating along the way. What is still missing is a systematic analysis of all papers published before the 15th conference, taking place in 2018, which is precisely the research gap our contribution aims to address. Our research question is: **What are trends of ISCRAM research, especially with regard to the share of social media content, the distribution of social media platforms, the consideration of crisis events and the focus on crises in different regions?**

3. METHOD

In order to investigate how social media research developed over the years, which trends emerged and if there are any correlations between crisis events, the creation of platforms and the publishing of papers in ISCRAM, a quantitative study on the development of the vocabulary used in ISCRAM papers was performed. To achieve the best overview, a census of all papers was carried out. We downloaded the papers from the ISCRAM digital library and performed a systematic literature and vocabulary analysis. From the resulting 1339 papers, two were excluded from the statistics due to being full proceedings of the conferences in 2016 and in 2017 and thus providing redundant content already present in the digital library individually.

The texts of all papers were extracted automatically using Apache Tika[5] resulting in approximately 6.8 million words. Subsequently some basic cleaning (removal of sentence markers, punctuation, etc.) was performed, casing adjusted and some mappings for alternative spellings of words applied (e.g. Sg. tweet vs Pl. tweets). Moreover,

[5] https://tika.apache.org

the reference section of each paper was eliminated before further analysis. All papers were assigned to their respective year and all words counted on a per-paper and per-year basis. Stop words were excluded (resulting in approx. 3.9 million words) and a ranking based on frequency generated. For the actual analysis we extracted from this ranking the top 1000 (Top1k) words. As the papers had been grouped by year, we ensured that the overall top-ranking words were considered across all years, even if a particular word would not have been among the top-ranking words of a particular year. In addition, the top-ranking words were extended with a set of words, which had been selected to be of importance for our study. Those extensions take three important categories of ISCRAM and the survey's main pivot point into account:

(1) The main focus of this survey is social media. Therefore, the platform names are an immanent part of the word-set and needed to be included (such as Twitter, Facebook, etc.). Likewise, platform-specific terms like "tweet" or "retweet" were included.

(2) Since the conference covers a broad variety of topics concerning crisis situations, the different kinds of disasters had to be included as well. Man-made crises and disasters were not specifically addressed.

(3) Further word sets were required which enabled the authors to narrow down the socio-cultural and economic region mentioned by the papers. Hence, country names were also included in the word set variables.

These three additional sets enable us to identify past, current and upcoming trends in social media and allow us to link them to particular locations and events. By doing so, general distributions have been generated over the three main categories listed above. The platforms themselves provide the focus of identifying social media content and were hence chosen as the starting point of our analysis. A time-related analysis across platforms was performed with temporal comparisons across the different years. Each year was also analyzed separately to investigate potential links and correlations between the three categories.

In the visualizations, the lower 2.5 percent (lower quantile) of every figure were excluded in order to factor out papers with weak relations to the focus of the study. Papers with significant correlation are assumed to have a linear relationship and were checked.

4. RESULTS

Figure 1 below shows the years of creation of different social media platforms found to be of relevance within the scope of media coverage of disasters. Several platforms date back to the mid-2000s with Twitter, the most frequently referenced and researched platform, coming into existence in 2006. All statistics below concerning the use and reference of platforms should be viewed in the context of this timeline.

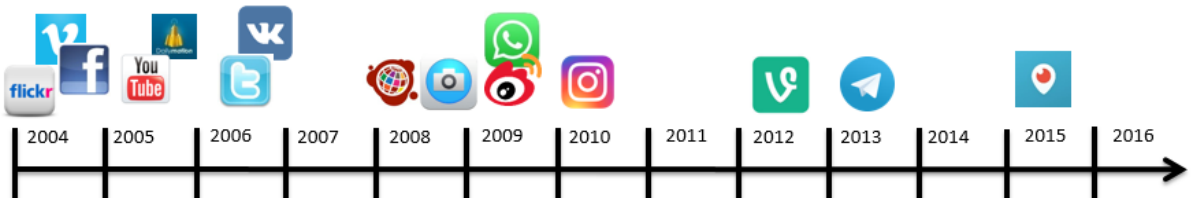

Figure 1. Year of Creation of Social Media Platforms (own illustration)

4.1 Share of Social Media Content – From 0% to 60%

A close look at the general statistic in Figure 2 shows that social media-related content was first published at ISCRAM in 2008 and then noticeably picked up momentum in 2012, passing the 20% line. Until 2014, this increase continued, whereas after this year, the overall number of published papers stagnated and even decreased considerably. While an increase in the total number of papers is observed from 2014 to 2015, this jump is not reflected in the number of contributions on social media. In the following years, the overall amount of papers started to decrease once more, but social media were not affected by this development. On the contrary, the percentage of social media-related research increased compared to the overall number of papers, reaching a peak of almost 60% in 2017.

From the numbers, we can conclude a general trend for the coverage of social media to get stronger over time. However, this trend is not straightforward and some of the years are worth taking a closer look: Those years are 2010, 2011, 2012, 2014, 2015 and 2017.

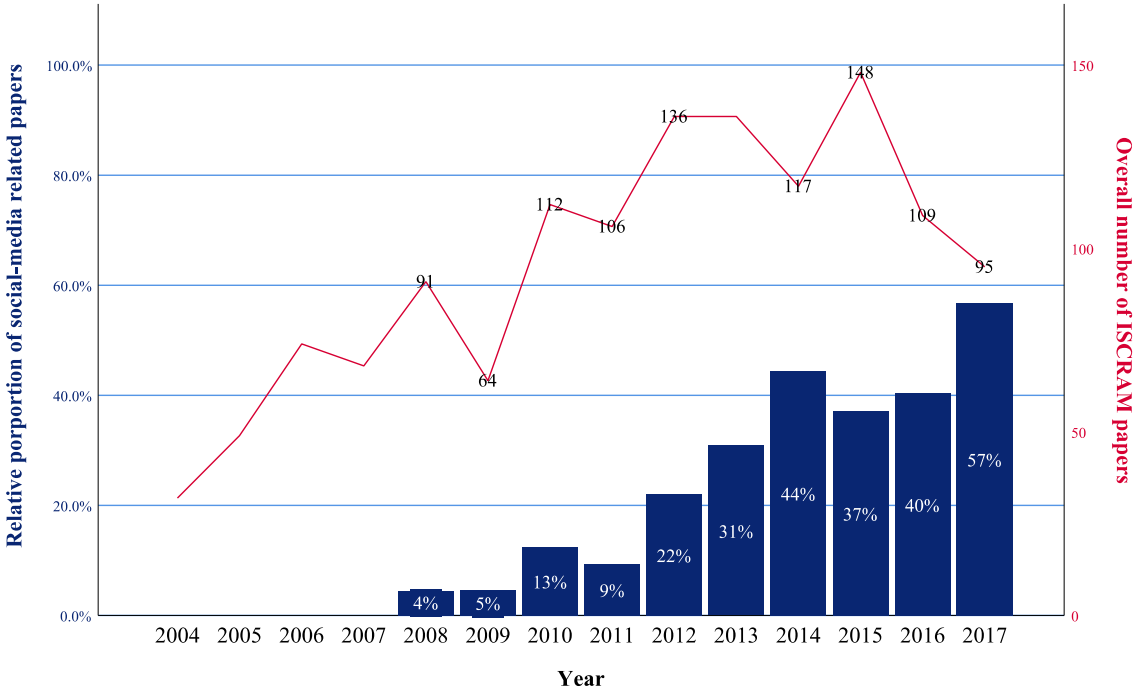

Figure 2. Percentage distribution of papers with social media content

4.2 Social Media Platforms – Twitter, Twitter and Twitter

The reference to particular platforms provides a central point of interest in our study. Therefore, we analyzed the distribution of the different social media platforms addressed over the years. From the beginning, Twitter was in the focus of the most research papers. In the first year of its coverage, it developed identically to Facebook. However, already one year later, in 2009, the coverage of Twitter significantly increased, with another increase from 2009 to 2010 (see Figure 3). In 2010, papers related to Twitter were published about twice as often as works on all other platforms. However, their numbers declined by nearly 50% in 2011, whereas other platforms did not exhibit a similar drop in coverage.

The year 2012 witnessed a comeback of Twitter increasing its share again by close to two thirds of the initial percentage of 2011. In the following years, the amounts of content related to Twitter constantly increased (see Figure 3), until it peaked in 2014. More recently, between 2014 and 2017, we can observe that contributions related to Twitter were no longer as frequent as in previous years.

During the same time-span, Facebook-related papers developed quite similarly to those covering Twitter, except for their absolute amount. In 2010, works mentioning Facebook also increased in absolute numbers. However, those papers only amounted to a lower 5% range. A significant increase can first be detected in 2012 and unlike the studies concerning Twitter, this increase continues up to 2015. In the following years, we can observe the same development as with Twitter-related research, only on a lower scale.

On an even lower scale, works related to Ushahidi show quite a similar distribution of the publishing numbers. Even though the first studies were published in 2009, they also had their first peak in 2010, declined in 2011 and then increased again until 2014. 2015, on the other hand, shows a significant decrease in the share of published papers covering Ushahidi. This trend did not continue in the following years when the amount of contributions in question constantly expanded.

Papers dealing with OpenStreetMap developed in a different way compared to the other platforms. With the appearance of contributions in 2010, the first peak took place in this year, while the numbers decreased in the following year and then constantly went up again until 2016. This behavior stands in contrast to Facebook- and Twitter-related papers which stagnated earlier. OpenStreetMap then could not keep up with the overall increase of works concerning social media topics. All further platforms seem to play only a marginal role, with the percentage of coverage never exceeding 4%.

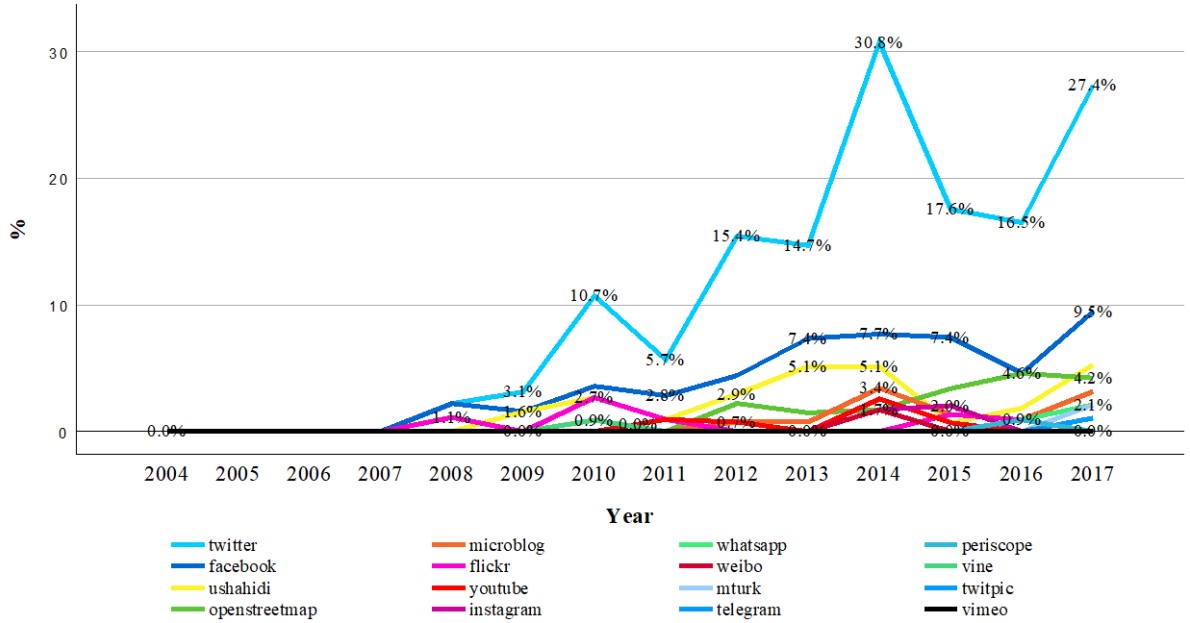

Figure 3. Distribution of the social media platforms across the years (Appendix 1)

4.3 Crisis Events in Social Media – Fire, Floods and Earthquakes

Next, we addressed the question of how those papers – or the social media platforms – are related to specific kinds of crisis events. A prominent topic in all the works (including those outside the social media track), is their relation to fires, earthquakes and floods (see Figure 4). Within the events and platforms, we can find a significant correlation between hurricane and Twitter (r= 0.267). However, the most significant correlations can be found with landand mudslides and the social media platform YouTube (r=0.524, r= 0.495). On average, the social media platforms and the event categories correlated significantly ($r_{(mean)}$ =0,237), even stronger than within the social media platform category ($r_{(mean)}$=0.213). A closer look at the individual years indicates that in 2010 (n=112), there were strong correlations between the publications dealing with the social media platform Ushahidi with earthquakes and hurricanes (r = 0.695, r= 0.648).

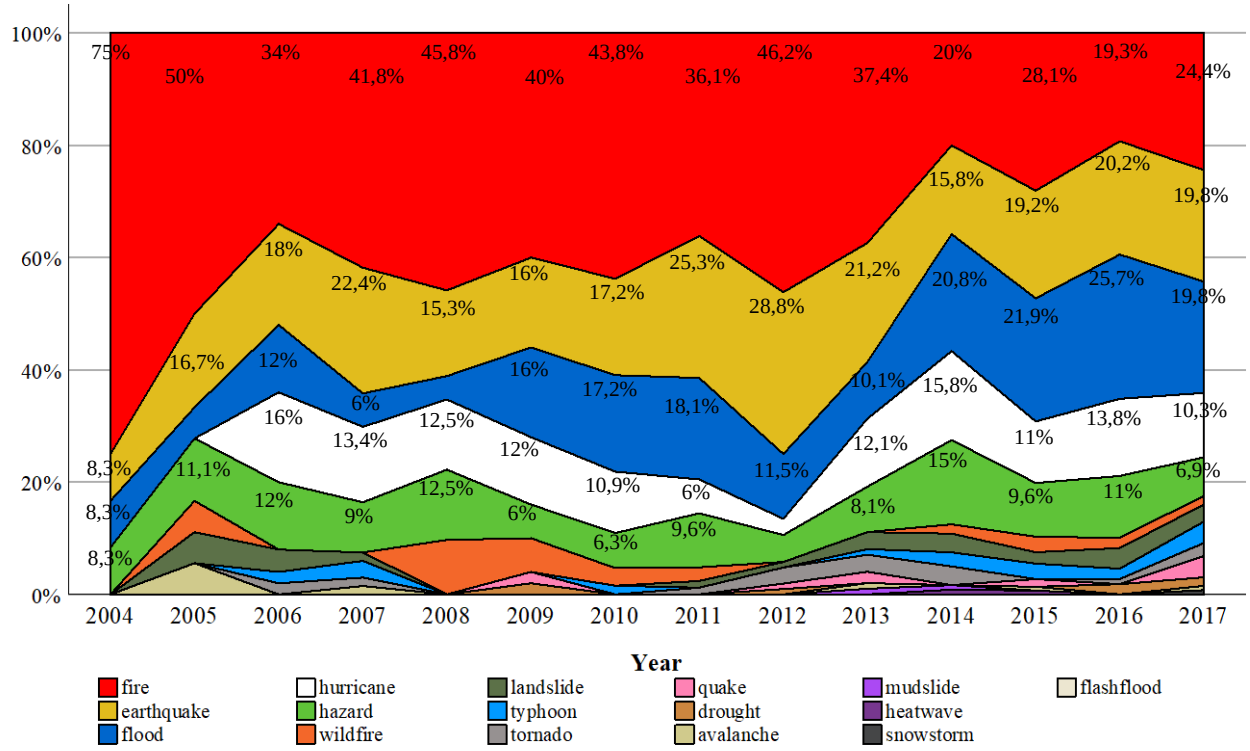

Figure 4: Distribution of crisis events in the papers (Appendix 2 numbers in total)

In the following year, 2011 (n=106), the trend towards correlations between social media platforms and types of disasters was prevalent. Especially the correlation between Flickr and YouTube (r = 0.998) proved to be very strong. In 2012 (n=136), this trend continued, less pronounced than before, but nevertheless showing a strong relation between events and platforms. In particular, the works on tornados and the social media platform Ushahidi (r = 0.482) indicated a significant correlation. Contributions in 2014 (n=117) extended this trend, however with a more intense focus on inter-social-media-platform relations, the correlation between Weibo (also a microblogging platform) and Microblog (r = 0.852) being the most significant one. It is also noticeable that the most significant correlations between events and the social media platforms are all related to either to hurricanes or floods. In 2015, the correlations were again more equally distributed. Therefore, there are no further interesting results from a correlation-based point of view in 2015. However, 2017 (n=95) again shows a strong trend towards a correlation of events and social-media-platforms. Extraordinary in this case is the correlation of typhoon-related papers to those working with OpenStreetMap (r = 0.541).

4.4 Regions – Dominance of European Studies

We will now switch our perspective to a regional point of view, to elaborate on the topic as to which geographical regions were most often referred to in social media-related papers. Overall, Europe has been the focus of most publications, with a rising tendency from the 2017 conference (see Figure 5). The amount of papers on North America has been approximately 20% after a peak in 2006, while South America stays low over the years. Asia increased from 0% to almost 20% over that time, with the tendency still rising. This trend corresponds well with the frequency and impact of disasters and the high social media usage in the region.

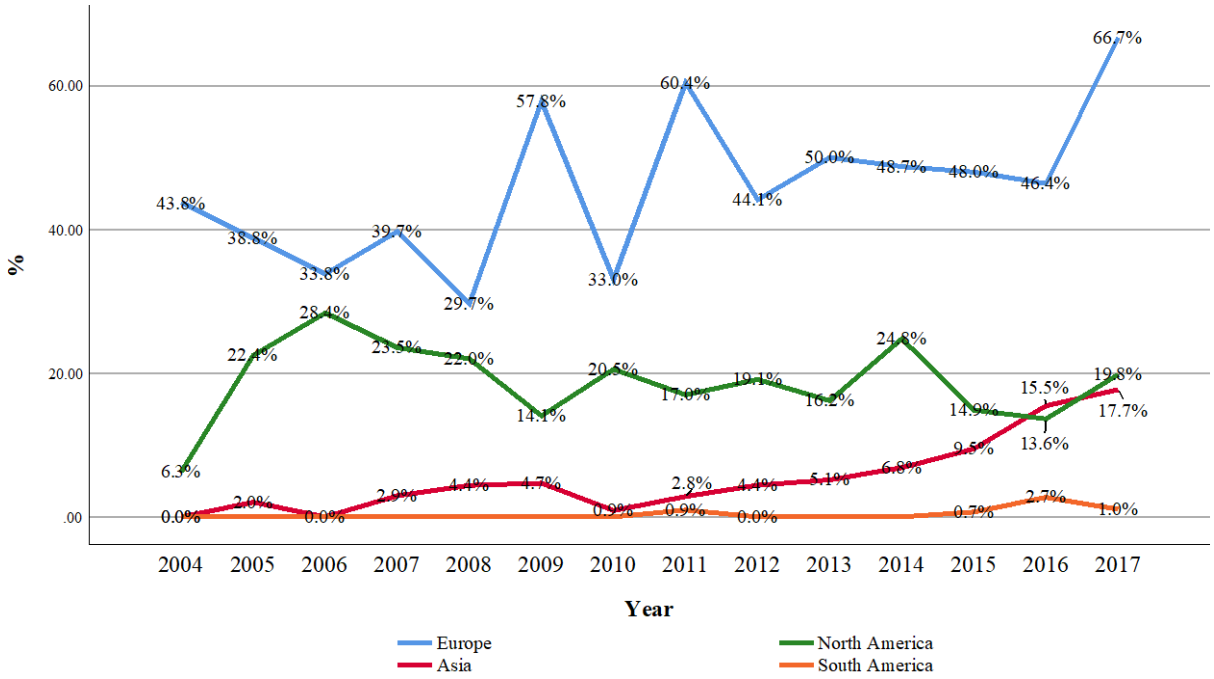

Figure 5: Distribution of continents

Overall (n=1337), if a paper concerns social media and at the same time correlates to certain continents or countries, most cases apply to North America: this is the case for Twitter (r =0.100) and Weibo (r = 0.073). However, the most significant correlations can be found for Asia and OpenStreetMap (r = 0.285) as well as Twitpic (r = 0.155). Hence, a closer look is required again. The results for 2010 (n=112) show that especially Flickr-related publications were of interest in terms of continent- and platform-related papers. Studies on events in North- and South America displayed strong correlations to Flickr (r = 0.416, r = 0.969), with South America being especially significant in this year. One year later, in 2011 (n=106), the trend towards Flickr-related works also followed for crises in Europe (r = 0.241), together with a similar trend for YouTube (r = 0.237). At the same time, Europe-related research dominates the output of ISCRAM in general (see Figure 5).

2012 (n=136) was the year when Twitter was most strongly connected to publications referring to South- and North America (r = 0.327, r = 0.245). South America was also significantly correlated to Ushahidi (r = 0.318). Meanwhile, North America was rather related to contributions concerning Microblogs (r = 0.172), and also to

Ushahidi (r = 0.173). In 2014 (n= 117), Asia could be found in a large number of papers addressing social media, particularly OpenStreetMap indicated strong correlations (r = 0.523). For South America, we could also observe correlations with works concerning Twitter (r = 0.375). The following year, 2015 (n=148), publications on disasters in North America tended to be more correlated to social media papers: Twitter and Facebook show significant dependencies to this continent (r = 0.256, r = 0.240), while Flickr-related research particularly correlated with Europe (r = 0.176). In 2017 (n=95), social media-related studies were less strongly related to specific countries. Only Asia showed correlations with OpenStreetMap (r = 0.231) and North America indicated dependencies to Twitter (r = 0.251).

5. DISCUSSION

What are the conclusions for the trends of research at the 15th ISCRAM conference? What has been researched in ISCRAM, especially in the area of social media? In order to answer our research question (**What are trends of ISCRAM research, especially with regard to the share of social media content, the distribution of social media platforms, the consideration of crisis events and the focus on crises in different regions?**) we collected and processed all research contributions (*n*=1339) from the past 15 years of ISCRAM and analyzed their quantitative development as well as their content with a focus on social media use in emergency situations. In particular, we investigated potential dependencies between platforms, types of crises and locations described in the papers, deriving tangible results.

- Our results indicate that the platforms named in most publications addressing social media generally correlate eaqually with each other as well as with events, such as fires, hurricanes and earthquakes.
- Concerning the correlation between and within platforms and crisis events in works related to social media, Twitter proved to be the most prominent among all social media platforms, therefore being of particular significance to the analysis. Over the entire time-span of 15 years, contributions related to Twitter present the vast majority – mostly over 30% – of all papers related to social media, underlining this platform's dominant position.
- However, the correlations between the platforms and the crisis events in a particular year suggest that the results need to be viewed in a more differentiated way. Ushahidi and OpenStreetMap, for example, correlate strongly in the years with earthquakes, hurricanes and tornados.
- With regard to a focus on the regions, the survey shows a significant amount of research concerning social media platforms is correlated to Europe, North- and South America as well as Asia.

Lifetime: The first social media platforms that gained the attention of works published at ISCRAM originated in 2004, and further ones have constantly been emerging since then. However, it was only in 2008 that papers explicitly examining social media were first contributed to the conference, which is in line with observations that analysis of social media use during crises, disasters and emergencies took hold only in 2007 (Palen & Hughes, 2018). The number of such works has been increasing over time and their focus changing constantly. Meanwhile, Twitter consistently remained the champion of all social media platforms mentioned in these papers.

Platforms: Examining the general development of platforms addressed in papers, we observe a rise with one or multiple peaks for a few years after the emergence of each platform, then a steep decrease followed by another climb. This reflects the dynamics of social media which are introduced, temporarily drawing the focus of entire communities and research on them, and then declining in use or interest over time, possibly being replaced by newer networks. Temporal variations may also be related to the corresponding events in which they have been used. We found a number of correlations, indicating a dependence on papers' country of origin, the locations where characteristic disasters tend to occur and certain platforms are popular at a given time. Furthermore, the regular fluctuations can be explained by the conference location alternating between Europe and North America, resulting in each of these continents producing a peak number of papers every two years.

Types of Crises: Within our focus on research concerning natural disasters, we found that the distribution over the different kinds of disasters was rather comparable, the most frequent ones being fires, earthquakes, floods and landslides. Although there is still a strong focus on Twitter based studies, the location of analyzed crises receives a more international backdrop (Olteanu et al., 2015; Reuter & Kaufhold, 2018). Considering the recent increase of terrorist attacks in Europe, such as the 2015 Paris shootings (Wiegand & Middleton, 2016), 2016 Brussels bombings (Mirbabaie & Zapatka, 2017) or 2016 Munich shootings (Nguyen et al., 2017), we anticipate an increasing effort, in terms of papers and projects, of research of social media use during human-induced crises in Europe. This alley could potentially also lead to increased contact and cross-fertilization of ISCRAM with security-related events, journals or conferences (such as the European Intelligence and Security Informatics Conference, EISIC[6]).

[6] http://www.eisic.eu/

Languages and Regions: Limitations in platform and language processing capabilities are evident: Most studies deal with social media content in English, predominantly on Twitter (Reuter & Kaufhold, 2018). Due to the conference's origin in Belgium, it is no surprise that - especially in the first years - Europe was the focus of the majority of ISCRAM publications. Here, we observe a contrast to earlier studies on crisis management publications where the focus was found to lie firmly on the US (Reuter & Kaufhold, 2018).

Over time, an increasing amount of papers focuses on crises in North America and Asia. Such works also significantly correlate with the use of Twitter, which could explain the prevalence of this particular network in ISCRAM research. Interestingly, even though a substantial part of the population of the US speaks Spanish as a first or second language, research on the use of Spanish social media content is scarce. Furthermore, even though social media are used and investigated in the context of Australia and New Zealand, these seem to be all but missing from ISCRAM. Especially in 2010 and 2011, both states were hit by major disasters: The Queensland floods (Bruns et al., 2012) and the earthquake in Christchurch (Bruns & Burgess, 2012), where social media have been used by both citizens and emergency managers to a similar extent as in other examined countries.

With these biases, conducting a quantitative analysis on ISCRAM papers on the use of social media in crisis situations does not produce a representative picture of the actual situation. The topic of how the foundation of analyzed data can be extended to avoid such a limited focus will have to be addressed in the future.

Data Processing: Another obstacle for a broader analysis of social media in general is the trend towards privacy, which is likely to lead to even more complicated data-extraction scenarios. Terms of use are restricting the further processing of social media posts, such as the deprecation of Facebook's public post search[7] (Apr 30, 2015) and the introduction of Instagram's sandbox mode[8] (Nov 17, 2015). The upcoming "European General Data Protection Regulation (GDPR)[9]" may reduce the amount of user data publicly available and processable dramatically.

Automatic processing of data and especially the field of sentiment analysis have been examined by many ISCRAM papers and various solutions have been implemented. However, these still encounter problems such as gaps in NLP and text classification tools. Although these areas, along with Machine Learning, are advancing fast, there is work to be done to allow for an efficient process of information extraction, filtering, categorization and interpretation. Most of the frameworks described in papers are prototypes or theoretical results. Besides increasing the data processing capabilities, Imran et al. (2015) argue that human-centered approaches are required "toward making the computing research the foundation of viable systems that emergency responders can implement."

Technology and Industry: Our analysis indicates a relatively small contribution to actual technology and industry. Papers presented at ISCRAM are mostly written with the aim to facilitate the work of first responders and emergency managers, dealing with variations in communication supply and requirements from citizens. From a technological point of view, we observe a trend towards multimedia content supported by the heavy increase in mobile devices, faster and cheaper connectivity, and general technological advances reflected in the platforms themselves. Most contributions concentrated on text-based posts. Whereas textual content will certainly **not** disappear in the foreseeable future, media types other than text and further developments will become more frequent and relevant in crisis communication. Such shifts will require further analyses in the future.

Since its inception, being established by scholars, the conference has had a rather academic, theoretical focus. However, as we have seen from the quality of contents, ISCRAM has the potential to be the base for technological innovations and to provide substantial contributions to the area of disaster communication and management where ICT has become indispensable. By adding corresponding tracks, adjusting evaluation criteria towards practicability, and drawing experts from industry to the venue, this trend could be redirected in the future.

6. CONCLUSION AND RECOMMENDATIONS

In this work, we have carried out a quantitative analysis of all ISCRAM papers related to social media, published until 2017. Referring to the trends in social media research in the emergency management context, we found related contributions starting in 2008 and constantly increasing their shares, representing more than half of the submitted papers in 2017. Apart from analysis of predominantly English-language social media posts, a focus on the platform Twitter and on crises occuring in Europe and North America could be observed.

Our limitation to papers addressing social media in the natural-disaster context from a single conference does not allow us to offer a comprehensive overview of all research on ICT in emergency management. Furthermore, a purely quantitative review does not replace a thorough investigation of trends, problems and suggestions found in ISCRAM papers over the years. However, it did allow us to identify gaps which can be filled by future work in

[7] https://developers.facebook.com/docs/graph-api/using-graph-api/v2.0#search
[8] https://www.instagram.com/developer/changelog/
[9] https://www.eugdpr.org

this area.

To broaden the overview of contributions in the area of emergency management, a similar review will need to be carried out for other related and established conferences and journals, such as CHI, ICIS, and ISCRAM venues in localized contexts. Our suggestions also include further examination of human-induced events, works in other languages apart from English, and suitable media to support planning for, responding to and recovering from different types of crisis, as well as warning and communication for different stakeholders. The theory on users' preference of familiar social media platforms in such events can be further pursued at this point. Insights into this context can contribute to a diversification of ISCRAM research, overcoming biases found in earlier examinations of the area's literary landscape.

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APPENDIX 1: DISTRIBUTION OF THE SOCIAL MEDIA PLATFORMS ACROSS THE YEARS (FIGURE 3)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Facebook	2,20%	1,56%	3,57%	2,83%	4,41%	7,35%	7,69%	7,43%	4,59%	9,47%
Flickr	1,10%	0,00%	2,68%	0,94%	0,00%	0,00%	0,00%	1,35%	0,92%	2,11%
Instagram	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,71%	2,03%	0,00%	2,11%
Microblog	0,00%	0,00%	0,00%	0,00%	0,74%	0,00%	3,42%	1,35%	0,92%	3,16%
Mtruk	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	2,11%
OpenStreetM	0,00%	0,00%	0,89%	0,00%	2,21%	1,47%	1,71%	3,38%	4,59%	4,21%
Periscope	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,92%	0,00%
Telegram	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,05%
Twitpic	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Twitter	2,20%	3,13%	10,71%	5,66%	15,44%	14,71%	30,77%	17,57%	16,15%	27,37%
Ushahidi	0,00%	1,56%	2,68%	0,94%	2,94%	5,15%	5,13%	0,68%	1,83%	5,26%
Vimeo	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Vine	0,00%	0,00%	0,89%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Weibo	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,71%	0,00%	0,92%	0,00%
WhatsApp	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,92%	2,11%
YouTube	0,00%	0,00%	0,00%	0,94%	0,74%	0,00%	2,56%	0,68%	0,00%	1,05%

APPENDIX 2: DISTRIBUTION OF CRISIS EVENTS IN THE PAPERS (FIGURE 4)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
earthquake	0,2%	1,7%	6,4%	4,5%	4,0%	2,3%	2,9%	5,2%	8,5%	9,7%	7,9%	9,8%	17,3%	19,8%
flood	0,3%	0,6%	1,5%	4,4%	1,5%	6,3%	4,7%	7,1%	3,3%	3,7%	14,0%	14,8%	21,7%	16,0%
hurricane	0,1%	0,2%	3,8%	6,3%	6,6%	4,6%	4,3%	7,1%	3,1%	6,1%	10,9%	10,5%	18,1%	18,2%
hazard	0,4%	1,1%	3,5%	6,0%	5,7%	3,3%	1,8%	8,5%	4,4%	5,7%	19,1%	16,3%	15,4%	8,8%
wildfire	0,0%	1,9%	0,3%	0,0%	17,0%	10,4%	8,8%	5,8%	2,7%	1,6%	5,5%	16,4%	16,4%	13,2%
landslide	0,0%	4,2%	1,8%	4,2%	1,3%	0,2%	0,4%	2,2%	1,3%	5,8%	31,3%	4,4%	18,7%	24,0%
typhoon	0,5%	0,0%	4,1%	3,7%	0,5%	0,5%	1,4%	0,0%	0,9%	6,4%	15,5%	33,8%	9,1%	23,7%
tornado	0,0%	0,9%	1,9%	3,4%	0,6%	0,3%	1,9%	3,7%	20,4%	12,0%	38,6%	4,0%	3,1%	9,3%
quake	0,0%	0,0%	0,4%	0,9%	0,4%	1,8%	0,9%	0,9%	5,8%	12,4%	1,3%	4,4%	1,8%	69,0%
drought	0,0%	0,8%	3,2%	2,4%	3,2%	4,0%	0,8%	3,2%	7,3%	2,4%	6,5%	1,6%	29,0%	35,5%
avalanche	0,0%	8,2%	2,0%	8,2%	2,0%	0,0%	2,0%	0,0%	0,0%	14,3%	4,1%	34,7%	4,1%	20,4%
mudslide	0,0%	0,0%	0,0%	15,4%	0,0%	3,8%	0,0%	0,0%	0,0%	15,4%	38,5%	3,8%	7,7%	15,4%
heatwave	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	66,7%	33,3%	0,0%	0,0%
snowstorm	0,0%	0,0%	0,0%	15,0%	10,0%	0,0%	5,0%	0,0%	5,0%	5,0%	0,0%	20,0%	0,0%	40,0%
flashflood	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%	0,0%	0,0%	0,0%	0,0%
fire	2,1%	1,8%	2,5%	5,5%	5,7%	6,8%	6,3%	6,7%	7,6%	5,5%	3,5%	11,7%	15,6%	18,6%

Terror Management and Twitter: The Case of the 2016 Berlin Terrorist Attack

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ABSTRACT

There is evidence that people increasingly use social networking sites like Twitter in the aftermath of terrorist attacks to make sense of the events at the collective level. This work-in-progress paper focuses on the content of Twitter messages related to the 2016 terrorist attack on the Berlin Christmas market. We chose topic modeling to investigate the Twitter data and the terror management theory perspective to understand why people used Twitter in the aftermath of the attack. In particular, by connecting people and providing a real-time communication channel, Twitter helps its users collectively negotiate their worldviews and re-establish self-esteem. We provide first results and discuss next steps.

Keywords

Terrorist attacks, social networking sites, social media, Twitter, topic modeling, terror management, sense-making.

INTRODUCTION

Terrorism is a constant imminent threat and issue of great concern affecting nations and people worldwide (Rogers et al., 2007). Modern terrorism seeks to affect high numbers of victims, aims for global transformation of the world, and is often motivated by religious beliefs. Moreover, terrorists are frequently willing to commit suicide and use weapons of mass destruction. The organization of terrorism is often decentralized and diffuse, with its purveyors united by common goals and/or experiences rather than through direct personal interaction (Crenshaw, 2000). Further, the internet makes it particularly easy for terrorists to receive critical information, such as bomb-making tutorials, which increases the threat of lone actors (Cohen et al., 2013).

Generally, it is recognized that terrorist attacks will continue, thus increasing individuals' fear of becoming a victim (Kruglanski et al., 2013) and creating an increased sense of uncertainty and anxiety (Bux and Coyne, 2009). In the aftermath of terrorist attacks, people have been found to exhibit anxiety-reducing behavior, such as praying, searching for meaning and value, engaging in prosocial and altruistic behavior, exhibiting greater degrees of prejudice or stereotyping, and showing less tolerance and greater hostility toward groups different from themselves (Pyszczynski, 2004; Yum and Schenck-Hamlin, 2005).

Terror management theory (TMT) (Greenberg et al., 1986) provides a valuable and widely used explanation of human reactions in the terrorism context (e.g., Das et al., 2009; Dunkel, 2002; Landau et al., 2004). According to TMT (Greenberg et al., 1986), when people are reminded of their vulnerability and mortality due to terrorist attacks, they tend to employ psychological defenses aimed at reducing anxiety by embracing their worldviews (e.g., Western values and lifestyle) to overcome other worldviews (e.g., religiously motivated terrorism) and at enhancing their self-esteem (Dunkel, 2002; Pyszczynski et al., 2003). The validation of cultural worldviews and the maintenance of self-esteem are accomplished largely through interactions with others. Agreement and approval from other people provide support for the "correctness" of one's worldview and help maintain self-esteem, whereas disagreement and disapproval reduce the stability of these psychological factors (Greenberg et al., 1986).

There is also evidence that people increasingly use social networking sites (SNS), such as Facebook and Twitter, in the aftermath of terrorist attacks to make sense of the events and express sympathy at the collective level (Kaufmann, 2015). For instance, shortly after the Charlie Hebdo attacks in Paris in January 2015, the hashtag #JeSuisCharlie ("I am Charlie") spread across Twitter and Facebook as people expressed solidarity with the victims. It was the most frequently used hashtag on Twitter in the hours after the attacks (Kiwan, 2016). As TMT explains, exchanging opinions and feelings is very important for coping with terrorist attacks and reducing anxiety from the increased need to validate one's feelings and behaviors. Thus, people may use SNS to complement interpersonal communication—for example, to discuss their opinions related to an attack and to receive affirmation from others regarding their own worldviews (Fischer et al., 2016).

Typically, TMT studies use an experimental design and observe human behavior at the individual level (Burke et al., 2010). Despite this rich body of individual-level TMT research, we have less data on and understanding about the reaction to terrorism at the collective level. Therefore, the purpose of this study is to investigate how increased perceptions of mortality salience due to the terrorist attack on the Berlin Christmas market influenced the online behavior of German-speaking Twitter users. To accomplish this goal, we conduct a case study analyzing Twitter content related to the terrorist attack in Berlin on December 19, 2016. The Berlin attack took place at a time of heightened Islamist terrorist activity in Germany and neighboring countries. We provide the theoretical background and first analysis of our Twitter data in this work-in-progress paper.

The paper is organized as follows. In the next section, we provide the theoretical and conceptual background on terrorism, Twitter, sense-making, and TMT. We then present our data-collection process and methodology. Subsequent sections explain our planned data-analysis approach, next steps, and conclusion.

THEORETICAL AND CONCEPTUAL BACKGROUND

Impacts of terrorism

A terrorist attack aims to kill non-combatants as a means of influencing the attitudes and actions of individuals, nations, and their leaders (Arquilla, 2007). It is a strategic attack through which a terrorist pursues a goal motivated by religious and/or political commitment (Arquilla, 2007; Kruglanski et al., 2013). This underlying goal is typically motivated by an ideology that justifies terrorism—that is, a collective belief system to which the terrorist subscribes (Kruglanski et al., 2013, p 561). Indeed, terrorists justify their actions with the moral conceptions they form of themselves and of the world through an ideology (Atran and Ginges, 2012) that establishes a belief system in which violence against real or imagined enemies is glorified as an effective and worthy way to help one's own group or community (Kruglanski et al., 2013).

Terrorist attacks can be more psychologically threatening and devastating than other types of crises, such as natural disasters, and thus often have a greater impact on society (Danieli et al., 2005). Despite the violence, the ultimate aim of terrorism is psychological (Bux and Coyne, 2009). Anyone in the wrong place at the wrong time can become a victim, which causes people to feel personally and collectively threatened. Such attacks not only injure and kill people, but they also have the potential to destabilize governments, economic development, and civil harmony (Baez et al., 2017). Thus, because these attacks affect many individuals beyond those directly harmed physically, they constitute a social threat (Lerner et al., 2003).

As terrorist attacks are intentional, random, and catastrophic by design, they create high levels of uncertainty and feelings of fear, vulnerability, and distress (Rogers et al., 2007; Bux and Coyne, 2009). They can have both immediate and long-term effects on public health, such as acute or post-traumatic stress disorder (Rogers et al., 2007), and their random nature in terms of who may be targeted also creates an ongoing threat and can increase general perceptions of risk among a populace. For instance, Rubin et al. (2005) stressed that after a bombing attack in London, the majority of Londoners believed they or their family were still in danger. Other researchers have found that the threat of terrorism can influence social behavior, including compelling people to avoid mass events, public places, and public transit (Bux and Coyne, 2009; Crijns et al., 2017).

In summary, terrorism creates feelings of anxiety and threat in broader society and often affects people's behavior. For our context, a particularly relevant behavioral effect caused by the increased fear, uncertainty, and anger after terrorist attacks is an overall change in individuals' media usage, including their social media use (Boyle et al., 2004).

In the next section, we discuss people's SNS usage in the aftermath of crisis events.

Twitter and collective sense-making in the aftermath of crisis events

Generally, SNS platforms allow users to construct unique profiles, access digital content, and protect that content from search mechanisms. They further enable users to connect with other users of the platform and view their own connections and those between others (Kane et al., 2014). In this study, we focus on Twitter, an SNS that allows users to send and receive short texts with a maximum length of 140 characters at the date of data collection. Twitter also allows users to "follow" other users of interest, which generates notifications of new followers, likes, or repostings of tweets (so-called "retweets" of a user's content). These connections do not require reciprocity; that is, a user who is followed does not have to follow back (Huberman et al., 2009). Content on Twitter is often categorized by annotating tweets with hashtags (e.g., "#prayforberlin"). The hashtag feature is a crucial mechanism for information diffusion on Twitter and other SNS platforms in the course of crisis events.

Especially during uncertain and ambiguous crisis events, people engage in sense-making, which we define in accordance with Weick et al. (2005) as the process through which people deal with an uncertain and ambiguous situation by searching for meaning, settling for plausibility, and proceeding. During sense-making, people try to fill the cognitive gaps caused by some uncertain events and thus search for information. As Heverin and Zach (2012) explained, sense-making involves communication between individuals to find missing pieces of information, and during uncertain crisis events, this sense-making process relies heavily on interactions with others.

Making sense of crisis events is, of course, not enabled solely through SNS, but the role of SNS in crisis events has been increasing (Simon et al., 2015; Sutton et al., 2014). Because SNS enable users to interact, collaborate, and upload user-generated content in real time from devices with internet access, such as smartphones, the platforms can be of tremendous use during highly dynamic crisis situations (Mendoza et al., 2010). In addition, the real-time two-way communication and many-to-many information-broadcasting tools provided via SNS allow the public to actively participate during crisis events by browsing others' published information, posting, and leaving public comments (Palen et al., 2009). Thus, people who are not at the crisis scene can also make sense of those events by sharing, commenting, and accessing information posted in SNS (Blum et al., 2014).

Sense-making of crisis events via SNS has also been observed in man-made crises. Heverin and Zach (2012), for instance, investigated people's Twitter usage for collective sense-making during three campus shootings. They found that by following specific hashtags, people could observe not only the specific information posted by others but also their feelings, perspectives, and views. The authors concluded that Twitter served as a communication channel to connect the individual to the collective and helped Twitter users make sense of the events. Also in the aftermath of terrorist attacks, people have a need to discuss and negotiate the meaning behind the attacks with others to develop an understanding of such events (Yum and Schenck-Hamlin, 2005).

The next section introduces TMT, which argues that people who perceive an existential threat take certain social actions and uphold a particular set of values and beliefs.

Terror management theory and Twitter

The psychological effects of existential threats on people's behavior and attitudes have widely been examined through TMT (Burke et al., 2010). According to TMT, people who have been threatened existentially by reminders of their mortality (i.e., who are under conditions of what is called *mortality salience*) try to buffer their death anxiety by maintaining their self-esteem and defending their cultural worldviews (Greenberg et al., 1986). TMT claims that when thoughts of death are brought into focus, people immediately try to remove these thoughts by, for example, denying their vulnerability to death (Greenberg et al., 2000). The problem of death, however, resides beneath consciousness, so after a brief distraction from the death-related thought, the so-called distal defenses—that is, the maintenance of worldviews and self-esteem (Pyszczynski et al., 1999)—are typically triggered to buffer death anxiety. The distal defenses are outside the awareness of consciousness and are therefore not particularly obvious to individuals as they employ the defensive behavior (Burke et al., 2010).

One's *cultural worldview* is a human-constructed belief regarding the nature of reality shared by individuals in a group that helps manage the fear of death by providing a meaningful explanation of life and a comforting conception of the world. The cultural worldview also provides standards for good or bad behavior—namely, a way of life, as in a cultural, religious, or political systems—that directs people's behavior to acquire self-esteem. People's *self-esteem* is their feeling that they are significant and important contributors to their worldview; it helps people attain a literal or symbolic sense of immortality (Greenberg et al., 1986). Self-esteem and cultural worldviews are maintained by social consensus and by individuals' influencing others in accordance with their own worldviews (Pyszczynski et al., 2003).

By outlining why it is so important for people to re-establish their self-esteem and cultural worldviews after death reminders, TMT explains various human behaviors and attitudes after such reminders (Burke et al., 2010). For

instance, mortality salience can increase positive feelings about others who share similar religious and political beliefs and negative feelings toward those who differ in these aspects (Cohen et al., 2005), motivate aggression against worldview-threatening others (McGregor et al., 1998), influence people's political preferences (e.g., Landau et al., 2004; Weise et al., 2007), increase people's stereotypical thinking (Schimel et al., 1999), and lead to pro-social behavior (e.g., donating) among those who value these behaviors as a source of self-esteem (Jonas et al., 2016). Taken together, reminders of death make people aware of their mortality, which in turn triggers their need to protect their beliefs through defense strategies for maintaining self-esteem and upholding their cultural beliefs.

According to Pyszczynski et al. (2003), terrorist attacks are "natural" death reminders and can further be seen as attacks against people's cultural worldviews (e.g., basic Western beliefs and values like democracy). In this context, SNS like Twitter help users collectively negotiate their worldviews through their social environment by connecting people and providing a real-time communication channel. In particular, the hashtag feature makes it very easy to follow and find relevant information. The information sent by many different users helps the individual build an overall picture and acquire understanding (Heverin and Zach, 2012). In addition, offering their opinions or personal views helps people verify their feelings and re-establish a secure value system of meaning (Pyszczynski et al., 2003).

In summary, TMT gives us a framework to investigate the utility of communication via Twitter in the aftermath of the Christmas market attack. Hence, to make sense of our data, we use the following eight common distal terror-management reactions based on Pyszczynski et al. (2003) that were identified by Yum and Schenk-Hamlin (2005) after the 9/11 attacks as a classification scheme for our further analysis: (1) an increase in the search for meaning and value; (2) nationalistic sentiment, decreased tolerance, and greater hostility toward different values and views; (3) actively countering bigotry; (4) altruistic or prosocial behaviors; (5) gratitude for "heroes" associated with the attacks; (6) increased personal communication; (7) increased information seeking and sharing; and (8) no action.

In the next section, we describe our Twitter data on the Christmas market attack in Berlin, show our initial results from our data analysis, and explain our classification scheme in more detail.

METHOD

Case description

On December 19, 2016, a truck was hijacked and then intentionally driven into a crowded Christmas market at Breitscheidplatz in Berlin, Germany. Before the truck was finally stopped by its automatic brakes, 12 people had been killed and more than 50 people were injured. One victim was the Polish truck driver who was found murdered in the cab. Shortly after the attack, a Pakistani suspect was arrested but released without charge after the police determined he had not been involved in the attack. The police stated that the actual perpetrator was still on the loose, possibly armed and dangerous. On December 21, Anis Amri—a Tunisian who had failed to gain asylum in Germany and was said to have pledged allegiance to the Islamic State terrorist group—was announced as the chief suspect. He was found in Italy on December 23 and shot dead by police after he opened fire (dpa, 2017).

From the time of the initial terrorist attack and over the following days, public authorities used Twitter to inform the public about the investigation.

Data collection and descriptive statistics

We chose Twitter for our data collection because so many people used the platform to exchange information in the aftermath of the Berlin Christmas market terrorist attack. Although Twitter is not as widely used in Germany as Facebook in terms of general social media activities, it is a crucial platform on which user-generated instant reports of news events circulate. We connected to Twitter's application programming interface (API) to acquire tweets related to the Berlin attack. The API offers several endpoints to extract tweets, most notably the "Search API," which can be utilized to retrieve historical tweets published in the past seven days, and the "Streaming API," which generally allows for retrieving at most a 1% sample of all tweets for a given query (Morstatter et al., 2013) in real time. To avoid any rate limits, we collected our data with the Search API and collected all tweets including the following (translated) hashtags, which were used in the week of the Berlin attack in Germany: #berlinassassination, #breitscheidplatz, #berlinattack, #berlinattacks, #christmasmarketattack, #prayforberlin, #prayforgermany, #Iamaberliner, #weareberlin, and #bestrongforberlin.[1] More specifically, we constructed a query for retrieving all tweets that contained at least one of these hashtags created between December 19 and 25,

[1] Table A1 in Appendix A shows the original German spellings for these hashtags.

2016. We removed retweets and kept only tweets Twitter classified as being in the German language for two reasons. First, our empirical approach requires proper interpretation of a statistical model fitted on large quantities of textual data for which mixing texts of different languages is problematic. Second, because the terrorist attack happened in a German city, we made the assumption that Germans—and thus German speakers—were most likely exposed to the attack by media or locally in Berlin. This approach is not without limitations: for example, Germans could have tweeted in other languages. However, other approaches, such as filtering data by geolocation, are not appropriate alternatives because only a very small share of tweets include information about user location. While our approach might underestimate the total number of tweets referring to the terrorist attack, it enabled us to create a robust data set of relevant tweets. After applying the filtering procedures, our final dataset includes 51,256 tweets posted by 22,439 users.

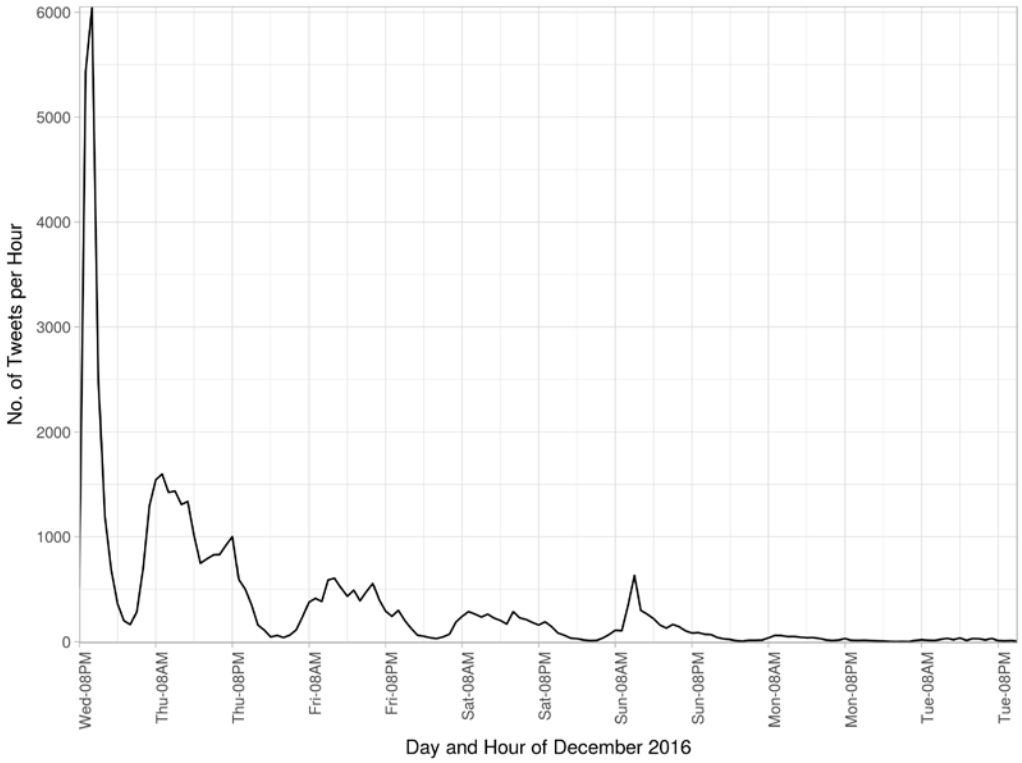

Figure 1. Number of tweets per hour in Germany in the December week of the Berlin attack

Figure 1 shows the number of tweets per hour on the day of the attack and on subsequent days. The plot shows that our sample includes tweets that were posted immediately after the attack took place (around 8:00 p.m.). In addition, most of the Twitter content related to the terrorist attack was posted during the first two days. In contrast, only about 15% of all tweets were posted between December 21 and December 25. This is not surprising given that both desire for information and uncertainty are high shortly after a terrorist attack happens—when lives are at stake—and people will urgently seek to clarify the situation to ease their own anxiety and uncertainty (Lachlan et al., 2009).

Topic modeling

Ideally, human coders would examine and manually annotate each tweet of a dataset to gain detailed insights into SNS usage related to terrorist attacks. As this was not feasible for a dataset comprising more than 50,000 observations, we instead relied on topic modeling as a method for automatic content analysis. Topic models enable the automatic discovery of latent topics from text documents. A topic is a set of words representing interpretable themes within documents (tweets in our dataset). Documents, in turn, are represented as a mixture of these topics. Therefore, after fitting a topic model, a tweet contains proportions of several topics. Generally speaking, a tweet might be ascribed mainly to one certain topic (e.g., with a proportion of 60%) and to other topics with a smaller proportion (e.g., a proportion of 30% to a second topic and 10% among remaining topics). As the tweets at the time of the terrorist attack were limited to 140 characters, their content often strongly refers to one specific topic. As an illustration of this concept using our data, 80% of topic proportions of the tweet “Our wholehearted sympathy for all victims and their families” posted on December 20 relate to a single topic of one of our topic models. In addition, each topic is modeled as a probability distribution over words, which indicates the most

important words of a topic. For instance, among the most important words of one of our topics are "happened," "why," and "dead."

To prepare for topic modeling, all tweets were processed into a corpus using common text-analysis methods. Tweets were treated as bags of words, with each term representing a feature and word order being disregarded. In addition, terms without semantic meaning, such as German equivalents for the stop words "the" or "a," were removed from the corpus. Furthermore, to group words with similar semantic meaning, we applied stemming to all words (i.e., reducing inflected words to their word stem), which means that terms like "family" and "families" reduce to the word stem "famili" (Grimmer and Stewart, 2013). In considering the most probable terms, we excluded hashtags that were used to identify tweets related to the Berlin attack such as #berlinattack because they do not reveal any new information on the topic.

As our data includes not only tweets on the day of the terrorist attack but also of the following days, we expected that content related to the Berlin attack would differ over the course of time. For that reason, we utilized a special variant of topic models called the structural topic model (Roberts et al., 2014; Roberts et al., 2016). In addition to representing documents as distributions over topics, structural topic models allow for the inclusion of document-specific covariates that influence topic proportions for each document. Drawing on this feature, we incorporated a dummy variable in our model indicating whether a tweet was posted on the day of and the day after the terrorist attack or in the five days following.

Although topic modeling is very useful to categorize large text corpora, it is limited as one must manually determine the number of topics. To fit a model that best represents the data given our attempt to gain insights about Twitter usage during and after terrorist attacks, we fitted four different models with 10, 20, 30, and 40 topics. To determine the best model, we then calculated semantic coherence and exclusivity, which are measures that quantify necessary statistical properties: semantic coherence is higher if more probable words in a topic frequently co-occur together (Mimno et al., 2011), whereas exclusivity is higher if more words are exclusive to their corresponding topics (Lucas et al., 2015). Figure A2 in Appendix A illustrates the average and median values for both measures and all four models. In terms of desirable statistical properties, the figure shows that smaller models with 10 and 20 topics outperform the larger models with 30 and 40 topics.

Manual analysis and next analysis steps

In addition to statistical diagnostics, validation by humans is the most important way to evaluate topic models (Chang et al., 2009; Wallach et al., 2009). To ease the evaluation procedure, we built a web application based on the R Shiny framework (Winston et al., 2017), which reports the key results and figures of a topic model and thus helps in qualitative data analysis.[2] In the next step, two of the paper authors will independently investigate the models with 10 and 20 topics by analyzing the most likely words and tweets with the highest proportions for a given topic to determine if the structure makes sense. We will assign corresponding labels in accordance with the highest proportions of words and highly representative documents for each topic. Thereafter, we will compare our results and check the inter-coder reliability (Debortoli et al., 2016). The model that turns out to be the best and most intuitive model in relation to our research task will be chosen as our final model.

Similar to the procedure before, we will make sense of the topics by independently mapping the topics of our final model to typical TMT reactions based on the definitions by Yum and Schenk-Hamlin (2005). Table 1 gives an overview of the eight reactions and corresponding examples.

Table 1. List of TMT reactions

No.	Reaction	Examples
1	Search for meaning and value	Prayer, going to religious services, candlelight vigil
2	Nationalistic sentiment, decreased tolerance, and greater hostility toward different values and views	Prejudice, stereotyping, listening to more traditional patriotic songs, derogating different cultural values
3	Counter-bigotry activism	Calling for tolerance and understanding
4	Altruistic or prosocial behaviors	Empathy, comforting, donation

[2] At the time of writing, the web application is publicly available at http://www.polsoz.uni-bamberg.de/stminsights_berlin. Should the URL become unavailable, please contact the authors of this paper.

5	Gratitude for "heroes" associated with the attacks	Respect for firefighters who helped in the aftermath of an attack
6	Personal communication	Calling friends and family, bolstering the value of relationships
7	Information seeking and sharing	Watching TV, talking to people for relevant information
8	No action	-

CONCLUSION

Our purpose is to identify common terror-management reactions on Twitter in the aftermath of the 2016 Berlin Christmas market terrorist attack. According to Pyszczynski et al. (2003), terrorist attacks are "natural" death reminders, and thus, the Twitter users in our data set (i.e., Twitter users who posted something related to the Christmas market terrorist attack) were under conditions of mortality salience. Using TMT, we provide a meaningful explanation of the emergence of psychological needs in the aftermath of terrorist attacks that drive SNS usage—that is, increased needs to defend cultural worldviews and maintain individual self-esteem. Ultimately, the study will contribute to our understanding of people's SNS usage behavior and sense-making via Twitter in the aftermath of terrorist attacks at a collective level.

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APPENDIX A

Table A1. Translation of hashtags

Original spelling	Translation
#anschlagberlin	#Berlinattack
#berlinattack	-
#berlinattacks	-
#berlinattentat	#Berlinassassination
#breitscheidplatz	-
#christmasmarketattack	-
#ichbineinberliner	#IamaBerliner
#prayforberlin	-
#prayforgermany	-
#wirsindberlin	#weareBerlin

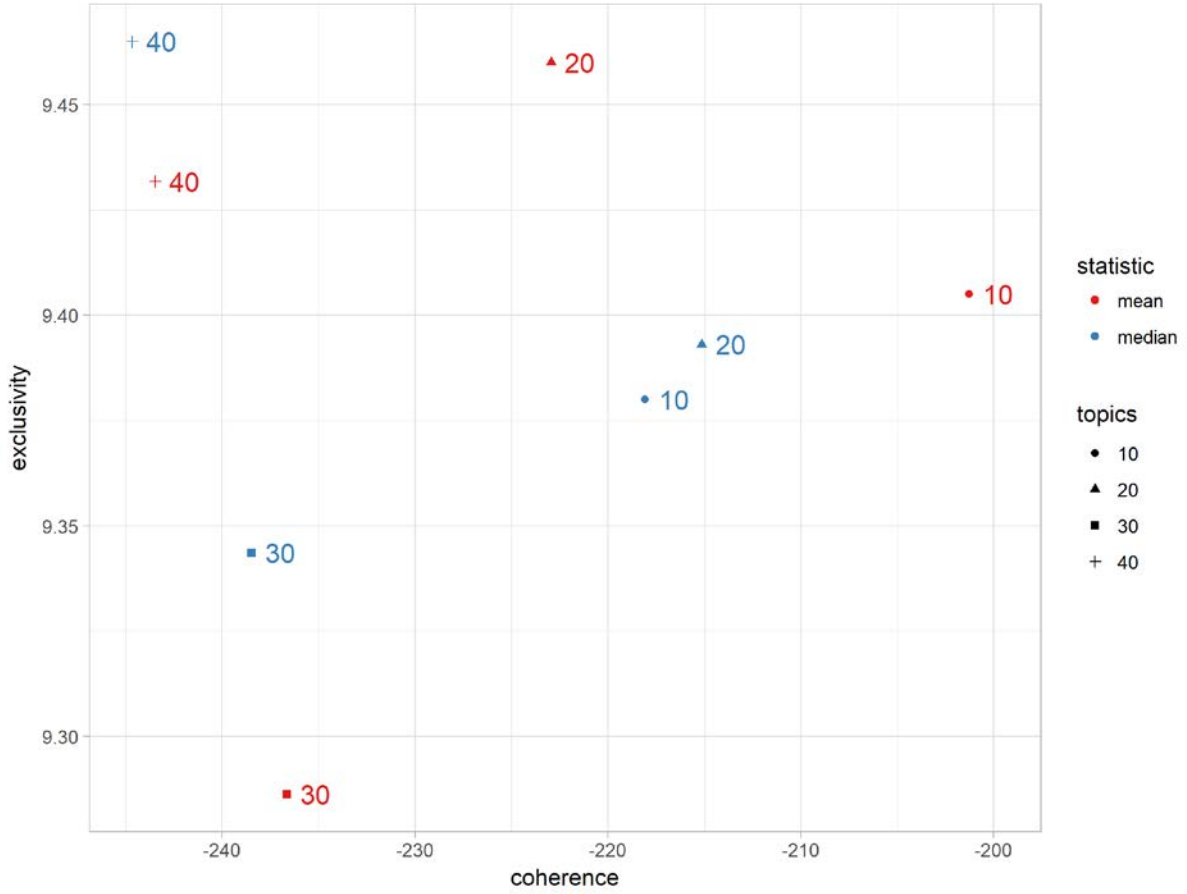

Figure A2. Model diagnostics for structural topic models. Mean and median statistics are computed over all topics of the corresponding model

Communicating Crisis with Persuasion: Examining Official Twitter Messages on Heat Hazards

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ABSTRACT

Official crisis messages need to be persuasive to promote appropriate public responses. However, little research has examined the content of crisis messages from a persuasion perspective, especially for natural hazards. This study deductively identifies five persuasive message factors (PMFs) applicable to natural hazards, including two under-examined health-related PMFs: *health risk susceptibility* and *health impact*. Using 2016 heat hazards as a case study, this paper content-analyzes heat-related Twitter messages (N=904) posted by eighteen U.S. National Weather Service Weather Forecast Offices according to the five PMFs. We find that the use of descriptions of *hazard intensity* is disproportionately high, with a lack of use of other PMFs. We also describe different types of statements used to signal the two health-related PMFs. We conclude with implications and recommendations relevant to practitioners and researchers in social media crisis communication.

Keywords

Persuasion, crisis communication, susceptibility, social media, heat hazards.

INTRODUCTION

Government agencies often communicate messages to the public during a crisis to help the public appropriately respond and thus decrease adverse impacts. Previous studies have recognized that crisis messaging should be constructed in an up-to-date and informative manner (Mileti and Sorensen, 1990; Reynolds and Seeger, 2005). However, little research attention has been paid to probing the content of crisis messages for its potential contribution to persuasion, especially when those messages are sent through social media. The persuasive perspective of crisis messages refers to a message's ability to persuade members of the public to take appropriate action. The lack of recognition of message content that potentially contributes to message persuasion (i.e., persuasive message factors, PMFs) may result in noncompliance to lifesaving crisis messages by members of the public. To bridge this knowledge gap, we identify five PMFs indicative of effective persuasion for natural hazards. We then investigate the usage of these PMFs in crisis messaging by analyzing the content of Twitter messages ('tweets') posted by National Weather Service (NWS) Weather Forecast Offices (WFOs) about heat hazards.

Some PMFs that play different and potentially critical roles in persuasion are often overgeneralized in previous studies with an emphasis on the informativeness of crisis messages. For example, studies in the natural hazards field often combine descriptions of the physical characteristics of a hazard itself and descriptions of hazard impacts as one content theme regarding hazard information (Mileti and Sorensen, 1990; Sutton et al., 2015a). However, this theme includes

multiple PMFs such as the intensity of a hazard, the uncertainty of a hazard, the subgroups that are vulnerable to hazard impacts, and the potential consequences of being affected. From an informative perspective, the nuances of message content may not be significant enough to be separate content themes. However, from a persuasive perspective, descriptions of hazard intensity, hazard uncertainty, sensitive groups, and potential health impacts can be viewed as four types of message content because they may have varying roles in message persuasion.

PMFs warrant greater attention in crisis messaging because they have been shown to have significant effects on message compliance in other communication fields such as health communication (Maddux and Rogers, 1983; Murray-Johnson and Witte, 2003). A lack of investigation and recognition of PMFs in the context of natural hazards may result in the absence of well-designed PMFs in crisis messages, especially when messages are communicated via short messaging channels such as Twitter. This research deductively identifies five PMFs indicative of persuasion in the context natural hazards, especially two under-recognized PMFs: *health risk susceptibility* and *health impact.* We then, for the first time, investigate to what extent each of the PMFs is included in crisis messages and what typical statements are used to communicate the two under-examined PMFs. To our knowledge, such investigations have not been conducted for crisis messages communicated through any platforms, no matter social media or traditional media. Our investigation of PMFs through social media could have implications to promote crisis messaging communicated via other platforms such as word-of-mouth and television. For some vulnerable subgroups, such as the elderly who may be less reachable via social media messages, our research findings could benefit them by contributing to better crisis messaging communicated via other platforms.

Crisis Messaging over Social Media

In recent years, social media have provided an expanded communication channel where emergency responders can share and gather timely information during crisis events (Hughes and Palen, 2012). Past research has looked at how emergency responders and other sources of official information have used social media to communicate with the public (Chauhan and Hughes, 2017; Denef et al., 2013; Hughes et al., 2014). Studies have focused on the informational content of responder messages (Chauhan and Hughes, 2017; Hughes et al., 2014), the style of communication that responders use (Denef et al., 2013), or the ways that responders seek to foster trust in their messaging (Hughes and Chauhan, 2015). No studies have examined how crisis messages, shared through responder social media, persuade members of the public toward protective action.

Crisis messages on Twitter, Wireless Emergency Alerts, and text messages are brief due to character limits (Sutton et al., 2015b). However, character limitation should not compromise the persuasiveness of messages, but highlight the urgency of providing evidence-based suggestions on which PMFs are critical for effective communication.

Identifying Five PMFs

The five PMFs deductively identified in this paper are 1) *hazard intensity*, 2) *hazard uncertainty*, 3) *health risk susceptibility*, 4) *health impact*, and 5) *response instruction*. Among them, *health risk susceptibility* and *health impact* are also called health-related PMFs. This study identifies the five PMFs based on previous research, following the deductive approaches outlined by Schreier (2014).

Hazard Intensity and Hazard Uncertainty

Hazard intensity refers to the intensity of a hazard itself, e.g., the temperature during heat hazards. *Hazard uncertainty* is the uncertainty of an event occurring, e.g., the possibility of a flood happening. The intensity and the uncertainty of a hazard itself are components commonly involved in crisis messages. Although a growing body of literature tests the effectiveness of alternative ways of communicating hazard uncertainty (Spiegelhalter et al., 2011), it is unclear to what extent *hazard uncertainty* and *hazard intensity* are communicated in crisis messages. Previous studies for natural hazards often combined the two PMFs and other message content such as impacted areas as one single theme (Sutton et al., 2015a; Vos, 2016), and as a result little is known about the degree to which each of the two PMFs was included in crisis messages. This paper separately examines the usage of *hazard intensity* and *hazard uncertainty* because they may influence different psychological aspects of how the public processes crisis messages.

According to the Extended Parallel Process Model (EPPM) and related empirical studies, perceived susceptibility and perceived severity are two critical persuasive concepts for information-processing and decision-making under risks

(Murray-Johnson and Witte, 2003; Witte, 1992). Perceived susceptibility describes an individual's belief regarding the likelihood of experiencing the adverse impact of a threat, and perceived severity refers to the magnitude of harm an individual feels as the result of the threat (Murray-Johnson and Witte, 2003; Witte, 1992). People are likely to simply ignore crisis messages if they do not feel themselves to be at risk or that potential impacts are significant (Mileti and Sorensen, 1990; Murray-Johnson and Witte, 2003). Although future research is needed to empirically test how each persuasive concept (i.e., perceived susceptibility and perceived severity) is influenced by descriptions of *hazard intensity* and *hazard uncertainty*, we hypothesize that communicating the uncertainty of a hazard happening is likely to influence audiences' perceived susceptibility of being impacted since both perceived susceptibility and *hazard uncertainty* are related to probability. On the other hand, *hazard intensity* described in crisis messages may influence an individual's perceived severity of being impacted, and further influence decisions about whether protective action is needed.

Health Risk Susceptibility and Health Impact

The PMF of *health risk susceptibility* refers to message content depicting which subpopulation and/or what behaviors are vulnerable to the health impacts of hazards. The PMF of *health impact* mentions illness or death as health outcomes of hazards. These two PMFs are also called health-related PMFs in this paper.

The message content regarding *health risk susceptibility* and *health impact* have not been well defined and recognized in the field of crisis communication during natural hazards. We identify *health risk susceptibility* in light of communication challenges suggested by previous empirical studies on heat risk perception. Conventional heat-health messages often single-out the elderly as a particular vulnerable subgroup, and several studies on extreme heat hazards have put forward alternative ways to communicate heat-health vulnerability due to undesired outcomes of traditional messaging (Wolf et al. 2010; Sampson et al. 2013). Past studies found that although elderly respondents knew older people are vulnerable to the impacts of heat, many seniors defined older or elderly people as those with ages above their own, not themselves, and thus denied they are personally vulnerable to heat-health impacts (Wolf et al. 2010; Sampson et al. 2013). According to EPPM theory discussed above, if people think adverse consequences cannot happen to themselves, they may well ignore the risks communicated via crisis messages (Murray-Johnson and Witte, 2003). In addition to specific subgroups such as the elderly and the sick, who are vulnerable to heat-health impacts due to compromised thermoregulatory capacity, everyone can be vulnerable to health impacts from heat hazards caused by risky behavior such as outdoor activities in high-heat conditions (Mora et al., 2017). As a result, it is critical for crisis messages to clarify which subpopulation and what behaviors are vulnerable to health impacts. In response, our study identifies *health risk susceptibility* as one message factor to examine.

We identify the *health impact* PMF based on the affect heuristic theoretical framework and prior empirical research in the natural hazards field. The affect heuristic describes the important role affect plays in influencing decisions and motivating behaviors (Slovic et al., 2007). Negative feelings motivate individuals to take actions that are expected to avoid the negative feelings, and positive feelings stimulate actions predicted to repeat such positive feelings (Slovic et al., 2007). Previous empirical research has found that stronger negative affect associated with the consequences of a flood may explain better flooding preparation for people with previous flood experience, compared to those who were not affected (Siegrist and Gutscher, 2008). Accordingly, scholars called for better communication that "help people to envisage the negative emotional consequences of natural disasters" (Siegrist and Gutscher, 2008, p. 771). In response, we identify *health impact* (which includes mentions of illness and death) as one PMF, because these mentions may invoke unpleasant feelings associated with personal or vicarious adverse health experiences. Such feelings may trigger protective actions to avoid the adverse health impacts of hazards as well as the negative feelings.

Response Instruction

The last PMF investigated in this paper is *response instruction* (i.e., providing advice on protective actions). *Response instruction* has the potential to improve perceived efficacy of recommended actions (i.e., resulting in higher confidence both in performing recommended actions and in achieving desired outcomes) which may lead to better adaptive behaviors under risks (Murray-Johnson and Witte, 2003). Unlike the other four PMFs, this PMF has been frequently coded as a separate category in crisis messages (e.g.,Vos, 2016), and this paper also codes *response instruction* as a separate PMF.

Heat-related Tweets and Heat Warning Tweets

Our investigation focuses on heat hazards, the leading cause of weather-related fatalities in the U.S. over the past few decades (NWS, 2017). We propose two research questions in this study. 1) To what degree are the five PMFs (i.e., *hazard intensity*, *hazard uncertainty*, *health risk susceptibility*, *health impact*, and *response instruction*) included in heat-related tweets and heat warning tweets posted by U.S. NWS WFOs? 2) How do heat-related tweets describe the two health-related PMFs (i.e., *health risk susceptibility* and *health impact*)? For the first research question, we quantify the usage of the five PMFs among two types of messages: heat-related tweets and heat warning tweets. For the second research question, since this is the first effort to investigate detailed statements of the under-examined health-related PMFs, this paper focuses on heat-related tweets in general, and does not separately investigate heat warning tweets.

Heat-related tweets refer to specific current and/or upcoming heat events. We further separate heat-related tweets into two categories, heat warning tweets and non-warning heat-related tweets. To be considered a heat warning tweet, a heat-related tweet must mention at least one of the three NWS's heat-related watch, warning, and advisory (WWA) products: 1) an Excessive Heat Watch, 2) an Excessive Heat Warning, or 3) a Heat Advisory product. If heat-related tweets do not mention any active heat WWAs, these heat-related tweets are non-warning heat-related tweets. For example, the tweet "LOT continues Excessive Heat Warning for Kendall, Will [IL] till 7:00 PM CDT https://t.co/fCPmYyYojR" (the URL linked to a map showing the affected areas of this excessive heat warning) is a heat-related tweet and also a heat warning tweet. However, the following tweets are heat-related tweets but not heat warning tweets, since they alert the public about current and/or upcoming heat events but do not mention any current or upcoming in-effect heat WWAs: "225pm: Now officially a high of 118 in Phoenix. Ties for the 5th hottest temperature ever recorded in Phoenix." and "High of 94 degrees at #Shelton today! Hottest day since June 5. #wawx".

In this paper, we quantify the usage of PMFs for both types of messages: heat-related tweets and heat warning tweets. All heat-related tweets and the subset of heat warning tweets are important types of heat risk messages and need to be persuasive to protect public health from heat hazards. Heat warning tweets alert the public about extreme heat events. The official heat WWAs mentioned in heat warning tweets indicate potentially dangerous conditions for much of the population (NWS, n.d.b). Heat-related tweets contribute to protecting the public from adverse impacts of all heat events, both extreme heat events and non-extreme heat events. Extreme heat events are dangerous. For non-extreme heat events when heat conditions were not hot enough or their duration was not long enough to issue heat WWAs, negative heat-health impacts are still possible for heat-sensitive populations such as children and the elderly, and those working or being active outside. Prior studies on heat-health impacts have found that in addition to the intensity of temperature and humidity, social vulnerability factors such as age and adaptive behaviors are key determinants of heat-health impacts (Bouchama et al., 2007; Kovats and Hajat, 2008). Measuring usage of these PMFs in heat-related tweets will help describe an aggregate level of factor usage for all tweets alerting the public about heat-health risks. By quantifying factor usage for both heat-related tweets and heat warning tweets, we improve our understanding of factor usage and inform message design for both heat risk messages in general and warning messages about extreme heat events.

METHOD

We selected eighteen NWS WFOs across the U.S. from among the total 123 WFOs using purposive sampling. These sampled offices (see Figure 1) reflect critical variations among the field offices regarding the local climate of forecast areas and regional variation across the four NWS regions in the continental U.S.

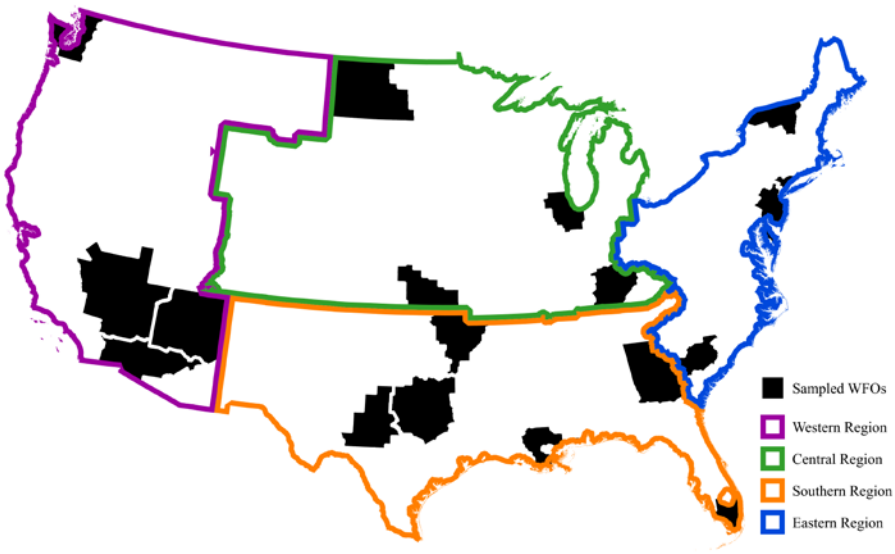

Figure 1. Map showing the distribution of the sampled NWS WFOs, and the NWS regional offices' operational boundaries. White lines separate adjacent WFOs. No WFOs are across NWS regional boundaries.

Second, for each of these sampled offices, the most recent 3200 tweets were collected from their official Twitter accounts using the Twitter Search application programming interface. To narrow the scope to tweets most likely to be heat-related, we extracted tweets containing the English words "heat" or "hot" in the message text. We also restricted the data collection window to the meteorological summer of 2016 (June 1- August 31, 2016, UTC), when most heat events happen. Only original public tweets were included in the final *Heat Data Set* by removing public retweets and reply tweets. The final *Heat Data Set* contained 1,139 tweets for the next step in the analysis, human coding.

Each tweet in the *Heat Data Set* was first coded as heat-related tweets, "other on-topic" tweets, or off-topic tweets. No further coding took place for "other on-topic" tweets and off-topic tweets. This topic variable aims to identify heat-related tweets that are suitable and comparable to code for the five PMFs. For example, we found intensity and uncertainty of a specific heat event often were not applicable for general education tweets independent from specific heat events. Heat-related tweets indicated that specific current and/or upcoming heat events either are occurring or will occur in the forecast areas. "Other on-topic" tweets were on the topic of heat but not dependent on specific current or upcoming heat events. These tweets included general education messages independent from specific heat events, tweets stating a break in recent heat events, and tweets in which it was difficult to tell without local knowledge whether the weather condition reported in the tweets was cool or hot (e.g., tweets reporting forecast heat indices less than 100 °F or temperature less than 95 °F and containing no other information signaling that the forecast condition is hot). Off-topic tweets were not on the topic of heat, for example, tweets posting photos of storms or hail and containing no heat information. The first author was the first coder and an undergraduate researcher worked as the second coder. Two coders split coding tasks. A 20% subset of tweets was randomly selected and both coders coded the subset independently to check the reliability of the coding process. For intercoder reliability, the Cohen's Kappa for this topic variable was 0.83. Among the heat-related tweets, we further coded heat warning tweets which mentioned at least one of heat WWAs that are or will be in effect (Cohen's Kappa = 0.97).

Next, we developed a coding scheme for PMFs with a directed approach of content analysis (Hsieh and Shannon, 2005). We deductively identified five PMFs as initial coding categories: 1) *hazard intensity*, 2) *hazard uncertainty*, 3) *health risk susceptibility*, 4) *health impact*, and 5) *response instruction*. Based on a sample of tweets, we clarified operational definitions for each category. The operational definitions were tailored in response to heat hazards and captured key message content corresponding to each PMF. The coding scheme (see Table 1) was finalized after pilot coding and discussion. All information in each tweet that is visible to Twitter users was included in the coding, including the displayed text (which has a character limit of 140) and textual information in attached images. We coded all heat-related tweets, including heat warning tweets, for different PMFs. If a single tweet contained more than one PMF, multiple codes responding to each PMF mentioned by the tweet were applied to this single tweet. The intercoder

reliability coefficients, Cohen's Kappa, were above 0.93 across these five factor variables.

PMF	Definition	Tweet Example
Hazard Intensity	Refers to tweets that mention Heat Index (HI) and/or the temperature of current and/or upcoming heat events	"The #heatwave continues w/ heat indices of 105-111 expected today!"
Hazard Uncertainty	Refers to tweets that contain the degree of forecast uncertainty with the temperature or HI for the upcoming weather.	"6-10 DAY OUTLOOK TEMPERATURE PROBABILITY. (With color ramps showing) Probability of Below (Normal) and Probability of Above (Normal)."
Health Risk Susceptibility	Refers to tweets that contain information signaling who, which behaviors and/or which places (e.g., outdoor, on the beach) are vulnerable to heat-health impacts.	"Who's At High Risk? Much of the population, especially those who are heat sensitive and anyone without effective cooling and hydration."
Health Impact	Refers to tweets that contain at least one word indicating heat-related illnesses and/or deaths.	"Take frequent breaks, stay hydrated and wear light-weight clothing to avoid heat-related illnesses."
Response Instruction	Refers to tweets that contain generic and/or specific heat safety tips.	"Stay cool! – Use air conditioning if possible; fans alone DO NOT provide enough cooling when it is very hot outside."

Table 1. Coding Scheme and Examples for PMFs

RESULTS

In total, 904 tweets were identified as heat-related tweets. Among them, 224 (25%) were heat warning tweets. All eighteen sampled accounts posted at least thirteen heat-related tweets, with an average of 50 (SD = 30). Fifteen accounts posted heat warning tweets, with the exception of the official Twitter accounts for the NWS WFOs of Atlanta/Peachtree City (Georgia), Bismarck (North Dakota), and Burlington (Vermont). We found in some cases, heat-related tweets did not mention co-occurring heat WWAs. For example, the Atlanta WFO did issue a heat advisory and the Bismarck WFO issued an excessive heat warning and a heat advisory during the same time period the tweets were collected (Iowa Environmental Mesonet, 2017), but the corresponding heat-related tweets in both accounts did not contain any mention of these heat WWAs. We suspect that a lack of coordinated social media practices may have contributed to these two accounts missed co-occurring heat WWAs.

Descriptions of Health-related PMFs

We investigated two health-related PMFs including *health risk susceptibility* and *health impact*. Given that previous studies have rarely examined these two health-related PMFs in the field of natural hazard communication, here we provide detailed descriptions on how heat-related tweets communicated these two factors.

For *health risk susceptibility*, four types of statements, separately or jointly, appeared in heat-related tweets to explicitly or implicitly signal susceptibility to heat-health risk. First, some messages indicated that a certain subpopulation such as children and/or the elderly is more vulnerable to health impacts from the heat event. These were "subpopulation" statements. Second, some messages signaled higher heat-health risks associated with certain behaviors and/or certain places such as traveling, working outside, or going to the beach. These were "behavior/place" statements. Third, some messages emphasized that heat can potentially harm everyone without appropriate adaptation (see the susceptibility example in Table 1). These were "anyone" statements. Last, some messages indicated that it is worth paying attention to heat-health risks everywhere, not just in specific places. These were coded as "everywhere" statements. In "behavior/place" statements and "everywhere" statements, the place does not refer to the administrative areas such as a county or a city, but generic situations such as outdoors, indoors, the workplace, the home, etc. The

health risk susceptibility PMF either used one type of these statements or simultaneously used several types of statements to illustrate the concept of susceptibility.

For the other health-related PMF, *health impact*, some messages conveyed the health consequences of sickness or death with generic statements such as "Avoid risk of heat related illness" and "deadly heat". Some messages specifically stated health impact with a long list of symptoms of heat exhaustion and heat stroke, and/or heat-related fatality statistics in recent years.

As an illustrative example, the heat-health message in Figure 2 combines "subpopulation" statements, "behavior/place" statements, and "everywhere" statements for *health risk susceptibility*, and generic statements for *health impact*. This image appears on the NWS heat safety website (http://www.nws.noaa.gov/os/heat/), and was also attached to some of the heat-related tweets in our data set. In the message contained in the image, "subpopulation" statements include "Check up on the elderly, sick and those without AC" and "Never leave kids or pets unattended – LOOK before you LOCK" which implicitly indicate that certain subpopulations are vulnerable to heat-health risks. Moreover, "behavior/place" statements were used in this message by listing four places exposed to heat-health risks, i.e., "Job Sites", "Indoors", "Vehicles", and "Outdoors". Last, the statement "Practice HEAT SAFETY Wherever You Are" is one example of an "everywhere" statement that implies all places have potential for heat-health risks.

Although the statements in Figure 2 implicitly pointed out the associated risks, the four types of statements (i.e., "subpopulation" statements, "behavior/place" statements, "anyone" statements and "everywhere" statements) can also be explicit. The example of susceptibility found in Table 1 states "Who's At High Risk? Much of the population, especially those who are heat sensitive and anyone without effective cooling and hydration." In this example, the heat-health risks are explicitly linked to heat sensitive populations and anyone with poor adaptation ability by asking, "Who's At High Risk?" Figure 2 also includes a generic statement of *health impact*: "Heat related deaths are preventable."

Figure 2. A heat-health message posted on the NWS heat safety website and used by some heat-related tweets. This message illustrates how heat-related tweets describe *health risk susceptibility* and *health impact*. Source: http://www.nws.noaa.gov/os/heat/

Descriptive Statistics of PMFs

Results indicate (Figure 3) that *hazard intensity* was by far the most frequently used PMF in heat-related tweets (84%) and heat warning tweets (71%) as well. More than half of all heat-related tweets (n=484, 54%) only contained the *hazard intensity* PMF, without mention of any of the other four PMFs. *Response instruction* was the next most used PMF (heat-related tweets: 37%, heat warning tweets: 46%). A relatively small percentage of tweets contained the PMF of *health risk susceptibility* (heat-related tweets: 20%, heat warning tweets: 29%), and even less for the PMF of

health impact (heat-related tweets: 11%, heat warning tweets: 17%). *Hazard uncertainty* was rarely mentioned in both heat-related tweets and heat warning tweets, possibly because the forecast of heat is generally perceived as accurate (EPA, 2006). Three PMFs—*health risk susceptibility*, *health impact*, and *response instruction*—were more frequently included in heat warning tweets than overall heat-related tweets, but the differences were small. The use of each PMF had the same position rank in both heat-related tweets and heat warning tweets.

For both heat-related tweets and heat warning tweets, tweets using only one of the five PMFs accounted for the largest proportion (heat-related tweets: 56%, heat warning tweets: 30%). Surprisingly, many heat warning tweets contained none of the PMFs investigated in the paper (n= 53). For example, "LOT continues Excessive Heat Warning till Jul 22, 7:00 PM CDT https://t.co/fCPmYyYojR" (the URL linked to a map showing the affected areas of this excessive heat warning). For both types, more than half of the tweets used zero or one PMF (heat-related tweets: 54%, heat warning tweets: 64%). The proportion of tweets containing at least one of the two health-related PMFs were less than two fifths, 24% for all heat-related tweets and 38% for heat warning tweets.

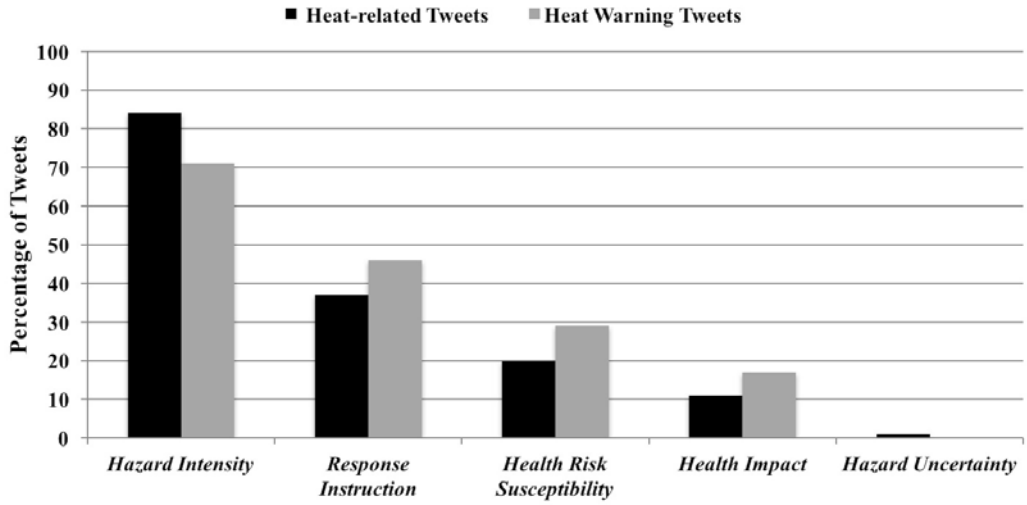

Figure 3. The Percentage of Each Type of Tweet Containing a Certain PMF

The Number of PMFs	Number of Heat-related Tweets (n=904)	Number of Heat Warning Tweets (n=224)
0	75(8%)	53(24%)
1	506 (56%)	67(30%)
2	132(15%)	26(12%)
3	157(17%)	66(29%)
4	33(4%)	12(5%)
5	1(0%)	0(0%)

Table 2. The Number of Each Type of Tweet that Contain Varying Numbers of Different PMFs.

DISCUSSION

During the meteorological summer of 2016, 904 tweets posted by 18 sampled NWS WFOs were heat-related tweets that alerted the public about current or upcoming hot weather. Three quarters of these heat-related tweets were not heat warning tweets, which means only one quarter of heat-related tweets mentioned active heat WWAs. This suggests

that although heat warning tweets are a critical subset of social media messages that communicate about heat risks to the public, heat warning tweets—which alert the public about specific extreme heat events—do not capture all heat-related tweets which alert the public to both extreme heat events and non-extreme heat events. During non-extreme heat events, heat-related tweets were also post-worthy since they address preventing possible extreme health impacts by alerting the heat sensitive population such as the sick and those engaged in potentially risky behaviors such as being physically active outside. To date, little research attention has been paid to crisis messages related to avoiding serious impacts of non-extreme hazards. Compared with crisis messages posted during extreme events, crisis messages surrounding non-extreme events may require different susceptibility statements and behavioral instructions to be effective, which warrants more research attention in the future. During extreme heat events when WFOs did issue heat WWAs, we found some corresponding heat-related tweets missed mentioning co-occurring heat WWAs. An important implication of this finding is that the communication process in social media must be well planned (Veil et al., 2011). In this case, official messages have the responsibility to share information about active heat WWAs to assist the public to make informed decisions.

Our research provides insights into how official crisis messages posted on Twitter communicate two health-related PMFs in the context of natural hazards: *health risk susceptibility* and *health impact*. Most previous studies on crisis messaging for natural hazards, to our knowledge, have not specifically examined the use of health-related PMFs. One exception is a social media study specifically investigating public health messages during the flooding in Boulder, Colorado in 2013 (Sutton et al., 2015b). The health-related content investigated in that paper was limited to health-related instructions such as drinking water safety and hand washing/hygiene, without an investigation of other health-related PMFs (Sutton et al., 2015b). Drawing on prior theoretical and empirical studies, this paper identified two health-related PMFs: *health risk susceptibility* and *health impact*. We find that Twitter messages about hot weather jointly or separately used four types of statements for pointing out *health risk susceptibility*: "subpopulation" statements, "behavior/place" statements, "anyone" statements and "everywhere" statements. The four types of statements respectively state that certain subpopulations, certain behaviors/places, anyone, or everywhere is vulnerable to heat-health impacts. For both heat-related tweets and heat warning tweets, the two health-related PMFs were much less used than PMFs of *hazard intensity* and *response instruction*.

This paper identifies five PMFs that have the potential to persuade the public to appropriately respond to natural hazards. We find the use of descriptions of *hazard intensity* is disproportionately high among heat-related tweets, with a lack of use of other PMFs. 54% of heat-related tweets exclusively used the *heat intensity* PMF by mentioning the Heat Index and/or temperature (n=484). For both heat-related tweets and heat warning tweets, more than half contained zero or only one of the five investigated PMFs. To enhance the persuasiveness of crisis messages about heat hazards and other types of hazards, future research should empirically test whether the five PMFs persuade or not, which specific statements depicting health-related PMFs are more persuasive, and whether different people respond to the same PMFs differently. This study provides a foundation for future message-testing studies by identifying these five PMFs and by specifying the different types of statements used to communicate health-related PMFs.

CONCLUSION

In this paper, we examine the content of crisis messages from a persuasive perspective. We deductively identify five PMFs that have the potential to persuade the public in the context of natural hazards. Using heat hazards as a case study, we contribute to understanding persuasive content in crisis messaging by quantifying to what degree each PMF is contained in official heat risk tweets. We quantify the use of PMFs not only among tweets mentioning active official heat alert products (e.g., an Excessive Heat Warning), but also among all tweets alerting about specific heat events that may or may not be extremely hot. We also provide insights into the different types of statements used to convey the two under-examined health-related PMFs: *health risk susceptibility* and *health impact*. Future experimental research is needed to empirically test how persuasive the five PMFs are in terms of promoting appropriate public thoughts and behaviors in the context of natural hazards.

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Evaluation results for a Social Media Analyst Responding Tool

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ABSTRACT

We take a human-centered design approach to develop a fully functional prototype, SMART ("Social Media Analyst Responding Tool"), informed by emergency practitioners. The prototype incorporates machine learning techniques to identify relevant information during emergencies. In this paper, we report the result of a user study to gather qualitative feedback on SMART. The evaluation results offer recommendations into the design of social media analysis tools for emergencies. The evaluation findings show the interest of emergency practitioners into designing such solutions; it reflects their need to not only identify relevant information but also to further perceive the outcome of their actions in social media. We found out there is a notable emphasis on the sentiment from these practitioners and social media analysis tools need to do a better job of handling negative sentiment within the emergency concept.

Keywords

Situation Awareness, Social Media, Emergency Management, User Study.

INTRODUCTION

Effective usage of social media data in emergency management can lead to successfully restoring safety and recovering essential services. However, the widespread usage of social media data makes it hard for authorities and emergency responders to make sense of thousands of incoming messages. During emergency events people actively broadcast different kinds of emergency-related information (Hughes and Palen, 2009). Affected people no longer wait for official communications (Cameron, et al., 2012; Plotnick, et al., 2015). Since Twitter is one of the most widely used real-time microblog services (Stieglitz, et al., 2017), we use Twitter as an example of social media streams that can provide relevant information in emergencies. For example, Twitter reported that during Hurricane Sandy in 2012, people sent more than 20 million tweets about the storm within 6 days (Marina, et al., 2015). A closer inspection of these social media posts shows that in the hours after the event, people provided on-the-ground information including eyewitness descriptions, impact on the community, requests for help, and expressions of fear (Chokshi, 2015; Imran, et al., 2014). Users outside the emergency area may also contribute to social media platforms by sharing information about wishes, volunteering and donations, caution and advice, or posting about people in the affected areas. This up-to-date information may enhance the disaster response teams' situation awareness (SA) by helping them allocate resources and coordinate rescue actions. However, not all the shared information in the affected areas is related to the disaster event, and not all related information contributes to situation awareness of emergency responders (Hughes, et al., 2014). In addition, information often arrives at a high rate which makes it difficult for analysts in the Emergency Operation Centers (EOCs) to manually filter through, monitor, and analyze such texts in a time-critical emergency (Hiltz and Plotnick, 2013). Finally social media brings reliability and trust issues (Marcelo, et al., 2010). Emergency practitioners face challenges such as determining the credibility of social media sources, or dispelling rumors (Marbouti and Maurer, 2016; Plotnick, et al., 2015). On the other hand, the expectation of the crowd from official responders has changed. People expect authorities to be able to catch quickly urgency requests and

enquiries using these new communication channels but the authorities are not there yet (Flizikowski, et al., 2014; Marbouti and Maurer, 2016; Reuter, et al., 2016b). The goal of this study is to bring insight into the design of expert-informed machine learning solutions for identifying relevant information from social media.

We iteratively designed and developed a Social Media Analyst Responding Tool (SMART) using a human centered design approach (Constantine and Lockwood, 1999). The target users are those who are monitoring and analyzing social media information during emergency events. Depending on the organization, the terminology of what the role can be called can be different (e.g., digital communication officer, public information officer, or social media analyst). Regardless of naming, all of these roles monitor social media information to get a sense of a situation (e.g., what public and media are saying about an event, what are the trends, rumors). In this study, we refer to this role as ***social media analyst*** or sometimes as ***analyst***. Initially, we interviewed emergency practitioners and social media analysts in the emergency domain to understand their challenges and requirements when monitoring social media (Marbouti and Maurer, 2016). After the initial interview phase, we pursued a scenario based design approach (Carroll, 2000) to consider the variety of context in which the tool might be used and shape the feature set. We focused on designing a prototype to help develop advanced filters using the analyst's knowledge combined with machine learning classifiers. The machine learning classifier identifies SA tweets by aggregating textual, social, location, and tone based features to increase precision and recall of SA tweets (self-citation). The design process proceeded with producing low-fidelity paper prototypes. We showed these to social media analysts to gather their reaction and comments. Using this feedback, we evolved the prototype to a fully functional web based prototype (SMART). SMART involves analysts in determining the filters according to their tasks and help them identify relevant tweets.

In this paper, we focus on the result of our evaluation of SMART. The goal is to evaluate the usefulness of the proposed design and gather qualitative feedback. It was important for us to see if the proposed design matches analysts' expectations during a disaster. The evaluation findings can bring insight into the design of social media analysis tools. To incorporate machine learning classifiers into the design of social media analysis tools, the training tasks should fit within social media analysts' existing workflow. According to our findings, emergency practitioners care a lot about sentiment, but sentiment analysis tools need to do a better job of handling negative sentiment to be useful to those people.

RELATED WORK

Many recent studies discuss the importance and rise in the usage of social media (Reuter and Kaufhold, 2018). In this section, we provide an overview of the current approaches to identify relevant tweets during emergencies.

Supervised Classification based studies

Some studies applied machine learning models to solve the problem of separating relevant tweets from irrelevant ones in large-scale emergencies (Moon, et al., 2013). Some studies applied binary classifiers to detect small scale incidents like car crashes (Schulz, et al., 2013) or to detect fires (Power, et al., 2013). Verma et al. (Verma, et al., 2011) study designed a classifier model to distinguish tweets that are contributing to SA from tweets that are not. The classification based studies, demonstrated the applicability of learning models with text mining techniques to automate Microblog filtering (Hughes, et al., 2014) but they do not provide applicable tools. Imran et al. (Imran, et al., 2015) surveys different studies for processing social media in mass emergencies. In our study, we embed supervised machine learning classifiers into a fully functional prototype to address the needs of practitioners.

Social Media Analysis tools

Several papers explored how to extract relevant information from social media data and more specifically from Twitter and resulted into social media analysis tools. SensePlace2 (MacEachren, et al., 2011) is a web-based tool that was built upon Twitter data to provide situation awareness and sense-making by revealing the connection between people, places, topics, and organizations. While this study provided useful tools for monitoring and filtering tweets, they provided simple filtering techniques such as keyword based filtering or filtering by location. In Rogstadius et al. (Rogstadius, et al., 2013) disaster awareness tweets were extracted using sets of keywords, constructing stories, and clustering tweets using their lexical similarity. The Twitcident system (Abel, et al., 2012) used to filter relevant information about an incident using handcrafted rules. This method enabled filtering, searching and analyzing tweets in real-time. Twitcident used semantics techniques to filter tweets. They gathered geo-tagged tweets and employed a learning model based on handcrafted rules (e.g., if a tweet contains specific attributes then it is classified in a specific category). In our proposed prototype, we

provide machine learning classifiers to identify situation awareness and user-defined tags and we let users train the classifiers in real time.

Emergency Situation Awareness (ESA) (Yin, et al., 2012) provides a Microblog mining tool to extract and visualize real-time information that can contribute to situation awareness about an incident. ESA distinguishes those tweets that are reporting an infrastructure damage using classification learning method based on NLP and social based features. The other proposed a visual classifier tool named Scatterblogs (Bosch, et al., 2013) for Microblog analysis and classification. Scatterblogs utilized a binary classifier based on text similarity to distinguish emergency-related tweets. This method allowed users to visually filter related tweets in real-time then train and update the classifier model. In Thornton et al. (Thornton, et al., 2016), the feedback-based techniques were used to improve situation awareness instead of traditional key-word based by updating the selected features in the learning model. AIDR (Artificial Intelligence for Disaster Response) (Imran, et al., 2014) study proposed a platform to apply automatic classification on emergency-related microblog posts. Their objective was to classify microblogs into a set of user-defined categories, combining machine learning classification techniques and human participation in labeling emergency-related microblogs in real-time. These tools provide automated methods for analyzing and exploring Twitter data. However, none of these approaches directly addresses the needs of social media analysts or emergency practitioners.

Our work extends these studies (Hughes and Shah, 2016; Reuter, et al., 2016a; Reuter, et al., 2017) that designed and developed an application based on the social media needs in the emergency context. However, in their applications they do not incorporate machine learning filters. In this study, we also designed and developed a prototype based on the needs of social media analysts but our evaluation brings insights into the design of applications that embeds supervised machine learning classifiers in monitoring social media during emergency scenarios. As far as we are aware this is the first tool to explore this concept in social media analysis for emergency management.

SMART

SMART is a social media analysis prototype that allows analysts to identify relevant information during emergencies. SMART combines the ability to collect, search and sort tweets alongside the functionality to filter and organize them with machine learning classifiers. A more detail description can be found elsewhere (Marbouti, et al.).

SMART utilizes set of data **collectors** to provide historical and live data gathering (Figure 1-A). SMART can extract "**Topics**" (Figure 1-B) using Latent Dirichlet allocation (LDA) topic modeling (Blei, et al., 2003), which helps the user find sub-events or trends within a larger event. These topics are defined by a list of five top keywords.
Users can further narrow down their search by creating **Filtered Events** (Figure 2). A filtered event can be populated based on the tweets that analysts manually forwards to the filter (we refer to it as manual filtered event) or automatically based on keywords. Figure 2 shows a filtered event view. The tweet and the buttons below (Figure 2-C) allow quick interactions for labeling and reading tweets at once. The color of the border around each tweet displays the sentiment of individual tweets. We embedded two main machine-learning classifiers to facilitate interactive filtering. The solution let users label tweets to train the classifiers. Any automatically assigned label can also be changed by the analyst if necessary. Users can label tweets based on SA or based on user-defined labels:
(1) Filtering by situational awareness (SA): We embedded a SA classifier in SMART. In the interface, SA is tracked by a lit or unlit lightbulb symbol for each tweet (Figure 2-C). If the SA classifier predicts situational awareness, the lightbulb symbol will have a red background to allow analysts to distinguish between classifiers' output and manually labeled tweets. **(2) Filtering by tagging:** To facilitate categorization of tweets into user defined labels we embed a multinomial Naïve Bayes classifier using basic textual features (Bag of Words (Aggarwal and Zhai, 2012) and TF-IDF (Salton and Buckley, 1988)). As an example, an analyst manually tagging tweets to categories such as Detail, Questions, Media, Misinformation or user-defined categories will also train the classifier to tag similar tweets with the same tags (using the tagging button in Figure 2-C), thus increasing the speed that information can be filtered. The automatically tagged tweets will be red in color, and can be changed if the tag is deemed inaccurate by the user.
Figure 2-A shows **the map view** in which users can see information regarding the location of the tweets, and the location of the users based on their profile information. If SMART extracts the location of the tweet from its text, using the embedded location extraction process (Marbouti, et al.), it will be red. **The graph button** (Figure 2-D) allows the map to be toggled off and display graphs for sentiment, interestingness, situation awareness and tags.

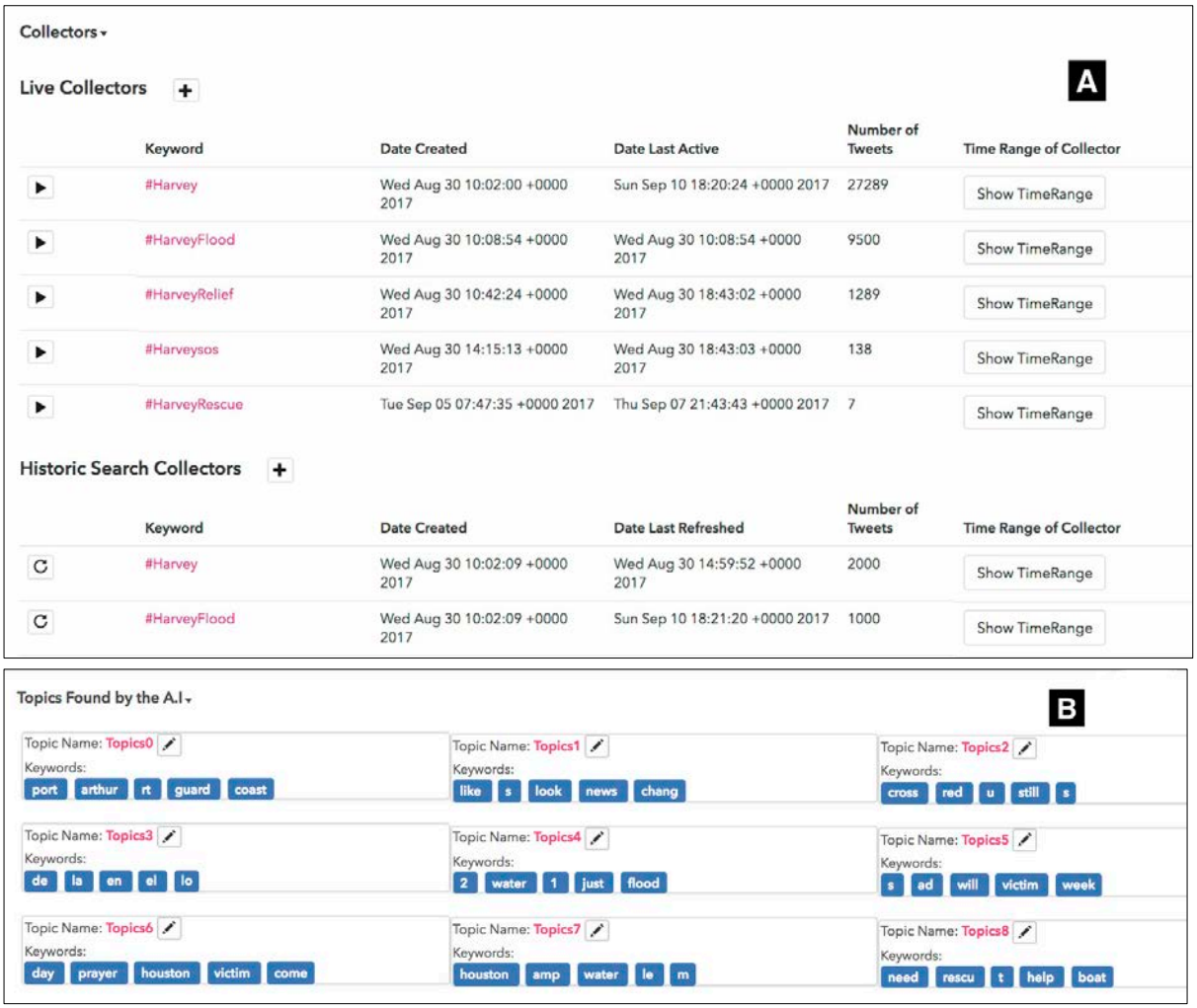

Figure 1- shows a list of live and historical collectors for hurricane Harvey(A) and a list of topics regarding the event (B)

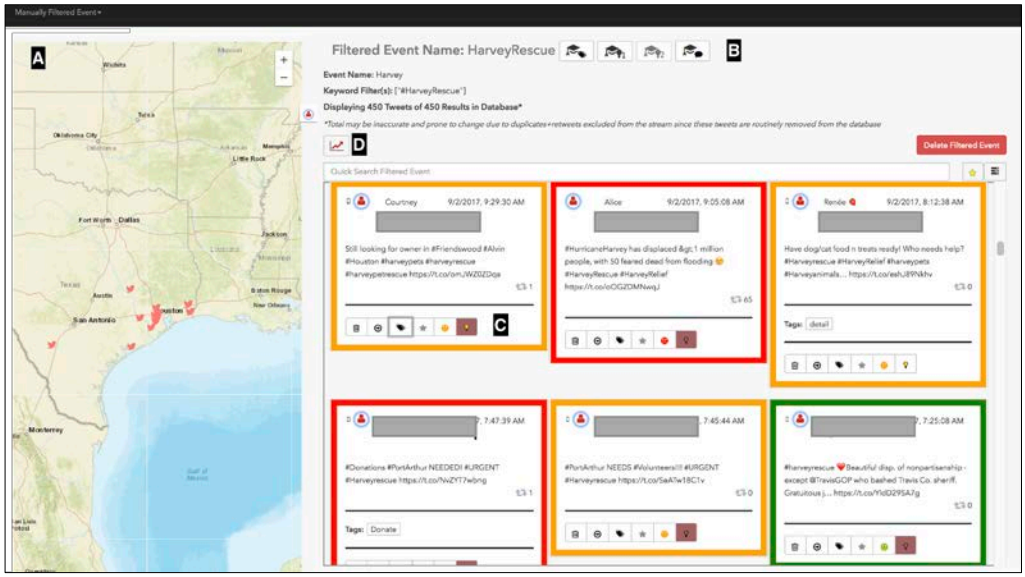

Figure 2. SMART Filtered Event Page: This view shows the filtered event page in which users can view and label streams of tweets. The graduation hats (Figure 2-B) are used for training the tagging and SA classifiers. Users can also view the users' and tweets' locations in the map view.

EVALUATION STUDY

In this section, first we elaborate the evaluation procedure, participants' profiles, emergency scenarios and finally we discuss our findings.

Evaluation Procedure and Participants

We conducted four evaluation sessions with nine participants. Although this is a small number, it is still relevant, because it is difficult to schedule meetings with emergency experts. We conducted one group session with six participants and three individual sessions. We recruited emergency practitioners and social media analysts in the emergency domain for evaluating SMART. For conducting a usability session, we contacted Calgary Emergency Management Agency(CEMA), and scheduled a time with their communication team. We preferred one on one meetings with each of their staff but it was not possible due to the nature of their work, so we conducted a group session. Six out of nine participants have direct social media responsibilities. These six participants monitor social media in their daily tasks and because the nature of their organizations they also monitor social media data extensively at the time of emergencies. Participants belonged to public sector organizations including CEMA, Calgary Police, Fire department, City of Calgary, and County of Frontenac. All participants had experienced dealing/monitoring social media data in at least one emergency event.

All study sessions were conducted on a laptop in places like the participants' workplace, in a coffeehouse near their workplace or remotely through Skype. Since we knew all participants (except one) from our previous interview studies, we did not conduct any pre-interview at this phase. Study sessions took between 90 to 120 minutes. After consenting to be in the study, we gave the participants an overview of different parts of the system. We also emphasized that participants should see the tool as proof of concept and do not expect the commercial stability. All features of SMART were demonstrated and explained for participants such as how to create events, how to create historic and live collectors. We also showed them how to create filtered events and how to train the filtered events for identifying situation awareness and user defined tags. We demoed the tool using historic events that we already had in the tool. Depending on working on a live or historic event, we either asked participants to create new events or work with the already created events. We asked participants to perform the following tasks as these are common tasks according to prior work (Marbouti and Maurer, 2016) and the fact that these tasks cover the core components of SMART:

T1. Give an overview of the situation: Participants are asked to find relevant messages and events
T2. Find the important topics that people are talking about
T3. Find the region most affected by the event
T4. Provide a report of the tweets in which people provided detail

We also asked participants to think aloud (Lewis and Rieman, 1993) during the study, we observed their use of the tool, took notes, and responded to their questions. We interviewed them after the study. To analyze the notes we followed a process inspired by grounded theory (Glaser and Strauss, 2009). Grounded theory involves iterative coding of concepts (open-coding) and finding patterns apparent in the text (axial coding) in order to form typologies.

Emergency Scenarios

We evaluated the tool based on real emergency scenarios. In the event page of SMART, we had several emergency events. We demoed the tool usually based on familiar events for participants such as Alberta Floods and then proceeded with another one or two events upon the desire of participants. For 3 sessions with individuals, we focused on events such as the Fort McMurray fire event or Hurricane Harvey pretending these events are happening real time at the time of the study. For the group study, we found a real-time emergency that was happening in Queensland Australia; a few days before our scheduled meeting we noticed there was a tropical cyclone in Queensland Australia called Cyclone Debbie. We started gathering tweets around that event to get familiar with it. We decided to focus on that event during our study with CEMA. Cyclone Debbie started on March 23rd, 2017 and intensified to a named cyclone on March 26th. The cyclone made landfall near Airlie Beach, just north of Prosperine, on March 28th. The cyclone caused major damage. Many communities went out of power and phone reception. The group session took place on March 28th at the Calgary Emergency Management Agency (CEMA). During the study, some participants noticed a plane crash in Saskatchewan and started gathering data around that incident as well. Since both events were going on at the time of study we used real time data.

Findings

In this section, we provide detail over analysts' feedback when performing the given tasks. The tasks were not performed in a specific order. We asked participants to assume that they are on a response team in the designated scenario and start performing tasks. We asked some participants how much these tasks match to what they are currently doing, one(P8) put it in this way: *"we do these tasks very unconsciously, first we do a situation report, participants are asked to find relevant messaging and events, and then what we do start developing messages [to push out to public]"*

Finding relevant keywords

To get an overview of the situation participants started creating events and gathering tweets (T1). Participants mostly used live collectors; the historical search collectors were less used among the participants. On the utility of live and historical search collectors P7 expressed: *"I want to start following this thing , all of sudden 100 thousand hockey fans spill out of 17th avenue , so I need to monitor red mile tonight, so I start a live collector, for my keyword red mile right now, BUT maybe they were indicators yesterday or last week throughout the playoffs that this may happen, so then I would create a search [historical] collector, same keyword red mile , to go back two weeks to search for people talking about partying on 17th Ave."*

For real time events in the group session, participants often started with general trending keywords from the twitter website or news articles and then added more detailed keywords. For example, in the Cyclone Debbie event one participant started with general hashtags such as #cyclonedebbie (both live and search), #cyclone (live), #qld(live), #debbie(live) at 13:29 and then added a hashtag regarding one of the landfall locations: #Mackay(live) at 14:24. Another participant added #injuries at 13:46 to the historical collector.

One participant (P5) liked to be able to delete previously saved keywords with all their collected data. They were trying to gather data around some plane crash event in *Saskatchewan*. Initially they used *Saskatchewan* hashtag but then later they realized that the hashtag was not useful for this event and they were getting lots of unrelated data using that hashtag. Another participant (P4) also asked for the ability to edit collectors to reflect past changes. For example, they wanted to remove all previously collected data for a specific hashtag.

Many participants expressed the difficulty and challenges they are facing with finding appropriate hashtags and keywords to pull data. As mentioned by one participant, general hashtags and keywords are not enough for them to make sense of the situation specially at the early hours of an emergency event. Participants expressed excitement towards the **topic modeling** view, because it helped them find sub events and topics that people were discussing. They used topic modeling keywords as a basis to create filtered events. For example, in Cyclone Debbie event, one participant created a filtered event for collecting data regarding the evacuation with keyword "evac" which he noticed in the topic keywords detected by the topic modeling component. In the case of the Hurricane Harvey event, one participant added port Arthur as a filtered event since it was being detected by the topic component module. For the individual sessions based on historical events we added a set of collectors with general hashtags. In these sessions, all three participants usually looked at the general hashtags, then added additional collectors based on the topic modeling keywords. For example, P8 started from the Fort McMurray event page, saw a collector with hashtag #ymm with 500 tweets behind it, then moved to the keywords in topic modeling and said (as he was viewing the words in the topic view): *"OK donations, OK umm safety stay…or Hgwy 63 and then based on that I create a filter say Hgwy 63"*.

We also noticed three participants added some collectors and filtered events regardless of tweets' content that made common sense such as injuries with keyword "injuries", landfalls with keyword "landfall". Since the keywords were not based on the underlying tweets vocabulary, these filtered events were not very successful in gathering relevant data.

Need to facilitate reading tweets

The filtered event view includes a tweet text box view, and they could also toggle between a map/analytics view. At the beginning of the study some participants (4) that mainly monitor social media as a part of their daily tasks had much less interaction with the map/charts and they would like to view the tweets in a more prominent way. Two participants asked if they could have a more prominent view of tweets and see more tweets in one view. One (P4) stated *"In terms of display I think it would be nice to without having to just go into one keyword group, to be able to see the tweets more prominently than all the charts and graphs on the side and to have more of a broader view of what's going on"*. However, as they were getting to know the location extraction

module their use of map view increased. Another participant made another point in this regard that labeling would be easier for them in a view with more tweets.

Sentiment in the Emergency Concept

All participants expressed attention towards public sentiment during an emergency event both on their early interaction with the filtered event view and later when they were exploring to see what topics people are talking about. Four participants, sentiment was the first thing that caught their eyes when they entered a filtered event. They were also curious about the sentiment in the chart page. In cyclone Debbie, one participant t(p5) noticed the big chunk of negative and neutral sentiment in the pie chart for the first few hours. They saw that as some sort of instant feedback. Another participant(P2) in the emergency management agency added**:** "I would *see that on one of our big screens on top Iive [in the emergency operation center], continuously…anybody can check that out all the time to see what are we doing right, where are the gaps…it's like hey [Author's name], we are trending negatively on this, what's the problem, and somebody says what's killing you is the roads".* One participant suggested to click on a sentiment in the pie chart graph and see the keywords or tags changes at the bottom, specific to that negative sentiment. Regarding sentiment, another participant (P8) added that he only cares about sentiment to the degree it relates to the safety of people: *"In crisis we want to know what people thinking, yeah, but first we want to make sure that people are safe."* Another participant (P2) suggested to be able to search for sentiment under certain hashtags for things like *"fail, poor service, tax dollars…."* Mostly participants saw negative sentiment as a combination of feedback to their service and as request for help. One(P9) put it in this way when we asked how he perceived negative sentiment: *"by sentiment I meant something that I'm not happy with your response, but they are both, if somebody injured I expect that tweet to be red and if somebody says the road to my house is blocked I expect that tweet to be red"*

Search Box Utility

The **search box** capability in the filtered event view had utility when exploring the filtered event (T1 &T2). One (P2) participant used it to search for injuries for the cyclone Debbie event and another used it to put a question mark in a filter to find questions and enquiries from people (See Figure 3).

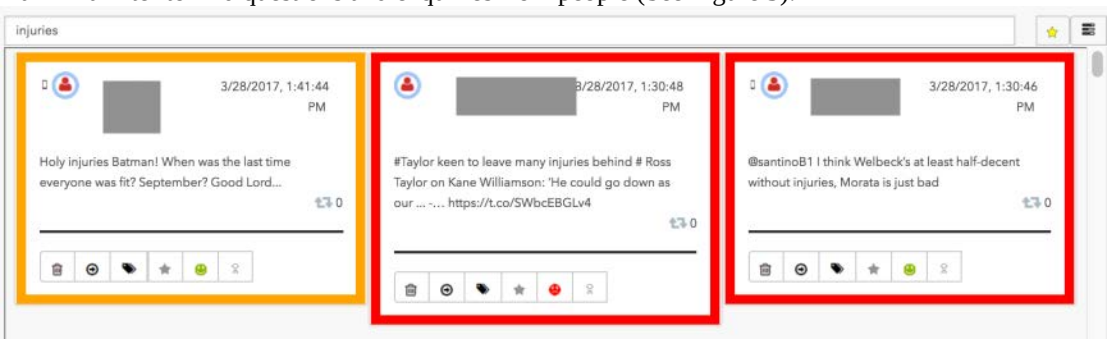

Figure 3. This figure shows a view of search box within a filtered event

Location extraction component utility

To find the most impacted regions impacted by event (T3), participants considered **location extraction** useful. One participants mentioned the geolocation tweets on the map as the first thing they would like to view when entering a filtered event and the reason was: *"Cause this tells you where people are experiencing certain problems"* For example, in the Harvey Hurricane one participants noticed the geo-located tweets on the map about a sub region called Port Arthur (Figure 4). The location extraction component identified 5 tweets on that region in which people were asking for help (more specifically for boats). However, two participants had concerns toward the credibility of such information. When viewing the first tweets P8 was more cautious: *"It's pretty vague this tweet "boats needed in Port Arthur", I'd flag this we are getting people that need boats in Port Arthur, but where in Port Arthur, I'd respond there hey what do you need? we want to help you, how many people are you, where are you exactly, is anybody injured"* However, as he was viewing more tweets on that location on the map, he was getting a better picture of the problem. After viewing a few tweets on that location, he noticed two tweets that had addresses in their text:

> *323 Pinehurst Avenue, Port Arthur needs rescue of 40 animals & 2 women*

- *56 patients need to be evacuated from 4225 Lake Arthur Drive in Port Arthur (nursing home; nurses gone*

Afterwards, P8 mentioned *"ok we are getting six tweets from port Arthur area, …I'd respond and say ok hold tights…if there are injured people I'd say ok we need boats there maybe helicopter…"* Another participant(P9) also noticed these geo-located tweets from the Harvey Hurricane. These tweets were 2 from 34 tweets that were grouped by our location extraction component for that sub region in Port Arthur:

- *PLEASE HELP MY GREAT GRANDFATHER!!!340 West 17th St. Port Arthur,*
- *Children □□□ #sosharvey 500 Natchez Ave. PORT ARTHUR #cajunnavy @insuranceboy no phone injured adult #harveysos @CNN*

We asked him, what he would do when he sees such tweets, P9 said *"I probably want to check if that is already in the 911 system or in my call system… did they tag cnn? … next thing you know CNN is calling me and they are saying why did you go to 500 Natchez Ave?... if it turns out that is a very important call and I ignored it that's also not good!"* similar to the previous participant, he also expressed doubt toward the reliability of the information, he referred to the text in the tweet that says *"no phone injured adult"* and said *"that's pretty serious but you don't know if that's true!"* We asked P9 how he would verify such information, his response was: *"[with] basic stuff check username, check the number of previous tweets, profile photo, history, that stuff that I can do myself, I call superintendent that I communicate with, I'd say hey I hear that there's an injured adult have you heard about this?"*

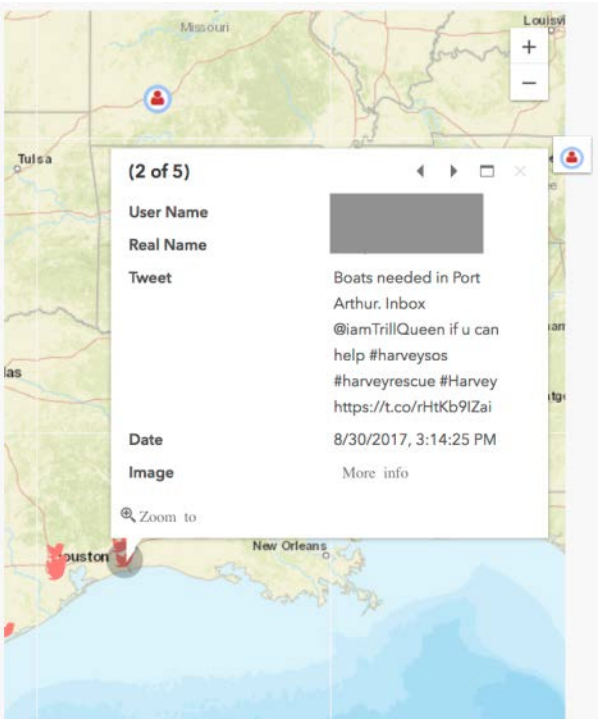

Figure 4. Geo-located Tweets in Hurricane Harvey Map View

Reliability of tweets' authors

During the sessions we heard from two participants that despite having this information aggregated for a user, they still would like to go and check people's profiles because that gives them a better sense of reliability and because there still might be some flaws with the characteristics: *"For me sometime I'd like to go to the native profile cause I want to have a look to say volume of tweets, but if I go to their profile and see they tweet for every meal they had „…,then volume of tweets does not necessarily speak to the credibility of that user(P7)."* P7 also mentioned an example for fake accounts: *"for dealing with trolls and detractors that hate us, 90% of the time they just created that account in the last 24 hours to just hate the police, so I'd say ok I want to be able to search ok who's had a profile longer, but then some people may had a profile since 2007 and they never user it, so I really can't put value to that."* For these reasons, P7 still would like to go the users' profile and scroll down to say is this a normal twitter user or not.

Manually populated filters

To create a report of relevant messages (T4) the forwarding button to a manual populated filter has the most utility. However, due to the time limitation, few participants did that. One participant was curious about the forward button, when we explained using the forward button he could send a post to a manual stream he expressed interests toward that feature and mentioned a possible use case as P8 was thinking aloud: *"I see somebody wants help with the address, normally what I would do is just I go print it off and hand it to EM response managers, hey go check that out, … [so using forward button]… I can create a manual stream and forward it to them? Ok I like that!"* Participants used manually populated filters to keep track of the urgency tweets and to be able to share them with the rest of the team.

Training the classifiers

To find more details regarding an event, participants were training the SMART classifiers**.** For simplicity, we called this training ability Artificial Intelligence (AI) in the study. The feedback towards the training was very positive. All six social media analysts' participants mentioned that they were willing to use this capability, as it would save them lots of time. *"We tag all of our incoming messages and it's 100% manual, so any starting point is an advantage…(P4)"*. One of them (P6) asked if we could add the same functionality behind the sentiment identification as well. *"I like the tool, how you filter and how you filter it over a large event, it's very positive very positive, to not have sort through those tweets manually, to be able to program and empower the AI, AI empowered around sentiment would be good too."*

One participant (P8) expressed that their emergency response tasks should be combined with training the classifiers. He went to the highway 63 filtered event page in Fort McMurray event and started labeling and viewing the tweets, After one round of training he noticed one with a red border color (which represented negative sentiment): *"So I'm gonna go here, ok this one here is red, what's going on here…[tweet text:]Lineup for gas here is at least 50 cars long. Traffic on the highway still moving slowly.#ymm,"* He also referred to another tweet that said: *"Go north if you're north of Gregoire. The fire has jumped the highway"* and mentioned that he would like to cross reference that with the information that he had. When participants saw such tweets that brought situation awareness for them usually they used the forward button to push the tweet to a manual stream so that they can refer to it later. However, there were some tweets that we might have considered as situation awareness but one participant was not interested in them. For example, on this tweet: "*Highway 63 is being blocked by police because the fire is on both sides of the highway. Please turn around & go north!"* P8 said*: "nothing there!"* Another participant had a different point of view regarding the combination of response and training the classifiers, he thought for this capability to work this should be separated from the response, and so there should be a dedicated person that monitors and trains the system. Although we did not explicitly ask the rest of participants regarding this combination, we noticed that most of them liked to perform their emergency response tasks (such as cross referencing the information, reply to the users) while they were training the classifiers.

When labeling the tweets in the filtered event view, one participant mentioned that they would automatically skip the green tweets (that means positive sentiment) and stop on the red ones (negative sentiment) that's why it's important to combine urgencies with the negative sentiment (see for Figure 2).

Two of the participants suggested simplifying the training for non-technical users. A participant (P2) that was an emergency manager expressed that he prefers a refresh button instead of a training button (The graduation hats in Figure 2-B). Another social media analyst participant mentioned that assigning tags should take the least amount of time, because what he's doing now is just scanning the tweets quickly to find the important ones so he might not have time in chaos of a disaster to click on the tagging button, assigning a tag and then click save.

On the other hand, one participant (P4) requested for more complex tags that could possibly help with their daily tasks. For example, P4 suggested tags such as identifying which business department within an organization a post belongs. *"I also don't think that tags are too complex, if we going to have more complex tags for example, see which business of city of Calgary that person is talking about …."*

We also asked participants explicitly which type of training (assigning a tag such as detail, media or labeling as SA or not SA) they would use. All of them liked to keep both options but some more comfortable with assigning tags as the tags made common sense and they could have users defined tags. Another reason was that tagging help them to get rid of irrelevant posts. An analyst in the police department gave us an example that once he was entering a keyword "Calgary COP", but he found tweets talking about Canada Olympic Park

(COP), he would have liked to tag that tweet as irrelevant and as a result the next incoming tweets about Canada Olympic Park (COP) would be tagged as irrelevant. However, one participant (P7) mentioned he would slightly prefer SA tagging as it will be faster to label and during chaos of an emergency they don't have much time: *"I use light[bulb] for the urgent [tweets]"*

One participant (P7) was interested toward the misinformation and sympathy tag types to be able to train the classifiers to identify tweets that are contributing to a rumour: *"Misinformation is pretty straightforward that might be an opportunity for us to provide education that we don't necessary have an answer for but if we do it we may have calmed the masses during an emergency and then sympathy is an interesting one, cause at first I thought I wouldn't really need that. Sympathy to me is more sentiment … it could be related to like compliments or something."*

Two of the participants mentioned that for a social media analysis tool to be useful in the times of a real emergency, the design has to be useful for their day to day tasks so that they have enough training and familiarly with the tool beforehand: *"When there's a real emergency you don't want to learn something new you have to know it works absolutely perfect, and you have to completely rely on it. If you do not practice with it a lot then you have to wonder, what tool am I gonna go with first (P9)"*

Finally, on training the classifiers P9 mentioned that he likes the control he has over training the system in our design because he did not have that control in social media platforms: *"[he was talking about Social Media platforms] what I found really annoying the tweets are not selected in the order they issued, I get to see posts that they think I want to see, I find that very annoying... and in Twitter and Instagram you can't even change it. you have no choice, they provide the posts in the order they want... but in your program, I control what AI can do"*

DISCUSSION

Overall the findings show the interest of participants into embedding machine learning classifiers for determining SA related and user defined tags. We found that to use such capabilities in real time scenarios the design of a monitoring tool should allow for the combination of labeling the tweets (training the classifier) and emergency response tasks. As requested by some participants (2) social media analysis tools should also support their daily tasks to be effective during a disaster. Analyst needs to be familiar with a tool before its use in an emergency. They need to be able to trust the classifiers capability in identifying relevant information before an emergency occurs. Participants suggested some interface enhancement to make the labeling faster and more intuitive; for example, one suggested to represent the urgency of tweets by a border color instead of sentiment or to combine urgency with negative sentiment. However, they saw the training capability as one piece in the whole pie. The interactive filtering allows them to get relevant information from their community faster. But getting informed is not enough, they want to influence how their responses are being perceived. They want to act based on the information that they are getting from interactive filters and they want to further explore what difference their actions are making in the social media data. One (P3) said: *"that AI piece exists but its only in its ability to further provide information …it's like now you have that data, how can you further mine it, filter based on negative, positive [sentiments] , now can you influence what is decided and fix those things and then also as we react, can [the tool] attract the difference that is making"* In other words, these analysts were not only interested to learn what has happened but to reflect what is going to happen using a social media monitoring tool. In addition to use training based filtering, analysts can still view the social media posts in the usual chronological order, so in this way they can get a sense of how well the underlying classifier is performing in terms of recall.

We designed SMART with focus on pulling and monitoring social media data. However, the participants expressed the importance of being engaged with people which means the ability to push out information and reply to people questions and concerns. They expected that a desirable tool should have both capabilities (pulling data and pushing out information) at the same time. As one stated in the first eight hours of any emergency they are pushing out information. We noticed most of the participants are going back and forth to the Twitter. They mentioned that they were doing the same with the commercial tools such as Hootsuite. This could be because Twitter website is still the easiest platform for them to work with but also because of lack of trust in the other tools that they wanted to verify the contents, and sometimes because the engagement options that Twitter can provide for them like replying, and exploring users' profiles. Some of them asked if they can have access to the native form of a tweet through a link from inside the SMART.

LIMITATIONS AND FUTURE DIRECTIONS

Viewing sentiments of tweets both in charts and in filtered event view was a critical benefit for participants. What they perceived as negative sentiment was different from the general perception. Negative sentiment for them was a combination of urgency tweets and concerns and complains toward their response. Some (4) participants expressed interest towards having interactive filtering for identifying posts with negative sentiment. That kind of insight from the community provides them a way to see how their actions are perceived and help them coordinate their resources. This could be an interesting direction for future research. P6 imagined that by using such interactive filtering they could train the filters to identify negative sentiment*." [P6 was referring to a tweet] 'why route to the foothills hospital is closed, come on you guys'… have we got somebody on that, oh we don't , we've got people doing xyz, but we have lots of patients coming out of this incident, we need those roads to be open, we need some way to say we're responding, and then suddenly you see a tweet come out [from their department] that says 'hey we are clearing the road, please retweet' people say it's awesome, we phone mayor and say hey can you retweet this for us, and then suddenly we shift twitter traffic from negative to positive"*

We noticed that participants try to pull the required information by querying general emergency related keywords such as injuries, landfall. One useful feature for a monitoring tool would be to find similar words with the underlying datasets and suggest them to the users.

SMART focuses on Twitter data since it is easily accessible and it is being widely used by the public in a crisis. However, two participants encouraged us to gather Facebook data as it helped them to know about public comments and concerns and quality of their service. One of them stated that the character limitation in Twitter makes it more challenging for people to express their views. Another advantage of Facebook is that people comment below a post so the conversation is more focused around a topic compared to Twitter where the conversation is very wide and diverse.

CONCLUSION

In this paper, we discussed the user study that was conducted for a social media analysis tool. The goal was to evaluate effectiveness of the tool by gathering qualitative feedback from social media analysts based on real emergency scenarios. We designed study tasks in such a way to demonstrate if the tool would be effective during an emergency scenario, and we asked domain experts to participate in the evaluation. All our participants had several years of experience in the emergency field. Our findings revealed that identifying the most appropriate keywords, especially at the early hours of an event, is one of the challenging tasks for social media analysts. We also found that to combine human expertise with machine intelligence, the training tasks should fit practitioners' current workflow. According to our findings analysts are not only interested in finding relevant information using a social media analysis tool but further to perceive how their actions impact the public sentiment. Our results also show the importance of sentiment and the perception of emergency practitioners around negative sentiment. The findings highlight the need for identifying negative sentiment in the emergency concept for developing future applications.

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Sydney Siege, December 2014: A Visualisation of a Semantic Social Media Sentiment Analysis

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ABSTRACT

Sentiment Analyses are widely used approaches to understand and identify emotions, feelings, and opinion on social media platforms. Most sentiment analysis systems measure the presumed emotional polarity of texts. While this is sufficient for some applications, these approaches are very limiting when it comes to understanding how social media users actually use language resources to make sense of extreme events. In this paper, the authors apply a Sentiment Analysis based on the Appraisal System from the theory of communication called Systemic Functional Linguistics to understand the sentiment of event-driven social media communication. A prototype was developed to code and visualise geotagged Twitter data using the Appraisal System. This prototype was applied to tweets collected during and after the Sydney Siege, a hostage situation in a busy café in Sydney's inner city at the 15th of December 2014. Because the Appraisal System is a theorised functional communication method, the results of this analysis are more nuanced than is possible with traditional polarity based sentiment analysis.

Keywords

Social Media, Sentiment Analysis, Systemic Functional Linguistics, Extreme Events, Crisis Communication

INTRODUCTION

In the morning of the 15th of December 2014, a hostage situation unfolded at Sydney's Martin Place (Commonwealth of Australia 2015; State Coroner of NSW 2017). A gunman took eighteen hostages in a busy café and chocolate shop (Lindt Café). After seventeen hours, the gunman executed one of the hostages and the police were forced to resolve the situation violently. In the resulting firefight, the gunman and a further hostage were killed. The event attracted a worldwide interest and large media and social media coverage. In this study, the sentiment of Twitter communication generated during and after the event is analyzed and visualized based on the Appraisal framework (Martin and White 2005).

Social media microblogging services, such as Twitter, are a common channel for communication and distribution of facts, rumors, and opinions in extreme events (e.g.: Chatfield et al. 2014; Fraustino et al. 2012; Hughes and Palen 2009; Jeannette et al. 2013; Liu et al. 2014; Oh et al. 2013; Sutton et al. 2008; Sutton et al. 2012; Westerman et al. 2014). Examining social media channels can provide insights into how social media communities are feeling and reacting towards specific extreme events. These insights can be used to infer the sentiment of the broader population of citizens. In extreme events like the Sydney Siege, emergency management organizations are interested in how the effects of the event are influencing the communities in order to better tailor their response online and offline. Armed with knowledge of sentiment, these organizations can fight rumors being spread using social media or provide information concerning how to provide or receive assistance. Analyzing social media data offers the potential for fostering better situational awareness for

Emergency Management Organizations by providing novel information about the event, how the general public is reacting towards the event, or revealing abnormal and emergent patterns of human behavior. One way in which social media can help Emergency Management Organizations is by providing indications of sentiment, a broad term that can indicate feelings and emotions, opinion and reactions or indicate outlooks or perspectives of those who are communicating.

Part of the difficulty in determining the utility of sentiment analyses is how to actually define the concept of 'sentiment'. The usual ways of determining social media sentiment are based on algorithms where words are classified according to a presumed emotional polarity (Medhat et al. 2014; Montoyo et al. 2012). Unfortunately, these approaches can only provide a rather limited view of the attitudes and sentiments expressed by social media users. In this paper, the authors adopt an different approach to the analysis of social media sentiment by adopting a functional theory of communication called Systemic Functional Linguistics (Halliday 1985; Martin 1992) to unpack the attitudes and sentiment of social media messages during extreme events. A functional theory of language is employed because we are interested in how social media users actually use language resources to create meanings (Sampson 1980). Of particular interest, here is the language resource called Appraisal that includes those features that encode attitudes and feelings.

In this paper we use the Appraisal System (Martin and White 2005) as a form of sentiment analysis which can better help to understand sentiment in extreme event social media data in comparison to traditional polarity based approaches. We developed a prototype which helps us to conduct an Appraisal analysis and visualization of Twitter data. We use this prototype to illustrate the utilisation of the Appraisal System based on extreme event data.

The remainder of the paper is structured as follows. First, the appraisal system used as a novel form of sentiment analysis is described. Second, the case event of the Sydney Siege 2014 is described in more detail. Third, the Twitter dataset is introduced. Fourth, a detailed description of the developed prototype is provided. Fifth, the findings of the Appraisal-based social media sentiment analysis are summarized. In the final section, the findings are discussed and the contributions of this approach are outlined.

SENTIMENT ANALYSIS EMPHASIZING APPRAISAL RESOURCES

Information Systems applications of sentiment analysis have been employed in applications as diverse as assessing the sentiment surrounding political actors (Bakliwal et al. 2013; Ceron et al. 2014; Unankard et al. 2014), sport events (Yu and Wang 2015), brand perception (Morinaga et al. 2002), product perception (Jansen et al. 2009; Mostafa 2013), or stock market predictions (Das and Chen 2007). Our application involves determining the sentiment within social media posts surrounding an emergency incident, the Sydney Siege that occurred December 2014. Unfortunately, the usual approaches to sentiment analysis are extremely limited. They mostly utilize approaches based on emotional polarity that is assumed to be associated with particular words occurrences in messages (Medhat et al. 2014; Montoyo et al. 2012). A determination of emotion based simply on polarity yields a very limited view of what social media users are feeling about an extreme event. Construing polarity as an indication of emotion, conflates the potential analysis to only one dimension of sentiment. Perhaps more importantly for organizations- especially in this context, emergency management agencies- polarity sentiment analysis while arguably providing the means for organizations to 'socially listen' renders them simultaneously incapable of acting on what's been heard.

Issues with Polarity-based Sentiment

Many problems associated with the reported poor performance of polarity sentiment applications and systems are due to the fact that they ignore how language is functionally organised in order to be used. There are several issues which can easily be considered here. These issues include a fundamental misunderstand of how language is organised, another involves the fact that lexis-based (word-based) polar sentiment fails from the perspective of construct validity, and finally that polar based approaches to sentiment analysis cannot distinguish any other dimensions of evaluative language. Sentiment analysis, as it is developed in the polar sentiment literature, seems only concerned with emotions (affect) and incapable of dealing with any of its consequences in the form of appreciation or judgements.

The problem with almost all polarity-based sentiment analysis products is that they do not come to grips with what sentiment actually is. Polarity-based sentiment is assumed to be a property of words; it is the static attribution of a polarity to a word that is the basis of all polarity-based sentiment analysis system. However from a functional perspective - that is when developing accounts of language that involve how it is used to make meanings - language comprises a number of compositionally organized layers of units, the so-called *rank scale*, that starts at words classes (nouns, verbs and so on) and proceeds to successively large units associated with the

group/phrase rank that are in turn organized into complete messages at the *clause/clause complex rank*. Likewise any sentiment attached to the messages in social media posts will not just involve word classes but also potentially other ranks. This is why the expression 'being between a rock and a hard place' can be associated with a single sentiment in this case at the group/phrase rank. In this example, the specific sentiment cannot be identified by using the constituent words of constitute the expression considered separately.

From a functional perspective, sentiment is an evaluative attitude to a situation or thing, so employing a *scalar* +, 0 - (a direction without a magnitude) does not in and of itself shed any light on which construct is being referred to. This limitation is referred to here as the *missing referent problem*. By comparing contrasting words like 'love' and 'hate' some of the problems of polar-based sentiment become apparent. For example, neither in kind or extent, is a little bit of 'hate' anything like any kind of 'love'. Different kinds of sentiment exist as distinct kinds of category- 'love' and 'hate' do belong to the same class- they are both examples of emotions (affect), but they are not co-terminus categories (extreme endpoints of the same kind of thing). From a classical *construct validity perspective* (Cronbach and Meehl 1955), the notion of 'polar sentiment' seems inadequate to the task of accessing the specific mood or opinion experienced by an individual or group engaged in evaluative language- the superset of language resources of which sentiment is apart.

Usually what is meant by the term 'sentiment' is actually strictly limited to considering a kind of emotional assessment of a word. But is that really all we want to know when we conduct a sentiment analysis? Clore and Huntsinger (2007) correctly point out that while "theorists commonly assume that people's attitudes and judgments reflect information about the object of judgment, people's evaluations also reflect information from their own affective reactions". Businesses want to know how customers are emoting because they want to know how they view our products, services and organisation is relation to others, and also what kinds of impressions they may form as a consequence. Emotion is one thing but these other forms of appreciation and judgement are equally as important for a useful sentiment analysis. For this reason, the remainder of this article concentrates on semantic sentiment which includes affect, judgement and appreciation.

The Appraisal System

In order to understand what communicated sentiment can be, a functional model of communication theory called Systemic Functional Linguistic (SFL) is selected (Eggins 2004; Halliday 1985). The reasons for selecting this model of language are beyond the scope of this paper, but the reader is directed to Clarke (2001) for a review of semiotic and communication-based approaches employed in Information Systems. While there has been a great deal of work in linguistics that concerns the description of interactional aspects of talk, there has been almost no theoretical or methodological development concerning communicated evaluative meanings. However, SFL accounts for communicated evaluative meanings using its Appraisal system. The Appraisal system is employed in this paper to provide a more elaborate and nuanced sentiment analysis than is usually applied in the Information Systems discipline. The term 'system' in SFL refers to a collection of meaning-making resources that are employed by communicators to create meanings. System networks like those shown in Figure 1 are read from left to right from the most general option in the network- the so-called point of entry- to the most specific or right-most option. The square brackets indicate options that are in logical OR (selection) relationships between each other while the curly bracket indicate options that are in logical AND (combination) relationship with each other.

Figure 1 shows the system network for the Appraisal system. The Appraisal system was developed in order to account for the interpersonal assessment of speakers (or social media users) and associated attitudes (Martin and White 2005). Attitude includes different options for expressing evaluative statements in language. In particular, attitude is relevant to the evaluation of things, people's character and their feelings (Martin and Rose 2007; Martin and White 2005). This system is divided into three semantic regions covering "affect" (synonymous with emotion), "appreciation", and "judgement" (Martin and Rose 2007; Martin and White 2005). Each one of the semantic resources facilitates evaluation and is defined below:

Appreciation concerns the speakers' reactions to and evaluations of reality; typically, of a process of some kind or a completed act of communication. There are three specific types of appreciation, valuation, composition and reaction. These are organized in the system network using square brackets that indicate a logical OR relation exists between these options. This implies that if a stretch of language (in a tweet or other social media message) is being coded as an instance of 'appreciation' then it can be a 'valuation', 'composition', or a 'reaction'.

Affect involves a speakers' expression of emotional states, either positive or negative. This is the option that most closely resembles traditional sentiment analysis in Information Systems, although there are three specific kinds of affect recognized in Systemic Functional Linguistics. They include satisfaction, security and happiness.

Judgement relates to the speakers' judgements about the ethics, morality, or social values of others. The two types of judgement are social esteem and social sanction.

For the remainder of this paper, traditional sentiment analysis approaches are abandoned in favor of the Appraisal system from SFL (Martin and White 2005)

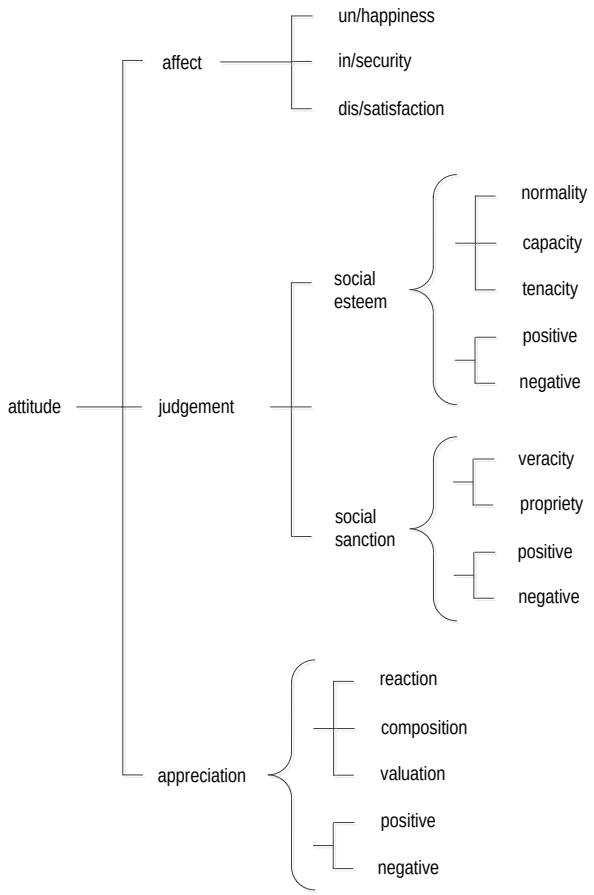


Figure 1. The Appraisal System (Martin and White 2005)

CASE STUDY: SYDNEY SIEGE 2014

The Sydney Siege of 2014 was hostage situation which unfolded at the 15th of December. The event was violently resolved by the police in the morning hours of the 16th December after a hostage was shot by the gunman. The event started at around 9:40 am as a lone gunman took eighteen hostages (eight employees of the café and ten customers) in the Lindt Café at Sydney's Martin Place.

While the Sydney Siege was unfolding the media perception was that this event was part of a broader organized terror attack and the police was treating it as such (Ralston and Partridge 2014). During the event, it was never clear whether the gunman was working alone or whether there were others working in the background. It was as well not clear whether the perpetrator was the only gunman within the café.

Apart from the immediate threat within the cafe, the gunman had claimed that there were several bombs located at Martin Place, Circular Quay, and George Street. These places are some of the busiest in Sydney's central business district and are also the locations of famous sightseeing spots frequented by tourists during that time of the year.

Only in the aftermath of the event it became evident that the gunman was a 'lone wolf' (Commonwealth of Australia 2015; State Coroner of NSW 2017) working without additional support. A provisional timeline for the Sydney Siege is provided in Table 1 to provide an overview about the event. This table was derived from media coverage and the official reports resulting from the event.

Table 1. Timeline for the Sydney Siege derived from media coverage (ABC-News 2014; Commonwealth of Australia 2015; Fallon 2014; Ralston and Partridge 2014; Safi 2015; State Coroner of NSW 2017)

Timeline	Description
15th December 2014	
08:33 am	later hostage-taker enters the café
~09:40 am	hostage-taker speaks to the manager; hostage situation unfolds
09:41 am	forced call to 000 (Australia's emergency phone number)
09:49 am	Police arrives at Martin Place
10:20 am (approx.)	Hostages were forced to hold black flag against the window
10:45 am	Sydney Opera House was evacuated (caused by suspicious package)
03:37 pm	Three hostages escaped the building
04:58 pm	Two more hostages escaped through another exit
16th December 2014	
2:00 am	Six hostages were fleeing out of the building; followed by one gun shot.
2:11 am	Second gun shot. Hostage escapes.
2:13 am	One hostage was shot. Police are storming the café.
2:14 am	Ongoing firefight; One further hostage was killed by stray bullet
2:44 am	Hostage situation is declared resolved through a NSW Police Tweet. "Siege over. More details to follow"

DATASET

In this study, we are exploring the sentiment of the Twitter community during and after the Sydney Siege through assessing the Twitter communication concerning the event. The corpus for this study comprised Tweets collected over a span of two weeks starting from the 15th of December 2014. These Tweets were harvested according to the following keywords "sydneysiege", "martinplace", "sydney", "lindt", and "chocolate shop". This yielded an initial corpus of 5,429,345 Tweets globally. From these tweets, we selected Tweets which were in English. As we are interested in the geographic distribution of sentiment, only geotagged tweets were used for the analysis. The final dataset consists of a corpus size of 50,670 tweets.

TWEET APPRAISAL CODING AND VISUALIZATION PROTOTYPE

A Tweet Appraisal Coding and Visualization Prototype was built to assist in (I) coding tweets using the Appraisal system and (II) visualizing Appraisal globally as the event unfolds. The prototype consists of three major components: A (1) User Interface to annotate Tweets, a (2) Classification Tool, and an (3) Visualization Tool for Twitter Datasets. The classifier (1) is a tool that helps the user to code Tweets according the Appraisal framework. With these manually (expert) coded tweets, the prototype can use different machine learning approaches (2) to learn the sentiment of tweets according to the Appraisal Framework. The third part of the prototype (3) is a tool that the user can employ to discover the spatial and temporal distribution of Appraised tweets for a given event. The classifier and visualization tool are described in the following sections.

User interface to annotate Tweets

The Interface to annotate Tweets in the existing prototype is shown in Figure 2. The appraisal analysis requires that individual tweets are segmented into their constituent messages called clauses. The tweet in Figure 2 consists of two clauses, “thinking of the hostages” and another dependent clause “in this terrible and frightening time”. The second clause is dependent because it cannot stand alone as a sensible message. Its job is to elaborate upon the situation being described. The segmentation of clauses is a simple manual procedure involving selecting where the boundaries between clauses should occur in the tweet. Once this first step has been completed, the next step involves locating the appraisal items. As shown in Figure 2, the first clause has ‘hostages’ as an appraisal item, while the dependent clause has ‘terrible’ and ‘frightening’. Indicating one or more appraisal items is very easy in this prototype. By simply clicking anywhere inside a word, that word will be selected. Alternatively dragging the mouse pointer across multiple words will select multiple words. The final step- the actual classification itself- involves determining what kind of appraisal should be assigned to each appraisal item, see Figure 2.

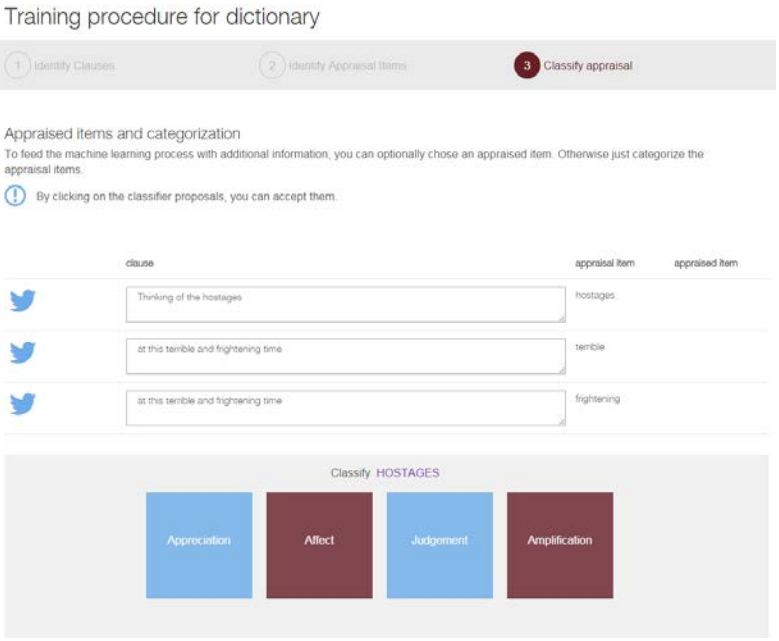


Figure 2. Classifying Appraisal Items

The examined dataset included 50,670 geotagged Tweets. With the help of the prototype we manually coded 792 Tweets according to the appraisal framework. The corpus was coded by a single expert, skilled in performing the clause boundary analysis and the use of systemic functional linguistics in general and appraisal in particular. Intercoder reliability measures did not need to be performed on this corpus as a consequence.

Classification of Tweets

The classification tool works as an environment to apply and test different classifier approaches. The prototype is modularly designed which allows us to add or exchange the classifiers. For this analysis, we initially evaluated a multinomial logistic regression and a Naïve Bayes classifier in different configurations, as shown in table 2.

The different configuration is allowing for different feature types and an up-weighting of appraisal items. In this initial case, the feature type for classification was either a binary bag of words model, where a document is represented as a vector of 0s and 1s representing the absence/presence of a word, a TF/IDF weighted feature vector, or a word frequency based vector. Increasing the weighting of relevant appraisal items, a classifier setting was introduced that increases the weight of features which were marked as appraisal items during the annotation process by a configurable factor which defaults to 1.7. The up-weighting of appraisal items is an idea borrowed from Liang (2006), who was able to improve classification results on sentiment in movie reviews by up-weighting the relevance of adjectives.

Table 2. Overview and evaluation of classifier settings

Setting	Base Classifier	Feature Type	Appraisal Boost	MAP	MR
Setting 1	Naïve Bayes	binary	X	46.59%	47.58%
Setting 2	Naïve Bayes	TF/IDF	X	45.53%	46.20%
Setting 3	Naïve Bayes	frequency	X	49.26%	49.70%
Setting 4	Naïve Bayes	TF/IDF	1.7	45.98%	45.63%
Setting 5	Naïve Bayes	frequency	1.7	49.72%	48.92%
Setting 6	Logistic Regression	binary	X	48.59%	49.82%
Setting 7	Logistic Regression	TF/IDF	X	44.63%	46.33%
Setting 8	Logistic Regression	frequency	X	50.24%	52.04%
Setting 9	Logistic Regression	TF/IDF	1.7	48.92%	47.72%
Setting 10	Logistic Regression	frequency	1.7	51.46%	50.92%

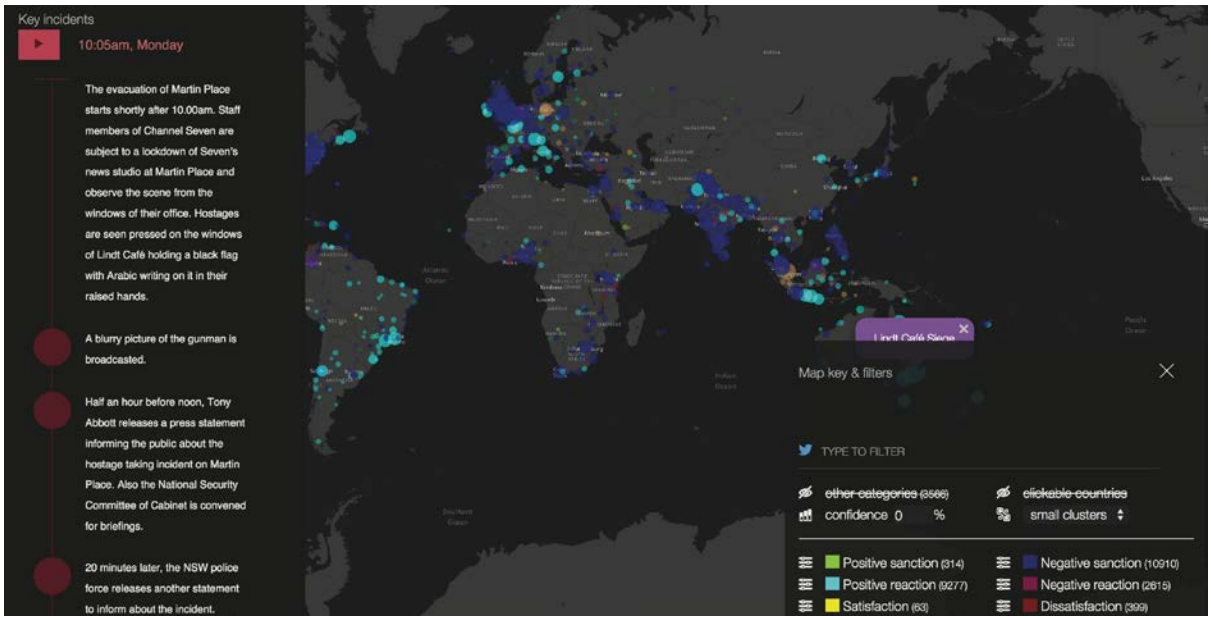
In the configuration to classify the Sydney Siege dataset of this study a multinomial logistic regression classification approach was used which was utilizing a frequency 'bag of words model' with an up-weighting of appraisal items (setting 10). The setting was identified through 10-fold cross-validation (Burman 1989) and comparison of the mean average precision (MAP), i.e. the averaged proportion of correct classifications in all classifications per fold over all folds and all iterations, and the mean recall (MR) of each setting. The latter is a metric which is used in information retrieval to describe the proportion of retrieved relevant documents to the total amount of relevant documents (Goel and Yadav 2012).

Visualization of Appraisal in Space and Time

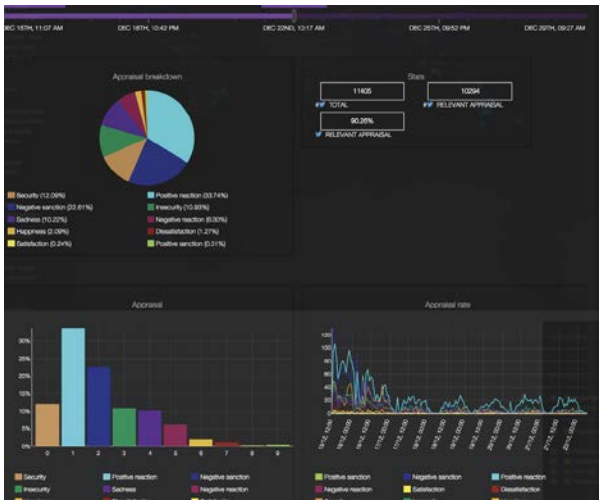
The visualization tool helps to analyze the sentiment of an event through the location and time of the event. The left-hand side panel of Figure 3 (a) shows a set of controls that are used to operate the visualization component of the prototype. Corpora for different events can be selected, and maps can be centered on different parts of the world for example Australia, Europe, United Kingdom, or the United States. Another control in this panel displays the chronology of the event. Significant events that have been entered into the system can be displayed in chronological order. The Twitter traffic associated with these events can be shown on the tweet appraisal map on the right-hand panel of Figure 3 (a). Controls can be used to select a time/date interval of interest, for example only the daytime hours, and this selection in turn is used for displaying only those classified tweets that were communicated during the selected interval. The temporal unfolding of the event, as revealed through its tweets, can be animated. This visualization reveals the extent to which this siege captured a great deal of international media exposure.

Various metrics can be displayed on the right-hand side panel as a visualization. The first of these is provided by showing aggregated data for the overall dataset or a region, or the data for a specific location on a map, Figure 3 (b). The display is in the form of a pie chart that shows the proportion of tweets classified according to the appraisal system (breakdown of categories and an associated key), a proportional timeline that shows the change over time, the percentage of different categories of tweet appraisal, and the actual classified tweets themselves. Figure 3 (c), shows the possibility to look into the actual Tweets and their appraisal category. The findings of the analysis of the Sydney Siege tweet corpus are provided in the next section.

(a)



(b) **(c)**



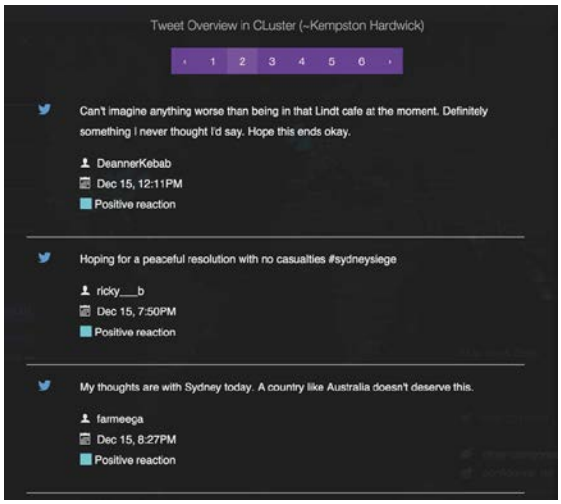


Figure 3. Global visualization of different appraisal categories over time (Sydney Siege 2014)

FINDINGS

The examined dataset included 50,670 geotagged Tweets. With the help of the prototype we manually coded 792 Tweets according to the appraisal framework. These classified Tweets were used to train the prototype and subsequently preliminary classify the entire dataset. The prototype and several keyword filters were then used to analyze the Sydney Siege dataset.

All of the Tweets in the dataset are geocoded and this permits an analysis of the communicative behavior of citizens in specific regions and countries over time. However, the dataset was limited to Tweets in which the language setting of the individual users was English. This resulted in a higher Tweet activity from countries in which English is predominantly spoken and excludes other countries.

While the dataset included Tweets from all over the world, in this paper we focus on the Australian perspective. In particular, we are analyzing four facets of the Twitter communication behavior accompanying the Sydney Siege extreme event:

- Overall Sentiment - Australia;
- Sentiment towards Victims - Australia;
- Sentiment towards Islam - Australia;
- and Sentiment around #Illridewithyou - Australia.

Overall Sentiment - Australia

As shown in Figure 4, the Twitter communication in Australia peaked shortly after noon of the 15th of December and then decreased over the subsequent development of the event. In contrast to the behavior in Australia, the Twitter communication in the overall dataset increases over time. We can account for these contrasting patterns through the assumption that most people in Australia went to bed before the major event changes occurred. The police were forced to storm the café shortly after 2 am. At 2:44 am local time the Siege was declared over. This resulted in a small increase of the Twitter communication in Australia. Communication participants at other parts of the world were at this time awake and commented much more about the extreme event. In Australia, the communication increased again after people were waking up.

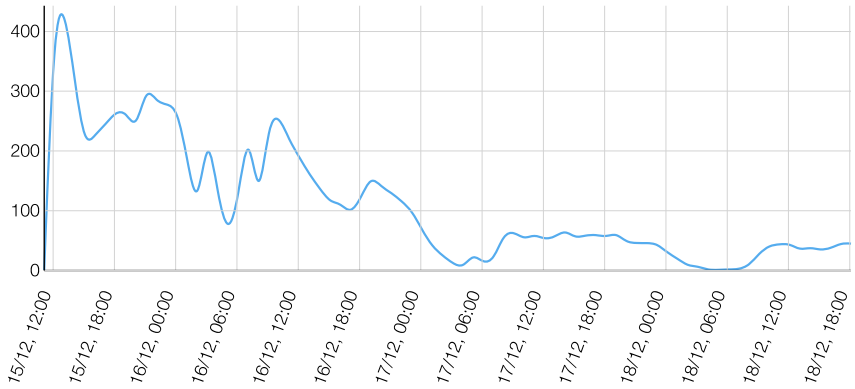


Figure 4. Hourly tweet rates in Australia, December 15 - 18

The distribution of the appraisal categories of the overall Australian dataset is shown in Figure 5. The most dominant appraisal categories in Australia were "Appreciation" in form of a "positive reaction" followed by "Affect" in form of "Insecurity" and "Security", and "Judgement" in form of a "negative social sanction". At first it sounds counterintuitive that such an overwhelmingly negative extreme event would create a lot of positive reactions. However, a deeper investigation into the content of the Tweets reveals that the positive reactions were given in the form of emotional support and the expression of hope for a positive outcome in the short term.

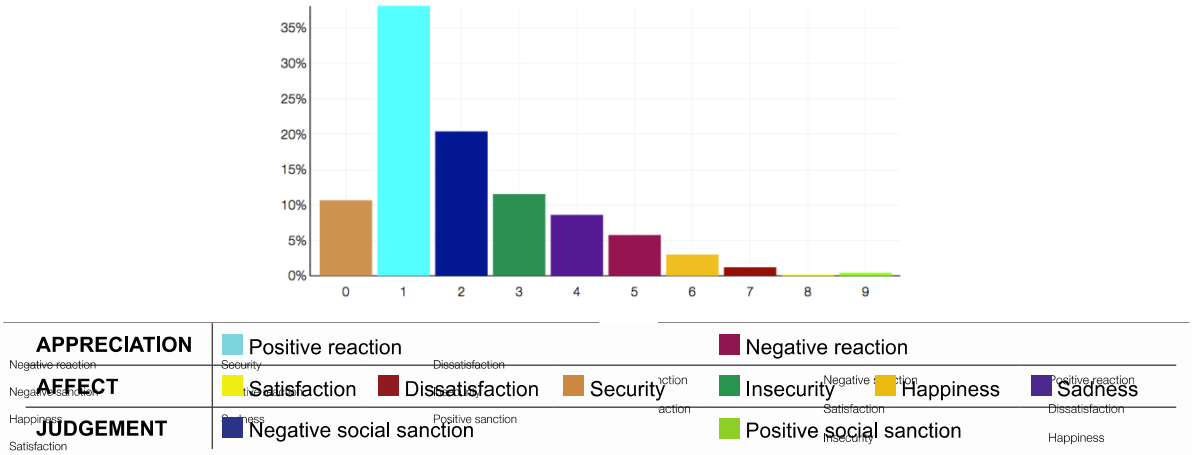


Figure 5. Overall sentiment proportions - Australia

Figure 6 shows the proportion of the sentiment over time. While the event was unfolding "negative social sanctions" are most dominant, closely followed by the "positive reactions" towards the event. Before the situation needed to be resolved by force there was a high level of "positive reactions" in the Tweets. A closer investigation into these types of Tweets revealed that they were in the form of emotional support and the hope that the situation could be resolved without a further escalation. The moment the situation changed and the police needed to storm the café, the reaction turned mostly into "Judgement" in form of "negative social sanctions". In the aftermath of the event most Tweets were classified towards "Appreciation" in form of "positive reactions". Most of these tweets were some derivation of "*praying for the victims*".

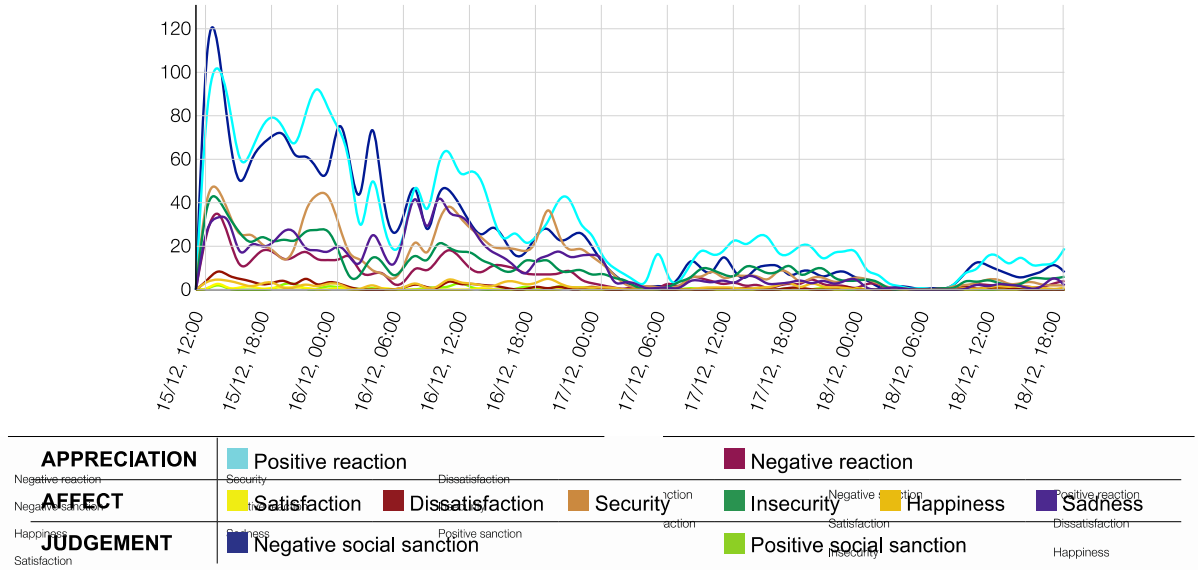


Figure 6. Hourly sentiment rates in Australia, December 15 – 18

SENTIMENT TOWARDS VICTIMS - AUSTRALIA

To explore the sentiment towards the casualties of the event, we filtered for Tweets that included at least one of the following keywords: “Katrina Dawson”, “lawyer”, “Tori Johnson”, “innocent”, and “funeral” (the names are those of the victims). As shown in Figure 7, the Appraisal categories reveal that the sentiment regarding the killed hostages comprised a high level of “Affect” in form of “Sadness” and “Insecurity”, as well as “Appreciation” in the form of “positive reactions” and “Judgement” in form of “negative social sanctions”. It is not surprising that the proportion of messages that express “sadness” in this subset of the data is more than double that in the overall dataset. The frequent “positive reactions” can be explained through prayers for the victims and expression of emotional support for the families. The negative social sanctions show the resentment against the event.

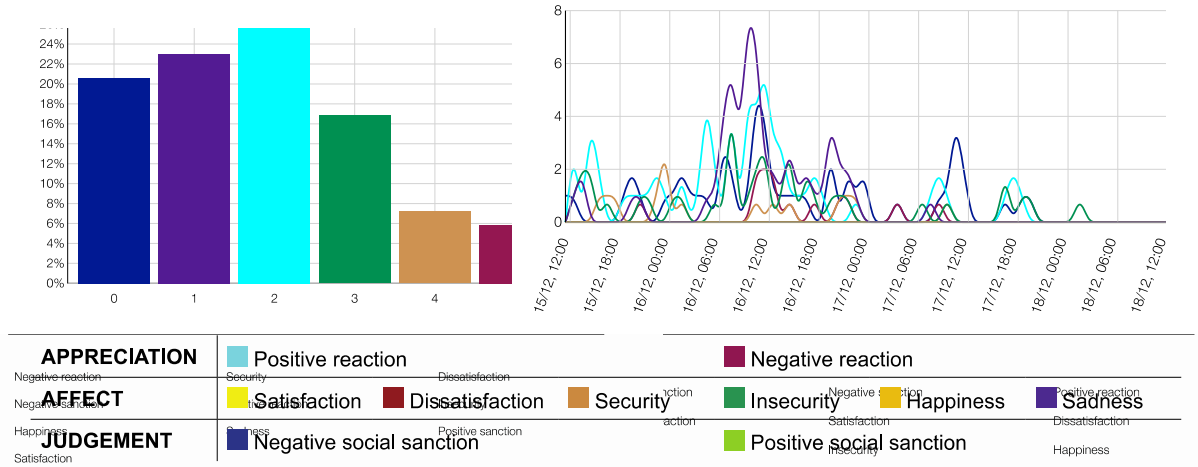


Figure 7. Sentiment proportions towards victims – Australia

More surprising in this specific subset, is the higher proportion of insecurity especially in the morning after the event. “Insecurity” in the Appraisal framework is a representation of fear that is expressed through these Tweets and might serve as a potential explanation for the observed pattern.

SENTIMENT TOWARDS ISLAM - AUSTRALIA

To filter for Tweets related to a sentiment towards Islam we applied the neutral keywords “Islam”, “Muslim”, “Koran”, “Quran”, “Qur’an”, and “Allah”. We intentionally excluded negative connoted Tweets which included the keywords “ISIL”, “ISIS”, “terror”, “jihad”, and “djihad”. Figure 8 shows that the resulting sentiment proportions is negative and categorized under “negative social sanction” and are a form of “Judgement” in the appraisal framework.

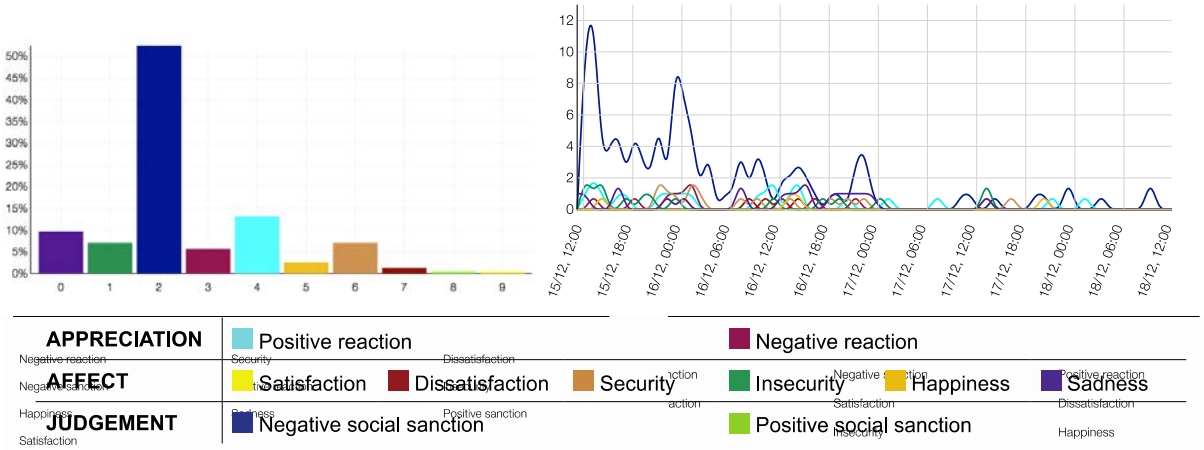


Figure 8. Sentiment proportions towards Islam - Australia

A closer examination of the relevant Tweets reveals three main groups. The first group are individuals who anticipate that Muslims will be demonized and they communicate their disapproval towards this kind of behavior. An example of such a Tweet is *"The people holding hostages in Sydney do not in any way represent all Muslims, and hating them for the act of a minority is wrong"*. The second group consists of Muslims who distance themselves and their religion from the gunman and his action. The last group are individuals who show anger towards Islam and attempt to spread hate; for example: *"Why is it that all terrorists are of a particular faith #sydneysiege #morningexpress"*.

SENTIMENT AROUND #ILLRIDEWITHYOU – AUSTRALIA

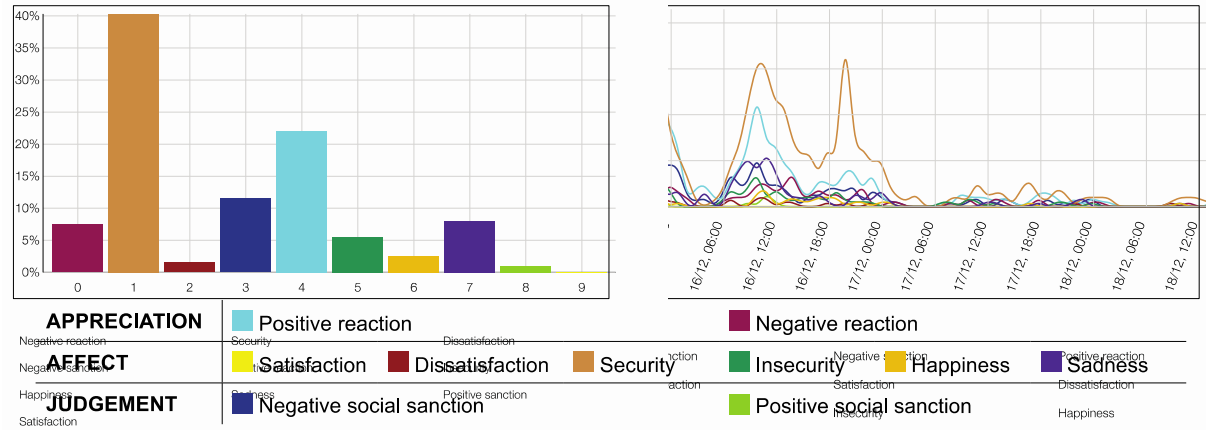


Figure 9. Sentiment proportions towards #Illridewithyou – Australia

The last pattern considered here is the hashtag #Illridewithyou. The hashtag emerged in Australia and was then picked up worldwide to support and build community cohesion as well as opposing any fear concerning Muslims during the Sydney Siege and its immediate aftermath. The hashtag started as a result of a Facebook post in which a user reported that a distressed Muslim woman was removing her hijab on public transport (ABC 2014). The Facebook user told her to put it back on and that they would travel together for safety. Following the Facebook post, a Twitter user offered to ride with Muslims who were using a specific bus line and who feared reprisals or hostility based on their religion. This Twitter user suggested the hashtag "#illridewithyou" and this immediately went viral. In our corpus, this hashtag showed a high level of use during the Sydney Siege and in the two days after the event. As shown in Figure 9, "Affect" in form of "Security" and "Appreciation" in form of "positive reactions" dominates the Tweets that included the #illridewithyou hashtag. An exemplar Tweet employing this hashtag was *"Praying for the safe release of the #sydneysiege victims, C'mon Aussies, of all religions, we will all stick together #illridewithyou"*.

DISCUSSION AND CONCLUSION

Our study involved a corpus of 50,670 Tweets collected during the Sydney Siege with a view to developing and applying a for extreme event social media communication new class of social media sentiment analysis (using Appraisal resources) developed within a functional and semantic theory of communication (Systemic Functional Linguistics). The analysis utilized the appraisal system and revealed patterns that would have stayed invisible with a pure polarity measuring sentiment analysis approach. At first, some of the observed patterns seemed counterintuitive to what would have been expected to see in such an extreme event. It was assumed that the communication would be categorized negatively with an overall high degree of sadness and judgement. In fact, the unexpected result was that a high proportion of Australian Tweets were classified with a "positive reaction" towards the event. A closer investigation of the relevant Tweets revealed that this behavior could be explained through statements of 'hopes and prayers' for a positive outcome of the event. While the event created a noticeable amount of fear ("insecurity") in the communication, an equal amount of the tweets involved attempts to comfort ("security") users of the social media platform. Attempts to build solidarity, comfort and security were especially prominent with the #illridewithyou subset of the data.

Unexpectedly there was a relatively low amount of anti-Muslim sentiment within the tweets of the Australian cohort. A more detailed analysis of the tweets with neutral Islam related keywords nonetheless showed a high amount of Judgement in form of "negative social sanctions". However not all of these Tweets were against Muslims or Islam in general, some of them showed resentment toward, and condemnation of, racism directed at members of the Muslim community because of the actions of one individual. Also, these Islam related Tweets did not show a high amount of "insecurity" that would have indicated fear.

Another surprising result was the development of hashtags and associated societal action like the #illridewithyou hashtag that actively promoted the support of Muslim women on public transport who chose to wear Islamic identified garments. This kind of sentiment promoted inclusive community cohesion evident in the "security" category in the Appraisal Framework. This movement generated a noticeable amount of Tweets especially in the two days following the hostage situation. The communication regarding Islam was prominent both during the event and for a day after.

The communication around the two casualties of the event showed a relatively equal distribution "positive reactions" in form of prayers and expression of emotional support, "negative social sanctions", "sadness" and "insecurity". While we were expecting the former categories, the high amount of fear ("insecurity") in the messages was unexpected.

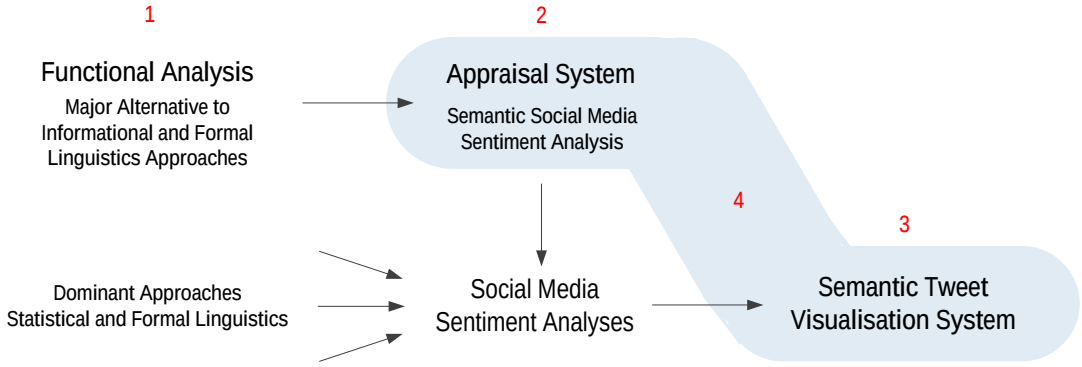


Figure 10. Functional Analysis using Appraisal together with global visualization

These results while interesting would not have been possible without a substantial change to the kind of approach used to determine the sentiment associated with these Tweets. The major and distinct theoretical contribution arising out of this study is the application of a functional linguistics to social media sentiment analysis (see 1 in Figure 10). A methodological contribution to social media sentiment analysis is the use of appraisal resources to identify different types of interpersonal assessment (see 2 in Figure 10). Another methodological contribution of this study includes the ability to visualize the semantics of social media messages over space and time, specifically the meanings associated with reactions to a crisis event (see 3 in Figure 10). The world of functional linguistics is a world centered on meanings in social and institutional settings. The detailed training necessary to understand these ideas is not usually available to computer scientists, likewise the disciplines of text mining classification and visualization is not usually accessible to those who study social systems. Much of the knowledge we have acquired conducting this research lies at the bridges we built between these worlds (see 4 in Figure 10), which needs to be further explored in ongoing research.

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Bad Weather Coming: Linking social media and weather sensor data

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ABSTRACT

In this paper we leverage the power of citizen supplied data. We examined how both physical weather sensor data (obtained from the weather underground API) and social media data (obtained from Twitter) can serve to improve local community awareness during a severe weather event. A local tornado warning was selected due to its small scale and isolated geographic area, and only Twitter data found from within this geo-locational area was used. Our results indicate that during a severe weather event, an increase in weather activity obtained from the local weather sensors does correlate with an increase in local social media usage. The data found on social media also contains additional information from, and about the community of interest during the event. While this study focuses on a small scale event, it provides the groundwork for use during a much larger weather event.

Author Keywords

Twitter; weather; sensor data; social media;

INTRODUCTION

With the evolution of technology, we have empowered everyday people to become expert data collectors. This data comes in many forms; through the messages they post on social media, the geo-coded images they share, or simply the information such as traffic data. All this information has the potential to provide critical data to those who seek to leverage it.

The concept of humans as sensors is not one that is new to the field of crisis research (Goodchild, 2007). Often people have been placed in strategic places to report observations back to those in command. However, more recently there has been an upsurge in attempting to understand how we may be able to take data produced by people in the field and integrate it into a situational awareness model (Vieweg et al. 2010). Using humans as sensors is not without its flaws as we are left with the questions of; where does it come from? Who provided it? And how much of it is representative of factual data? Even without these questions answered the value of the information may outweigh our doubt of its source.

During a crisis there are also additional sources of information that can be gained from the community. One example is that of weather sensor data found through the weather undeground API (Wunderground, 2017)[1]. This data is comprised of both personal weather stations and officially managed weather stations such as those found at airports. While these sensors provide raw weather data such as wind and gust speed, temperature and rainfall, they do not provide reactionary data about how it has, or is, affecting the community. Thus we are left with questions of how can this data be used, what does it say and how is the community affected by a severe weather event.

In order to enhance both the information gained from weather sensors and that found on social media, this paper will examine how physical weather sensor data correlates with how people react within social media. This serves two purposes. The first is to improve the validity of social media messages during an event. That is, through outlining the timeline of a local event through the use of weather sensor data, we can begin to understand how

[1] https://www.wunderground.com/weather/api/d/docs - A weather API designed for developers

severely and area is affected by the event in question. For example, it would allow us to know when the weather event peaks in its severity. Establishing this timeline thus allows us to know when a given area is experiencing the greatest impact. Second, through investigating social media data and how it corresponds to this timeline we can begin to understand how the community of this area is reacting to the event. Furthermore through a contextual analysis of the local social media data from the affected area, we can develop an understanding of how the said community is reacting to the event. In doing this we can further the information gained from digital sources. That is, the raw sensor data is elaborated upon through the use of social media messages and the social media data is supported by the raw sensor data through establishing a factual timeline.

For this study we selected the college town of State College located in central Pennsylvania, USA population of approximately 100,000 people. This location is not known for being highly tornado active, as such we believe that a severe weather warning would have an effect on the amount of weather related Tweets found from that area. In addition on May 1st, 2017 there was a severe weather alert issued for the area that corresponded to tornado and high wind watches. The storm did hit the area later that evening but only caused minor damage to houses and other infrastructure. There were no fatalities reported. While this event may have been only minor in comparison to other historical storms, it was selected because of this. That is, we wanted to find an event that was representative of common occurrences across the country as our focus is to see how even minor weather events can affect how people react on social media.

RELEVANT LITERATURE

Social media has it all. Any topic, any idea and any issue is likely being discussed somewhere. This makes it an ideal candidate for data mining however, due the abundance of information available, makes mining it problematic. While this does hold true in most areas of interest, in crisis response there is an immense effort to obtain only the data related to a particular crisis. It is important to realize that social media has become a crucial tool in communication that has allowed both the general public and governmental agencies to reach populations of an area that may be or is being affected by a severe event (Kavanaugh et al., 2012). Previous works by Crooks, Croitoru, Stefanidis, & Radzikowski, (2013) and Sakaki, Okazaki, & Matsuo, (2010) have shown that Twitter can indeed be used as a social sensor to detect earthquakes. In some cases providing information about the quakes where sensors may not have been available. Furthering this line of thinking, Takahashi, Abe, & Igata, (2011) asked and suggested that Twitter data may actually be able to replace that of traditional sensors. Their work found that Twitter could indeed be used to detect the pollen count for a given area through detecting certain keywords related to hay fever. While their goal was to replace the use of sensors for detecting pollen count by observing Twitter data feed, we feel that rather than replace sensors we could instead complement them. That is, in our paper we examine weather sensors which provide wind speed. Knowing that a weather event is occurring in a given area allows us to determine what impact it is having through the use of social media feeds. In addition, it may also provide insights to first responders should the impact be severe. A further example that can be very quickly applied to the domain of crisis response is that of detecting traffic delays (Daly, Lecue, & Bicer, 2013). While the author's focus was outside this domain, the examples of social media usage to extend traffic diagnosis could be used to provide valuable information about evacuation routes during a crisis event.

In a study by Mccormick, (2016) the author discusses the obstacles of use and implementation of social media tools for the crisis responder. She outlines four major barriers of the adoption of social media data which include the verification of data, security of the information, the liability issues and the subjectivity of the information. It is described in the article that data cannot always be verified or fact checked. As such, carefully constructed rumors have a tendency to propagate the network as quickly as the truth. To combat this, research has attempted to address this issue through the use of trust and credibility detection. As described by Mendoza, Poblete, & Castillo, (2010), there is a prevalence of false tweets and rumors. While, this false information does propagate through the network differently, it still requires it to spread before it can be detected. In addition, Gupta, Kumaraguru, Castillo, & Meier, (2014) developed a tool to detect real-time credibility called TweetCred. This leverages machine learning and examines 45 key features such as account age, tweet age, word usage, follower to followee ratio, etc. Research on filtering social media topic data, specifically in relation to a crisis, can be found in the works by Olteanu, Castillo, Diaz, & Vieweg, (2014). In this work they describe the development of a lexicon used to filter and mine data from social media blogs with the goal of reducing the amount of human effort required to separate relevant information from noise. While reducing the amount of information is an important first step in utilizing social media data within a crisis, the next step becomes one of determining how accurate this information is.

One major drawback to detecting credibility or trust within a social media network is being able to compare data thought to be valid. Gupta et al., (2014) used a method of crowdsourcing and labeled data to establish this "ground truth". Jurgens, Finnethy, McCorriston, Xu, & Ruths, (2015) used geo-locational meta-data to establish the ground truth of a user's location as they found self-report to be less than adequate. Yin & Tan, (2011) argue that ground

truth for a large dataset can be deduced from a small sample set, but that the small set must still be verified. Unfortunately, all these methods require a great deal of human effort in their implementation. In this paper we aim to show that through the use of sensor data this ground truth can be established quickly and efficiently. In order to improve the concept of finding credible tweets we take a first look at how sensor data can be linked to messages found on social media sites such as Twitter. Through showing that they can indeed be linked we provide another method by which tweets can be programmatically fact checked. For example, if a sudden surge in the amount of information concerning a storm comes out of a certain area, checking this against weather sensor data from that area allows us to determine if these messages have validity.

In addition to utilizing weather sensor data for credibility verification, researchers have shown the importance of weather data to emergency managers. Baumgart, Bass, Philips, & Kloesel, (2006) show that these emergency managers have trouble integrating advanced radar imagery into their decision making process due to issues of interpreting velocity. Furthermore, most weather related decisions are made through the use of data provided by the National Weather Service (NWS) which is discussed by Miller, Black, Williams, & Knox, (2016). Here they describe how the National Weather Services (NWS) wind warning systems may be too conservative. Leveraging social media data within this decision making process could help emergency management better understand when and where the weather event is at a particular time.

To investigate how both weather sensor data and social media data can complement each other we developed the following research questions:

- Is there an association of a weather event described by sensors, and social media behavior?
- How important is the amount of tweets that can be of further help, in providing decision makers with information that is complementary to the sensors' data?

Our findings indicate that there is indeed a strong correlation between the data found on social media and the timeline generated by data found from the weather sensors for a given area. Furthermore, the contextual analysis of the social media data did provide further information usable by those responding to the crisis.

Overall, while our analysis was based on a severe weather warning, it is believed that utilizing similar methods of analysis during a severe event that has a much greater impact would yield a larger correlation and provide much more contextual data within social media.

METHODS

Data Collection - Social Media

Data was live collected from Twitter using the Twitter API and customized software for the event on 05/01/2017 (0:01-23:59). In total there were 5,143 tweets contained one or more of the keywords or key phrases found in the crisislex limited to an area 50 miles around the center point of State College. This was achieved using the Twitter "near this place" call seen on the advanced search page. The timeline for this event can be seen from both Twitter data and the weather sensor data. Throughout the morning many warnings indicating a potential storm were issued, and at approximately 14:09 the NWS issued an official tornado watch. The highest rate of weather related tweets was 65 between 17:10 and 17:15 with the wind speeds peaking at approximately 18:24.

As we collected all the tweets for this time period and location, we began the process of refining them. In order to ensure only crisis related words were filtered we leveraged the lexicon found at http://crisislex.org/crisis-lexicon.html[2] (Olteanu, 2017) which consisted of 380 terms. These terms included words such as "flood, storm, tornado, torrential rains, etc" and filtered out tweets that did not contain these words. This left us with a total of 5,143 tweets over the 24 hour period. The frequency of these tweets is shown in Figure 1 below in a 5 minute interval.

[2] http://crisislex.org/crisis-lexicon.html - A recommended lexicon for Twitter querying contains an automatically-generated and human-curated list of terms found to be frequently related to disasters

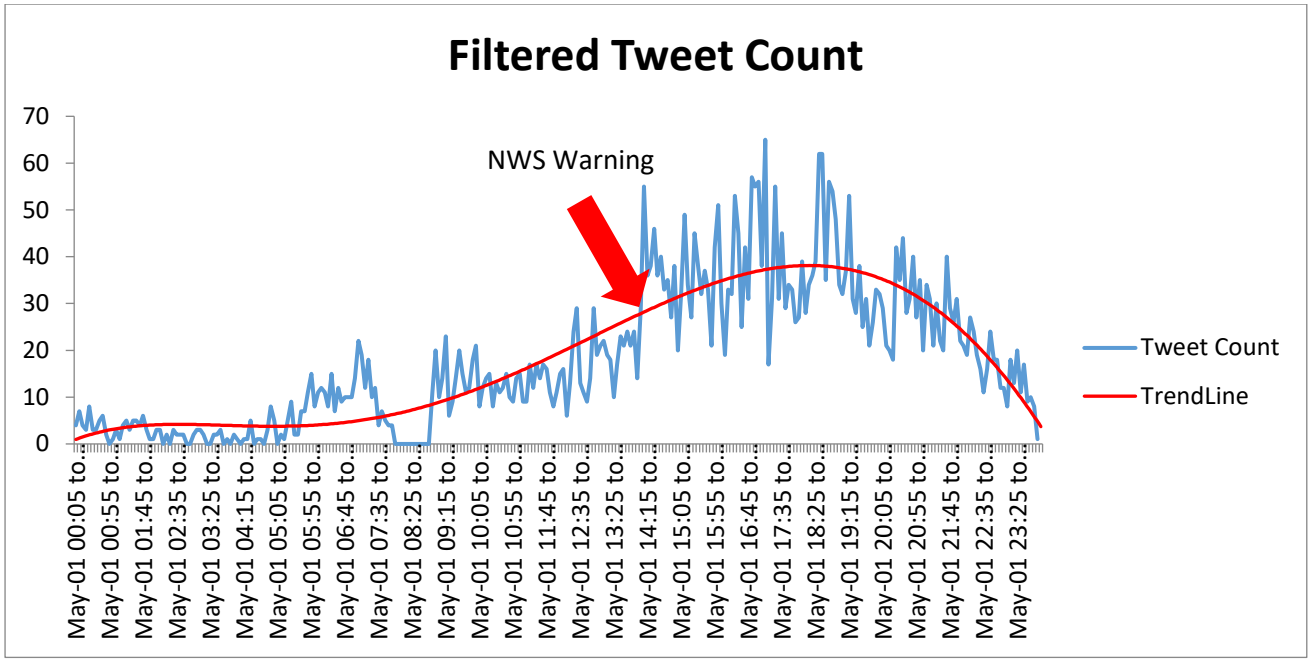

Figure 1 - Filtered Tweet Count

Data Collection - Weather Sensor

Weather sensor data was collected from 34 weather stations located in the area using the Weather Underground API (Wunderground, 2017). The locations of these weather sensors can be seen in Figure 2 - Weather Sensor Locations.

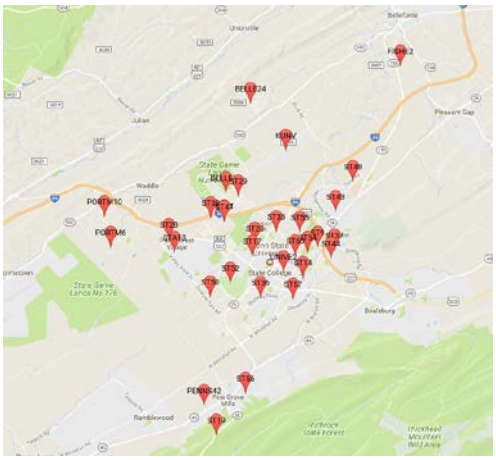

Figure 2 - Weather Sensor Locations

Twelve weather stations were removed from our data source due to inactivity or not having the ability to measure wind speed. From each of the weather sensors, we collected wind speed (in miles per hour) from the remaining 22 active sensors in 5 minute intervals. 4all sensors to give us the wind speed data for the area of interest. This data is shown in Figure 3 below.

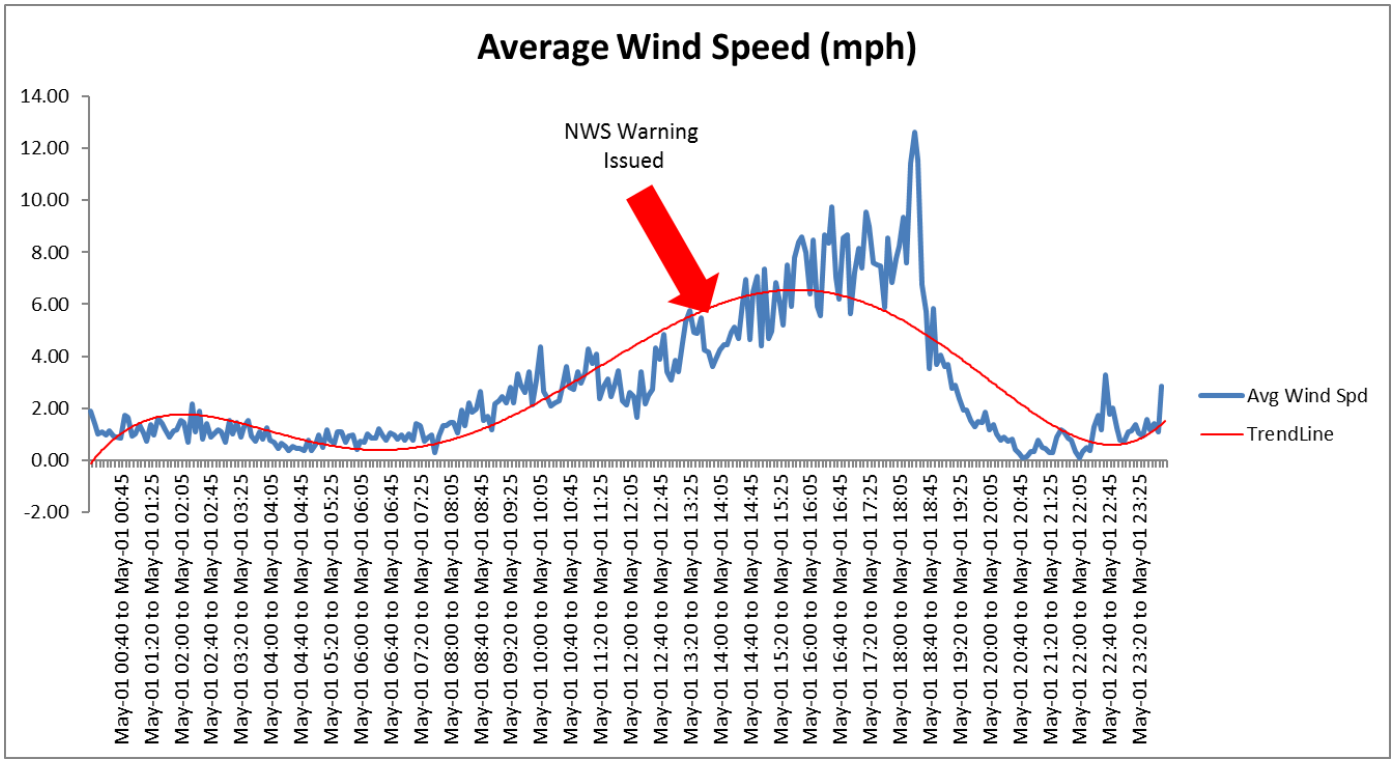

Figure 3 -Average Wind Speed (mph)

Statistical Analysis

To examine our first research question of how closely social media data correlates with weather sensor data for a day in which a severe weather warning occurred, we utilized a simple linear regression. To set this analysis up we used the number of Tweets related to weather data as our dependent variable with the wind speed as our independent variable. We postulated a positive correlation between the wind-speed and the number of tweets produced. To examine this, we used the R studio with the built in "lm()" functionality (R Core Team, 2015).

To examine our second research question, we performed a contextual analysis of the tweets for two time periods. The first was eight hours before the peak wind conditions from 10:54 am to 11:54 am and the second between 17:54 and 18:54 which corresponded to half an hour before and after the peak winds. This data was then coded to fit into one of 4 categories;

- Weather warning tweet or retweet for example: "*Thunderstorm warning and tornado watch in full effect. Finals remain on.*"
- Informational tweet for example: ("*Power flickering on Vairo Blvd in State College. Ton of rain &wind but not much thunder & lightning. Best storm in a long time! #PAwx*"),
- Tweet related to the event but containing no information for example: "*Well this is a freaky storm*"
- Unrelated tweets for example: "*One person suffered a nonlife threatening gunshot wound inside Norrell Annex. Three others were inside. Un-injured.*"

FINDINGS

For 05/01/2017 a total of 5,143 tweets contained one or more of the keywords or key phrases found in the crisislex dataset. From this data, as a first analysis, the Pearson correlation coefficient was calculated between the number of Tweets and the average windspeed, and, as intuitively observed when comparing Figure 1 and Figure 3, the result seems promising with a positive correlation of 0.63. In line with this correlation between the two features, a simple linear regression was calculated to predict the number of weather related Tweets based on the wind speed gathered from personal weather stations. A significant regression equation was found ($F(1,285) = 191.4$, $p<0.0001$), with an R^2 of 0.3997. The number of weather related Tweets is equal to (wind speed) miles per hour when tweets are counted. The number of tweets increased 3.770 for each mile per hour of wind speed. A scatter plot of these results can be seen in Figure 4 - Tweets vs Wind speed.

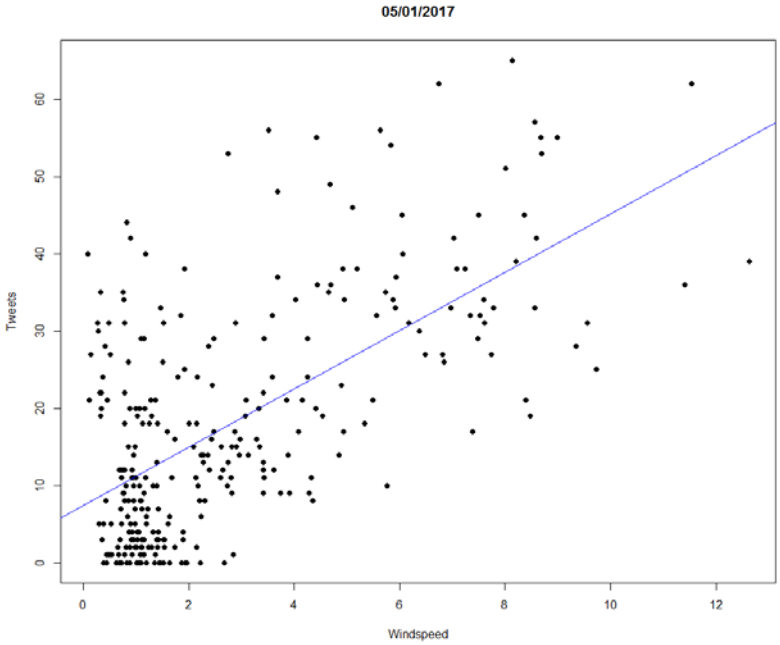

Figure 4 - Tweets vs Wind speed

For the second part of this study we examined the context of the tweets to determine what information, if any, was being distributed during the peak winds. This was done by having a set of coders look through the tweets and determine if the tweet had any information related to weather such as mentioning, rain, wind, clouds, sunshine, etc. As some of the tweets could belong in multiple categories it was decided that the most representative category should be used. In the case of the "warning" categories, if a message contained both a warning and informational data such as "Severe Thunderstorm Warning in effect in Beaver Greene and Washington Counties until 215 PM #pawx", but was in the format above we placed it in the warning category due to the standard format i.e. starts with "Severe Thunderstorm Warning in effect….". An example of an informational message would be that of "Police scanner: Tree down on Camp Meeting Road near Leet/Leetsdale. Just up the hill from Beaver Street."

One hour was selected for both coders to label to determine the inter coder reliability. A Cronbach alpha score of 0.92 was achieved. Due to this high inter coder reliability we then separated the rest of the data for labeling in which each coder was given a partial dataset. For the first interval (interval 1), there were 159 weather related tweets found the morning of the storm between 10:54 am and 11:54 am. In Figure 5 we can see a chart of the breakdown of tweet context for this time period.

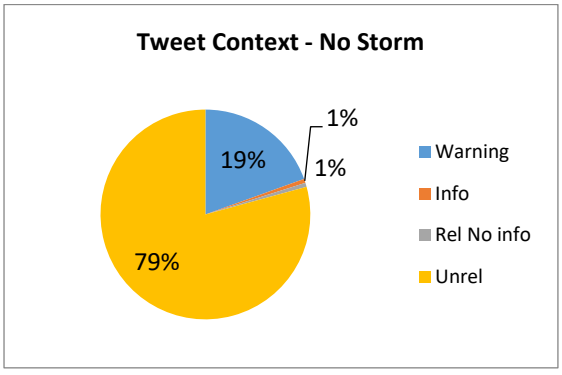

Figure 5 - Tweet Context - No Storm –Interval 1

It is important to note that while there was no active storms in the area of interest during this time period, there were tweets related to storms and flooding in Eustace Texas and DC Metro that were able to bypass our search filter. For the second interval (interval 2), there were 510 weather related tweets found half an hour before and after the storm event (17:54 through 18:54) in our area. In Figure 6 we can see a chart of the breakdown of tweet context for the half an hour before and after the storm.

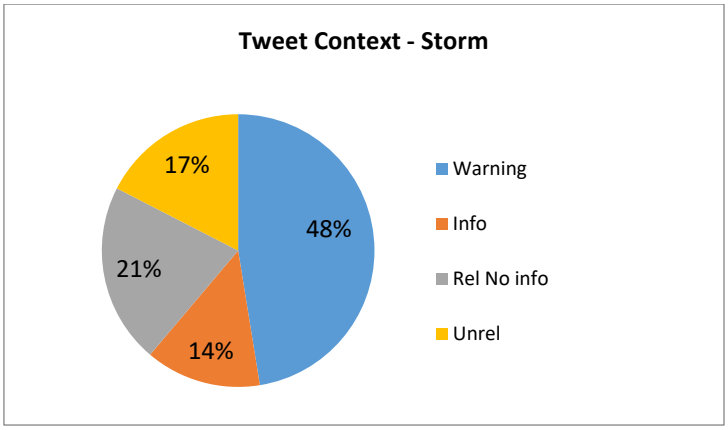

Figure 6 - Tweet Context - Storm

DISCUSSION

Leveraging the power of citizen sourced data is one way in which crisis response managers can gain insights into an effected area during a crisis event. In the case of this study we leveraged citizen sourced data in two ways; the first is through the posts of local users found in Twitter, and the second is from personal weather stations provided by local community members through wunderground.com[1].

Our findings indicate that there was indeed a positive correlation between the amount of weather related posts and an increase in wind speed for a local area. This supports the idea that when an event, such as a severe weather warning, occurs, people will turn to Twitter to discuss and share information about it. While our study is limited to only a particular area, and a particular event, further work could leverage similar methodologies to determine if our findings are supported in other geographic locations. From the contextual analysis we can see that despite using a well-known lexicon, we are still left with tweets that are unrelated to the event we are interested in.

Rather than relying on a "fuzzy" data source such as Twitter, to detect the occurrence of an event, using sensors data allows a more efficient and accurate result. In turn, the study shows that social media are still an important source of data, mostly because it brings complementary information. However, it was observed that even during this small scale event we can see that a majority of the weather related tweets are those that share the weather warnings, followed by related tweets to the event without information as well as unrelated tweets. Only small proportion of the tweets contain informational data which would be invaluable to enhance the situational awareness of the decision-makers. Further work would thus be needed to refine our filtering methods to exclude the weather warnings, non-informational and unrelated data allowing us to obtain only data with actionable information.

The second part of this research was to examine the categorical makeup of tweets both before and during a particular event. It is hypothesized that that the output of information that is related to the event would increase during the peak wind speeds. While we acknowledge the defined categories can be further refined and expanded, our findings show that a much larger percentage of Tweets are event related when a particular event is occurring. In the case of this research we found that before an event only 21% of Tweets contained information that could be linked to the storm, however during the event 83% of the Tweets contained some information related to the storm. While most of these messages were warning related Tweets and retweets making up 48% of the total filtered Tweets for this time period, 14% of these did have some informational component associated with them and 21% contained no information but were still storm related. Further work would be needed to examine how these findings could be used. One possible avenue could be in determining when a particular threshold has been reached that could then be leveraged for automating the detection of weather related events. Additionally, by expanding the categories beyond related and unrelated to an event, one could begin categorizing different types of Tweets to serve as markers for determining event type, impact and scale. In addition, while we did find that the weather related Tweets did increase during and event further work would be needed to examine the scale of the event impacts what proportion of Tweets are related to it.

For example, this small scale event contained 5,143 locally filtered Tweets half an hour before and after a storm. Of those, 510 were weather related. Of the 510 weather related tweets, only 70 contained actionable information. Even within these 70 tweets 39 were retweets leaving only 31 original tweets. This means that even through rigorous filtering we are left with very few tweets which would be useful to crisis responders.

CONCLUSION

This paper illustrates the importance of taking into account both sensors and social media data, because of the complementarity of their intrinsic nature – rational but limited in the value it can take in the first case, and fuzzy but rather open in terms of value in the second case – and of their reliability rates – rational sensor data is most likely to be more reliable and objective than human-written data.

In this sense, we have shown in this paper that utilizing physically located sensor data allows us to gain an understanding of what is happening in an area. That is, through the use of weather sensors we'd be able to determine when a weather event of anomaly has occurred. However, this information does not allow us to understand in what way a particular event affects the community. In combining weather sensor data with data found on a social media website, we can begin to understand how the community is reacting to the event.

Utilizing Twitter as a source to elaborate on the data found from the sensor data we can provide much more granularity about the impact of an event. Not only does it provide us with more details for a given area, but it opens the door for time sensitive analysis to take place. This is especially true in the crisis related domain were time is a precious commodity. Sensor data can be regarded as factual information provided the sensor is working accurately. In our work utilizing multiple sensors within an area insures that the probability of false data is minimized. This, combined with the Twitter data, allows us to determine the severity of the event and the impact it has on the community. In the case study provided in this paper we saw that the impact was minimal resulting in only minor damage such as flooding and downed trees. However as the scale and magnitude of the event increases, it is predicted that this would be reflected in the social media data along with the weather sensor data.

While, the event we selected was small in scale, a larger scale event may yield more fruitful results. That is, while there were severe weather warnings, no actual weather event occurred in a populated area. Further research would be needed to examine a local event that did actually affect a higher populated area. While increasing the scale of an event would also yield a larger number of informational tweets, it adds additional complexity to the filtering process. In addition, further work would also be needed to determine if these findings hold true beyond a particular geographic region. Also, examining how language or cultural differences influence Twitter usage during an event could also provide valuable insight. Using weather sensor data could provide the ability to pinpoint the location and time of an event, which could in turn be used to further investigate and improve filters.

FUTURE WORKS

This paper begins to examine the potential for providing additional data to elaborate on traditional sensors through the use of social media. That is, sensor data may provide an indication that an event has or is occurring, whereas social media data could potentially provide more detailed information concerning that event. This work takes a first look at how these two data sources are linked laying the ground work for future work. The first area where this work could prove useful is in establishing some sort of ground truth. That is, through using sensor data which is believed to be truthful, we can verify and vet information found of social media. While this paper focusses on weather data, many other sensors could provide valuable data which then in turn could be used to validate social media data. Social media data however, would allow us to expand beyond just the information gained from the sensors.

In addition, another area of future work is to further expand upon the contextual analysis. While we only focused on if the data was related to the storm or not, this can be expanded to provide much more granularity with respect to the categories a Tweet may belong to. For example, Tweets could be categorized into those which provide information related to damage, impact or scale. These in turn could be used to provide insights into how the community has or is being affected by the event.

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It's what's outside that counts: Finding credibility metrics through non-message related Twitter features

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ABSTRACT

Social media data, such as Twitter, enables crisis response personnel and civilians to share information during a crisis situation. However, a lack of information gatekeeping processes also translates into concerns about both content and source credibility. This research aims to identify Twitter metrics which could assist with the latter. A 2 (average number of hashtags used) x 2 (ratio of tweets/retweets posted) x 2 (ratio of follower/followee) between-subjects experiment was conducted to evaluate the level of influence of Twitter broker metrics on behavioral intention and the perception of source credibility. The findings indicate that follower/followee ratio in conjunction with hashtag usage approached a significant effect on perceived source credibility. In addition, both Twitter awareness metrics and dispositional trust played an important role in determining behavioral intentions and perceived source credibility. Implications and limitations are also discussed.

INTRODUCTION

"I don't know if that's right" may be the first thought when browsing through one's Twitter feed and seeing a post with an abundance of hashtags and mentions. This tweet composition may even lead one to question the intentions of the author-- do they actually want to share this information with everyone or are they just trying to get attention? Examining the source account, one notices the high number of followers, as well as the high number of message retweets the account experienced in the past. As an avid Twitter user, one might consider these features and conclude this account is actually an opinion leader and, thus, an online broker of information. With this shift in perception, the thought of "I don't know if that's right" changes to one of "maybe it is accurate." While message content certainly plays a role in influencing perceptions of source credibility, so too do the interface cues available to us through the platform environment. In this research, we expand upon this notion and begin to examine which features are significant in influencing how likely a user is to trust the data. (Castillo, Mendoza and Pobletem 2011) associated Twitter with the sharing of relevant information and reporting of news. The inclusive nature of this social media platform enables and encourages everyday people to post on the ground, real-time updates of offline events. Twitter users have the benefit of receiving real-time information not yet available in the mainstream media. Furthermore, social media platforms may also serve to quickly disseminate information and reach a large-scale population (Stewart and Wilson 2016). It is this information exchange that can provide valuable and unique resources to crisis response personnel and civilians during times of an emergency or disaster.

Ironically, this very element of inclusiveness, which renders social media useful in times of crisis, is also a limiting factor. The "gatekeeping" processes which defines traditional information publication and dissemination is lacking on social media. That is, a gatekeeper is a person or entity which decides what information is worth sharing and to what extent said information should be shared. Anyone can post anything. Consequently, much of the information posted on social media platforms which could be relevant and helpful to crisis response efforts is lost among the noise created by the sheer volume of posted information and content thus leading to information overload. For example, the Red Cross tracked more than 2 million posts during the

week the Hurricane Sandy was in active crisis. The Pew NewMedia Index published data after Hurricane Sandy and Twitter data revealed that users posted over 20 million tweets about the storm between October 27 and November 1, 2012 (Stewart & Wilson 2016). These tweets ranged in both content and intent and included messages which 1) reported news, information, and facts, 2) visually documented the storm with pictures and videos, 3) contained prayers and well wishes, 4) contained jokes or humor, or 5) represented a political agenda (Stewart & Wilson 2016). Another example of information overload occurred during the Fukushima disaster in Japan, 2011, when over 300 million tweets were posted in relation to the disaster (Thomson et al. 2012). To address the challenge of information overload, Ludwig et al. (2015) underscore the importance of techniques and tools for appraising the quality of citizen-generated content in emergency situations. Referencing Wang and Strong (1996), they note 15 different dimensions of information quality, one of which is credibility.

The ability to sift through messages and act on information posted in social media, wherein both relevant and irrelevant information is disseminated by unverified or unfamiliar sources, partly depends on perceived credibility of both the message content and the message source. With no real barrier to posting, concerns about credibility associated with information published on social media arise (Tapia, Moore and Johnson 2013). The quality of news reported on social media is not uniform. Users might receive tweets containing spam, false rumors, and information from imposters' accounts (Morris et al. 2012). Moreover, the researchers pointed out a trend in social media consumption in which it is growing increasingly more common for users to seek out information about a topic, rather than follow an author and wait for information to be presented to them. As such, one could make a case that the ability to accurately assess credibility of an information source becomes even more important.

RELEVANT LITERATURE

The concept of source credibility has long been examined with the main objective of identifying elements and establishing criteria such that one could surmise whose information is most likely to be valid, factual and free from manipulations. One approach to this endeavor is found in the philosophical analysis of source credibility (Umeogo 2012). Here, the theory of source credibility is assessed through three main models, each focusing on a different component. The first, the factor model, describes how credible the user determines the source to be. The second, the functional model, describes to what extent the source must satisfy the needs of the user in order for the user to perceive the source as credible. Finally, the constructivist model is used to examine what the user does with the information from the source. This delineation of source credibility is similar to the Grabner-Kräuter, Kaluscha, and Fladnitzer (2006) model of trust, a concept closely related to source credibility. In this model, the act of trust is described as: 1) trusting beliefs (trustee beliefs about the trust characteristics of trustor); 2) trusting intention (extent to which a trustee is willing to trust); and 3) trusting behavior (an action by the trustee from the trust interaction). Consideration of these models can assist one's understanding of the formation of perceived credibility. However, traditional models and metrics for measuring perceived credibility offline do not necessarily transfer to the online environment, where additional factors such as source anonymity are increasingly likely. Accordingly, research has been conducted to explore the implication of an online environment, particularly in social media, on perceptions of credibility.

Even through casual use of social media, one is able to detect a difference in patterns within messaging that exhibit honesty and those that exhibit deception. That is, we have a tendency to know when someone is being dishonest or truthful. Xu (2013) references dual-process models to explain how we make these judgments. Notably, it is not always message content which is prioritized in the assessment of credibility but rather a conjunction of content and external metrics that is used. This is further supported by theories related to limited processing capabilities, there is a tendency to use heuristic shortcuts and focus on features that are not related to message content to form our perceptions of credibility (Xu, 2013). Support for this claim can be found in works by (Metzger, Flanagin and Medders 2010), in which it was found that users often rely on others for credibility assessments; participants routinely took heuristic shortcuts, such as feedback systems or user comments, to judge credibility of information and its source. This behavior is known by some as the bandwagon effect heuristic (Sundar 2008).

Scholars and researchers have made the case for creation and design of tools, platforms, and functionalities which automatically provide metrics related to the bandwagon heuristic upfront and essentially leverage this behavior to manage information overload and reduce the amount of cognitive processing power needed to sift through information, by highlighting only those messages deemed most influential (Lin, Spence, & Lachlan, 2016; Sherony & Sundar 2015). Unfortunately, due to individual differences, the amount of trust one may have in a systematically generated credibility assessment may differ from person to person.

While their assessment is website-specific, some of their ideas could be applied to the social media domain. For example, within the dimension of content design is the recommendation for online merchants to display

company background details and disclose "patterns of past performances" (Wang and Emurian 2005). Applied to social media, online merchants would be the equivalent of information senders or posters, company background details could be measurements of user-based features for the sender (number of followers, number of followees, age of account, profile icon), and patterns of past performances could be measurements of message-based features from past activity by the sender (number of retweets, number of hashtags used, use of URLs). Implicit here, however, is the assumption that those who receive or encounter information on social media are aware of the various metrics which could be leveraged to assess source and message credibility.

Reuter et al. (2017) explore this notion of credibility, or *believability*, of citizen-generated content and present a three-level model of current approaches for credibility assessment. Referencing analysis of two algorithm-driven tools, *TweetCred* (Gupta et al., 2014) and *FB credibility* (Saikaew & Noyunsan, 2015), level 2 of this model suggests potential criteria for determining credibility: 1) various independent sources, 2) familiar and reliable sources, 3) contain evidence, 4) subjectivity/emotionality, 5) collective intelligence, 6) popularity/range, 7) geographical reference, 8) addressee, 9) filtering keywords and signs, and 10) existing "local knowledge" (Reuter et al., 2017). Notably, these criteria are not only related to the message content, but to the message endpoints (sender and receiver), as well. Similarly, Kumar and Geethakumari (2014) lay out four parameters influencing perceived credibility of Twitter messages in their study on the propagation of misinformation on social media. The first two, *consistency of message* and *coherency of message*, pertain to message content and the remaining two, *credibility of source* and *general acceptability*, pertain to message endpoints. Of note, it is posited that the latter parameters only come into play if there is a question about the content received. That is, if a receiver is already convinced that information is credible or not credible, they will not bother to further evaluate the source (Kumar & Geethakumari, 2014).

Further relating to message endpoints in the context of credibility perception is a concept known as dispositional trust. Dispositional trust can be defined as a user's willingness to trust others in a given situation (McKnight and Chervany 2001). Users with a high dispositional trust are more trusting in general and are more likely to find a source credible than those with a low dispositional trust, who tend to be more skeptical. Researchers have demonstrated the influence of dispositional trust on perceptions of other values and behaviors (Bianchi and Brockner 2012). Understanding and controlling for this influence allows us to hypothesize who may benefit the most from up front metrics of social media data. In addition to dispositional trust, variance in basic awareness of these metrics and their implications will affect the formation of perceived credibility. In their review of credibility in the domain of ecommerce, (Wang and Emurian 2005) posit design and display decisions of websites could actually serve as measures which influence online consumers' perceptions of online merchants, categorizing dimensions of graphic design, structure design, content design, and social-cue design. In their analysis on Twitter source credibility automated ranking strategies, (Canini, Suh and Pirolli 2011) defined credible information sources as those in which both domain expertise and trust are associated with the source. However, in crisis response or other time-sensitive situations—when real-time, first-hand accounts are desired—domain expertise may not be an appropriate metric for assessing which tweets are relevant and should be considered.

As a means to both assess source credibility and account for contextual relevance in a crisis situation, the concept of brokerage, borrowed from the domain of social network analysis, is considered in this study. (Burt 2009) introduced the term brokerage in social network theory to refer to intermediary links in systems of social, economic, or political relations who facilitate trade or transmission of valued resource that would otherwise be very difficult. Brokers bridge gaps in social structure and help goods, information, opportunities, or knowledge to flow across those gaps. The role of broker has much value to the community in terms of strength in community vision and enabling collective action. Essentially, brokers are entities who have organically emerged as hubs of information within a network. Their network placement, as well as their ability to effectively distribute information or resources translates into some level of perceived credibility by others in the network.

In situations where source credibility must be estimated, but traditional metrics for measuring such are either inapplicable or inappropriate, it is our belief that the metrics of brokerage might inform perceptions of source credibility. Consequently, so as not to miss the opportunities afforded by use of social media data in crisis response, there is a real need for an identification of those metrics which 1) can assist in the assessment of Twitter source credibility and 2) are appropriate to consult in these situations. The following research questions informed and guided our study.

> **RQ1:** For recipients of crisis-related tweets, controlling for Twitter familiarity, dispositional trust, and Twitter metric awareness, what is the relationship between broker metrics and perceived source credibility?
>
> **RQ2:** For recipients of crisis-related tweets, controlling for Twitter familiarity, dispositional trust, and Twitter metric awareness, what is the relationship between broker metrics and behavioral intentions?

METHODOLOGY

Based on 3 independent variables, we created a 2 (Hashtags: high vs. low) x 2 (tweets/retweets: high vs. low) x 2 (follower/following ratios: high vs. low) factorial design experiment, splitting each variable into two categories of high or low. We opted for an online questionnaire based data collection method and utilized Qualtrics to create a self-report online survey. Within this survey, participants were all given the same, very basic scenario. After, each participant was randomly shown one of thirty-two different stimuli (manipulated images of fabricated tweets). The thirty-two stimuli were generated from 2 x 2 x 2 conditions with 4 different message contents in order to control for the message information. Then, all participants were asked the same questions related to the topics of behavioral intention, perceived credibility, predisposition to trusting behavior, perception of information brokerage, social media use, and demographics.

Independent Variables

The independent variable to be manipulated in this experiment is broker metrics, operationalized as three sub concepts:

1. Avg # hashtags (HT) indicates the average number of hashtags used by the source over the entire lifespan of the account. Stimuli was manipulated to show either a high (3.6) or low (1.4) average based on the works of (Weerkamp, Carter, & Tsagkias, 2011).
2. Tweets/retweets (TRT) indicates the ratio of original tweets to retweets posted by the source of the entire lifespan of the account. Stimuli was manipulated to show either a high or low ratio. We opted to use visual representations (bar graphs) to display the ratio, instead of numerical values.
3. Followers/following indicates (FF) the ratio of followers to followees of the source. Stimuli was manipulated to show either a high or low ratio. We opted to use visual representations (bar graphs) to display the ratio, instead of numerical values.

Dependent Variables

Source credibility was operationalized as two dependent variables: behavioral intentions and perceived credibility.

1. Behavioral intention was calculated using an established measure from (Hu and Sundar 2009) which included a 7-point strongly disagree to strongly agree Likert-type scale used to determine a person's behavioral intentions. This was done through statements such as "I would retweet the information to my acquaintances." In total, there were three items on this scale which were combined through a simple index process to give us an overall behavioral intention score representing a participant's likeliness to act on the stimuli provided.

2. Perceived source credibility was calculated using an established measure of trust based on (Ohanian 1990) which was used to determine the perceived source credibility of the message source. It included a 7-point scale used to rate the message on categories such as dishonest to honest and untrustworthy to trustworthy. In total, there were nine items on the scale which were combined through a simple index process to give us a perceived source credibility score.

Control Variables

1. Twitter familiarity was measured through a single question asking participants to indicate their agreement with the statement "I consider myself familiar with Twitter" on a 7 point Likert scale ranging from strongly agree to strongly disagree.

2. Dispositional trust was measured using the "general trust scale" scale by (Yamagishi and Yamagishi 1994). This scale consisted of six items asking the participants how much they agreed with statements such as "Most people are basically honest" on a 5-point scale ranging from strongly agree to strongly disagree. The responses were then combined through a simple index process to give us an overall score for dispositional trust.

3. Twitter metric awareness was measured through a non-established ten item 7-point Likert scale ranging from strongly agree to strongly disagree. This scale asked participants about the importance of certain elements in their assessment of credibility of Twitter information, such as "the number of tweets sent

by and account is important" and "following count is important". The responses were then combined through a simple index process to give us an overall score for Twitter metric awareness.

Experiment manipulation and stimuli

All stimuli (images of fabricated tweets) shared the same layout, profile icon, username and handle, and number of hashtags (two) used in the tweet. The standard Twitter message metrics (likes, retweets) stripped away and replaced with our three-broker metrics (average number of hashtags used by the source, tweet to retweet ratio, and follower to followee ratio). We opted to use visual representations (bar graphs) for the two ratios, instead of numerical values. We had thirty-two different stimuli. We had every combination of the three metrics, plus four different message contents for each combination, to control for message content (Appendix A). Manipulation checks were not included in the survey, to avoid potential sensitization of responses. An example of the stimuli can be seen in Figure 1 and Figure 2 below.

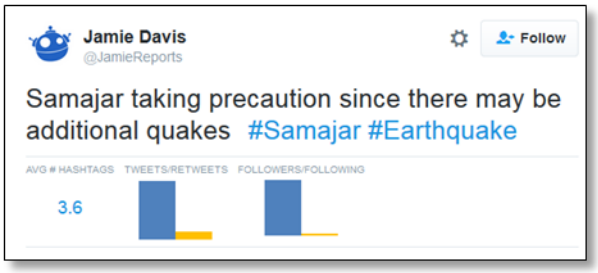

Figure 1 - Stimulus with content 1, high HT, high FF, high TRT

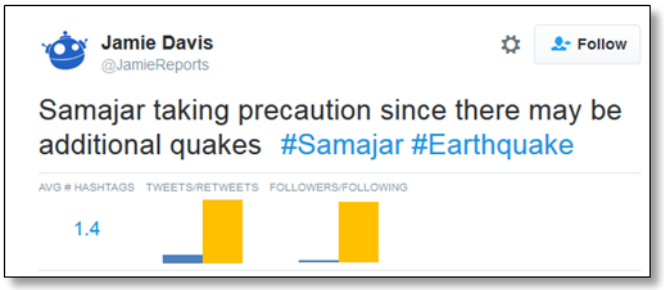

Figure 2 - Stimulus with content 1, low HT, low FF, low TRT

Participants

Participants were solicited via Amazon Mechanical Turk and compensated a nominal ($0.20 USD) amount for their participation in the study, which was done remotely. The Amazon Mechanical Turk (MTurk) is a crowdsourcing Internet marketplace that enables researchers to co-ordinate the use of human intelligence to perform tasks that computers are currently unable to do.Utilizing crowd sourced data, such as Amazon Turk, is representative of the volunteers that could be found during a crisis and using this resource to obtain our data is supported by various works by (Dailey and Starbird 2014) and (St. Denis, Hughes and Palen 2012).

DATA COLLECTION

Procedure

An online, self-report survey was created using Qualtrics and provided the means for data collection in this study. Before participants were able to begin the survey, they had to read and agree to a statement of informed consent (Appendix B). Within the survey, participants were first presented with a uniform scenario outlining a hypothetical situation in which they were residents of a fictional town called Samajar and just encountered tweets relating to an earthquake in their region. After the scenario, each participant was shown one of thirty-two different stimuli. Then, all participants were asked the same questions about behavioral intention and perceived source credibility associated with the stimuli, as well as general questions related to topics of Twitter familiarity, dispositional trust, Twitter metric awareness, and basic demographics.

All data was exported from Qualtrics into Excel to be cleaned. Comprehensive scores for behavioral intentions,

perceived source credibility, dispositional trust, and Twitter metric awareness were calculated using simple index procedures. Data was then uploaded into JMP for analysis.

Data analyses

For the dataset, a five-way, 2 (hashtags) x 2 (tweet/retweet ratio) x 2 (follower/followee ratio) x 4 (message content), factorial analysis of variance (ANOVA) was conducted to determine the influence of the independent variables on the perceived credibility and behavioral intentions based on research by [Field 2007]. Hashtags, tweet/retweet ratio, follower/followee ratio each had two levels (high/low) whereas the perceived credibility and behavioral intentions were measured on a 7-point Likert scale. This allowed the researchers to examine which of the main effects and which of the interaction effects of the factors contributed significantly to the perceived credibility and behavioral intentions scores and was consistent with those found in previous research.

RESULTS

Participants

A total of 199 participants recruited from Amazon MTurk participated in the study. Of that original figure, 9 were dropped due to incomplete data and another 1 was dropped due to claiming and age of 119. For the analysis data from 189 participants (100 Males, 81 Females, 8 unknown, Mean Age 32.76, SD=9.67) were used. Participants voluntarily signed up for a HIT through the MTurk program and were compensated for their time. Their participation was in accordance with all regulations from the university's Institutional Review Board. Participants completed the study via an online secure website with restricted access to only research participants. The study took approximately 10-15 minutes to complete.

Descriptive statistics

All statistical analyses were run using the JMP software suite from SAS Institute (JMP 2016). We controlled for message content our study by including four separate messages content within the different stimuli. The distribution across all four messages is depicted in Figure 3. For each of the hashtags, follower/followee, and tweet/retweet ratios conditions the distribution can be seen in Figure 4. The distribution for perceived source credibility (M = 4.50, STDEV = 1.61) can be seen in Figure 5 and the behavioral intentions (M = 4.61, STDEV = 1.92) in Figure 6.

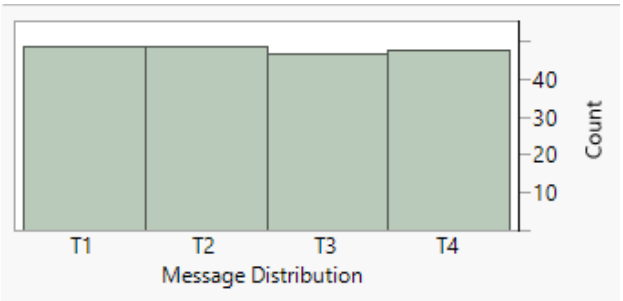

Figure 3 - Message content distribution across all participants

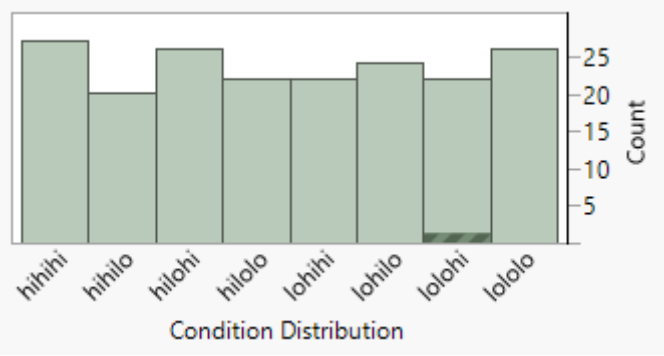

Figure 4 - Condition distribution across all participants

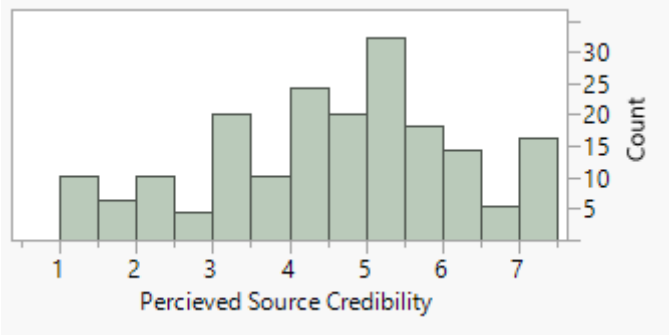

Figure 5 - Distribution for perceived source credibility

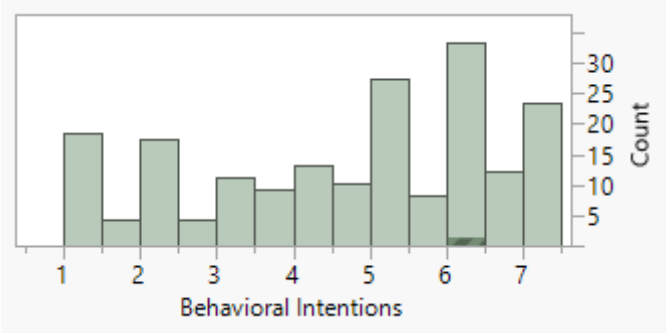

Figure 6 - Distribution for behavioral intentions

Inferential Statistics

Calculated, comprehensive scores

In order to determine the internal reliability of each of our scales the Cronbach's alpha was taken for each of the measures used [Cronbach 1951]. The behavioral intentions scale consisted of 3 items ($\alpha = 0.94$), the perceived trust scale consisted of 9 items ($\alpha = 0.97$), the Twitter metric awareness scale consisted of 10 items ($\alpha = 0.93$), the Twitter familiarity scale consisted of 1 item, and the dispositional trust scale consisted of 6 items ($\alpha = 0.8991$).

Behavioral intentions

For behavioral intentions, an MANOVA was used. We found no main effects or interaction effects for the number of hashtags, tweet to retweet ratio or follower to followee ratio were significant. However, dispositional trust $F(1,188)=4.997$, $p=0.0179$ and Twitter metric awareness $F(1,188)=5.7120$, $p=0.0267$ had a significant effect on the behavioral intentions, as shown in Figure 7.

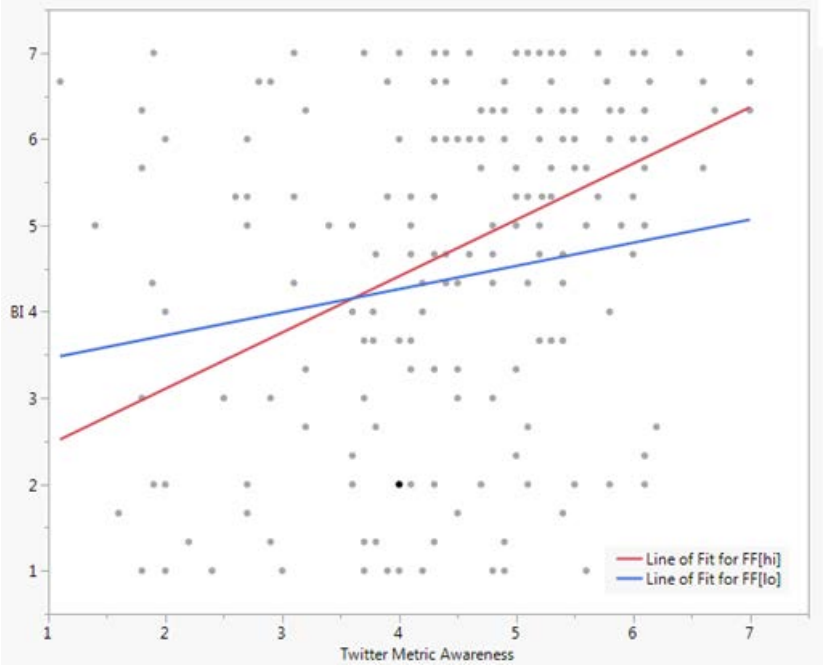

Figure 7 - Twitter Metric awareness on FF (Behavioral Intentions)

Perceived Credibility

For perceived credibility, no main effects for the number of hashtags, tweet to retweet ratio or follower to followee ratio were significant. The interaction effect of number of hashtags and follower to followee ratio did approach significance with ($F(1,188)=3.4117$, $p=0.0665$). Likewise, dispositional trust also approached significance ($F(1,188)=4.1729$, $p=0.0837$) indicating that a person's dispositional trust influences their credibility assessment. Further, Twitter metric awareness ($F(1,188)=4.1729$, $p=0.0426$) had a significant effect on the perceived source credibility, as shown in Figure 8.

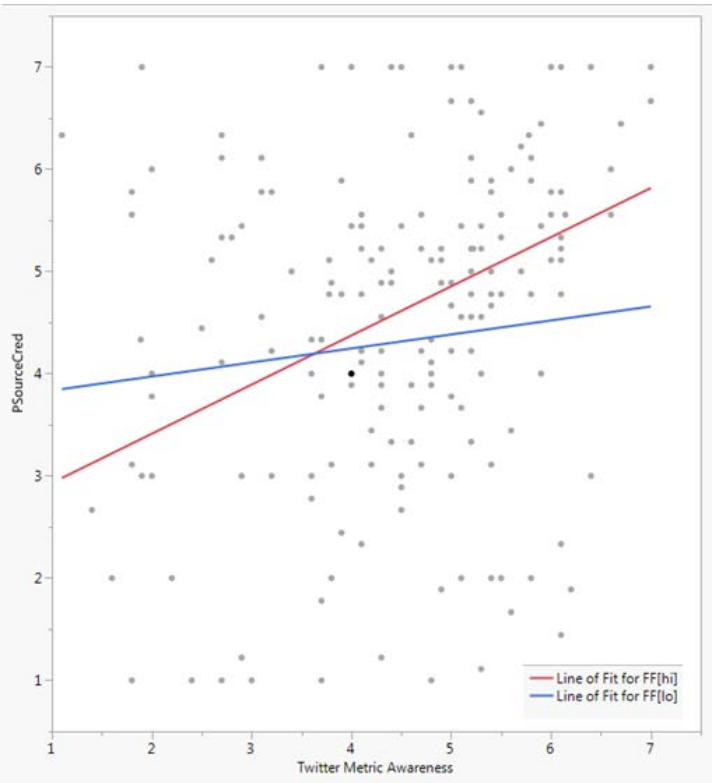

Figure 8 - Twitter Metric awareness on F/F (Perceived source credibility)

While no one broker metric alone was a good predictor of perceived source credibility or behavioral intentions, the combination of number of hashtags and follower to followee ratio did approach significance.

DISCUSSION

Given the vast amount of information available to us online and through social media, filtering and sifting through it is no easy task. Despite these barriers, the potential value of the information found within has been recognized by many researchers. The issue however is how to separate the good from the bad. Within this study, we attempted to leverage heuristic based on metrics of Twitter messages in a way that would allow data such as; average number of hashtags, follower/followee, and tweet/retweet ratios, to be displayed upfront for use of the message consumer. We then proceeded to examine how these metrics affected behavioral intentions and how they would influence perceived credibility of the source. It is important to note that we are not trying to measure the real impact of the source credibility in this initial research. Instead, we are focusing on the perceived credibility of the source. Therefore, this research presents a reasonable base for future investigations in this topic.

No main effect for hashtags, follower/followee, or tweet/retweet ratios was found to be significant for behavioral intentions. However, the results did seem to suggest awareness of Twitter metrics and dispositional trust were significant predictors of a person's behavioral intentions. The finding of dispositional trust supports previous research which showed that a higher dispositional trust was a strong indicator for compliance to new water policies (Hamm et al., 2013). In our case, higher dispositional trust led to participants being more likely to share the stimulus tweet. As Twitter metric awareness was another predictor of behavioral intention we believe that this metric served as a moderator.

For perceived credibility of source, we did not find any significant main effects of hashtags, follower/followee, and tweet/retweet ratios. We did however find an interaction effect that approached significance between hashtags and follower/followee ratio, as seen in Figure 9. In this effect, we can see that when a person has a high follower/followee ratio and they use a lower average number of hashtags their perceived credibility is increased. If, however they have a low ratio of followers to followees and use a low number of hashtags their perceived credibility is decreased. We suggest that this is due to people's tolerance of attempts to gain attention. In the case where people already have a higher number of followers to followees they are assumed to have an established Twitter account, thus users may be less tolerant of hashtag spamming. Whereas people who have a lower number of followers to followees are expected to include more hashtags in order to build their social network.

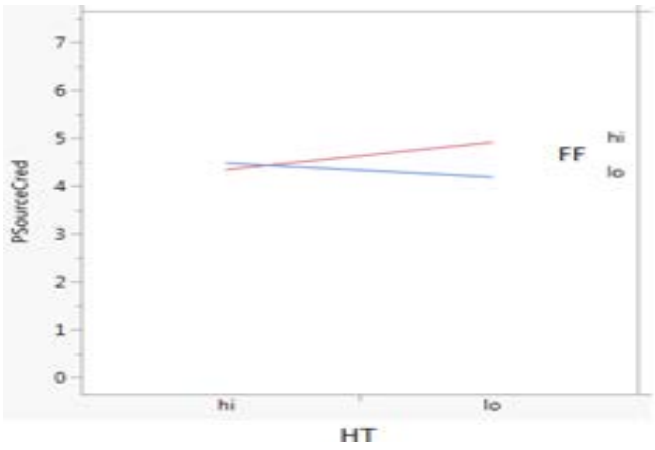

Figure 9 - HT*FF Interaction influence on perceived source credibility

Twitter metrics were found to be a significant indicator of perceived credibility. This again supports our belief that in order for our metrics and perceived credibility to be significant the participants must understand what the metrics are and how they are used within the Twitter platform. Likewise, dispositional trust approached significance indicating that those who are more likely to trust found messages more credible. Our theory is that those with a low dispositional trust would be less likely to trust Twitter metrics regardless of how valid of an indication those metrics are.

IMPLICATIONS

Our study has both theoretical and practical implications. In terms of theoretical advances, this study furthers the research on credibility of sources in the field of crisis response, through the contribution of the concept of

brokerage. In terms of practical implications, implementation of our suggested broker metrics into the Twitter front-end could provide a feasible means of assessing source credibility which could prove useful for both crisis response personnel and civilians in a time-sensitive crisis situation. In particular, adoption of the broker metrics suggested could assist with information overload by reducing the amount of information to even be considered in such a situation.

LIMITATIONS

This study aimed to identify Twitter metrics and proposed to use those metrics to asses Twitter source credibility. This work provided significant findings but had limitations. First, we will point out the external validity limitations. Using Amazon MTurk to recruit participants limited the coverage of our findings. This has the potential for generalization limitations since our approach applied convenience sampling instead of random sampling and only online users were included in the analysis. This work also presented self-selection bias because MTurk´s participants chose which surveys to complete. Additionally, the randomization method used did not offer equal distribution of stimuli among participants; as quotas were filled and counts went down, participants did not have an equal chance to receive each stimulus.

This research study also had some internal validity limitations. This experiment was based on an online survey which had potential for instrumental issues such as categorization of questions, constraints on answers, bias in question-formulation and, existence of meaningless questions. There is also the possibility of display effects such as difference in interaction with and perception of instrument, and difference in responses from smartphone or laptop due different size monitors. In addition, our statistical tests may present limitations due the low number of participants. As mentioned, this study used broker metrics as one of the independent variables. However, brokerage concept may not have been fully explored, as only three metrics were selected to keep the study feasible for this assignment. Therefore, this study may lack content validity.

In this work, the applied scales were either borrowed from prior studies or we developed our own scales. We did not test any of the proposed scales against already established scales or vice versa. For that reason, this study may also present lack of concurrent validity. Finally, this study did not consider participants reaction to images, profile icon and, handle presented in the stimuli. It is possible that participants were reacting to the use of visual representations of our ratio metrics, instead of the ratio measure itself. This situation would raise questions of discriminant validity.

CONCLUSION AND FUTURE RESEARCH

Despite the limitations of our first iteration, we believe our study presents results which indicate there may be value in pursuing broker metric implementation in Twitter messages to influence source credibility. As next steps, we would like to rerun this experiment with amended survey questions, implementation of a manipulation check, and recruitment of a larger number of participants. We expect to validate the approached significance found between hashtags and follower/followee ratio and dispositional trust, and to confirm our theories. It may also be worthwhile to explore the influence of other broker metrics on perceived source credibility and behavioral intentions to assess if there may be a better option than the three tested within this study.

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Appendix A

Tweet Content

1. My local Samajar news ppl just reported a quake. They're not reporting it on main cable news #Samajar #Earthquake

2: Samajar taking precaution since there may be additional quakes #Samajar #Earthquake

3: Confusion and inconsistencies: How US plans to distract public from real truth about Samajar #Samajar #Earthquake

4: Earthquake in Samajar. It's all so surreal! Hard to believe a quake would happen #Samajar #Earthquake

Appendix B

Statement of Informed Consent

Title of Project: It's what is outside that counts: finding credibility metrics through non-message related Twitter features

You are being invited to volunteer to participate in a research study. This summary explains information about this research.

- Purpose: The purpose of this study is to assess participants' perceptions of twitter message source credibility.
- Procedure: Participants will be exposed to a single Twitter message (a "tweet"). Participants will then be asked a series of questions related to their perception of the message source.

Statement of Confidentiality: Your participation will remain confidential. If this research is published, no information that would identify you will be written. All data related to this study will only be accessible to the principal investigator and the student investigators for this study and will be kept in locked closets and/or secured computers of the investigator and student investigator desks, in the investigator's university offices and/or private residences. The Office for Research Protections and the Institutional Review Board (IRB) may review records related to this project. The Pennsylvania State University's Office for Research Protections and Institutional Review Board, and the Office for Human Research Protections in the Department of Health and Human Services may review records related to this project.

If you have questions or concerns, you should contact the principal investigator at XXX-XXX-XXXX. If you have questions regarding your rights as a research subject or concerns regarding your privacy, you may contact

the Office for Research Protections at XXX-XXX-XXXX.

Your participation is voluntary and you may decide to stop at any time. You do not have to answer any questions that you do not want to answer. Your participation implies your voluntary consent to participate in the research.

Please click "Yes, I agree to participate" if you would like to continue with the study. Please click "No, I do not agree to participate" if you would not like to participate in the study.

Damage Identification in Social Media Posts using Multimodal Deep Learning

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ABSTRACT

Social media has recently become a digital lifeline used to relay information and locate survivors in disaster situations. Currently, officials and volunteers scour social media for any valuable information; however, this approach is implausible as millions of posts are shared by the minute. Our goal is to automate actionable information extraction from social media posts to efficiently direct relief resources. Identifying damage and human casualties allows first responders to efficiently allocate resources and save as many lives as possible. Since social media posts contain text, images and videos, we propose a multimodal deep learning framework to identify damage related information. This framework combines multiple pretrained unimodal convolutional neural networks that extract features from raw text and images independently, before a final classifier labels the posts based on both modalities. Experiments on a home-grown database of labeled social media posts showed promising results and validated the merits of the proposed approach.

Keywords

Humanitarian computing, deep neural networks, multimodal learning, natural language processing, visual object recognition.

INTRODUCTION

In times of crisis, it is crucial that emergency responders reach all those affected in a timely manner. However, this task can prove to be challenging when first responders have limited knowledge about survivors; regular emergency communication channels, when accessible by those affected, cannot always handle all calls and prioritize response. With over 2.46 billion social media users (as of 2017) posting thousands of messages during natural disasters (Techradar, 2013), monitoring social media outlets for relevant content has recently become common practice among emergency responders. During Hurricane Sandy, about 25 first aid personnel monitored 2.5 million posts related to Sandy (Baer, 2012), and during Hurricane Harvey, social media came to the rescue of a woman tweeting for help as 911 wasn't responding (Rhodan, 2017). However, the huge number of posts makes it impossible for emergency responders to manually mine posts for relevant information, and takes valuable man-power away from other important tasks. Therefore, automating the extraction of actionable information from social media is essential to fully leveraging the benefits of this abundance of data.

An emerging goal of the humanitarian computing community is to build automated systems that detect and flag social media posts for disaster and crisis data. Such systems can be decomposed into three main modules: (1) retrieving possibly relevant social media posts which entails filtering through huge numbers of irrelevant posts while checking for authenticity and recency among other criteria; (2) classifying filtered posts into multiple damage and disaster categories while checking for informative content; and (3) summarizing posts containing disaster information that would be communicated to emergency responders.

In this work, we focus on module (2), identifying damage to infrastructure and environmental elements, in addition to human casualties in posts. Determining whether severe infrastructure damage has occurred in a highly dense city vs. mild damage to a rural town can aid first responders in recognizing each location's needs and optimally allocating resources; a highly dense city may need more shelter aid than a rural town that may need access to clean water instead. Both locations may have been affected by the same natural disaster or event that caused the damage; in our application, information about the type and degree of damage is more important than the cause of the damage. Identifying human casualties would also allow first responders to provide targeted aid in a timely fashion, possibly reducing the number of fatalities.

Our aim is to build a classifier that can handle multimodal data, such as images and text. One approach is to train an artificial neural network (ANN) on multimodal data, but this approach would not benefit from well-established unimodal models from the literature. Instead, we propose a multimodal framework based on pretrained unimodal models that are then combined to obtain a final classifier. Specifically, we adopt the Inception convolutional neural network (CNN) model (Szegedy et al., 2015), pretrained on ImageNet to process images, and we use a pretrained word embedding model to process the text which are then fed to a single layer CNN. Feature fusion (FF) combines the internal representations generated from the various layers of the CNNs to train a multimodal classifier. On the other hand, decision fusion (DF) combines the predictions of the unimodal classifiers to obtain better predictions by either using decision rules or training a classifier. We evaluate our framework on a home-grown labeled dataset of multimodal social media posts and show the advantages of using both modalities to make decisions.

Next, we present existing work on humanitarian computing, deep learning and multimodal learning. Then, we discuss our proposed methodology, describe the home-grown dataset and report on the experimental results, before concluding with final remarks.

RELATED WORK

Humanitarian Computing

Work leveraging social media posts has been developed for various humanitarian computing applications including event detection (Sakaki et al., 2013), alert systems (Breen et al., 2016), map generation (Cresci et al., 2015a) and actionable information extraction (Ashktorab et al., 2014; Caragea et al., 2011). Identifying the type and degree of damage, whether to buildings, natural landscapes or people, is crucial to extract actionable information and allow first responders to properly allocate resources. Damage identification work can be divided into those that processed text, images or both.

Imran et al. (2014) classified tweets by processing the text only to extract damage related information. Similarly, Cresci et al. (2015b) extracted damage information from tweets using natural language processing techniques to understand the linguistic content of these tweets. Nguyen et al. (2016) adopted deep ANN to process the contents of tweets and classify them based on their relevance.

Focusing on images only, Alam et al. (2017) developed an end-to-end framework to collect, process and assess the type and severity of damage in images using a deep learning approach. Nguyen et al. (2017) fine-tuned CNNs with domain specific images to improve damage identification from visual cues.

Finally, some work has investigated combining both text and images in a multimodal framework. Specifically, Jomaa et al. (2016) determined whether damage in tweeted images was to buildings or natural landscapes by extracting cheap visual features combined with bag-of-word processing of the accompanying text, which outperformed other unimodal classifiers.

Deep Learning

Visual scene understanding and semantic understanding are crucial components of identifying and assessing damage for actionable information extraction. Deep learning is one of the leading approaches in the literature to achieve scene and semantic understanding from large amounts of possibly unlabeled and unstructured data with minimal feature engineering (LeCun et al. 2015).

CNN is one such approach that was first developed for visual scene understanding (Krizhevsky et al., 2012) but has also been successfully applied to text (Kim, 2014) and audio processing (Abdel-Hamid et al., 2014). Trained on large amounts of unlabeled and labeled data, CNN can identify a wide range of object categories with super-human accuracies (Krizhevsky et al., 2012), by transforming the raw input (image pixel values) through successive convolution layers and a nonlinear pooling layer (LeCun et al., 2015). For example, CNN achieved an error rate of approximately 15% on the ImageNet database which contained a million images divided into 1000 categories, almost 11% higher than other methods (Krizhevsky et al., 2012). Inception, a 15-layer CNN, also achieved state-of-the-art results on image recognition tasks (Szegedy et al., 2017). Recurrent neural networks (RNN), another deep learning approach, has performed well on visual scene understanding. Specifically, long short-term memory, a type of RNN, achieved a high accuracy on image caption generation, which requires scene understanding (Xu et al., 2015).

Focusing on semantic understanding, deep learning has been used for word embeddings, where words are represented by dense continuous vectors. Sentence and text understanding using deep learning became possible after the introduction of word embedding tools such as Word2Vec (Mikolov et al., 2013a), which allowed ANN

to process the words through these vector representations. State-of-the-art results have been achieved on sentiment analysis (Glorot et al., 2011), sentence classification (Lai et al., 2015), text generation (Vinyals et al., 2015) and other tasks, using deep learning. Furthermore, CNN have contributed to deep learning's success on text classification (Conneau et al., 2016; Kim 2014; Zhang el al., 2015), sentiment analysis (Dos Santos et al., 2014), and learning semantic representations (Shen et al., 2014).

Multimodal Learning

With the diverse sources and properties of data, machine learning algorithms that can combine these various perspectives are necessary to maximize the utility of this data. Multimodal learning deals with this issue by developing or adapting machine learning algorithms to learn from multiple modalities. Guillaumin et al. (2010) improved image categorization by including tags in the feature vectors used to train a multiple kernel learning classifier, which resulted in almost 10% improved accuracy on some classes. Alqhtani et al. (2015) detected the occurrence of various events from Twitter by extracting semantic and visual features to train a k-nearest neighbor (KNN) classifier and achieved up to 8% improvement in classification accuracy compared to unimodal approaches. Jomaa et al. (2016) also adopted a FF approach, where feature vectors contained visual and semantic features extracted from images and text, respectively. These features trained a support vector machine (SVM) classifier that improved damage related classification by approximately 4%. Poria et al. (2016) performed sentiment analysis by processing text, audio and images using FF and DF approaches that exceeded the accuracy of state-of-the-art approaches by at least 20%.

While these references performed feature extraction and supervised learning separately, deep learning multimodal algorithms have been proposed to process raw data in unsupervised learning frameworks. These works include Ngiam et al. (2011) who trained deep ANN to learn representations based on raw audio and visual inputs, and Srivastava et al. (2012) who trained deep Boltzmann machines using images and text.

APPROACHES AND MODELS

The proposed deep learning framework consists of three main components: text processing, image processing and multimodal fusion, which can be at the feature or decision level. Next, we describe the unimodal deep learning classifiers for text and images, before discussing the DF and FF classifiers.

Text classification model

To classify text, we employ a shallow CNN based on Kim's proposed architecture (Kim, 2014). While RNN are popular in natural language processing since they can model the sequential structure of text, CNN have achieved equal if not superior performance in classification tasks (Yin et al., 2017). Proposed models in the literature range from one layer (Kim, 2014) to six layers (Zhang et al., 2015) and even 29 layers (Conneau et al., 2016). Recent empirical evidence has shown that deeper models do not necessarily increase accuracy; a wide and shallow CNN has beaten other deep CNNs on multiple datasets (Le et al., 2017).

The input to our CNN is a matrix where each row is a real-valued vector representation of each word in the caption or tweet. Our word-vectors are obtained from a pretrained word embedding model, a common method when a dataset is small (Collobert et al., 2011; Iyyer et al., 2014; Socher et al., 2011). The model architecture used to learn an internal representation of the text is depicted in Figure 1. The CNN is divided into 3 modules: convolutional layer, max-pooling layer and a fully connected layer with softmax outputs.

1) The convolutional layer is composed of three types of filters with height $H_f = [3,4,5]$, all of width $W = 200$ with n such filters of each type, where the filter weights $w_{i,j}$ are learned. We perform a dot product between the filter and the input matrix $\boldsymbol{x}$, recording the result, and then sliding the matrix one row at a time and repeating the process until the last row is reached. This process produces a vector, $\boldsymbol{c_i} = f(\boldsymbol{w} * \boldsymbol{x} + \boldsymbol{b})$, for each filter i, where $f(x) = max(0, x)$ represents the non-linear activation function called rectified linear unit or ReLU, $*$ is the convolution operation described in the preceding paragraph, and $\boldsymbol{b}$ is a bias term.
2) The max-pooling layer takes $\boldsymbol{c_i}$ and produces $\mathrm{m_i} = \max_{1 \le k \le |\mathbf{c_l}|} \mathbf{c_{i_k}}$. The results of each max-pooling operation are concatenated to produce a vector $\boldsymbol{m} = [m_1, m_2, \dots, m_{3n}]$.
3) The vector $\boldsymbol{m}$ is then fed into a fully connected layer, with dropout to avoid overfitting (Srivastava et al., 2014), followed by softmax outputs for each class.

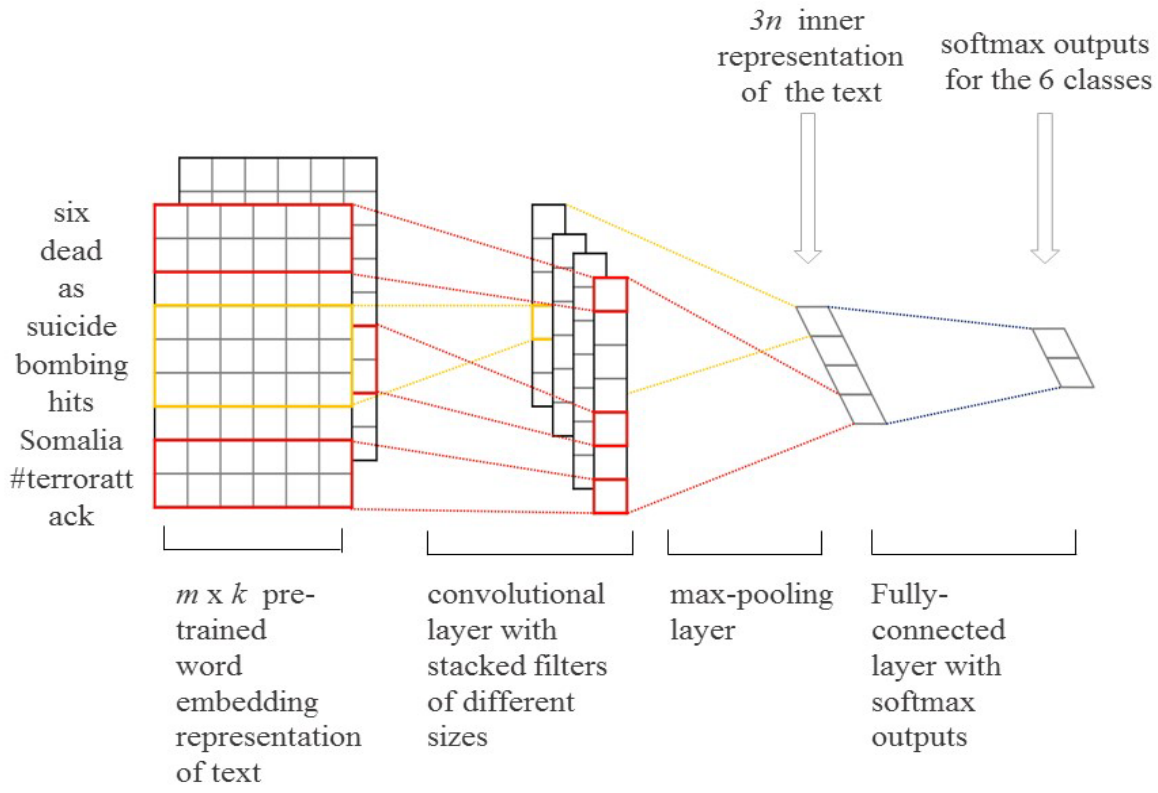

Figure 1. CNN for Text Classification (adapted from (Kim, 2014))

To reach an optimal performance, we modified the network design and tuned the parameters by following the guidelines in (Zhang and Wallace, 2015), as reported in the experiments section. Furthermore, we compared the GloVe model pretrained on the Twitter dataset of two billion tweets each of dimension 200 (Pennington et al., 2014) to the Word2Vec model trained on a Google News corpus of 3 billion words (Mikolov et al., 2013b), while varying the number of filters and the filter region sizes.

Image classification model

One of the more popular image classification approaches today involves using a CNN pretrained on a large dataset, and then adapting (fine-tuning) the model to the classification task at hand using context or domain specific data (Donahue et al., 2014; Sharif Razavian et al., 2014). The ImageNet dataset (Deng et al., 2009), which consists of over 14 million unlabeled images divided into over 1000 categories, has been commonly used to pretrain deep networks. One explanation for ImageNet's success is the broad range of categories it covers that are applicable to most classification tasks, but no definitive answer has been reached yet (Huh et al., 2016).

Current CNN architectures for image classification tasks include ResNet (He et al., 2016), VGG (Simonyan and Zisserman, 2014) and NASNet (Zoph et al., 2017). We opted to use the Inception architecture, first introduced in 2015 (Szegedy et al., 2015), for its near state-of-the-art accuracies on ImageNet while using a smaller network compared to other models. The network consists of stacked "Inception Modules", as described in Figure 2. Each module combines multiple convolution filters of varying sizes and pooling units. The input to the module, which consists of raw pixel values for the first layer, is concurrently passed through multiple convolution filters of different sizes starting with 1x1 convolution which average out the different channel components. The output of all these filters are concatenated to form the input to the next layer.

Inception-v4, the current Inception architecture shown in Figure 3, is a network of stacked inception modules followed by a softmax layer. The output of the last layer before the softmax block, called the bottleneck feature, is the feature vector used as a representation of the original image for the multimodal model.

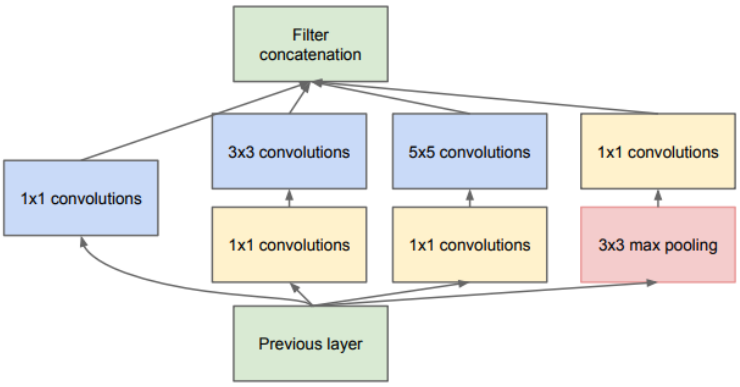

Figure 2. Inception Module Example (Adapted from Szegedy et al., 2015)

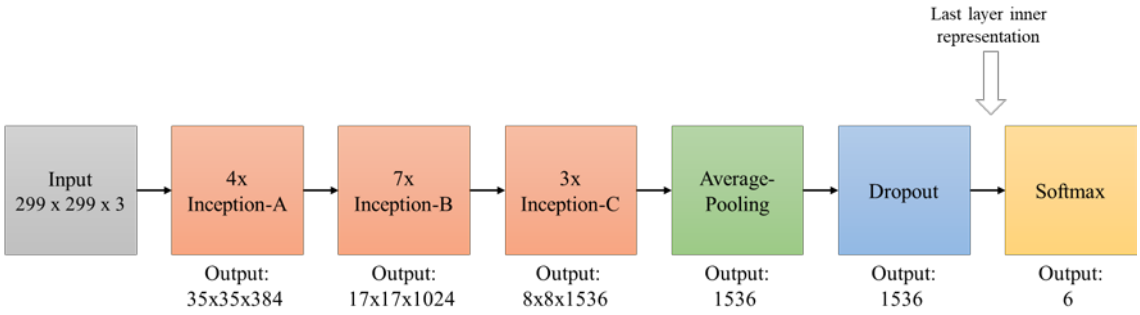

Figure 3. Simplified Inception-v4 Architecture

Decision fusion

To improve the overall classification accuracy, we turn to approaches in ensemble learning for inspiration on how to combine both modalities, where different learning algorithms are combined to form a better classifier on a given task (Zhou, 2009). The text and image models, $\boldsymbol{h_T}$ and $\boldsymbol{h_I}$ respectively, produce six-dimensional softmax outputs for each input, where the decision is based on the class corresponding to the index with the maximum value. A priori, we believe that both models are equally good, thus, we sum their outputs to obtain a new output vector: $\boldsymbol{h} = \boldsymbol{h_T} + \boldsymbol{h_I}$ and then decide on the class with the highest value; we refer to this approach as maximum decision rule.

It is not usually possible to interpret ANN softmax outputs as uncertainties as much as we would the outputs of classical algorithms such as logistic regression or naive Bayes. We observe that softmax outputs in ANN tend to have very sharp distributions, i.e. approximately equal to 1 for predicted class and 0 for the other classes, the networks were trained using a cross-entropy loss function. Therefore, we apply a softmax function with temperature τ to $\boldsymbol{h_T}$ and $\boldsymbol{h_I}$, to soften their distributions before combining them, as shown in (1). A higher τ implies a softer distribution, i.e. as $\tau \to \infty$, $\tilde{h}_T(\mathrm{i}) = \frac{1}{6}$.

$$\tilde{h}_T(i) = \frac{exp(h_T(i)/\tau)}{\sum_{j=1}^{6} exp(h_T(j)/\tau)} \forall i \quad (1)$$

However, this approach neglects the accuracy of each model, i.e. if the image model is significantly more informative than the text model, its predictions should be given a higher priority. To remedy this issue, we split our training set into two parts: one for training the models and another, called validation set, to obtain a per-class accuracy estimate for each model: $\boldsymbol{a_T}$ and $\boldsymbol{a_I}$. The class-model accuracy estimates are simply per-class misclassification rates. We scale the modified softmax outputs $\tilde{h}_T$and $\tilde{h}_I$ by their accuracy estimates, then take their sum, $h = a_T^T \tilde{h}_T + a_I^T \tilde{h}_I$, with the final prediction being the class with the maximum weight. This approach is referred to as weighted maximum decision rule.

Another approach is to learn this decision rule, instead of simply using the class accuracies and a maximum decision rule. We can train a meta-classifier on the validation set, where the input is the concatenation of $\boldsymbol{h_T}$ and $\boldsymbol{h_I}$. This approach is called stacking (Wolpert, 1992) in ensemble learning. We experiment using different learning algorithms for our meta-classifier such as linear models, SVM and ANN.

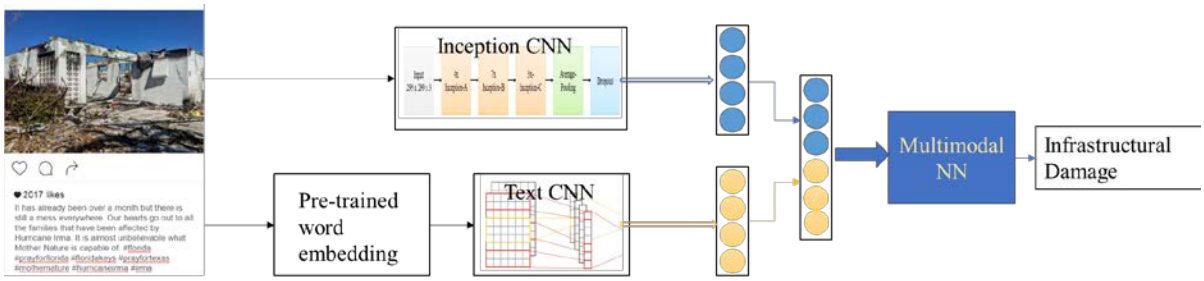

Figure 4. FF Model

Feature fusion

With DF, only the predictions or final output of the networks are used. Instead of taking the output of the softmax layer of the network, we can take of the outputs of any arbitrary layer of our networks and use them as input to our meta-classifier. Recall that the input to both models is the raw data; no prior feature engineering was performed. The text model uses word embeddings as its first representation of the text and then convolutions are applied on the embeddings to produce a second internal representation of the text. On the other hand, the raw image passes through different layers of convolutions; at each stage, an internal representation of the image is computed. ANN learn a representation of their input with each successive layer (Bengio et al., 2013); these representations can be used as a learned feature of the original data.

The question now is from which layer should we take our features from. In fact, the internal representation at each stage loses some of the information contained in the representation in the previous stage, a fact illustrated by the data processing inequality (Cover and Thomas, 2006), which states that processing will never result in a gain of information. In some sense, it is a sort of lossy compression of the information found in the input. However, what we gain from each stage of processing is a more separable dataset which is easier to classify. This can be seen if we look at the layers in reverse order: the softmax layer only requires a maximum decision rule, the pre-softmax layer requires a single-layer perceptron to achieve good results and so on. Therefore, there exists a trade-off between the ease of classification and the information content in the representations of the network layers. We propose to use the last layer before the softmax layer as our features for the text and the images from their respective models, since they would be easier to classify than earlier layers but still retain more information than the softmax outputs.

As with DF, we are faced with the issue of giving more weight to the more informative modality. Two factors affect the influence of each modality on the overall classification; (1) the dimension of the features: if the text has a higher dimension feature vector than the image, the meta-classifier may give more weight to the text and vice-versa; and (2) the sparsity of the feature representations (contain a large number zeros): a sparse feature vector would contribute less to the decision.

Figure 4 summarizes the FF approach. The images and text CNNs are first trained independently on the training set. Then, a meta-classifier whose input is the concatenation of the features from the layer before last of the networks, is trained on the same training set.

DATA COLLECTION

Next, we describe the collected dataset, and the techniques employed to filter and organize its content.

Captioned image retrieval

Social media platforms such as Instagram, Twitter and Facebook are among the first to report cases of emergencies and crisis situations; they represent a critical source of information. However, these sites are usually overflooded with posts that are either irrelevant or non-informative and make it hard to disseminate actionable information to first responders (Olteanu et al., 2015). Disaster related content filtering has been performed on Twitter posts for both the tweets (Abel et al., 2012; Chowdhury et al., 2013; Jomaa et al. 2016; Olteanu et al., 2015) and images attached to them (Alam et al., 2017; Jomaa et al. 2016). This paper investigates the interplay between the images and the captions in crisis situations. Thus, the Instagram platform represents a more natural choice since posts on Instagram are captioned images, reducing the need to search for tweets with images.

Figure 5. Sample of Hashtags Used for Data Collection

The main method of collecting data from these platforms is through hashtag or keyword queries using their application programming interfaces (API). However, this method heavily relies on the correct choice of hashtags which shape the resultant dataset (Olteanu et al., 2016). Even though hashtags can be considered as a form of tagging, their use is often inconsistent and may result in missing relevant data that was not properly tagged (Potts et al., 2011; Olteanu et al., 2016).

Olteanu et al. (2014) provided a publicly available crisis lexicon, "CrisisLex", which attempted to provide a more representative sample of crisis situations posted on social media. We used their lexicon to collect Instagram and Twitter posts and extended it to include event specific keywords such as "Hurricane Irma", "Hurricane Nate", and "Iran-Iraq Earthquake", to retrieve data from recent disasters. The approach of using a specified lexicon is not suitable for building an automated disaster detection system, as using event specific terms will only be possible during or after the event occurs, and broad terms won't capture the entirety of posts related to a specific event. Therefore, having a dynamic and adaptive lexicon is necessary.

More than 100 hashtags were used to collect data over different time periods to insure a representative sample of crisis related images and captions. Figure 5 summarizes some of the hashtags we used to collect social media posts. Furthermore, we augmented our text data with informative tweets from the CrisisLexT26 dataset (Olteanu et al., 2015) and human and infrastructure damage tweets from the CrisisNLP dataset (Imran et al., 2016). We also augmented our image data with images from google search using the same keywords and hashtags.

Data filtering

After collecting the raw data which consists of text, images, and captioned images, we divide the data into one of five different damage categories, with an additional background non-damage class:

(1) Infrastructural damage: damaged buildings, wrecked cars, and destroyed bridges

(2) Damage to natural landscape: landslides, avalanches, and falling trees

(3) Fires: wildfires and building fires

(4) Floods: city, urban and rural

(5) Human: injuries and deaths

The end goal of the classification is to direct the appropriate resources for each situation. For example, identifying human casualties would prompt first responders to deploy ambulances and first aid kits, while identifying a fire would result in the mobilization of fire trucks. We based our categories on this objective: we want the classes to be descriptive of the damage rather than specify the source of the damage to aid in resource allocation. Ideally, it is preferable to have categories for each type of disaster that could arise, however this high specificity would sacrifice accuracy with current methods. These factors determined our choices for the categories.

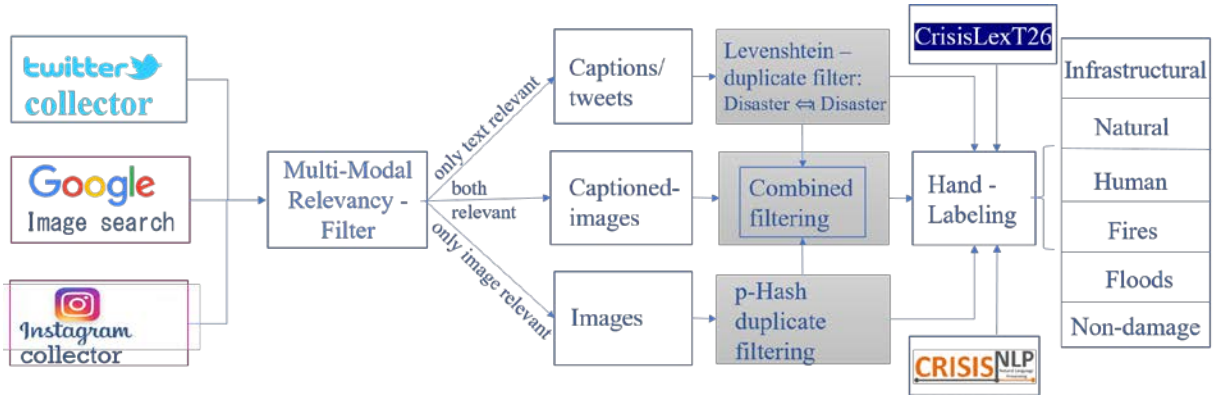

Figure 6. Data Collection and Processing Pipeline

Table 1. Dataset Statistics

Label	Captioned Images	Text	Images without captions	Total
Fires	349	1819	856	3024
Floods	385	3685	1236	5306
Natural landscape	515	1876	882	3273
Infrastructural	1418	3547	3002	7967
Human	240	2910	1008	4158
Non-damage	2972	5194	3891	12057
Total	5879	19031	10875	35785

To speed-up the labelling process, we first filtered out irrelevant and non-informative posts, including advertisements, selfies or memes. To do this, we hand-labelled a subset of the collected posts as either relevant to disaster situations or not relevant. Then, we trained relevancy classifiers on these posts to recognize relevant vs. non-relevant posts. We applied this classifier to filter out the remaining data that are non-relevant. The remaining posts were manually labeled by a group of 5 annotators, a majority vote determined the final annotations. The inter-annotator disagreement rate was equal to 2.6%. The collected data belong to three mutually exclusive bins: text, images, and captioned images.

First, to filter out irrelevant text data, we employed a similar system to Tweet4act (Chowdhury et al., 2013). We trained a binary version of our text model to classify damage vs. non-damage, and then we deleted duplicate tweets/text by first computing a pairwise Damerau-Levenshtein distance between every pair of captions. The Damerau-Levenshtein distance represents the number of operations (insertion, deletion or substitutions) required to transform one string of text to another. If the distance is less than 10% of the respective lengths of the captions, we arbitrarily removed the shorter length text. Most duplicate captions occurred in the cases of retweets or automated bot tweeting.

Second, to filter out irrelevant images, we used the Image4Act system (Alam et al., 2017). We trained a binary classifier version of our image model again to classify damage vs. non-damage, and then we removed duplicate images by computing a perceptual hash (pHash) for the images. The pHash is a hashing algorithm designed for images; the pHash value for similar images will be almost equal and is resilient to multiple modifications of original images. Thus, we iterate over pairs of images and arbitrarily remove one of them if their pHash values are almost equal.

Finally, to filter out irrelevant captioned images, we used a multimodal decision based system. The caption is fed into the text relevancy model and the image into the image relevancy model. If both models agree on relevancy, then we move the captioned image into its corresponding category. Otherwise, the text and image are placed in separate categories. Identifying duplicate captioned images is similar: both signals need to be duplicates of the corresponding signals of another post to delete the captioned image. If only the image part of the post is a duplicate, we remove it and place the text into its bin, and vice-versa, to avoid situations where one sample is in the training set and another in the test set. This filtering process is depicted in Figure 6.

(a) Infrastructural (b) Natural landscape (c) Fires

(d) Floods (e) Human (f) Non-damage

Figure 7. Sample Dataset Images

(a) Infrastructural (b) Natural landscape damage (c) Fires

(d) Floods (e) Human (f) Non-damage

Figure 8. Sample Captioned Images

Dataset Characteristics

Based on the database collection procedure illustrated in the previous subsections, a home-grown database of 35,566 samples was collected from various sources. Table 1 summarizes the number of samples per class and the number of unimodal (text and images without captions) vs. bimodal samples (captioned images). A few sample images from each class are reported in Figure 7 and Figure 8.

Table 2. Image Classification Performance

Pretrained model	Validation Accuracy (%)	Test Accuracy (%)
Inception-v3	**84.86±1.27**	83.78±1.48
Inception-v4	84.41±2.00	**83.98±1.72**
VGG16	81.32±2.42	82.19±2.46
InceptionResnet-v2	84.16±1.58	83.61±0.82

Table 3. Text Classification Performance

Word Embedding	Number of filters	Validation Accuracy	Test Accuracy (%)
Word2Vec	256	**91.18±1.34**	**89.88±0.70**
Word2Vec	512	90.90±1.79	89.33±1.01
GloVe	256	89.56±1.60	89.22±0.69
GloVe	512	89.63±1.32	89.04±1.11

EXPIREMENTS

In this section, we evaluate unimodal deep learning classifiers and machine learning algorithms for the multimodal damage identification task. Experiments were run on a machine equipped with an Intel Core i7-6700 CPU with 4 cores and an Nvidia GTX1060 GPU with 6GB RAM running a Windows 8 operating system. The algorithms were written in Python based on the Tensorflow 1.3 package. The code and dataset are publicly available on Github[1]. The captioned images dataset was split into 4-folds to perform cross validation. Furthermore, each fold is split into a test set (70% of fold or 18% of original data) and a validation set (30% of fold or 7% of original data). The unimodal image and text models were trained on their respective unimodal datasets augmented with the training set of captioned images set for each fold. All results are averaged over the four folds, with the mean and standard deviation being reported.

Unimodal Classification

For the image model, we experimented with four different CNN architectures. All the models were pretrained on ImageNet and the weights of the networks' last layers were fine-tuned on our dataset. The networks were trained until the loss converged with the default hyperparameters. Table 2 reports the accuracy (mean±standard deviation) on the validation set for the various CNN models which were used to select the best model for the multimodal fusion. Additionally, we reported the test set accuracies for comparison with multimodal models. While all models achieved similar performance, Inception-v3 marginally outperformed other models on the validation set, and it was also the fastest model for training and prediction.

For the text model, we resorted to Kim's CNN architecture (Kim, 2014). We compared two different pretrained word embeddings: GloVe trained on 2 billion tweets and Word2Vec trained on a 3 billion words Google News corpus. For the network parameters, we used filters of size 3,4 and 5 with 256 or 512 filters for each size. Table 3 summarizes the performance of the CNN trained on the home-grown database portion reserved for training and tested on the validation set. The number of filters did not have a significant effect on the accuracies; default parameters of the network were effective for this text model. Word2Vec outperformed GloVe on the validation set by more than 1%, but only marginally outperformed it on the test set.

Based on the validation set results, we chose the Inception-v3 image model and the Word2Vec-256 text model as the basis for the multimodal classifiers discussed in the following sections.

Multimodal Classification

We first evaluated the DF multimodal approach. For the rule-based classifiers, we obtained validation set predictions of the best unimodal classifiers (Inception-v3 and Word2Vec-256) to compute the a priori weights for the weighted maximum decision rule model. Then, we applied the test set to the end-to-end system. For the simple maximum rule DF approach, we simply applied the test set to the unimodal classifiers and obtained the final class using the maximum decision rule. We trained the stacking classifiers on the training set, used the validation set for hyperparameter selection, and evaluated on the test set.

[1] https://github.com/husseinmz/multimodal-deep-learning-for-diaster-response

Table 4. Performance of DF Classifiers and Rules

DF algorithm	Test Accuracy (%)
Maximum decision rule	91.85±1.01
Weighted maximum decision rule	91.67±0.83
DFMC with ANN	92.30±1.09
DFMC with KNN	92.57±1.36
DFMC with SVM (gaussian kernel)	**92.62±0.89**

Table 5. Performance of FF Meta Classifiers

Classifier	Test Accuracy (%)
ANN	**92.60±0.77**
KNN	89.40±0.77
SVM (linear kernel)	92.27±0.53
SVM (gaussian kernel)	90.74±0.51

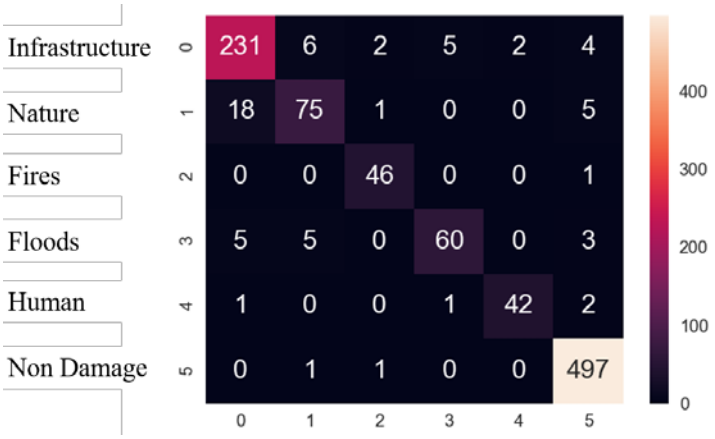

Figure 9. Confusion Matrix for Best Model

Table 4 reports the accuracies (mean±standard deviation) of various DF classifiers on the test set. All multimodal classifiers outperformed their unimodal counterparts by a minimum margin of 2% which hints at the effectiveness of using both modalities. Specifically, the DFMC with SVM outscored the best unimodal text model by 2.74%. We note that the stacking meta classifiers performed better than the decision rules. Furthermore, the weighted maximum decision rule scored slightly worse than the regular maximum rule which might be due to noisy class-estimates on the small validation set.

Next, we focused on the FF approach where the bottleneck feature i.e. the last layer generated from Word2Vec-256 and Inception-v3 networks were concatenated and used to train the meta classifier on the annotated images dataset. Multiple classifiers were compared including a 4-hidden layer ANN with 128, 64, 32, and 16 neurons per layer, SVM with linear and gaussian kernels, and KNN. Table 5 reports the accuracies on the test set, where the ANN classifier achieved the best accuracy of 92.60% and SVM with linear kernel was a close second. However, the best FF classifier and the best DF classifier achieved comparable accuracies (0.02% difference).

Figure 9 displays the confusion matrix of the best end-to-end model (DFMC with gaussian SVM whose input is obtained from the Inception-v3 image model and Word2Vec-256 text model). Our model could distinguish non-damage from damage data well; it achieved a 99.6% true positive rate for the non-damage class. Focusing damage related classes, the true positive rate per class ranged from 75.8% (for nature) to 97.9% (for fires). We notice that many of the nature images were classified as infrastructure which could be due to the existence of man-made structures such as houses or cars in the natural landscapes. The model correctly identified human casualties with a true positive rate of 91.3% but may have been affected by background scenes in images which often included buildings when misclassifying some of the data into infrastructure or non-damage.

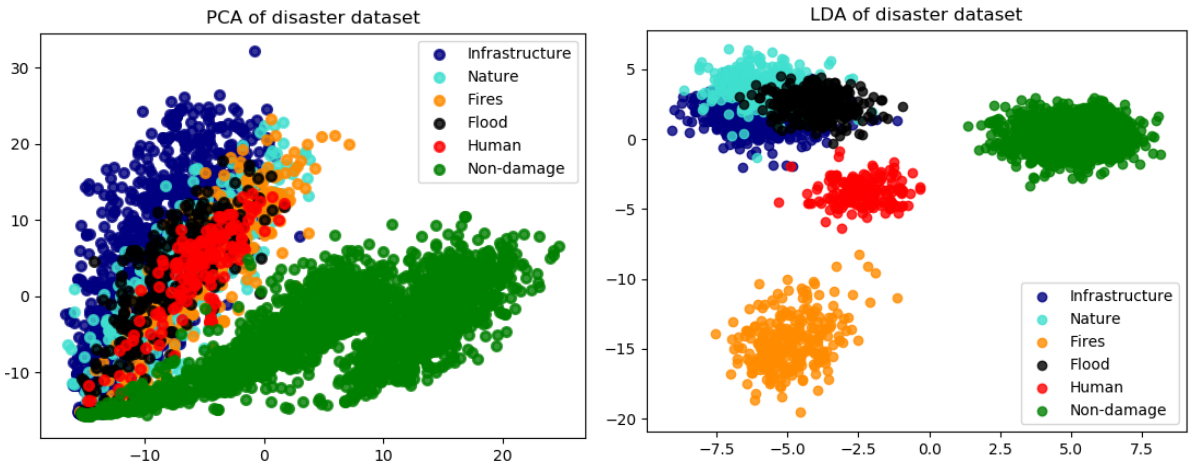

Figure 10. Results of PCA (Left) and LDA (Right) feature reduction

Class Separability Analysis

A principle component analysis (PCA) and latent discriminant analysis (LDA) were performed on our database to examine the separability of the investigated classes. The features obtained from the best image classification (Inception-v3) and text classification (Word2Vec-256) models were used as input to the PCA and LDA algorithms. Figure 10 plots the distribution of the data after performing PCA and LDA to reduce the dimensionality of the data to 2. The LDA plot shows that most of the classes are easily separated which confirms that our categories are distinct with only noticeable overlap existing between the flood and infrastructure damage data. The PCA plot shows that damage and non-damage classes are easily separable, which may explain why simple classifiers such as KNN performed well. This shows that the deep learning models learned class specific features well.

CONCLUSION

Identifying damage and human casualties in real time from social media posts is critical to providing prompt and suitable resources and medical attention, to save as many lives as possible. With millions of social media users continuously posting content, an opportunity is present for machine learning algorithms to learn a damage and human casualty recognition model. In this work, we present a multimodal deep learning framework that classifies social media posts into five damage related categories including infra-structure damage, natural damage and human casualties. A CNN model based on the Inception pretrained model is used to process images, and a CNN model fed with the word embedding model's output is used to process text. Combining both inputs in a multimodal learning framework achieved an accuracy of 92.62%. Future work will investigate developing other multimodal deep learning models for a finer categorization and new online techniques for data collection and filtering.

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Harnessing Data to Create an Effective Drought Management System

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ABSTRACT

Drought is a billion-dollar weather and climate disaster. It is a complex climate phenomenon that slowly emerges and quickly vanishes, making it hard for local stakeholders and the public to respond in a timely manner. To reduce the vulnerability of our society to future drought, a better understanding of how society responds to drought is critical. Here, we propose a pilot study about social response to a recent California drought through social media. In this study, we identify the most important users in the collected dataset using an extension of PageRank, the algorithm developed for Google Search. We investigate the key drivers of the peak of the Twitter activities in February, 2014, during the California drought. We also create a word cloud from the top 2,000 most retweeted tweets. Lastly, we specify the information sources from those tweets. The findings of this study show that big data can help us to improve current drought response plans through fundamental understanding of social response to drought.

Keywords

Droughts, social response, PageRank.

INTRODUCTION

Drought is a billion-dollar weather and climate disaster. In 2015, the California drought cost the U.S. 2.7 billion dollars and nearly 21,000 jobs (Howitt et al. 2015). In 2016, droughts across the continental U.S. cost 3.6 billion dollars because of the onset of a new drought in the eastern U.S. How can we give society the foresight and wisdom to respond to drought risk before they lead to multi-billion-dollar losses?

Drought is a naturally occurring, but rare, climate phenomenon lasting up to several years through the stages of initiation, onset, and recovery. Drought is initiated by a lack of precipitation over an extended period, is deteriorated by high water demand and persistent water supply deficit during the onset, and is terminated by an extremely intense precipitation event or a series of precipitation events. Because of the slow emergence and quick disappearance of drought, it is hard for local stakeholders and the public to respond in a timely manner (Switzer and Vedlitz 2017). The drought research community has believed that due to its persistency, drought allows society to plan and develop mitigation strategies ahead of time as long as citizens are given actionable information from a reliable drought monitoring and forecasting system. However, despite more reliable drought monitoring and forecasting systems, we have still faced multi-billion-dollar losses from recent droughts. Drought monitoring systems are limited in elevating the level of drought awareness and ultimately managing the social vulnerability to drought. To reduce significantly the vulnerability of our society to future drought, current research must shift to an examination of how society responds to drought. It is critical to stimulate timely social response to drought risk in order to mitigate its adverse effects on our society.

Social behavior and dynamics during the onset of drought have been poorly studied for several reasons. First, it requires an interdisciplinary collaboration approach; and second, there has been a lack of available data for social response. The hydroclimate research community can provide data regarding the stage and severity of drought. The social psychology research community can provide insight to social response to drought through theoretical models examining human reactions to disaster. According to the social-cognitive preparation model (Paton 2003), it has been

suggested that information from behavioral interventions for intention formation can inform education programs designed to facilitate environmental awareness and disaster preparedness in people (Ardalan et al. 2013; Ejeta et al. 2015). However, in order to maximize such facilitation, it is imperative to understand how risk communication and warnings are interpreted by the public prior to intention formation (Paton 2003).

The computer science research community can extract meaningful information for social behavior via big data and machine-learning techniques. In recent decades, significant advancements in these areas allow us to validate and investigate the governing mechanisms of social response to specific events. Integrating state-of-art knowledge and techniques across the disciplines of hydroclimatology, social psychology, and computer science is a key solution to tackle the challenge problem of drought mitigation.

Here, we demonstrate a pilot study about the above-mentioned problem in which we analyze social response to droughts. We downloaded Twitter data related to droughts in California using the date of range from 2010 to 2017. We chose California as it experienced multiple droughts during this period (Howitt et al. 2015). Our overarching research question was “What is a drought related lexicon to which the public is most responsive?" An effective drought management system must utilize such lexicon that makes social response to drought more timely.

In this study, we focused on a subset of data related to the period of the highest public activity on the recent California drought (2011 - 2014). The objectives of this study were to 1) to determine the most popular tweets during this period and the most important terms used in those tweets; and 2) to analyze the most important Twitter users in the collected dataset. Since this was a pilot study, we focused more on developing the methodology as a proof of concept, instead of finding the actual answers to our research question.

The rest of the paper is organized as follows. The next section discusses related work. The methodology section describes the process of creating a lexicon of important terms and how to rank Twitter users based on their importance. The experimental evaluation section presents results using real-world data. The final section concludes the paper and discusses potential implications of this work.

RELATED WORK

Research has shown that the use of Twitter for disseminating and receiving information during disasters such as floods and wildfires has grown over the years (Sutton et al. 2008). In particular, the use of Twitter changes during disaster events to focus on information broadcasting (Hughes and Palen 2009). However, it remains unclear how the use of Twitter changes as a function of silent, slow-growing disasters such as droughts. The general public appears to recognize the threat and need for information concerning floods, or even fires caused by droughts (Glaser 2007; Stelter 2017). But do they also recognize the threat and need for information concerning droughts themselves?

In general, it is known that several factors converge to influence human behavior in the face of impending disasters. According to the social-cognitive preparation model by Douglas Paton (Paton 2003), these factors can be organized into precursors, the formation of intention, and linking intentions to preparedness. It has been suggested that information from behavioral interventions for intention formation can inform education programs designed to facilitate environmental awareness and disaster preparedness in people (Ardalan et al. 2013; Ejeta et al. 2015). However, in order to maximize such facilitation, it is imperative to understand how risk communication and warnings are interpreted by the public prior to intention formation (Paton 2003). We argue that a trend analysis of human communication surrounding environmental hazards and disaster events can fill this gap and offer insights to improve risk communication and pre-disaster planning. Specifically, such a trend analysis should include an examination of social media conversations to uncover the following precursors to drought response, according to Paton’s model: 1) critical awareness of hazards, 2) risk perception, and 3) hazard anxiety.

The computer science research community has made significant advancements in the areas of big data and machine learning, which can allow us to investigate governing mechanisms for social response to specific events. Social media constitute, perhaps, the biggest source of unstructured big data, especially when their use rises during disasters (Imran et al. 2015). The huge success of deep learning in a broad area of applications, including natural language processing, has enabled the analysis of social media data at an unprecedented scale and with high accuracy (Tang et al. 2014; Severyn and Moschitti 2015).

The topic of measuring user influence in social networks has generated a lot of interest (Kwak et al. 2010; Bakshy et al. 2011). An in-depth comparison of three measures of influence has been presented in (Cha et al. 2010) and it was found that the top Twitter users had a disproportionate amount of influence. However, it was also noted that social users have varying amounts of influence in different subjects (Pal and Counts 2011). In addition, existing influence measurement techniques are vulnerable to sybil users, hence sybil-resilient systems have been introduced (Zhang et al. 2016).

Recently, Weng et al. (2010) proposed an extension of the PageRank algorithm called TwitterRank to measure the influence of users in Twitter. TwitterRank measures the influence taking both the topical similarity between users and the link structure into account. The topical similarity is computed using Latent Dirichlet Allocation (LDA) model, which is used to learn a set of latent topics. Each topic in LDA is a multinomial distribution over words. The link structure is based on "following" relationship. We also measure the influence of users in Twitter using an extension of the PageRank algorithm, but the link structure is based on the "reply" relationship. We also deal with a specific topic, "California drought", shared by all users in our dataset.

METHODOLOGY

Towards building a lexicon of important terms

An effective drought management system should not only implement a reliable drought monitoring and forecasting component, but it should also stimulate timely social response. In this study, we determined a lexicon of the most important terms related to droughts based on the public's activity. To achieve this goal, a dataset of tweets related to droughts is needed. Thus, we collected a dataset of tweets discussing California drought during a wide range of dates spanning multiple years.

Given the dataset of relevant tweets, we can compute the most popular tweets based on public's opinion. We used the number of retweets as a measure of tweet's popularity. A tweet can be forwarded to all of the user's followers, in which case it is known as a retweet. Retweets are used to pass along information on Twitter. Retweets indicate the popularity and network centrality of the tweet writer as opposed to the content of the tweet itself (Kwak et al. 2010), leading to potential bias towards messages posted by popular users.

Given a list of the most retweeted tweets, we can determine the most important terms in those tweets. There are different approaches to this problem, for example a frequently used TF-IDF scheme, short for term frequency-inverse document frequency (Salton et al. 1983). This approach builds a term-by-document matrix X whose columns contain the TF-IDF values for each of the documents in the corpus. However, this approach may not be applicable to Twitter as tweets (the documents in our corpus) can only have up to 140 characters.

An alternative approach to analyze texts is a word cloud. Word clouds generated for a body of text can serve as a starting point for a deeper analysis (Heimerl et al. 2014). Thus, we used a word cloud to distill the most popular tweets down to terms that appear with highest frequency. This also served as a visualization method for text.

Ranking users by importance

In this study, we identified the most important users in the collected dataset. Note that tweets do not exist in a vacuum. They are posted by real people who have a wide range of influence and activity in a given topic. We want to find the users whose posts on droughts attract the most amount of attention.

Our dataset consisted of tweets containing "California" and "drought" keywords. Each tweet also contains information whether it is an original tweet or a reply to another tweet. We built a graph based on users and their "reply" relationships.

Given the community of users who post tweets containing the mentioned keywords, we built a graph where such users serve as nodes. The links between nodes are represented by replies, such that the direction of a link is a directed edge from the responder to the original poster. Given the directed graph, we applied the PageRank algorithm (Page et al. 1999) to compute the importance of users in this community.

PageRank is an algorithm used by Google Search to rank websites in their search results. It is a way of measuring the importance of website pages by counting the number of incoming links to those pages to determine a rough estimate of their importance. In our study we treated users as nodes and used the number of replies to their messages as a measure of each user's importance. The more replies a user had, the higher importance score they received. Figure 5 shows the visualization of the proposed user rankings approach in the Experimental Evaluation section.

EXPERIMENTAL WORK

Data collection

We conducted a set of experiments using real-world data collected from Twitter. In these experiments, we focused on the 2011-14 California drought (Howitt et al. 2015). Droughts in California can have a severe economic impact since it is the most populous state in the United States and one of the major agricultural producers.

Table 1. Dataset Overview

	2010	2011	2012	2013	2014	2015	2016	2017	Total
Tweets	1,524	2,277	2,460	3,321	140,249	129,034	23,844	11,786	314,495
Users	1,085	1,618	2,014	2,465	58,592	64,366	14,137	7,835	128,945

For data collection, we used Twitter's advanced search feature1. It allows a logged-in user to specify multiple options for refined search, including specific date ranges. We used "California" and "drought" as search keywords and provided a range of dates from January, 2010, to November, 2017, as droughts can last up to several years. We exported the search results as HTML pages. HTML pages were then parsed, such that tweet IDs were retrieved among other information. Note that Twitter's advanced search returns only a subset of supported attributes for each tweet. Hence, to collect full information for downloaded tweets, we used Twitter's statuses/lookup API2 that returns detailed information for up to 100 tweets per request.

In total, there were about 310k tweets by 130k unique Twitter users during this period (Table 1). The tweets were not evenly distributed.

We released the collected dataset as a contribution to research community3. It is the first published dataset that contains Twitter data covering a 7 year period and dedicated to a comprehensive coverage of a particular event type. The dataset is provided as a listing of tweet IDs in accordance with the Twitter Developer Agreement and Policy4. The actual tweet contents can be retrieved using Twitter's statuses/lookup API.

Analysis of Twitter activity on California drought

We aggregated the tweets in our dataset by each month from 2010 to 2017 (Figure 1).

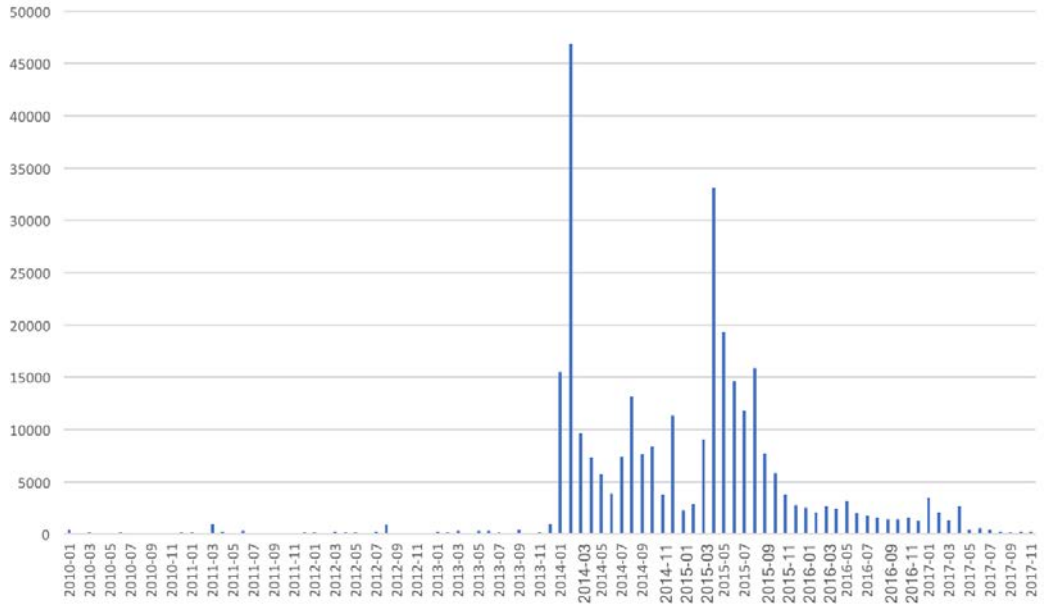


Figure 1. Monthly Twitter activity on droughts from 2010 to 2017

Results show that there are multiple peaks in this chart, including in years 2014 and 2015. For example, the largest peak occurred in February, 2014. To understand the key drivers of this peak, we analyzed Twitter activity during the months before and after the peak at a higher temporal resolution (the daily time step).

Figure 2 shows daily time series of Twitter activity from January through March of 2014, which represents a 30-time higher granular resolution of Twitter activity on droughts compared to the monthly resolution shown in Figure 1.

1https://twitter.com/search-advanced
2https://developer.twitter.com/en/docs/tweets/post-and-engage/api-reference/get-statuses-lookup
3http://aibek.cs.ua.edu/files/droughts_ids.txt
4https://developer.twitter.com/en/developer-terms/agreement-and-policy

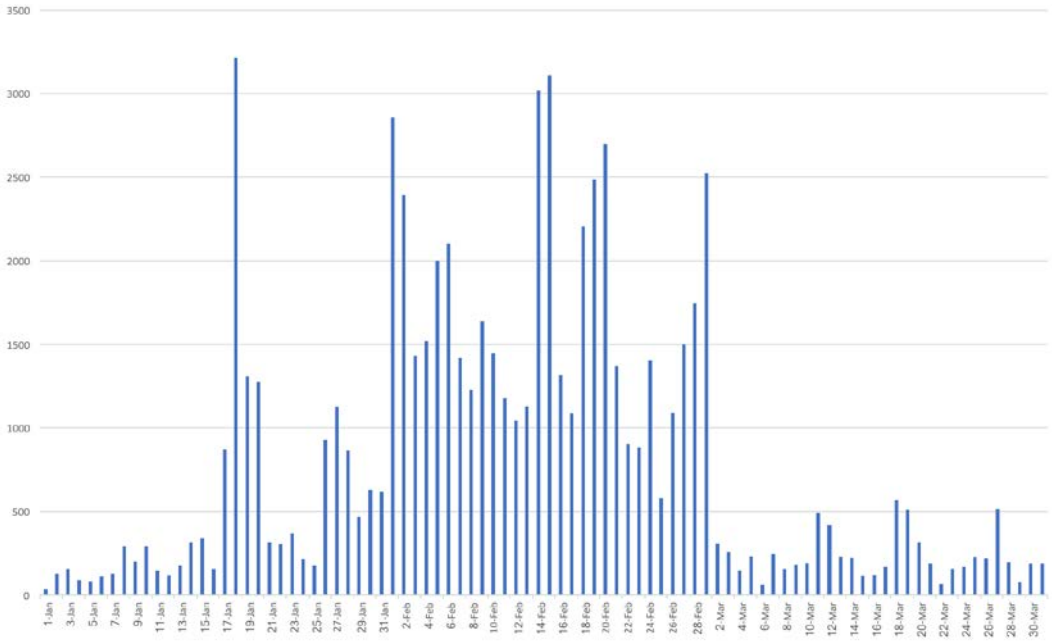


Figure 2. Daily Twitter activity on droughts from January to March in 2014

By February 1, 2014, California officials announced that they would not send any water from the state's reservoir system to local agencies amid severe drought conditions5. Figure 3 shows one of the most retweeted tweets that expresses a sentiment shared by many during this period. This tweet is posted by a regular user, which is why we cover it with an anonymous label to preserve her privacy.

Figure 3. The most retweeted tweet on California droughts

Table 2 shows the text of the top 10 most retweeted tweets with the number of retweets and posted date. Note that we preserve the original spelling and punctuation. These results provide us key words for the lexicon used by the most popular social media messages.

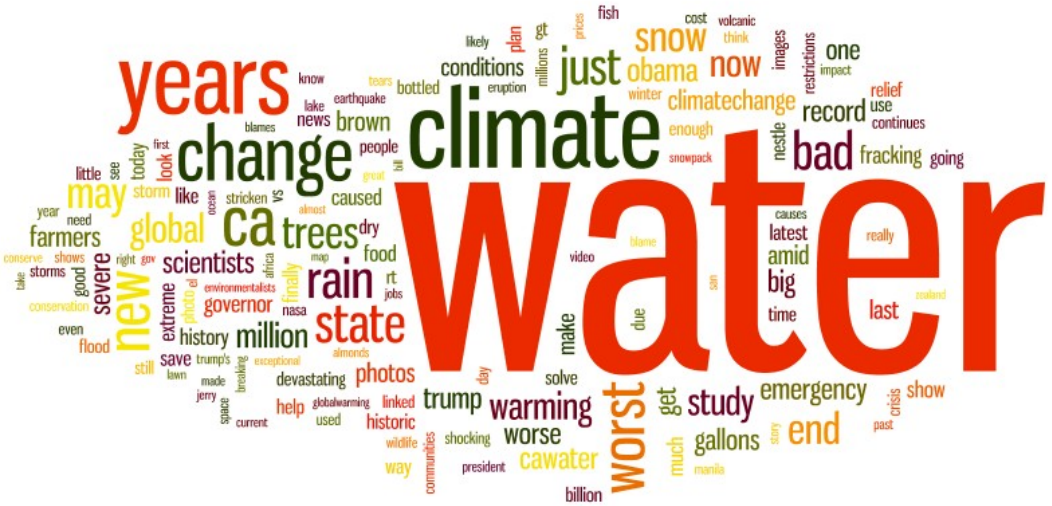
5https://www.washingtonpost.com/national/health-science/amid-drought-california-agency-wont-allot-water/2014/02/01/7477aa5c-8b88-11e3-916e-e01534b1e132_story.html

Table 2. Top 10 most retweeted tweets on California droughts.

Text	Retweets	Date
this California drought is no joke	5,770	2014/08/23
Snow in Africa, Drought in USA, Flood in Manila, Volcanic Eruption in New Zealand ...	4,548	2012/08/08
California drought: before and after	2,918	2014/08/20
crying enough water to supply the California drought	2,431	2015/05/12
all my tears could fix the California drought	1,717	2015/05/24
Hundreds of Muslims pray for rain in drought hit California	1,358	2014/02/03
Unbelievable images that show the scale of #California' drought	1,313	2014/09/06
Analysis: 11 trillion gallons of water needed to replenish California drought losses: #AGU14	1,198	2014/12/16
How bad is the California drought? Some startling before and after photos	918	2014/08/24
Top Story: SeaWorld Responds To California Drought By Draining Animal Tanks Halfway	899	2015/04/11

Analysis of important terms

What are the most important terms among all tweets in our dataset? To answer this question, we computed the top 2,000 most retweeted tweets, such that the number of retweets for those tweets ranges from 5,770 down to 17. We removed "California" and "drought" from this list as we already knew each tweet will contain them. Using the tweets with the remaining terms we generated a word cloud[6]. Figure 4 presents a visualization of the word cloud from the top 2,000 most retweeted tweets. As expected, the word "water" is the most important word. Similarly, both "climate" and "change" are also significant according to this visualization.


water
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worst
study
emergency
end
gallons
worse
cawater
drought
may
new
severe
extreme
flood
save
help
historic
linked
wildlife
shocking
president
billion
make
solve
get
last
time
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latest
causes
video
fish
cost
volcanic
one
relief
use
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nestle
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worse
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due
blame
really
images
restrictions
impact
winter
bottled
eruption
earthquake
lake
blames
first
today
look
see
little
year
need
storm
like
stricken
ocean
almost
africa
finally
map
right
gov
shows
storms
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conservation
even
still
lawn
made
jerry
space
current
used
globalwarming
breaking
exceptional
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plan
millions
prices
know
tears
lake
earthquake
blames
first
today
look
see
little
year
need
storm
like
stricken
ocean
almost
africa
finally
map
right
gov
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storms
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globalwarming
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prices
fish
cost
volcanic
think
one
impact
relief
use
continues
record
climatechange
winter
enough
snowpack
nestle
bad
fracking
going
causes
latest
amid
big
time
last
really
video
blame
due
make
solve
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study
emergency
crisis
show
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warming
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devastating
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almonds
exceptional
trump's
save
photo
history
million
state
rain
trees
dry
food
nasa
jobs
rt
environmentalists
scientists
governor
extreme
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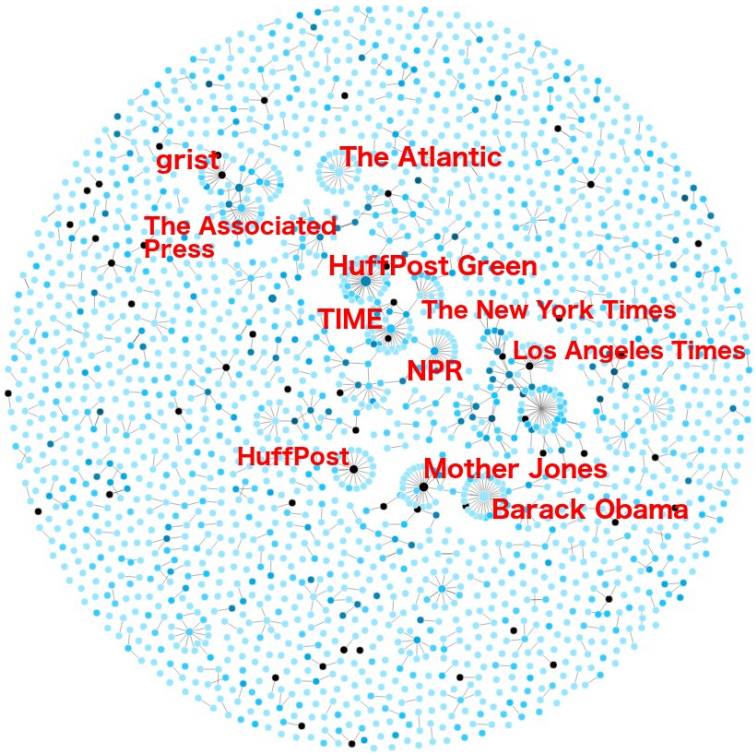

Figure 5. User ranking based on reply relationships

For visualization purposes, we have added labels to the users with the highest ranking scores. The majority of those users are news agencies, such as TIME, The Associated Press, and Los Angeles Times. There are also nonprofit online magazines, such as Mother Jones[7] and grist[8]. However, no federal or state agency dealing with droughts has a near the top ranking score. Twitter accounts among the top users include Barack Obama's account[9].

CONCLUSION AND FUTURE WORK

The results of this study show a new insight for how the public talks about drought via social media. Beyond that, we are also able to see triggers of public discussion during a recent California drought. While there was a spike in January, the entire month of February was riddled with high Twitter usage regarding drought. However, this change in use was caused less by the drought itself and more by a temporary change in policy pursued by the California government. After California officials announced they would be halting the transfer of water from state to local agencies, many Twitter users took to social media to discuss this.

This study finds that publicized decisions by the California government influence significantly Twitter activity about droughts, which inform of many potential implications for critical awareness and risk perception of the public during droughts. While the general public may be aware of droughts as they occur, it is possible such awareness increases dramatically as a result of high-profile discussions. This is supported by research that shows that mass communication can be used to alter public behavior (Abroms and Maibach 2008). Furthermore, state government communication strategies may be bolstered by several other variables on social media, such as the presence of high profile figures or news agencies in the discussion, and the presence of highly compelling posts by everyday users. Research has shown that there is a relationship between retweet patterns and the content of tweets themselves (Nagarajan et al. 2010). This study shows an example of a tweet with a powerful image seemingly became popular overnight. More research into this phenomenon could help us create/design specific strategies for adjusting critical awareness and risk perception during droughts.

These findings have several potential implications that need further exploration. It seems that news agencies, rather than government agencies, remain the go-to source for most individuals obtaining information regarding drought-related topics. However, it remains unclear why this is. First, individuals may not realize they can follow various government agencies such as NOAA on Twitter. Additionally, they may not find reports released by such

7https://twitter.com/MotherJones/
8https://twitter.com/grist
9https://twitter.com/BarackObama

agencies very approachable or interesting. Finally, there is the possibility that individuals reading about drought from news agencies simply stumble upon the information, and are not actively seeking it in the first place. They are instead taking a passive approach to information collection, and then responding to that information when they happen to notice it.

More research still needs to be done to better understand the sensitivity of social response to drought. This can be done via interdisciplinary research collaboration across computer science, hydrologic engineering, and social psychology. To that end, we will apply state-of-the-art techniques in computer science to examine big social data, and test the validity of the known theories for social disaster response. This will include the development of an algorithm to estimate society's levels of hazard anxiety, hazard awareness, and risk perception in relation to drought by applying a new model, fastText (Joulin et al. 2016). This algorithm will not only aid in understanding of social response to drought, but will allow us to pinpoint ways to help improve this social response.

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A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria

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ABSTRACT

People increasingly use microblogging platforms such as Twitter during natural disasters and emergencies. Research studies have revealed the usefulness of the data available on Twitter for several disaster response tasks. However, making sense of social media data is a challenging task due to several reasons such as limitations of available tools to analyze high-volume and high-velocity data streams. This work presents an extensive multidimensional analysis of textual and multimedia content from millions of tweets shared on Twitter during the three disaster events. Specifically, we employ various Artificial Intelligence techniques from Natural Language Processing and Computer Vision fields, which exploit different machine learning algorithms to process the data generated during the disaster events. Our study reveals the distributions of various types of useful information that can inform crisis managers and responders as well as facilitate the development of future automated systems for disaster management.

Keywords

social media, image processing, text classification, named-entity recognition, topic modeling, disaster management

INTRODUCTION

Three devastating natural disasters in 2017, namely Hurricane Harvey, Hurricane Irma, and Hurricane Maria, caused catastrophic damage worth billions of dollars and numerous fatalities, and left thousands of affected people. During such life-threating emergencies, affected and vulnerable people, humanitarian organizations, and other concerned authorities search for information useful to prevent a crisis or to help others. For instance, during disasters, humanitarian organizations and other government agencies, public health authorities, and military are tasked with responsibilities to save lives and reach out to people who are in need of help (Gralla et al. 2013). These formal response organizations rely on timely and credible information to make timely decisions and to launch relief efforts. The information needs of these stakeholders vary depending on their role, responsibilities, and the situation they are dealing with (Vieweg, Castillo, et al. 2014). However, during time-critical situations, the importance of timely and factual information increases, especially when no other traditional information sources such as TV or Radio are available (Vieweg 2012; Castillo 2016).

The growing use of Information and Communication Technologies (ICT), mobile technologies, and social media platforms such as Twitter and Facebook has provided easy-to-use and effective opportunities to the general public to disseminate and ingest information. Millions of people increasingly use social media during natural and man-made disasters (Castillo 2016; Hughes and Palen 2009; Purohit et al. 2014). Research studies have demonstrated the usefulness of social media information for a variety of humanitarian tasks such as "situational awareness" (Vieweg

2012; Starbird et al. 2010). Although, information available on social media could be useful for response agencies, however, making sense of it under time-critical situations is a challenging task (Hiltz and Plotnick 2013). For instance, due to high-volume and high-velocity of social media data streams, manual analysis of thousands of social media messages is impossible (Hiltz, Kushma, et al. 2014; Ludwig et al. 2015).

Making sense of social media data to aid responders involves solving many challenges including parsing unstructured and brief content, filtering out irrelevant and noisy content, handling information overload, among others. Over the last few years, a number of Artificial Intelligence (AI) techniques and computational methods have been proposed to process social media data for disaster response and management. These techniques aim to solve various challenges ranging from information filtering, overload, and categorization to summarization of information (Castillo 2016; Imran, Castillo, Diaz, et al. 2015).

This work presents an extensive analysis of the Twitter data collected during the three disasters, namely Hurricanes Harvey, Irma, and Maria. We employ a number of state-of-the-art AI techniques ranging from unsupervised to supervised learning for the analysis of these real-world crisis events. The techniques used in this paper have a range of applications in the field of crisis response and management. Specifically, we perform sentiment analysis to determine how people's thoughts and feelings change over time as disaster events progress. To help concerned authorities to quickly sift through big crisis data, we use topic modeling techniques to understand different topics discussed during each day. To help humanitarian organizations fulfill their specific information needs, we use supervised classification techniques to classify both textual and imagery content into humanitarian categories. We also make our data available at the CrisisNLP[1] repository for researchers and practitioners to advance research in this field. We publish tweet ids and a tool to download full tweet content from Twitter.

The rest of the paper is organized as follows. In the next section, we present objectives of our analysis followed by the literature review section. Next, we describe our data collection details. Then, we present our experiments, analyses, and a discussion of the results. Finally, we conclude the paper in the last section.

OBJECTIVES OF THE ANALYSIS

Depending on their role and capacity, the information needs of formal response organizations and other humanitarian non-governmental organizations (NGOs) vary. Moreover, local government departments such as police, firefighters, and municipality among others, seek information that is aligned with their response priorities as well as the given crisis situation, its context, severity, and evolution over time. For instance, many humanitarian organizations seek high-level information about a crisis situation such as the scale of the disaster event, affected population size in the disaster zone, overall economic impact, urgent needs of the affected people such as food, water, and shelter. In contrast, other organizations such as police forces seek information concerning individual emergency situations such as reports of trapped people that need to rescue, or injured people that need urgent medical assistance, etc. Such cases require immediate attention of the concerned authorities. These varying information needs of different humanitarian stakeholders can be classified into two main categories: (i) information needs that help authorities understand the "big-picture" of a situation, i.e., "situational awareness", and (ii) information needs that help authorities to launch a rapid response to an emergency situation i.e.,"actionable information".

In this work, we aim to analyze the data collected during three natural disasters to understand different types of information available on social media based on "situational awareness" and "actionable information". We perform a multidimensional analysis of both textual as well as imagery content on social media.

Textual content analysis

We seek to gain an understanding of the textual information posted on social media during disasters from different angles. With a target to fulfill both situational awareness and actionable information needs of different humanitarian organizations, in this work we employ several state-of-the-art AI techniques to analyze and understand useful information for humanitarian decision-makers and responders while filtering out irrelevant and unimportant information to reduce information overload burden on responders.

Targeting specific information needs using supervised classification

Many humanitarian organizations have predetermined information needs. For example, United Nations (UN) humanitarian organizations use a cluster coordination approach in which different organizations focus on different humanitarian tasks[2] (Vieweg, Castillo, et al. 2014). For instance, World Health Organization (WHO) focuses

[1] http://crisisnlp.qcri.org/
[2] https://www.unocha.org/legacy/what-we-do/coordination-tools/cluster-coordination

on health, United Nations Children's Fund (UNICEF) on children and education, and World Food Programme (WFP) on food security. In this work, we take a longitudinal approach to cover different information needs of UN organizations. First, we define a taxonomy of information needs learned from previous studies (Imran, Castillo, Diaz, et al. 2015), and then use supervised machine learning techniques to automatically categorize the collected data into the predefined categories. The categories included in our taxonomy are as follows:

Taxonomy representing several humanitarian information needs:

- **Injured or dead people:** corresponds to the reports of injured people and fatalities due to the disaster.
- **Infrastructure and utility damage:** corresponds to the reports of damage to infrastructures such as buildings, bridges, roads, houses and other utility services such as power lines and water pipes.
- **Caution and advice:** messages that contain warnings, cautions, and advice about the disaster that could be useful for other vulnerable people or humanitarian organizations.
- **Donation and volunteering:** corresponds to the messages containing requests for donations of goods, money, food, water, shelter, etc. and/or messages containing donation offers.
- **Affected individual:** corresponds to the reports of affected people due to the disaster.
- **Missing and found people:** corresponds to the reports of missing or found people due to the disaster.
- **Sympathy and support:** corresponds to the messages that show any type of sympathy or support towards the victims of the disaster.
- **Personal:** corresponds to the personal updates that are mostly useful for the author's family and friends, but probably not for humanitarian organizations.
- **Other useful information:** corresponds to the messages which do not belong to any of the above categories but are still useful and potentially important for humanitarian organizations.
- **Irrelevant or not related:** corresponds to the messages which are not in English or not relevant to the disaster or irrelevant for humanitarian response.

Topics of discussion on social media during different disasters vary and even within an event topics change rapidly (Imran, Mitra, and Srivastava 2016). One factor that influences a change in the discussion is the disaster phase. For instance, if we divide a disaster event into three phases: *"Pre"* (i.e., the time period between the detection and impact of a disaster), *"During"* (i.e., the time period during the impact), and *"Post"* (i.e., the time period after the impact), then the discussions during these three phases are expected to be different. Another factor that might cause a change in the topic of discussion is varying aid needs of affected people. To understand the temporal variance between the different informational categories in the taxonomy, we aim to investigate the distribution of the classified messages over time.

Learning concerns and panics of people

Determining the sentiment of people during disasters and emergencies can help understand people's concerns, panics, and their emotions regarding various issues related to the event. It also helps responders establish stronger situational awareness of the disaster zone (Caragea et al. 2014; Nagy and Stamberger 2012). To establish such an understanding, we aim to perform the sentiment analysis on the collected data. With this analysis, we expect to find issues that cause anger and negative sentiment among affected people and outsiders. Humanitarian organizations can see this as a tool to keep an eye on public sentiment to find critical issues affecting large populations and plan their response in a timely manner.

Tracking incidents using topic modeling

Large-scale disasters that are either too severe (e.g., intense earthquakes) or long-running (e.g., wars, conflicts) usually cause many small-scale incidents, which are troublesome to small communities or a limited number of people. Examples of such small-scale events include "airport shutdown due to an earthquake", "school closures due to hurricane warnings", etc. Many of such events are hard to anticipate by humanitarian organizations. Therefore, responders are usually not well-prepared to handle them. Timely identification of small-scale events after a big disaster can help humanitarian responders launch timely response to help those who are in need or address the issue. For this purpose, we introduced the "Other useful information" category in the taxonomy described above. This category contains messages that do not belong to any other informative categories in the taxonomy, but important information potentially useful for humanitarian responders. We expect small-scale issues and incidents to

appear in this category. Since the types of information present in the messages that belong to the "Other useful information" category are not known, we cannot use supervised machine learning techniques to understand what are those incidents or topics of discussion during a disaster. Instead, similar to (Imran and Castillo 2015), we use a state-of-the-art unsupervised machine learning technique called Latent Dirichlet Allocation (LDA) (Blei et al. 2003) to identify the latent events or topics in the "Other useful information" category.

Identifying dominant entities using named-entity recognition

Rapidly assessing a situation is critical for effective disaster response. Named entities such as the names of persons, organizations, and locations used in text messages provide ways to understand them better. Three typical entities have been recognized as fundamental elements in Natural Language Processing (NLP) (Finkel et al. 2005): "Persons", "Organizations" and "Locations". Among other ways, finding entities could help crisis managers rapidly sift through thousands of messages while discarding noise. For instance, a location unrelated to the event or the name of a past event can be used to filter out all messages that mention them. The name of a well-known organization (e.g., a non-governmental organization (NGO), a government agency or an established media corporation) mentioned in a message makes this message more trustworthy than if delivered by an unknown source. The location name of a specific street, bridge, park or river can help managers to send a rescue team to the right place. The name of a person can be used to identify a local contact or understand that an important person is missing. We use the Stanford Named-Entity Recognizer (Finkel et al. 2005) to extract the top 10 most frequent persons, organizations, and locations from our data.

Multimedia content analysis

Capturing the moment via images or videos, and sharing them online has already become a usual habit for many social media users. Thanks to this new phenomenon, social media users can easily share much more information in a much more effective way than just typing up text messages all the time to share their feelings and opinions. Therefore, analysis of this multimedia content (i.e., images and videos) bears significant potential, especially in the context of crisis response and management. For instance, an image can provide more information about the severity and extent of damage caused by a disaster, more detailed understanding of shelter needs and quality, more accurate assessment of ongoing rescue operations, faster identification of lost or injured people, etc. However, implications of the multimedia content on social media have not yet been studied in depth, unlike their text-only counterparts. There are only a few recent studies in this emerging research area that explore how social media image and video content can provide critical information, especially during crisis events such as natural disasters, for emergency management and response organizations.

Sifting through social media imagery data for identifying relevant and unique content

As shown by (Peters and Joao 2015; Chen et al. 2013; Nguyen, Alam, et al. 2017), social media images captured during a crisis event are oftentimes not related to the crisis event itself or do not always present relevant information for emergency management and response organizations. Social media users can post all sorts of images using event-specific hashtags (such as *#HurricaneHarvey*, *#HurricaneIrma*, or *#HurricaneMaria*) to advertise their content, even though this can be considered as unethical behavior during natural disasters and emergencies. Besides relevancy, redundancy in social media images is another important issue that needs to be addressed in order to extract succinct information useful for humanitarian organizations. People can just re-tweet an existing image (i.e., exact duplicates), or share slightly-altered (e.g., rescaled, cropped, text embedded, etc.) versions of an existing image (i.e., near duplicates). These images usually do not provide any additional contextual information, and hence, should be eliminated from the data processing pipeline for optimal use of time as well as human and machine computation resources during crisis situations. In light of the aforementioned studies, we investigate the feasibility of cleaning social media imagery data from irrelevant and redundant content and analyze whether social media imagery can be a source of information for crisis response and management.

Extracting actionable information for situational awareness

Detection of relevant and unique multimedia content is certainly necessary but not sufficient in the context of crisis response and management. Humanitarian organizations do need more concise situational awareness information to assess the overall crisis situation. In order to utilize the full potential of multimedia content available on social media, accurate machine learning models should be developed for each particular humanitarian use case. For example, understanding the extent of the infrastructure and utility damage caused by a disaster is one of the core situational awareness tasks listed earlier. Several studies in the literature have already shown that social media images can be analyzed for automatic damage assessment in addition to the textual content analysis (Daly and Thom

2016; Lagerstrom et al. 2016; Liang et al. 2013; Nguyen, Ofli, et al. 2017). Inspired by these studies, we perform an infrastructural damage assessment task on cleaned social media imagery content.

LITERATURE REVIEW

Current literature shows the use of social media such as Twitter, Facebook and YouTube for curating, analyzing and summarizing crisis-related information in order to make decisions and responses (Imran, Castillo, Lucas, et al. 2014; Vieweg, Hughes, et al. 2010; Imran, Castillo, Diaz, et al. 2015; Terpstra et al. 2012; Tsou et al. 2017). Among social media studies, most of them focus on Twitter, mainly because of its timeliness and availability of information from a large user base. In (Hagen et al. 2017), the authors analyzed Twitter network structure to understand the flow of information and how different actors and communities contribute towards influential topics. Avvenuti et al. investigate Earthquake Alerts and Report System, which exploits tweets, to understand how such systems can be useful during crisis-related events (Avvenuti et al. 2017). The system collects tweets during an ongoing crisis event, filters irrelevant content, detects an event, assesses damage, and for the sake of comprehensibility, it provides a visualization. Authors conclude that such a system is highly important for crisis-related events. The study of Kim and Hastak investigate how emergency agencies and organizations can better plan operation strategies for a disaster by utilizing individuals' information on a social network (Kim and Hastak 2018).

For the automatic analysis of social media textual and multimedia streams current literature report several AI and computational methods. Most of these methods mainly use supervised or unsupervised (e.g., clustering and topic modeling) techniques. The supervised techniques include classic machine learning algorithms such as Random Forest and Deep Neural Network such as Convolutional Neural Network (CNN), for a complete survey of these techniques and their applications in the crisis informatics domain see (Imran, Castillo, Diaz, et al. 2015; Castillo 2016).

The state-of-the-art research on sentiment analysis is mostly focused on classifying sentiment in either one of two labels (i.e., positive or negative) or five labels (i.e., very positive to very negative) from textual information (Pang, Lee, et al. 2008) such as movie-reviews (Pang, Lee, and Vaithyanathan 2002), tweets (Paltoglou and Thelwall 2010), and newspaper articles and comments (Celli et al. 2016). For sentiment analysis, one of the commonly used approaches is to use sentiment lexicon (i.g., SentiWordNet, Sentiment Treebank, and Psycholinguistic features) (Cambria et al. 2016; Socher et al. 2013; Alam, Danieli, et al. 2018) as features for designing the sentiment classifier. In (Nagy and Stamberger 2012), the authors report the use of emoticons along with SentiWordNet helps in improving the classification of sentiment from microblogs dataset collected during disasters and crises. Socher et al. present the use "Sentiment Treebank" can help in detecting sentiment labels with an accuracy of 80.7% to 85.4% (Socher et al. 2013). Other common approaches include the utilization of word embeddings along with deep neural networks. The extensive comparative studies can be found in SemEval tweet classification task (see Rosenthal et al. 2017). Over time several open-source tools have also been developed. Among them, one of the most widely used tools is the Stanford CoreNLP Natural Language Processing Toolkit (Manning et al. 2014), which supports all preprocessing to sentiment classification methods. In our study, we used Stanford sentiment analysis toolkit, which allowed us to classify tweets in five labels (i.e., very positive to very negative).

For general text classification task, current literature shows the use of classic algorithms such as Maximum Entropy, Logistic Regression, Random Forest, Naïve Bayes classifier, and Conditional Random Fields (CRFs) and deep learning based techniques such as Convolutional Neural Network (CNN) (Nguyen, Al-Mannai, et al. 2017), and Long-Short-Term-Memory (LSTM) (Rosenthal et al. 2017). For tweet classification of this study, we used an in-house developed classifier that uses the Random Forest learning scheme.

Since the supervised approach of text classification requires human annotated labels, the use of the semi-supervised and un-supervised approaches has been increased. For text analysis one of the well-known techniques is topic modeling, which uses Latent Dirichlet Allocation (LDA) (Blei et al. 2003),–a generative probabilistic model. It provides an explicit representation of a textual content. For tweet analysis, there are many studies which analyze tweets to extract information using different variants of LDA topic modeling technique (Mendoza et al. 2010; Chae et al. 2014; Yang et al. 2014; Hong and Davison 2010). Our study of topic modeling is based on LDA.

The extraction of Named Entity Recognition (NER) has a long history in NLP for extracting entities from newspaper articles (Alam, Magnini, et al. 2015) to biomedical text (Alam, Corazza, et al. 2016). The extraction of named entities from Tweets is more challenging due to the noisy structure of the data. Recent approaches for entity recognition from tweets include LSTM, Bidirectional-LSTM, and CRFs (Baldwin et al. 2015; Limsopatham and Collier 2016; He and Sun 2017). For NER task, we used Stanford NER toolkit, which is based on CRFs.

In addition to the textual content analysis, recent studies have also been focused on the analysis of imagery content shared on social media (Nguyen, Alam, et al. 2017; Nguyen, Ofli, et al. 2017; Alam, Imran, et al. 2017). Combining

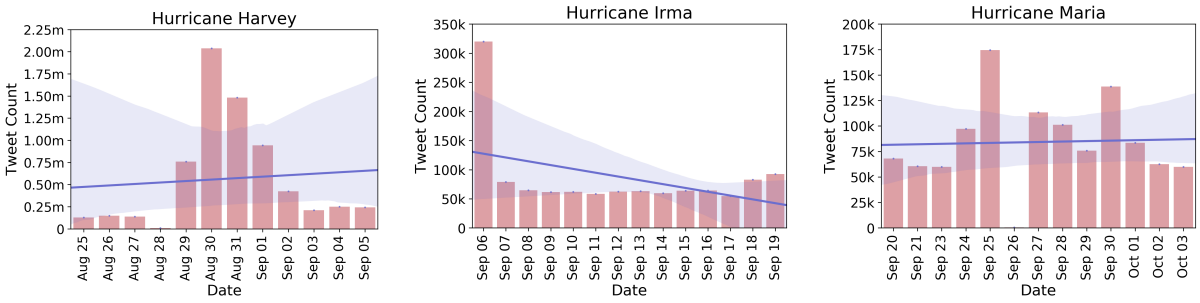

Figure 1. The total number of tweets collected for each event per day – Harvey (left), Irma (center) and Maria (right). Purple lines indicate trends in the daily tweet data volume.

textual and visual content could provide highly relevant information. In (Bica et al. 2017), the authors study the social media images posted during two major earthquakes in Nepal during April and May 2015. Their study focused on identifying geo-tagged images and their associated damage, local vs. global information fusion with images and they also developed an annotation scheme for image analysis. Their findings suggest that global twitter user emphasize recovery and relief effort while local user emphasizes suffering and major damage. In a most recent study, Alam, Ofli, et al. reported an image processing pipeline to extract meaningful information from social media images during a crisis situation, which has been developed using deep learning based techniques (Alam, Ofli, et al. 2018). For this study, we used the same system to execute all of our image processing tasks.

In summary, we used several supervised and unsupervised machine learning techniques in this study to analyze three natural disasters. We have conducted a large-scale data analysis comprising of textual and imagery content, which are automatically collected from Twitter. Our analyses include i) finding relevant topic using topic modeling, ii) classifying tweets into humanitarian categories using supervised classification, iii) extracting named entities using NLP techniques, iv) detecting sentiment, v) identifying duplicate images for filtering based on a perceptual hash technique, vi) finding relevant images, and vii) classifying damage severity level from images.

DATA COLLECTION AND DESCRIPTION

This study uses Twitter data collected during three natural disasters: Hurricanes Harvey, Irma, and Maria. We used the Twitter streaming API to collect tweets that match with event-specific keywords and hashtags. This API returns 1% of the whole Twitter data at a particular time. Next we describe each dataset in detail.

Hurricane Harvey

According to Wikipedia[3], Hurricane Harvey was a category 4 storm when it hit Texas, USA on August 25, 2017. It caused nearly USD 200 billion in damage, which is record-breaking compared with any natural disaster in US history. For Hurricane Harvey, we started the data collection on August 25, 2017 using keywords: *"Hurricane Harvey", "Harvey", "HurricaneHarvey"* and ended on September 5, 2017. In total, 6,732,546 tweets were collected during this period. Figure 1 (left chart) depicts the distribution of daily tweets in this collection. Surprisingly, we have a significantly lower number of tweets (i.e., less than 0.25 million per day) from August 25 to August 28[4] compared to the next five days where a 2-million-tweet peak can be observed on a single day, i.e., August 30. Among the Hurricane Harvey tweet data, 115,525 were found to have an image URL.

Hurricane Irma

Hurricane Irma[5] caused catastrophic damage in Barbuda, Saint Barthelemy, Saint Martin, Anguilla, and the Virgin Islands. On Friday September 8, a hurricane warning was issued for the Florida Keys and the Florida governor ordered all public schools and colleges to be closed. The Irma storm was a category 5 hurricane, which caused USD 66.77 billion in damage. We collected Hurricane Irma-related data from Twitter starting from September 6, 2017 to September 19, 2017 using the keywords: *"Hurricane Irma", "Irma storm", "Irma"*. In total, 1,207,272 tweets were collected during this period. Figure 1 (middle chart) shows the distribution of daily tweets of Hurricane Irma data. On the first day (i.e., September 6), we can see a surge of tweets in which more than 300,000 tweets were collected. However, during the next days the distribution stayed steady around 50,000 tweets per day. Besides, 60,973 of these Hurricane Irma tweet data contained image URLs.

[3] https://en.wikipedia.org/wiki/Hurricane_Harvey
[4] On August 28, due to a network issue, only 9,825 tweets were collected.
[5] https://en.wikipedia.org/wiki/Hurricane_Irma

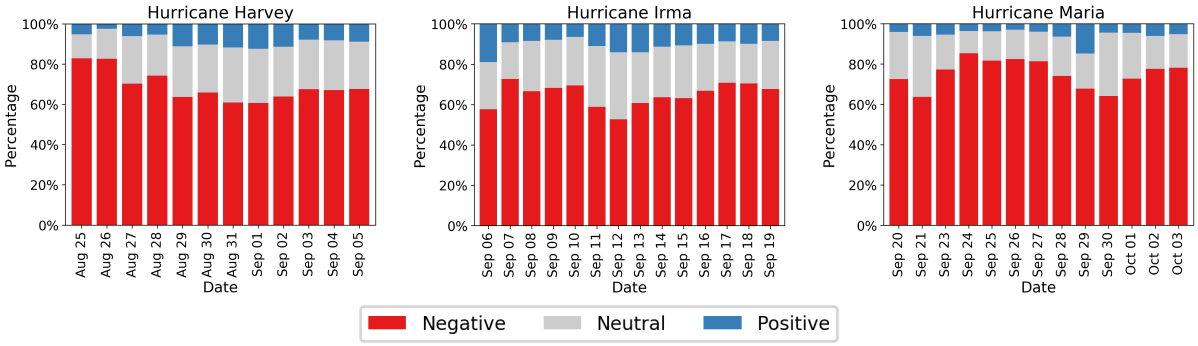

Figure 2. Sentiment analysis results: distribution of daily sentiment for Harvey (left), Irma (center), and Maria (right).

Hurricane Maria

Hurricane Maria[6], was a category 5 hurricane that slammed Dominica and Puerto Rico and caused more than 78 deaths including 30 in Dominica and 34 in Puerto Rico, while many more left without homes, electricity, food, and drinking water. The data collection for Hurricane Maria was started on September 20, 2017 and ended on October 3, 2017. In total, we collected 1,096,335 tweets during this period using keywords: *"Hurricane Maria", "HurricaneMaria", "Tropical Storm Maria", "Maria Storm"*. The right chart in Figure 1 shows the daily tweet distribution for the Hurricane Maria data. Of these Hurricane Maria tweet data, we found 19,681 tweets with image URLs.

We note that the keywords selected to collect data are high-level but specific to the hurricanes events. The Twitter API returns tweets that mention these keywords. However, high-level keywords could bring more noisy data compared to specific keywords. This is due to the irrelevant messages that people post about mundane events, advertisements, jokes, etc.

EXPERIMENTS, RESULTS, AND DISCUSSION

To analyze the three disaster events from the social media lens and to fulfill the objectives set in the objectives section, we perform an extensive experimentation using the collected datasets. This section provides details of our experimental setup and the analysis results.

Preprocessing

Since the tweet texts are noisy, preprocessing is required before using them in further analysis. The processing part of this study includes removal of stop words, non-ASCII characters, punctuations (replaced with whitespace), numbers, URLs, and hastags.

Sentiment analysis

To perform the sentiment analysis, we used the Stanford sentiment analysis classifier (Socher et al. 2013) to extract the sentiment labels that are being expressed or semantically represented in the tweets. The Stanford sentiment analysis classifier consists of 5 categorical labels such as *Very Negative*, *Negative*, *Neutral*, *Positive* and *Very Positive*. For each tweet the classifier assigns one of the five categories with their confidence. The classifier has been designed using Recursive Neural Tensor Network and exploiting sentiment treebank, which consists of fine-grained sentiment labels for 215, 154 *phrases* in the parse trees of 11, 855 *sentences*. The accuracy of the classifier for fine-grained sentiment labels is 80.7% as presented in (Socher et al. 2013). For our task, we fed the preprocessed tweet to the classifier to get the classifier's prediction. For the sake of presenting the results, we combined "Positive" and "Very positive" classes into a single class "Positive", and the "Negative" and "Very negative" classes into a single class "Negative".

In Figure 2, we present the distribution of sentiment results in terms of three classes for each day for the three events. One can clearly observe that the "Negative" sentiment dominates for all the three events throughout all days. We also observe that one of the factors that cause high negative sentiment in the early stage of a disaster is due to the use of aggressive language, e.g., using "F**k", "s**t", "b***h" like words, cursing disaster, complaining,

[6] https://en.wikipedia.org/wiki/Hurricane_Maria

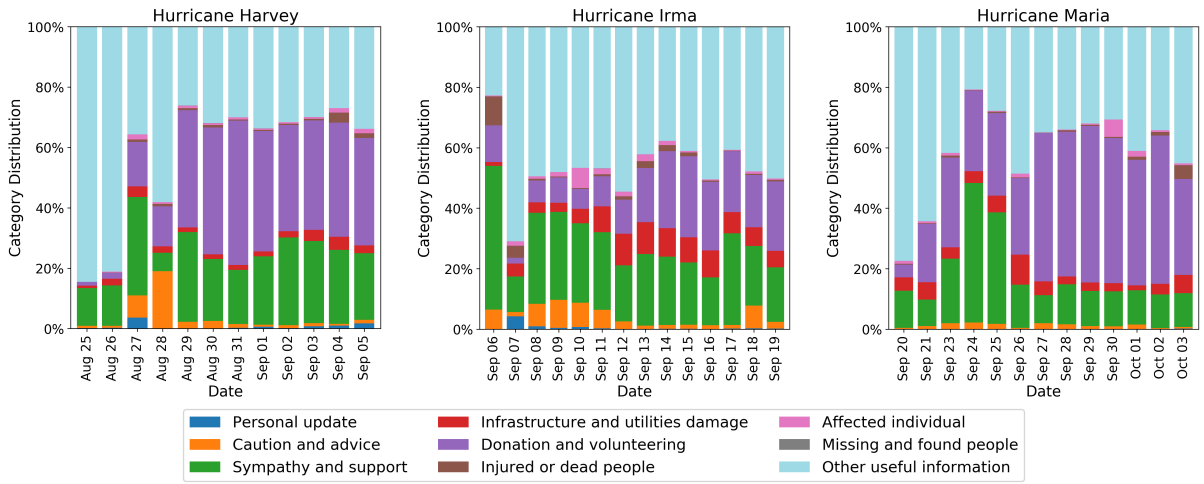

Figure 3. Temporal distribution of categories based on the automatic classification of tweet text into one of the humanitarian categories for Harvey (left), Irma (center) and Maria (right).

and expressing anger when someone's plan gets disturbed due to the disaster event. However, negative sentiment during the event is mainly caused by actual issues faced by affected people where there is no response from the government or concerned authorities or the response is slow. For example, this includes cases like a power outage, lack of drinking water, food, or other necessary facilities. Real-time monitoring of sentiment prediction of social media streams can be useful for the concerned response authorities to understand people's sentiment and concerns, and to guide their response efforts towards addressing those concerns.

Table 1. Data for Humanitarian Categories Classification

Classes	Train (60%)	Dev (20%)	Test (20%)
Affected individual	3029	757	758
Caution and advice	3288	822	822
Donation and volunteering	4278	1070	1070
Infrastructure and utilities damage	3189	797	798
Injured or dead people	2148	537	538
Missing and found people	405	101	102
Personal updates	968	242	242
Other useful information	4000	2000	2000
Sympathy and support	5504	1376	1376
Not related or irrelevant	4000	2000	2000
Total	30809	9702	9706

Classification of humanitarian categories

When information needs are known, as in the case of many humanitarian organizations, using supervised machine learning techniques is preferred over unsupervised techniques. In this section, we report the results obtained from the supervised classification of the three events' data. For this purpose, we used a decision tree based learning scheme known as Random Forest. To train the supervised machine learning model, we used human-labeled Twitter data from a number of past disasters (Imran, Mitra, and Castillo 2016). The labeled data were collected during more than 30 past disasters including hurricanes, earthquakes, and floods.

Table 1 shows the class distribution of our train, development (dev), and test sets. The train set is used to learn the model, the development (dev) set is used for parameter-tuning, and the test set is used for the model evaluation. To learn the model, we used a bag-of-words approach. The performance obtained using the test set in terms of the F-measure is $F1 = 0.64$ and accuracy of 0.66. In Table 2, we also present the results of individual classes. The trained model is then used to classify all the tweets of the three events.

In Figure 3, we present day-wise distribution of the automatically classified tweets for the three events. One clear pattern representing one of the most prevalent categories "Other useful information" across all the events. The

Table 2. Text classifier performance in terms of Precision (P), Recall (R), and F1-score.

Class	P	R	F1
Affected individual	0.70	0.72	0.71
Caution and advice	0.63	0.64	0.64
Donation and volunteering	0.69	0.80	0.74
Infrastructure and utilities damage	0.65	0.64	0.65
Injured or dead people	0.85	0.87	0.86
Missing and found people	0.64	0.21	0.31
Not related or irrelevant	0.68	0.73	0.71
Personal updates	0.66	0.64	0.65
Relevant information	0.68	0.40	0.50
Sympathy and support	0.55	0.77	0.64

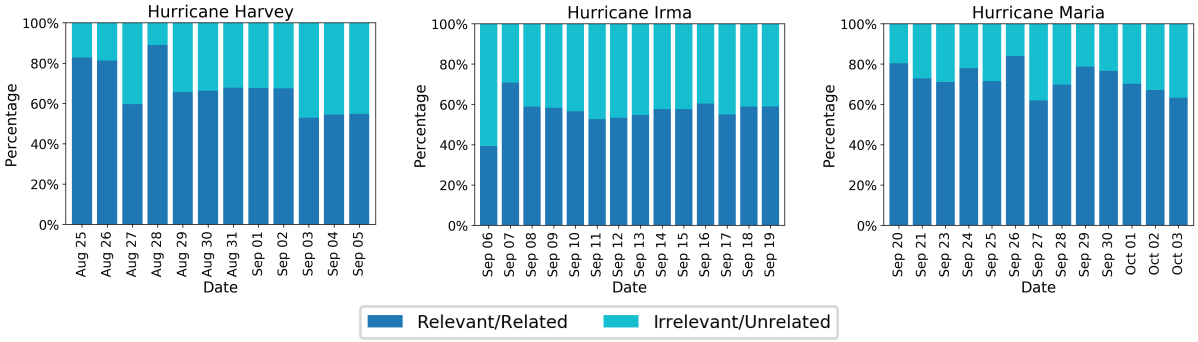

Figure 4. Daily proportion of unrelated or irrelevant tweets to related or relevant ones for Harvey (left), Irma (center) and Maria (right).

second most dominant category is "Donation and volunteering". This category contains tweets either requesting any kind of donations, or offering help or donations. However, the donation category seems to emerge slowly as the disaster event progresses. For instance, see the first few days of all three events when fewer donation-related data is found. The "Sympathy and support" category contains prayers and thoughts messages and it seems consistent across all the events and days except the last five days of the hurricane Maria event in which we observe the lower proportion of sympathy messages compared to the other two events. Caution and advice messages seem to appear mostly at the beginning of an event and slowly dispersed. The "Infrastructure and utilities damage" category gradually emerge and gets more prominent during the middle days of the events. The "Injured or dead people" category appears during some days of Irma and Maria, but the "Missing and found people" was among minority, as actually there were no missing or found cases reported during the three events. To compare the proportion of the informative categories with "Irrelevant or not related" category, in Figure 4 we show the distribution of Relevant versus Irrelevant messages for each day of the three events. The relevant category, in this case, is a combined version of all the informative categories described above. The proportion of relevant messages seems to follow a decreasing trend from 80% to 60% during Harvey unfolding while it looks approximately constant around 60% for Irma and 70% for Maria.

Topic modeling

To understand the topics of discussion on Twitter during the three disasters, we used LDA (Blei et al. 2003), which is a well-known topic modeling technique, to generate topics from large amounts of textual data. Topic modeling helps understand and summarize large collections of textual information. With topic modeling, we aim to discover hidden topical patterns that are present across different days of a disaster event. Moreover, with human intervention, we aim to analyze these topics and annotate them to summarize a discussion point. We apply LDA to generate 10 topics from the preprocessed tweets using each day's data from all three events. Due to space limitations, we do not present all the results of 10 topics for each day, instead, we show the top 30 most relevant words (i.e., words with a high probability of being associated to a topic) from the most prevalent topic among the 10 topics obtained from randomly selected four days of an event.

Figure 5 depicts the results obtained from the Hurricane Harvey data. Figure 6 shows the results obtained from the Hurricane Irma data and Figure 7 shows the topics results obtained from the Hurricane Maria data. Different than

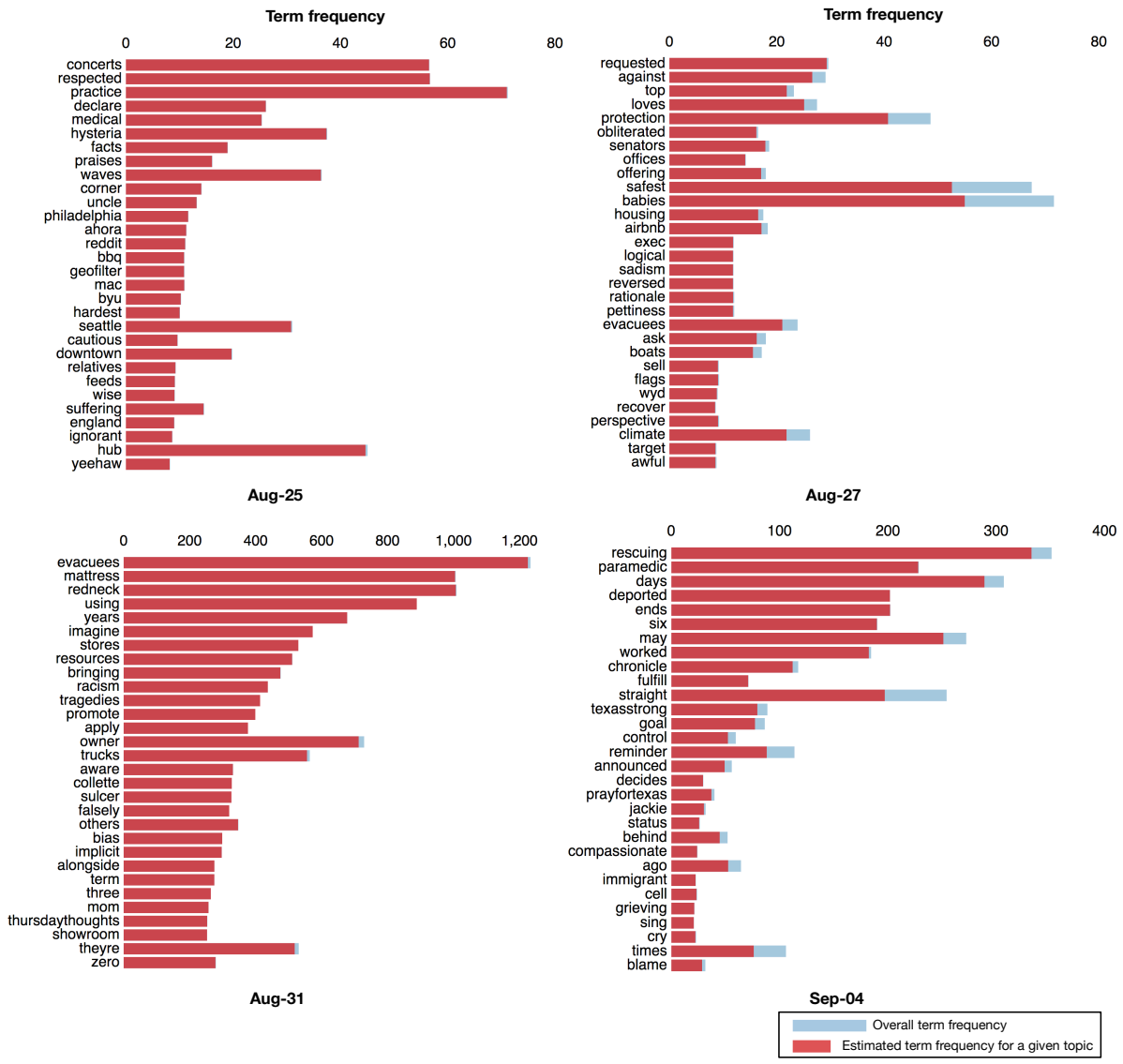

Figure 5. LDA generated topics from some selected days of Hurricane Harvey. We show top 30 most relevant words from the most prevalent topic among the 10 topics from a given day.

the traditional clustering techniques in which one data point (e.g., the text of a tweet in our case) can only belong to one cluster/topic, in topic modeling, it can belong to different topics. For example, a tweet can talk about different aid needs like food, water, shelter. For this reason, in the results, you might notice same words appear in multiple topics. The red bars indicate the word/term frequency for a given topic. The blue bars show the term frequency for a given day (i.e., how many times a word appear in a given day). All the words shown in a figure belong to one topic for a given day. For instance, the most prevalent topic emerged on August 31 during the Hurricane Harvey contains "evacuees", "mattress", and "redneck" as the top three most relevant words. The reason behind this topic was about a mattress chain owner who offered his stores for Harvey evacuees and his trucks for rescue operations. Similarly, on September 4 during the Hurricane Harvey, one of the discussion points was about "rescuing", "paramedic", "worked", as shown in Figure 5. Upon investigation, it appeared that the topic emerged due to a large number of tweets about a paramedic who reportedly worked six straight days to rescue Harvey victims, so the discussion built on the topic that he may be deported if Trump ends DACA.

One of the dominant topics that emerged on September 6 during the Hurricane Irma contains words: "help", "years", "supplies". This was due to a large discussion about *"Trump plans to ship 800,000 Dreamers back to Mexico...Mexico ships 25 trailers of supplies to help Americans..."*. Among the topics obtained from the Hurricane Maria data, there is a topic about people's concern regarding *"There will be no food in Puerto Rico. There is no more agriculture in Puerto Rico for years"*. However, on October 2, an important topic emerged about some strike of truck drivers in Puerto Rico delaying donation goods delivery. Overall, we observed the LDA generated topics

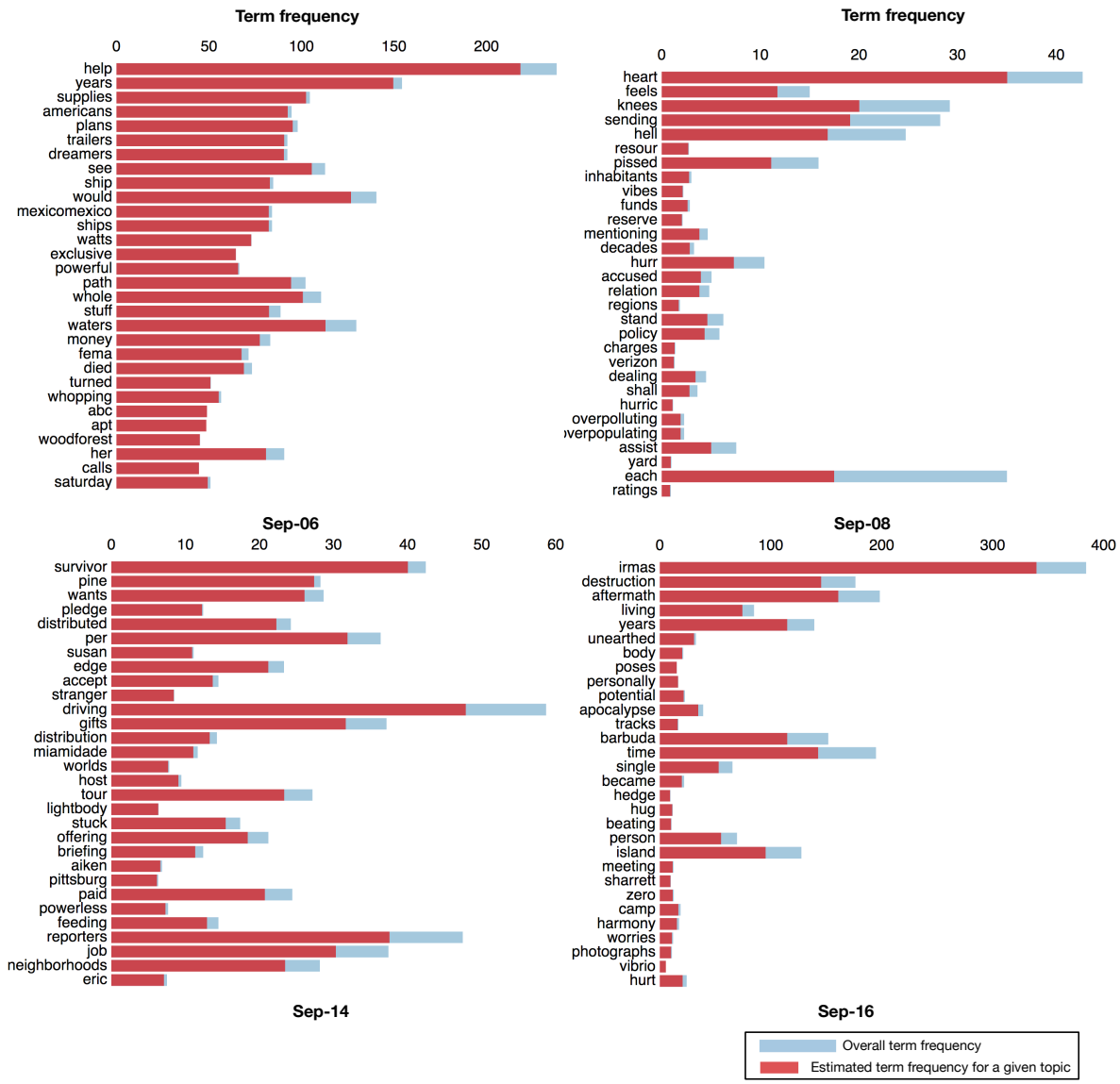

Figure 6. LDA generated topics from some selected days of Hurricane Irma. We show top 30 most relevant words from the most prevalent topic among the 10 topics from a given day.

could reveal critical public issues and concerns during disasters. For response organizations, anticipating such issues is hard. However, a system that identifies prominent and emerging topics over time (e.g., per day or per 6-hour period) to inform emergency managers about important issues that public is facing would be hugely helpful.

Named entity recognition

Named entity recognition has been proposed as part of a visual analytic tool in (Aupetit and Imran 2017) to extract top-k entities from tweets. We follow the same approach here, using the Stanford NER toolkit (Finkel et al. 2005) to analyze the three hurricanes in terms of top "Persons", "Organizations" and "Locations" mentioned in collected tweets. The reported F-measure of this NER system is 86.72% to 92.28% for different datasets.

Regarding Hurricane Harvey (Table 3), "Steve Harvey" is the most mentioned person with 7,014 tweets. Steve Harvey is an American comedian hosting "The Steve Harvey Morning Show" on a Los Angeles (CA) based radio. On August 24, Twitter user *@zwearts* tweeted a photoshopped picture of the hurricane with comedian Steve Harvey's face in the center[7], which soon got viral. We report that almost all the tweets associated with this particular entity are not helpful for disaster response, so a responder can simply ignore these $\sim 7k$ tweets. The entity "EPA" of type "Organizations" is the 5th most mentioned organization with 2,828 tweets from 1,959 unique messages.

[7] http://knowyourmeme.com/memes/events/2017-hurricane-harvey

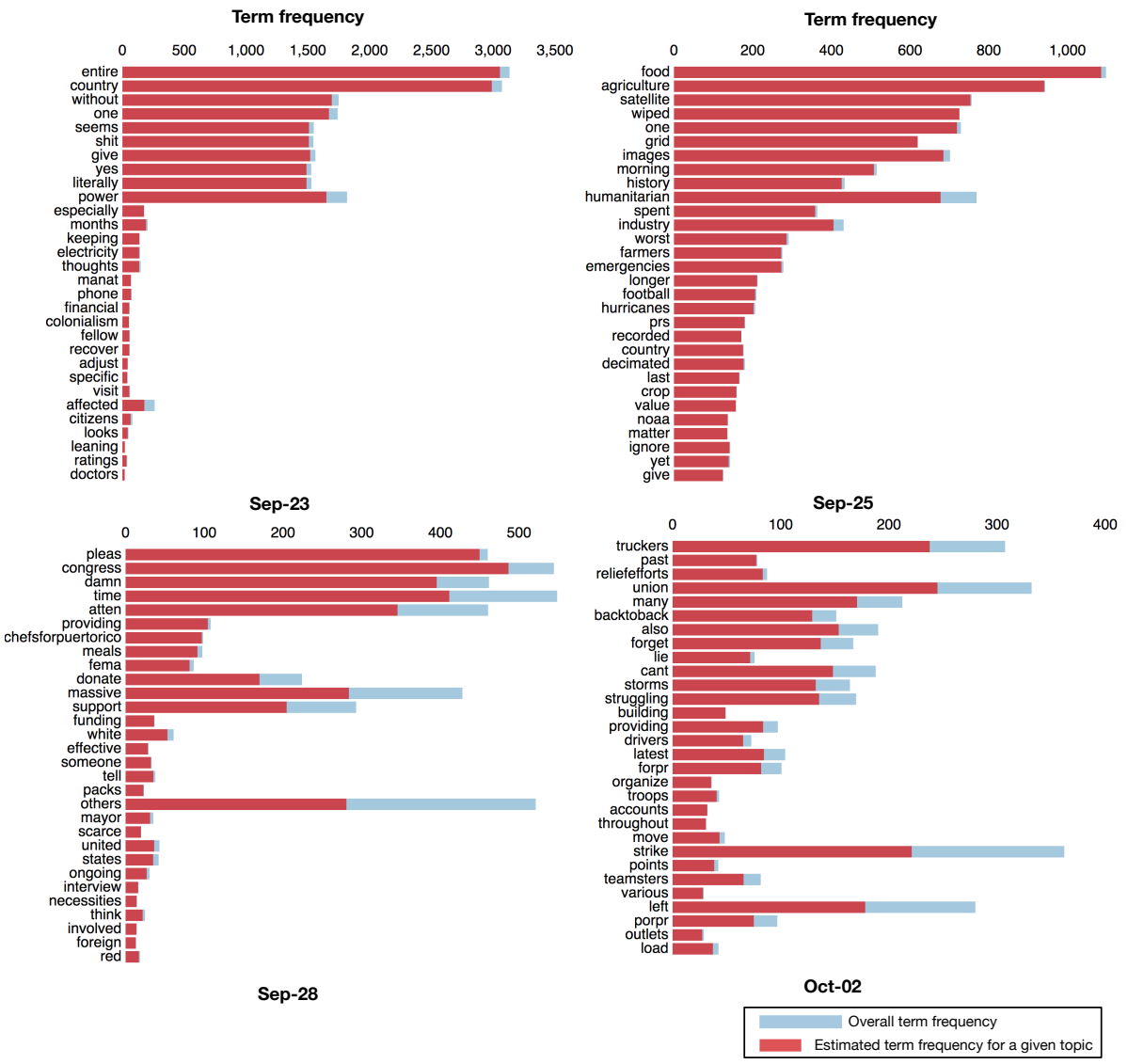

Figure 7. LDA generated topics from some selected days of Hurricane Maria. We show top 30 most relevant words from the most prevalent topic among the 10 topics from a given day.

EPA is the United States Environmental Protection Agency. Tweets relate lab testing of contaminated water and increased funding of the EPA due to Harvey event. The "Location" type entity "Oregon" is mentioned 1,087 times. Messages complain about Harvey and then announced Irma attracting more attention and funds while wildfire ravaged forests in Oregon[8]. Other tweets mentioning "Oregon" talk about the unexpectedly high number of natural disasters (Harvey, Irma and wildfires) occurring at the same time.

During Hurricane Irma (Table 4), the entity "Limbaugh" was the second most mentioned person's name with 1,918 tweets. Rush Limbaugh is a host of a Florida-based radio talk show, who angered many people by discussing that media and meteorologists were exaggerating the threat from Hurricane Irma to comply with a political agenda regarding the effect of the climate change. He eventually evacuated Palm Beach himself on September 8[9]. Another entity "Tim Duncan", a former NBA player, is ranked 2nd with 1,460 mentioning tweets. He launched a fund raising campaign starting on the 9th September for the U.S Virgin Islands where he was born and grew up[10]. "Trump Hotels" appear as the 2nd top cited organization with 1,500 tweets, following news reports[11] that some hotels, which

[8] https://www.usatoday.com/story/opinion/2017/09/20/wildfire-crisis-has-been-blanketed-hurricane-hysteria-ken-fisher-bruce-westerman-column/658959001/

[9] https://www.washingtonpost.com/news/the-fix/wp/2017/09/06/rush-limbaughs-dangerous-suggestion-that-hurricane-irma-is-fake-news

[10] https://www.theplayerstribune.com/tim-duncan-hurricane-irma-us-virgin-islands

[11] http://time.com/4931642/donald-trump-hurricane-irma-properties/

Persons		Organizations		Locations	
Steve Harvey	**7,014**	Congress	15,302	Houston	58,731
Donald Trump	5,181	FEMA Relief Funds	5,304	Texas	47,582
Obama	4,888	Coast Guard	4,111	Mexico	18,107
Jackie	4,719	American Red Cross	3,215	Florida	10,598
Bush	2,502	**EPA**	**2,828**	United States	3,579
Hillary	2,053	DACA	2,490	America	2,245
Mike	2,018	GOP	2,000	Haiti	1,435
Clinton	1,974	Justice League	1,897	U.S.	1,408
Alex Jones	1,763	Red Cross	1,819	Fort Lauderdale	1,176
Alonso Guillen	1,644	Republican Party	1,708	**Oregon**	**1,087**

Table 3. Hurricane Harvey top-10 entities. Numbers represent the amount of tweets mentioning the entities. In bold font, the cases discussed in the paper.

Persons		Organizations		Locations	
Bryan	4,427	Congress	2,583	Florida	61,195
Rush Limbaugh	**1,918**	**Trump Hotels**	**1,500**	Miami	14,876
Tim Duncan	**1,460**	Coast Guard	886	Caribbean	12,169
Rick Scott	1,362	CNN	866	Cuba	6,159
Marc Bell	848	American Red Cross	594	Virgin Islands	5,878
Donald Trump	784	NASA	537	Bahamas	4,880
Hillary	542	NYT	535	US	3,604
Katie	465	National Hurricane Center	521	Long Island	3,083
Robert De Niro	430	Red Cross	495	South Florida	2,868
Tim Tebow	386	BBC News	477	Orlando	2,691

Table 4. Hurricane Irma top-10 entities. Numbers represent the amount of tweets mentioning the entities. In bold font, the cases discussed in the paper.

are the properties of U.S. President Donald Trump might be hit by Hurricane Irma. It turned out that the same message was retweeted multiple times: "`RT @billprady: Correcting a rumor: Trump Hotels in FL are NOT housing displaced persons from Irma. Do not call 1.855.878.6700 all day long`". Still filtering out redundant messages, 25 unique messages related to "Trump hotels" were talking about the same fake news. Top-10 locations that are found from Irma data have no particular interest.

During Hurricane Maria (Table 5) the entity mention "2nd Class Brandon Larnard", a Naval aircrewman, was part of the military hurricane response efforts the Pentagon deployed on the island of Dominica and Puerto Rico. His picture[12] showing him carrying an evacuee toddler was retweeted 579 times putting his name in 2nd position of mentioned person's names. The organization entity "AOKBOKCreative" was top 3 organization cumulating 1,075 retweets after a message[13] claiming they raised 500K USD in 90 minutes to support Hurricane Maria victims. The location entity "Vietnam" is mentioned in 309 messages where it relates to a Vietnam veteran claiming Hurricane Maria was worse than war[14].

Overall, our study suggests that the identification of most mentioned named entities can help discover important stories either to filter them out ("Steve Harvey" case during hurricane Harvey) in order to focus on messages related to actual local emergency needs, or to consider some messages for further detailed analysis ("Oregon" case during Hurricane Harvey). Our analysis also illustrates the complexity of the named entity recognition problem, for instance "Harvey", "Irma", "Jose", "Katie", are all hurricane names detected as persons' names that require manual checking of the texts in tweets to decide about them. In other cases, "US" can be considered an organization or a location depending on the context. Therefore manual editing was necessary to correct for the automatically discovered named entities, emphasizing the needs for an interactive integrated tool, such as the one proposed in (Aupetit and Imran 2017).

[12] https://www.voanews.com/a/pentagon-names-three-star-general-to-head-up-puerto-rico-relief/4048825.html
[13] https://twitter.com/search?q=%23AOKBOKCreative&src=typd&lang=en
[14] http://edition.cnn.com/2017/09/25/us/puerto-rico-hurricane-maria-combat-veteran/index.html

Persons		Organizations		Locations	
Donald Trump	2,909	Congress	7,295	Puerto Rico	42,312
2nd Class Brandon Larnard	**579**	NFL	1,218	Virgin Islands	8,806
Carmen Yulin Cruz	443	**AOKBOKCreative**	**1,075**	San Juan	3,354
John McCain	343	National Guard	603	US	3,187
Luis Fonsi	306	White House	492	United States	2,004
Elaine Duke	271	GOP	402	Caribbean	816
Taylor	199	Army Corps	304	Puerto Ricans	551
Patty	189	DHS	288	Florida	464
Bush	152	Teamsters	268	Russia	452
Levine	120	NYT	234	**Vietnam**	**309**

Table 5. Hurricane Maria top-10 entities. Numbers represent amount of tweets mentioning the entities. In bold font, the cases discussed in the paper.

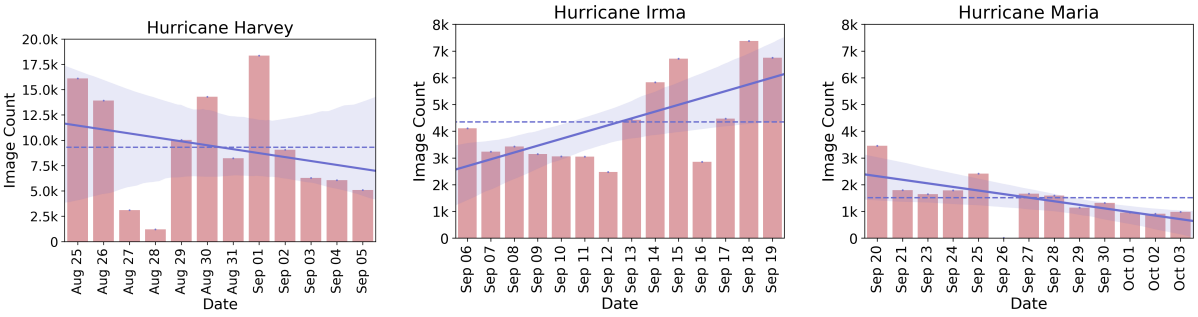

Figure 8. Bar plot of total number of image tweets per day for Harvey (left), Irma (center), and Maria (right). Horizontal dashed lines show the *average* number of image tweets per day whereas the solid lines indicate the changing trends in the volume of social media imagery data.

Multimedia content analysis

As discussed earlier, images convey more information about the disaster situation than simple words, and hence, analysis of social media image data bears significant potential for crisis response and management purposes. A reasonable proportion of tweets posted during natural disasters include imagery content. Specifically, Hurricane Harvey data include a total of 110,597 images, whereas Hurricane Irma and Maria data include a total of 60,932 and 19,681 images, respectively. Figure 8 shows the distribution of image tweets collected on each day for each event. On average, daily volume of image tweets is higher for Hurricane Harvey (i.e., $\sim 9.3k$) than those of Hurricane Irma (i.e., $\sim 4.3k$) and Hurricane Maria (i.e., $\sim 1.5k$). While the total number of image tweets per day exceeds $15k$ on certain days during Hurricane Harvey, the highest number of image tweets remains $\sim 7k$ per day for Hurricane Irma and $\sim 3k$ per day for Hurricane Maria. For Hurricanes Harvey and Maria, the trend lines indicate a decrease in the total number of image tweets per day as time passes, whereas we see an increase in total number of image tweets per day for Hurricane Irma.

For a detailed analysis of the imagery content, we employed our image processing pipeline presented in (Alam, Ofli, et al. 2018), which has readily available image classification models for relevancy filtering and de-duplication of images as described in (Nguyen, Alam, et al. 2017) as well as a model for damage severity assessment from images as studied in (Nguyen, Ofli, et al. 2017). For the sake of completeness, we next provide brief descriptions of these models and recap their performance scores. Relevancy filtering model operates like a "junk filter" that isolates images showing cartoons, banners, advertisements, celebrities, etc., which are deemed as *irrelevant* content by many humanitarian organizations during disasters. We trained this model as a binary (i.e., relevant/irrelevant) classification task using a transfer learning approach where we fine-tuned a pre-trained deep image recognition model for the relevancy filtering task at hand. On a held-out test set, the resulting model achieved 99% precision and 97% recall. De-duplication filtering model aims to identify exact- or near-duplicate images with little modifications such as cropping/resizing, padding background, changing intensity, embedding text, etc. We implemented this model using a perceptual hash technique to determine whether a given image is an exact- or near-duplicate of previously seen images. The similarity threshold was determined as the optimal operation point of the ROC curve, which yielded ~90% precision and recall. The damage assessment model categorizes the severity of damage

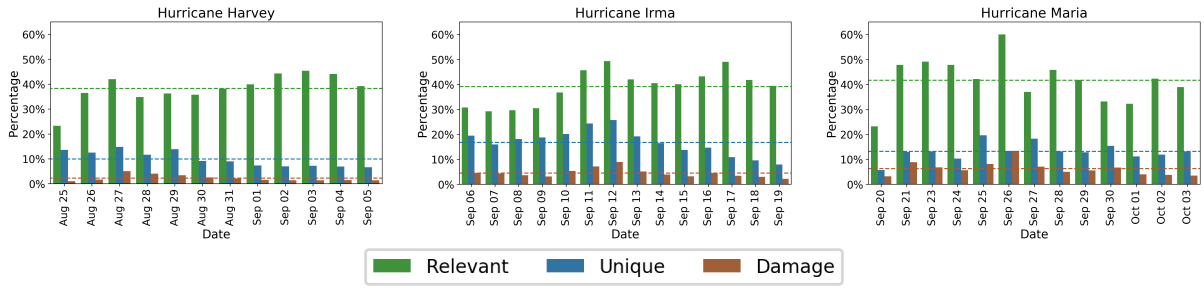

Figure 9. Ratio of daily images retained after relevancy filtering (green), de-duplication (blue), and damage assessment (brown) for Harvey (left), Irma (center) and Maria (right).

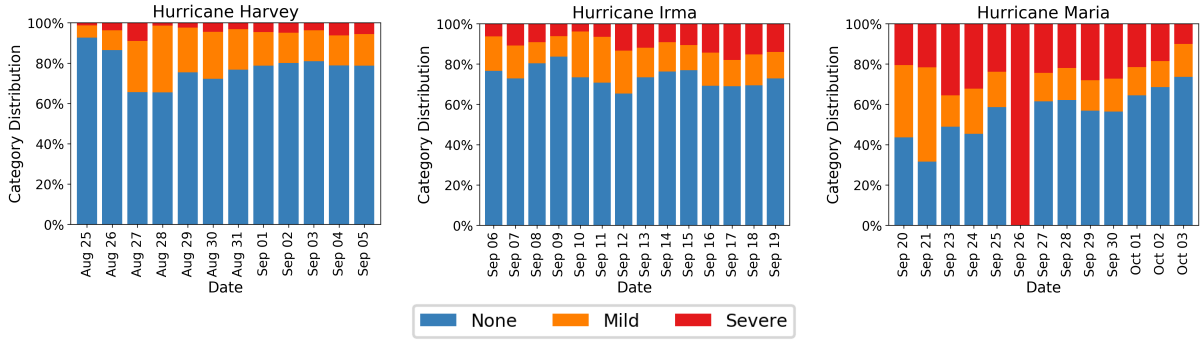

Figure 10. Distribution of *severe*, *mild*, and *none* damage images after relevancy and uniqueness filtering for Harvey (left), Irma (center), and Maria (right).

observed in an image into three categories, i.e., *severe*, *mild* or *none*. We trained this three-class classification model using ground truth disaster images annotated by humans following the same transfer learning strategy that we used for our relevancy filtering model. The overall accuracy of the resulting damage assessment models varied from 76% to 90% on held-out test sets depending on the disaster type.

We first analyze the proportions of relevant and unique images in social media imagery data collected during the Hurricanes Harvey, Irma and Maria. The results of our relevancy and uniqueness analyses are in conformity with the past observations of (Nguyen, Alam, et al. 2017) as illustrated by Figure 9. Specifically, around 40% of the images are deemed relevant to the actual disaster event in all Hurricanes Harvey, Irma and Maria, i.e., ~38%, ~39% and ~41%, respectively. Furthermore, Hurricane Irma data contain ~17% unique images whereas Hurricane Maria data contain ~11% and Hurricane Harvey data contain ~10% unique images on average. When looked at carefully, the ratios of both relevant and unique images are relatively higher in the later days of all hurricanes.

Next, we analyze the severity of damage (i.e., *none*, *mild* or *severe*) observed in the set of images that were deemed relevant and unique. Brown bars in Figure 9 indicate the percentage of images with some damage content (i.e., *mild* or *severe*). On average, ~2.5% of Hurricane Harvey images show damage content whereas ~4.4% of Hurricane Irma and ~6.2% of Hurricane Maria images show damage content. Moreover, this ratio can be twice as high in the later days of all disasters. Overall, an interesting observation is that even though the total volume as well as the daily volume of image tweets is relatively smaller for Hurricane Maria, the proportions of unique or damage images are higher than those for Hurricanes Harvey and Irma. Even though daily changes in prevalence of relevant and damage images during Hurricane Maria seem to be strongly correlated ($r = 0.71$, $p < 0.01$), we do not observe a statistically significant correlation between relevant and damage image tweet distributions for Hurricane Irma ($r = 0.41$, $p = 0.14$) and Hurricane Harvey ($r = 0.04$, $p = 0.90$). On the other hand, daily changes in prevalence of unique and damage images during Hurricane Irma seem to be very strongly correlated ($r = 0.85$, $p < 0.001$) whereas they seem to be only strongly correlated ($r = 0.62$, $p < 0.05$) during Hurricane Harvey. Even though we observe a moderate correlation between unique and damage image tweet distributions for Hurricane Maria, this correlation is not statistically significant ($r = 0.44$, $p = 0.13$).

In Figure 10, we take a closer look at the damage assessment analysis of images after relevancy and uniqueness filtering for all events. On any given day, only 20-30% of Hurricane Irma images that are relevant and unique depict some damage content (i.e., *mild* or *severe*), whereas this ratio varies between 30-60% for Hurricane Maria. Furthermore, among those Hurricane Irma images that depict some damage content, we see more examples of *mild*

Figure 11. Sample images with different damage levels from different disaster events.

damage than *severe* damage. On the contrary, images with damage content in Hurricane Maria data show more *severe* damage than *mild* damage. Among the three hurricanes, Hurricane Harvey data seems to contain the least proportion of damage content.

Figure 11 shows several example tweets with images classified into different damage categories. In some cases such as Figures 11(a)-(c) and (g)-(i), both tweet text and image content provide critical information related to infrastructure and utilities damage at different severity levels. However, unlike their image counterparts, tweet text in Figures 11(d)-(f) do not provide any significant information about the severity or extent of damage incurred by disaster events other than just stating that the disasters caused some damage. Similarly for tweets in Figures 11(j)-(l), images provide some crucial damage information related to power lines, roads, etc. whereas the corresponding text reports a dead person, questions why hurricanes are named, or mentions the path of the hurricane. More importantly, even though the tweets in Figures 11(m)-(r) do not show any damage content, they provide critical information for other humanitarian categories taxonomy. For instance, Figure 11(o) provides valuable insight for the quality of shelter. Similarly, Figure 11(q) illustrates an example of evacuation and displaced people.

CONCLUSION

The widespread use of social media during disasters and emergencies has created opportunities for disaster responders to find useful information for crisis response and management. In this work, we performed an extensive analysis of the data collected from Twitter during three natural disasters. We demonstrated the richness of the useful information both textual as well as multimedia contained in the tweets. By using a wide range of state-of-the-art machine learning techniques, we analyzed millions of tweets and tens of thousands of images to show the utility of the data and potential of the employed techniques for crisis management and emergency response. However, to make sense of the large amounts of crisis-related data on social media, especially during an on-going disaster is still challenging and requires efficient computational methods which can operate in real-time. Among other issues, when it comes to operational crisis management, addressing scalability issues of most of the techniques to process real-time data streams is essential. Furthermore, systems that include humans-in-the-loop for machine training need to deal with humans' limited processing capabilities to maintain high throughput. We consider this as a future work for us and for the crisis informatics community.

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Social Media Resources Named after a Crisis Event

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ABSTRACT

Crisis Named Resources (CNRs) are the social media accounts and pages named after a crisis event. CNRs typically appear spontaneously after an event as places for information exchange. They are easy to find when searching for information about the event. Yet in most cases, it is unclear who manages these resources. Thus, it is important to understand what kinds of information they provide and what role they play in crisis response. This paper describes a study of Facebook and Twitter CNRs around the 2016 Fort McMurray wildfire. We report on CNR lifecycles, and their relevance to the event. Based on the information provided by these resources, we categorize them into 8 categories: donations, fundraisers, prayers, reactions, reports, needs and offers, stories, and unrelated. We also report on the most popular CNR on both Facebook and Twitter. We conclude by discussing the role of CNRs and the need for future investigation.

Keywords

Crisis Informatics, Crisis Named Resources, Social Media.

INTRODUCTION

Individuals and organizations (such as crisis responders, governments, news media, companies, etc.) use social media during crisis events to share event updates, facilitate communication, offer help, express opinions, and show support and solidarity (Palen and Hughes 2018; Palen and Liu 2007; Sutton et al. 2008). Social media allow anyone with an Internet connection to participate in the exchange of information around a crisis event. In this paper, we draw attention to a phenomenon that occurs after most larger crisis events where people spontaneously create social media accounts and pages that are named after the event. We call these social media products Crisis Named Resources (CNRs).

CNRs are important to study for several reasons. First, CNRs appear to be dedicated venues for information exchange around an event, and they easily appear when searching for information about an event. Due to this visibility, these resources tend to attract more attention than other sources of information. Second, CNRs could be mistaken by the public as official sources of information, which could be harmful if these sources then shared false or inaccurate information (Lindsay 2011). Third, CNRs are typically created soon after a crisis occurs which leaves little to no opportunity for assessing the identity or intentions of a CNR's administrator(s) based on past activity. Lastly, most CNRs disseminate information about an event (though some do not), so it is critical to understand what kinds of information they provide and what role they play in a response.

To learn more about these resources, we analyzed the online activities of Facebook and Twitter CNRs created during the 2016 Fort McMurray wildfire. We report on the lifecycle (creation and deletion) of these resources, and how they were used for sharing information around the wildfire. We categorize these resources based on their social media profiles and posted content to understand the different roles these resources played in the crisis response. We also investigate the CNRs with the most number of Facebook likes and Twitter followers to discover why so many people followed them. The focus of this study is to determine the type of information disseminated by these CNRs, understand the role of CNRs in crisis response efforts, and lay a foundation for future analysis.

BACKGROUND

This research lies in the domain of *crisis informatics* (Palen et al. 2007; Palen and Anderson 2016) and is grounded in sociotechnical theory. This perspective advocates that technology and social systems are not only

intertwined, but they also dynamically and recursively shape and influence one another (Orlikowski 1992). We see evidence of this influence in the research literature that describes how social media can empower communities to participate in crisis response (Ling et al. 2015). Members of the public often use social media to provide information, relief assistance, and emotive and evaluative support around crisis events (Palen and Liu 2007; Liu et al. 2008). People also use social media to collaborate during disasters. For instance, in the aftermath of 2007 Virginia Tech Shootings, people worked together online to discover the names of those who had died in the shootings (Vieweg et al. 2008). A similar kind of self-organizing behavior of members of the public was also observed during the response and recovery phase of the 2010 Haiti Earthquake (Starbird and Palen 2011). These emergent uses of social media during crisis events have in turn, shaped social norms around social media use as well as the technical affordances of the different social media platforms.

Though social media have proved useful around crisis events, they have also contributed to the spread of false rumors (intentionally or unintentionally) during crises (Huang et al. 2015). These false rumors can lead people to make potentially life-threatening decisions (Starbird et al. 2016). Therefore, it is important to investigate who is using social media during a crisis event and how.

To better understand the sociotechnical role of social media in crisis response, researchers in *crisis informatics* have sought to identify the kinds of users who post and/or share crisis related information. Crisis informatics researchers have also tried to determine the types of information that these users share, and their intentions in doing so. For example, Olteanu and colleagues (2015) studied Twitter communications around 26 natural and human-induced crises and found that the provided information were mainly about the affected individuals, infrastructure and utilities, donations and volunteering, caution and advice, and sympathy and emotional support. They also reported that the sources of information, comprised eyewitnesses, government, non-governmental organizations, businesses, traditional or Internet media, and outsiders (individuals who are not personally involved or affected by the event). Similarly, Purohit and Chan (2017) studied the online communications around Hurricane Matthew and Louisiana floods, and classified users into three categories (organization, organization-affiliated, and non-affiliated). They also reported how users in each of these categories have unique ways of disseminating information, for example, the organization users are less likely to retweet in contrast to non-affiliated users who are the most likely to retweet. In this research, we take a similar approach as we seek to determine the types of CNRs that were created around the 2016 Fort McMurray wildfires and their purpose.

Prior *crisis informatics* research has also observed the existence of dedicated sources that are created in response to a crisis event. For instance, Shklovski and colleagues (2008) discovered that a community-based volunteer website was a useful information source during the 2007 Southern California Wildfires. Created by a member of a rural community that had been evacuated due to the wildfire, the website played an important role in reconnecting community members and facilitating information exchange about the wildfire status and humanitarian relief efforts in the area. More recently, we examined the online communications of official sources during the 2014 Carlton Complex wildfire (Chauhan and Hughes 2017), and found that many Facebook pages, Twitter accounts, and websites (or CNRs) were created in response to and were named after the wildfire. These resources played an active role in disseminating information around the event. However, in most cases, it was difficult to determine who administered these online resources, which also made it difficult to assess their credibility. In this study, we expand upon the Carlton Complex wildfire research with a deeper examination of CNRs. Our goal is to identify the types of CNRs that appear around an event and to learn more about the different roles they play in crisis response.

EVENT OF STUDY – THE 2016 FORT MCMURRAY WILDFIRE

A wildfire in the southwest of Fort McMurray, Alberta, Canada started on May 1, 2016. On May 3, the wildfire entered the city of Fort McMurray and forced a mass evacuation of 80,000 residents—the largest wildfire evacuation in Alberta's history (Fritz 2016). The wildfire burned nearly 600,000 hectares and destroyed over 2,400 structures (CBC News 2016). Evacuees experienced an extended period away from their homes and were only allowed to re-enter their city under a voluntary phased reentry program from June 1- June 15 (Ramsay 2016a). On June 13, 2016, the wildfire was classified as 'being held' (Giovannetti 2016) and the wildfire was finally considered 'under control' on July 5, 2016 (Ramsay 2016b).

DATA COLLECTION

Our data collection involved two activities. First, throughout the Fort McMurray Wildfire, we periodically looked for new CNRs while continuing to monitor the CNRs we had previously found. Second, we collected all

Facebook posts and tweets from the CNRs we identified during the wildfire timeframe. We discuss these activities in more detail below.

Identification and Monitoring of Crisis Named Resources

We recorded the creation and deletion dates of CNRs on both Facebook and Twitter once a day during the data collection time period (May 1 – July 5, 2016). Using Facebook and Twitter search engines we determined the Facebook pages and Twitter accounts, whose name had any of the following keywords- 'Horse River Fire', 'YMM Fire', 'Fort McMurray Fire', 'Fort McMurray Wildfire', 'Fort mc fire', and 'Fort Mac Fire.' This was done daily to ensure that we did not miss the CNRs that were created over the course of the event. The account creation date for all Twitter accounts was retrieved from their respective account profiles. For Facebook, we considered the date of their first post to be their account creation date since most of the pages did not have information about when they were created. We also recorded the number of CNR Facebook page likes and Twitter followers on the last day of the data collection timeframe.

We revisited all the identified Facebook and Twitter CNRs daily to see if they continued to exist. For the CNRs that were deleted, we recorded the date when we found this information.

Messages posted by Crisis Named Resources

All Facebook posts and tweets by Fort McMurray CNRs during the timeframe May 1- July 5, 2016 (the entire duration of wildfire) were collected using the Facebook Graph API and Twitter Search API respectively. Table 1 gives the number of CNRs and the number of messages posted by these resources on Facebook and Twitter.

	# of CNRs	**Total # of Posts (May 1 – July 5, 2016)**
Facebook	70	2657 messages
Twitter	13	5011 tweets

Table 1. Total Number of CNRs and Posts on Facebook and Twitter.

DATA ANALYSIS AND FINDINGS

We report the findings of our study in four subsections: (1) life of CNRs, (2) relevance of CNRs, (3) types of CNRs, and (4) popular CNRs. The first subsection reports the time at which the CNRs were created and deleted (if applicable). The second subsection determines if the messages posted by these CNRs were about the Fort McMurray wildfire. The third subsection examines different types of CNRs and the fourth subsection investigates the most popular Fort McMurray CNR on both Facebook and Twitter.

Life of Crisis Named Resources

To understand the lifecycle of CNRs, we determined their creation and deletion dates, and analyzed their longevity after the completion of the event.

Creation of Crisis Named Resources

A CNR's creation date is an indicator of whether a new resource was created or if an existing resource was adapted in response to a crisis event. For an event of prolonged duration, such as the Fort McMurray wildfire, a CNR's creation date might also correlate with a significant subevent within the event (e.g., an evacuation).

Table 2 gives the number of CNRs created on Facebook and Twitter before, during, and after the wildfire. Our findings show that most Facebook (98.5%) and Twitter CNRs (92.3%) were created during the wildfire. There were, however, 2 resources (1 Facebook and 1 Twitter) created before the wildfire.

Date of CNR Creation	**Facebook**	**Twitter**
before May 1, 2016 (before wildfire)	1 out of 70 (1.4%)	1 out of 13 (7.6%)
between May 1 - July 5, 2016 (during wildfire)	69 out of 70 (98.5%)	12 out of 13 (92.3%)

Table 2. Number of CNRs Created on Facebook and Twitter.

First, we look at the two CNRs created before the wildfire. The first CNR is a Facebook page that was created in April 2012 (4 years before the wildfire). According to the page description, it was created to increase safety on

Highway 63. The administrators of this page posted 4 messages during the Fort McMurray wildfire, all of which were relevant to the wildfire. The second CNR created before the wildfire is a Twitter account that was created in May 2014 (2 years before the wildfire). This CNR is owned by a woman who described herself as a proud mom of a UCLA bound student, an Ivy League grad, and an editor. During the fire, she changed her username to 'Support #ymmfire,' which is why the account was considered a CNR in our dataset. Later (on May 26, 2016) she changed her username back to her given name. She posted 27 messages during the data collection timeframe, none of which were relevant to the wildfire. From the data we collected, it is impossible to know why she changed the name of her account. We speculate that it could have been a way to show support for the wildfire affected population. We would have to interview the account owner to know for certain, which was not possible in this case.

Next, we look at the CNRs created during the wildfire. To find possible correlations between the CNR creation dates and the event progression, we determined the number of CNRs that were created each week of the wildfire (see Table 3). Findings show that most of the CNRs on Facebook (68.5%) and Twitter (53.8%) were created during the first week (May 1 – May 7) of the wildfire—the week that saw rapid wildfire growth and forced massive evacuations. Therefore, it appears that the creation of most of the CNRs in the first week of the wildfire reflects the chaos caused by the wildfire during that timeframe.

	May 1 - 7	**May 8 - 14**	**May 15 - 21**	**May 22 – 28**	**May 29 – Jun 4**	**Jun 5 – 11**	**Jun 12 – 18**	**Jun 19 – 25**	**Jun 26 – Jul 2**	**Jul 3 –5**
Facebook	48	8	7	1	1	1	0	1	0	2
Twitter	7	2	0	0	2	0	0	1	0	0

Table 3. Number of CNRs Created During the Wildfire.

Deletion of Crisis Named Resources

Table 4 shows the number of CNRs deleted from Facebook and Twitter during and after the wildfire. We were surprised to find that a significant number of CNRs were deleted during the wildfire, 16 (22.8%) Facebook CNRs (and none of the Twitter CNRs). When we checked for the existence of these CNRs in the month of March 2018 (just prior to submitting the final version of this paper), we found that an additional 27 (38.5%) Facebook and 2 (15.3%) Twitter CNRs have been deleted, bringing the total number of deleted CNRs to 43 (61.4%) on Facebook and 2 (15.3%) on Twitter.

Date of CNRs' Deletion	**Facebook**	**Twitter**
between May 1 - July 5, 2016 (during wildfire)	16 out of 70 (22.8%)	0 out of 13 (0.0%)
after July 5, 2016 (after wildfire controlled)	27 out of 70 (38.5%)	2 out of 13 (15.3%)

Table 4. Number of CNRs Deleted on Facebook and Twitter.

We did not investigate the CNRs that were deleted after the wildfire because the deletion of a CNR after the conclusion of an event is in alignment with the goal of serving as a resource during an event. However, the deletion of CNRs while an event is still happening needs more inspection.

We first looked at the number of Facebook CNRs deleted each week of the wildfire (see Table 5). The data show a fairly uniform distribution of the number of deleted accounts during the wildfire, and thus there seems to be no correlation with the deletion of CNRs and event progression. Since these 16 CNRs were deleted during the wildfire, we do not report on the details of these resources and the messages they posted. In some cases, the CNRs were deleted before we could even retrieve their messages.

The deletion of CNRs during an ongoing event prompts the question of why these accounts were deleted. We were unable to find any messages from the deleted CNRs that indicated why they were deleted, thus answers to this question are unknown. Also, since these CNRs left no record of their existence (such as an alternate page or account), questioning the administrators about the reasons for deleting their CNRs is now impossible.

	May 1 - 7	**May 8 - 14**	**May 15 - 21**	**May 22 – 28**	**May 29 – Jun 4**	**Jun 5 – 11**	**Jun 12 – 18**	**Jun 19 – 25**	**Jun 26 – Jul 2**	**Jul 3 –5**
Facebook	1	2	2	2	0	3	2	0	1	3

Table 5. Number of CNRs Deleted by Week During the Wildfire.

Crisis Named Resources After the Event

Next, we looked at the CNRs that continue to exist in the month of March 2018. We revisited all the CNRs identified earlier in the study and found that of the 27 Facebook CNRs and 11 Twitter CNRs that continue to exist, 18 Facebook CNRs and all 11 Twitter CNRs have not posted anything since the month the wildfire was considered under control, i.e., after July 2016. This means that even though these resources still exist, people are no longer contributing content to them. There were 9 Facebook CNRs that continue to exist and have shown some online activity after July 2016 (see Table 6).

Facebook Page Name*	**Page Description***	**#Likes and #Followers**	**# Posts Since July 2016**	**Content of Posts Since July 2016**
Fort McMurray CNR 1	The administrator was saddened by the wildfires and wanted to help in some way with this page.	60 Likes. 52 Followers.	1	Funny Video.
Fort McMurray CNR 2	This page was a place where people shared and collected photos of the event.	28,982 Likes. 28,675 Followers.	4	Post about community gatherings on the anniversary of Fort Mc wildfire, and some photos of wildfire.
Fort McMurray CNR 3	This page aims to help victims by collecting stories, information and offers of help.	160 Likes. 159 Followers.	17	Posts about legalizing marijuana, unemployment, immigration, oil and gas industry workers, B.C. wildfire, and Fort McMurray wildfire.
Fort McMurray CNR 4	-	31 Likes. 30 Followers.	1	Post about Roller Derby.
Fort McMurray CNR 5	This page was created to help Fort McMurray residents and family, but after the fire only posted about flowers and quilts.	40 Likes. 40 Follows.	23	Posts about flowers and quilting.
Fort McMurray CNR 6	A page to keep the pictures of displaced pets and livestock that are not yet claimed as a result of the Fort McMurray fire 2016	45 Likes. 45 Followers.	153	Posts about missing animals and animal care.
Fort McMurray CNR 7	This page took names and numbers of those who need a place to stay, and those that can provide a place.	479 Likes. 454 Followers.	17	Posts about B.C. wildfires, and a few about Fort McMurray fire.
Fort McMurray CNR 8	This page was created by a teen who wanted to help with relief efforts despite being told he was too young to help.	66 Likes. 62 Followers.	1	1 post about the plan of getting horses back to Fort McMurray.
Fort	This page posts information	436 Likes.	1	Posted a video about a dog

McMurray CNR 9	regarding the wellbeing of pets that the administrator is tending or has rescued.	407 Followers.	suffering in a hot car.

Table 6: Facebook CNRs That Have Posted Since July 2016 (* Page Names and Descriptions have been anonymized).

Table 6 shows that 4 of the 9 CNRs have generated only 1 post since the wildfire was under control. One of these resources (Fort McMurray CNR 8) was created by a teen, who felt that this Facebook page was the only way he could meaningfully help. His single post following the fire talked about how he still plans to continue his efforts in getting the displaced horses back to Fort McMurray and that he is still concerned about helping around the event. We also found that 1 CNR (Fort McMurray CNR 2) has posted only 4 messages. All these messages were about the Fort McMurray wildfire, so this resource is still being used for the wildfire response. Another CNR (Fort McMurray CNR 3) has posted 17 times after the wildfire. All these posts were about the issues and challenges at the local (public inquiry on Fort McMurray wildfire, mental health challenges and increased unemployment of wildfire-affected oil workers), state (increase in the unemployment rate of Alberta), and national level (immigration, use of toxic Bromine in British Columbia (B.C.), and the B.C. wildfire). Furthermore, we found one CNR (Fort McMurray CNR 5) that was created on May 2, 2016. The administrator(s) of this CNR posted on May 4, 2016, after which this resource became idle for a while. The page became active again during August – September 2017, when the administrator(s) of this resource posted 23 times. All of these posts were related to flowers and quilting; none were related to the wildfire. After this activity, the page has once again become idle. We also found 1 CNR (Fort McMurray CNR 6) that has expanded its mission of reporting on the animals affected by the wildfire to missing animals and animal care, in general, with 153 posts following the wildfire. Another CNR (Fort McMurray CNR 7) has been sharing information about a wildfire in the southern Cariboo region of B.C. Even though this CNR is informing (or hoping to inform) people about a recent wildfire in B.C., it is unclear how people, ones who are not following this resource, would come to know that it could be useful in getting information about the B.C. wildfire. The online activity shown by these CNRs demonstrate how after the completion of an event CNRs sometimes broaden their goals (e.g., by putting their efforts towards animal safety on a broader scale, or by informing people about surrounding wildfires) or change their goals (e.g., by talking about quilts).

Relevance of Crisis Named Resources

After identifying the Fort McMurray named resources on Facebook and Twitter, we assessed whether they were posting about the wildfire. We read each message posted by the CNRs that existed throughout the wildfire and marked each message as on-topic (event-related) or off-topic (not related to the event). Examples of on-topic posts included messages about the fire size, evacuations, fire containment, re-entry, etc. Off-topic posts included posts about other local and national wildfires, Canada Day, etc. We did not mark the messages posted by the CNRs that were deleted before July 5 (the day the wildfire was classified as 'under control') as on- or off-topic due to terms-of-service obligations that require consumers of this data to remove deleted social media posts (Maddock et al. 2015).

Table 7 shows that the majority of the messages posted by these resources on Facebook (99.3%) and Twitter (99.2%) were related to the wildfire. However, there were a few resources (12 (of 54) on Facebook and 3 (of 13) on Twitter) that have no posts, not even posts irrelevant to the wildfire. We include these resources because these resources can still potentially be seen as sources of information about an event (even if they have no posts). Among the remaining 42 Facebook and 10 Twitter CNRs that posted information about the wildfire, 35 Facebook and 7 Twitter CNRs had less than 100 on-topic posts. This means that there were only 7 (12.9%) Facebook and 3 (23%) Twitter CNRs that were heavily used during the wildfire.

	Total Number of On-Topic Posts
Facebook	2639 of 2657 posts (99.3%)
Twitter	4974 of 5011 tweets (99.2%)

Table 7. Number of On-Topic Posts by CNRs on Facebook and Twitter.

We compared the number of on-topic posts per week during the wildfire timeframe to see if there is a correlation between the number of on-topic posts and event progression. Figure 1 shows that the highest number of on-topic messages on Facebook and Twitter were posted during the first two weeks of the wildfire. This finding indicates most of the online chatter about the event fell on the days when mandatory evacuations were in place.

To identify the administrator(s) of these CNRs, we analyzed the CNRs' names, their descriptions, and the

messages they posted. We could only identify 9 (16.6%) CNR administrators on Facebook (1 via the CNR's description and CNR's posts, and the remaining 8 only through post content) and 2 (15%) CNR administrators on Twitter (1 via through the account description and the other via tweet content). The administrators for the other CNRs (i.e., 84% on Facebook and 85% on Twitter) are unknown.

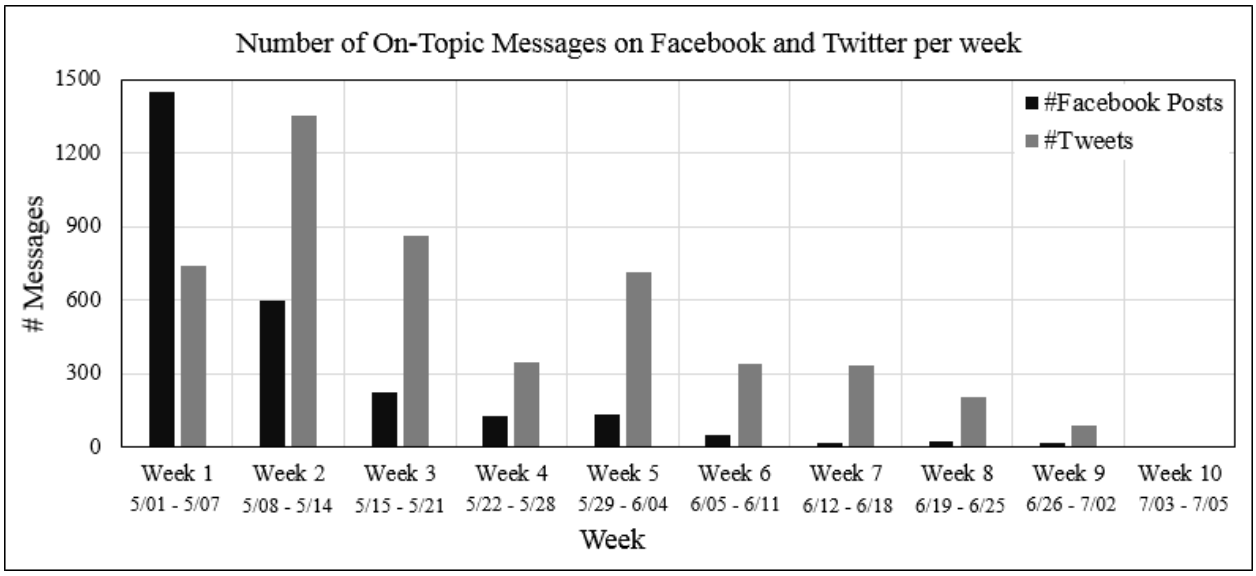

Figure 1. Number of On-Topic Messages Posted by CNRs over the Data Collection Timeframe.

Types of Crisis Named Resources

To better understand the different types of CNRs people create around a wildfire, we categorized each CNR by its content. We report only on the 54 Facebook and 13 Twitter CNRs that existed throughout the wildfire timeframe.

CNRs Categories	Definition	# Facebook Pages	# Twitter Accounts
Donations	Resources asking for money or items for the Fort McMurray wildfire victims.	8	0
Fundraisers	Resources used for selling or auctioning items, money of which was/would be used for the benefit of wildfire victims.	13	1
Prayers	Resources used for sending best wishes and messages of hope for wildfire victims.	1	2
Reactions	Resources used to express personal views and opinions about handling of the Fort Mac wildfire.	1	1
Reports	Resources used for reporting on the Fort McMurray wildfire event.	18	7
Needs & Offers	Resources used by people to ask for or provide help.	15	2
Stories	Resources that were asking for stories from individuals about their individual experiences, regarding evacuations, cheating, etc.	4	0
Unrelated	Resources that were named after the event but did not post about it.	0	1
Unclassified	Resources that lacked enough information to classify; ones with generic names (such as Fort McMurray wildfire), no self-description, and no posts.	3	2

Table 8. Types of CNRs.

We identified 3 parameters—the CNR 1) name, 2) description, and 3) message content—that could be used to categorize a CNR. We found that 8 (14.8%) Facebook pages and 6 (46.1%) Twitter accounts, in our dataset, had a generic name (such as "Fort McMurray Wildfire 2016" or "Fort Mc Fire"). Also, 15 (27.7%) Facebook pages and 6 (46.1%) Twitter accounts had no page or account description. Additionally, 13 (24%) Facebook pages and

2 (15.3%) Twitter accounts posted no messages. Thus, none of our three parameters were sufficient by themselves to categorize a CNR. As a result, we included all 3 parameters to categorize a CNR. We looked for purpose-defining keywords (such as recovery, support, fundraiser, etc.) in the name and description of the CNRs. We also read the on-topic messages posted by the CNRs to see if there were any posts from the CNR administrators that reveal their purpose for creating these resources, or if there are themes around the posts. Once we found a consistent theme around each CNR in its name, description, and/or messages, we assigned a brief description, such as 'collecting donations.' Over time, after a number of discussions between the authors, we grouped our CNRs into 8 categories. Table 8 lists these categories and the number of Facebook and Twitter CNRs that fit within each category. Note that a CNR could fall into multiple categories.

Table 8 shows that most creators of Fort McMurray CNRs reported information about the event (reports), sought and/or provided resources (needs and offers), and raised money for victims (fundraisers). The most frequent CNR type was the 'reports' category. Reports in our dataset, were mostly about wildfire updates (such as fire size, fire containment, etc.), evacuation notifications, alerts and advisories, or re-entry information. Reporting found in these CNRs was done through rebroadcasts (sharing or retweeting a web link), status updates, and links to other sources of information. The next most frequent CNR type was 'needs and offers,' the resources used by people to ask for things they needed, and to provide offers of help such as rescuing pets, building restoration, providing temporary accommodation, fuel, and other necessary items. Offers of help, in our dataset, were provided from individuals, families, and businesses. The third most frequently appearing type of CNR was 'fundraisers.' Fundraisers for this event included live auctions and the selling of items (such as sea salt scrub, hoodies and tanks, sports memorabilia, etc.).

Popular Crisis Named Resources

We define the most popular CNRs as those that received the highest number of Facebook likes or Twitter followers. A large number of page likes or Twitter followers indicates what resources people were paying attention to during this wildfire. 'Fort McMurray Evacuee Open Source Help Page' and 'YMMHelps' were the most popular CNRs in our dataset on Facebook and Twitter respectively (see Table 9).

	Most Popular CNR	**CNR Description**	**#on-topic posts**	**#likes/#followers (MAX)**
Facebook	Fort McMurray Evacuee Open Source Help Page	This is an open source page to help Albertan's Evacuating from Fort McMurray wildfires. Albertan's are encouraged to post offers of help. Website: https://ymmhelp.com	932 out of 932 (100%)	41,428
Twitter	YMMHelps (@YMMhelp)	Fort McMurray Evacuee Open Source Help Page - Crowdsourcing support for evacuees, and all subsequent volunteer/community rebuilding efforts. ymmhelp.com	950 out of 951 (99.9%)	1,446

Table 9. Most Popular CNR on Facebook and Twitter.

Looking at the self-descriptions for these resources (see Table 9), it appears they were administered by the same entity (the administrator of ymmhelp.com). To take a deeper look at these CNRs, we analyzed the messages they posted. Both Facebook and Twitter CNRs used the social platforms heavily to share wildfire-related messages with a rate of on-topic posts of 100% and 99.9% respectively. Also, both these CNRs are of the 'needs and offers' type i.e., they contained posts regarding the resources needed and resources available (known through offers of help). Both accounts acquired a large number of likes/followers, though the Facebook page had many more followers than the Twitter account (41,428 followers versus 1,446 followers).

Next, we looked at the distribution of on-topic posts for both of these CNRs over the wildfire timeframe, and also the number of likes/followers they gained over time. We found that both our most popular CNRs posted messages only in the month of May. The most on-topic posts on both the Facebook page (811 of 932; 87.0%) and Twitter account (616 of 951; 64.7%) were posted during the first week of the wildfire (May 1 – May 7). To break that down, the most number of on-topic posts on both the Facebook page (718 messages) and Twitter account (339 tweets) were posted on May 4, 2016 – a day after the massive evacuations (mass evacuations were forced on the night of May 3). Also, both of these accounts were created on May 3, 2016. The similarities

between the accounts is not surprising given these resources appear to be managed by the same party.

We also looked at their follower counts in March 2018 and found that the Facebook page has 38,764 likes and the Twitter account has 1,244 followers. These findings reflect a small decrease in the number of followers on both these resources after the wildfire was controlled.

DISCUSSION

In this paper, we examined the online behaviors of the 2016 Fort McMurray wildfire CNRs. Findings show that these CNRs primarily posted wildfire-related information and tried to help the wildfire-affected public in different ways. We also found that a large number of these CNRs were created during the wildfire, most of which became inactive or were deleted after the wildfire. Additionally, we discovered that most of the CNRs' owners did not explicitly disclose their identities, which raises questions of credibility. Below, we discuss these findings in more detail and offer broader implications and future directions for this research.

The CNRs in this study covered a diverse range of topics around the wildfire, from information dissemination (reports), to offers of help (donations, fundraisers, needs and offers), to expressions of solidarity (reactions, stories, prayers). We would expect to see more of these behaviors on a larger scale for larger events. We did not see any fake or malicious CNRs for the Fort McMurray wildfire, though that does not mean that they do not occur in other events. The list of categories developed in this work was specific to this event and would likely vary based on the context of the crisis event. Nonetheless, it does serve as a starting place for further investigation.

Most of the CNRs were used to post wildfire related information, but there were some resources that were never used to share anything. This is interesting because if someone creates a CNR, it implies that s/he intended, at some point in time, to post event-related content or something that would potentially be found by those looking for information about the event. Because the owners of these CNRs never posted or shared anything, it is difficult to evaluate the roles that these CNRs played in wildfire response efforts. We speculate that there could be multiple reasons for not posting. For instance, the owners of these resources may not have felt skilled enough to use their CNR, or they may have been directly affected by the wildfire leaving no time to use their resource.

While the majority of the Fort McMurray CNRs were created during the wildfire, we did find two CNRs that were created long before the wildfire but were adapted for the event. The owners of these two CNRs never stated reasons for changing the names of their accounts/pages, but there are likely many possible reasons for this behavior. First, changing the name to something related to the Fort McMurray wildfire could be a way to show support to the wildfire-affected public. Researchers saw similar behavior during the Virginia Tech Shootings of 2007, when Facebook users changed their profile picture to an image that demonstrated their support for the Virginia Tech community (Hughes et al. 2008). Second, it could be a way to publicly let people know they are participating in the wildfire response efforts. Third, it could be a tactic to gather more attention for their account/page. Fourth, the CNR owner may want to build on their current network instead of starting a new CNR as a way to share their wildfire-response efforts with a broader, already-familiar audience. Lastly, it could be a way for a CNR owner to build trust by letting everyone see their past activity, especially if they have prior experience in crisis response. Findings also indicate that many of the CNRs became inactive after the wildfire. However, a few CNRs are still in use, some of which continue to report on the Fort McMurray wildfire, while the others have either broadened their goals or have moved on to a new cause. This implies that the owners of these CNRs have found the social media platforms to be useful in working toward their goals.

Many of the CNRs created during the event were later deleted. Deleting a resource after an event concludes might be understandable, but it does make one wonder whether these resources should be curated to preserve a history of how people have responded to past events. Such archives might be useful for future crisis events. Most puzzling was the large number of CNRs that were deleted during the event. Unfortunately, we were unable to discern why these resources were deleted with the data we collected. Investigation of upcoming crisis events could provide opportunities to explore this phenomenon, though researchers would have to act quickly to collect the information before it disappears.

CNRs are named after events and thus are easier to find on social media when someone searches for information about a particular crisis event. Because of their naming convention, they also have greater potential to be mistaken as official sources of information. Surprisingly, we were unable to identify most of the administrators of the CNRs in our dataset. We were also unable to identify the intentions of CNRs that had a generic name, no account description, or had very limited to no posts. This finding is consistent with the findings of our previous study, where we studied the CNRs created in response to the 2014 Carlton Complex wildfire (Chauhan and

Hughes 2017). A similar finding was also reported in a study conducted by Zhao and colleagues (2008). The researchers in this study examined the identity construction of 63 Facebook accounts and found that the majority of these users did not provide explicit self-descriptions, and rather chose to present themselves indirectly by sharing their pictures, posting wall posts, and/or stating their interests and hobbies. The unknown administrators of these CNRs and the unknown intentions behind creating these CNRs could make it difficult to judge the veracity of the information provided by them. Further, there is cause for concern, because these anonymous resources could potentially spread misinformation or false rumor with little accountability, especially if they later delete the social media page or account. This concern is at least partially validated by Oh and colleagues (2013) who report that information with no clear source is the most important rumor causing factor on Twitter in crisis situations. Because CNRs are highly visible sources of information with potential credibility issues, emergency responders will likely want to quickly identify and monitor CNRs during a crisis event for potential misuse.

Limitations & Future Work

The data in this study is limited to publicly available Facebook pages and Twitter accounts and does not include CNRs found on websites, blogs, or other social media. To continue investigating CNRs, we plan to compare the roles played by CNRs in crisis response across different events. We also plan to interview the owners of CNRs of future crisis events to determine 'who' creates CNRs and 'why.' These interviews will also determine 'what' approach (if any) the administrators of these CNRs take to ensure the veracity of information that they share. Additionally, we plan to interview and survey people about how they perceive CNRs. The aim of these activities will be to determine the factors that people consider when evaluating the trustworthiness and usefulness of these resources.

CONCLUSION

This paper offers empirical insight into the lifecycle of CNRs, the relevance of CNR content to the events they are named after, and the types of informational content CNRs can offer. While the study revealed much about CNRs and their activity, it also raised many new questions for future investigation, such as: Why do people delete accounts about a crisis event while the event is still occurring? Why do some accounts named after a crisis event never post any information? What are the intentions of CNR administrators? This study lays the foundation for this future investigation.

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Possibility of Using Tweets to Detect Crowd Congestion: A Case Study Using Tweets just before/after the Great East Japan Earthquake

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ABSTRACT

During large earthquakes, it is critical to safely guide evacuation efforts and to prevent accidents caused by congestion. In this paper, we focus on detecting the degree of crowd congestion following an earthquake based on information posted to Social Networking Services (SNSs). This research uses text data posted to Twitter just before/after the occurrence of the Great East Japan Earthquake (11 March 2011 at 02:46 PM JST). First, we extract co-occurring place names, proper nouns, and time-series information from tweets about congestion in the Tokyo metropolitan area (TMA). Next, using these extracted data, we analyze the frequency and spatiotemporal characteristics of these tweets. Finally, we identify expressions that describe the degree of crowd congestion and discuss methods to quantify these expressions based on a questionnaire survey and tweets that contain a photograph.

Keywords

Twitter, crowd congestion, time-series analysis, linguistic expression, disaster mitigation.

INTRODUCTION

If we can quickly and precisely grasp where and to what extent it is crowded with people, it will be useful for prevention of accidents caused by congestion, safe evacuation guidance at large earthquakes, and so on.

There are some data or services (such as "Mobile Spatial Statistics[1)]" by NTT DoCoMo, "Density Map[2)]" by ZENRIN DataCom, "Crowd Radar[3)]" by Yahoo! JAPAN), which enable us to grasp the degree of congestion. In these data or services, the crowd density is estimated based on the location information of users who use some kind of mobile terminal like a smartphone. However, it is difficult to estimate the degree of congestion in each facility or on each street and to grasp congestion in real time because the space-time unit of these data is coarse (250 m x 250 m grid for every hour).

It is also important to analyze the mechanism of congestion that occurs in emergencies and to consider measures to control congestion in preparation for future large earthquakes (such as Tokyo Metropolitan Earthquake or Nankai Trough Earthquake). However, at the time of the Great East Japan Earthquake (11 March 2011 at 02:46 PM JST), which is known for large congestion caused by people who tried to go home on foot or to wait for resuming the service of public transportation in the TMA, there are few previous studies and data quantitatively indicating when, where, and how much local and sudden congestion by the crowd was occurring.

Based on the above background, we focus on the possibility of quantifying the degree of crowd congestion based on information posted to SNSs, which are excellent in immediacy and openness. In this paper, as a first step to discuss the usefulness of posted information for grasping the degree of congestion, we attempt to examine Twitter data about congestion at the time of the Great East Japan Earthquake. More specifically, we extract co-occurring place names, proper nouns, and time-series information from tweets about congestion in the TMA. Using these extracted data, we analyze the frequency and spatiotemporal characteristics of these tweets. Furthermore, expressions describing the degree of congestion are listed from the same tweet data and discuss the method to quantify the expressions based on the questionnaire survey and tweets with a photograph.

RELATED WORK

There are many prior studies on detecting events, emergency situations, or hotspots of crowds by utilizing social media. For instance, Toepke (2017) developed a system to collect tweets using Twitter API under AWS environment automatically. Using the collected tweet data with geotag (information on the location where users posted tweets) in five cities in the United States, the author analyzed the influence of the length of data collection period on the spatial distribution (heat map) of the number of tweets. Likewise, Toepke and Starsman (2015) compared the heat maps of the number of posts to between Twitter and Instagram.

In some studies, not only text information included in posts but also images are used together for grasping situations. For instance, Panteras et al. (2015) extracted geotagged tweets including hashtags consisting of place names and word 'fire,' converted these data to point data on the GIS map, and estimated the angle of view (AOV) by using EXIF information in Flickr images by triangulation. As a result, the authors demonstrated that the estimation accuracy (reproducibility) of the range affected by wildfires could be improved by combining Twitter and Flickr, rather than using only Flickr.

Furthermore, other studies considered social media users as one of the sensors (what is called "social sensor") for real-time event detection. Gottumukkala et al. (2015) constructed a framework of the real-time evacuation decision-making support system. As information obtained in real time, they proposed to use not only traffic sensors and video images but also hashtags included in social media such as Twitter. More specifically, they suggested it effective to utilize the relationship between hashtags and evacuation behaviors before/during/after disaster for real-time decision-making. For another example, Sakaki et al. (2010) constructed a particle filter for extracting events from geotagged tweets and validated the model comparing the actual seismic centers (also the observed trajectories of typhoons) with the positions estimated by the filter for tweets related to earthquakes (and typhoons).

Most of these studies used geotag information included in posts to SNSs. However, it is difficult to collect enough number of tweets with geotag in real time (or in a brief time) because the percentage of geotagged posts is considerably small. More specifically, the situation of crowd congestion varies from moment to moment, and sometimes the congestion by the crowd occurs locally and suddenly. Given this background, this paper attempts to complement the location information by using proper nouns and place names included in text data posted to Twitter.

Besides, the number of tweets is not necessarily correlated with the number of people actually there because the percentage of Twitter users depends on the composition of the crowd and Twitter users do not always post a tweet in the crowded situation. Therefore, we consider the usefulness of linguistic expressions describing the degree of congestion extracted from tweets as well as the number of tweets.

EXTRACTION OF TWEETS ABOUT CONGESTION

First of all, we randomly extract 10% of all tweets written in Japanese posted for 24 hours after 11 March 2011 at 02:00 PM JST (just before the Great East Japan Earthquake occurred). To collect the past tweets for the analyses in this paper, we use the Twitter data providing service[4)] (named as "Nazuki no Oto") by NTT DATA Corporation. Although this is a charged service, it enables us to collect the past tweets (even those posted seven years ago) satisfied with extraction conditions (e.g., keywords, duration, and location). The service ensures sampling rate, and here it is set to 10% due to cost restriction. Additionally, the service supports real-time streaming of tweets. When we extract tweets about congestion and utilize them for emergency response in real time in the future, the Twitter Streaming API will be more suitable in terms of introduction cost for collecting the tweets as well as the related study (Gottumukkala et al., 2012).

From the 10% tweets, we focus on tweets containing the *kanji* '混[5)]', which is used in words meaning "to mix", "to blend", "to confuse", "to be crowded", and so on. In other words, it is expected that people often use the *kanji* '混' when they post a tweet about congestion (Figure 1). Next, using the function [Search Words] of KH Coder[6)], we examine the common use cases of the *kanji* '混'. As a result, the words that are highly likely to be related to congestion can be roughly limited to the following three words: '混む[7)]' (pronounced as '*komu*', which means "to be crowded"); '混乱' (pronounced as '*konran*', which means "confusion"); and '混雑' (pronounced as '*konzatsu*', which means "congestion"). The composition ratios of these three words in tweets containing the *kanji* '混' are 31.6%, 30.4%, and 20.3%, respectively. Therefore, hereafter, we aim at tweets including any of these three words in the text in the 10% tweets.

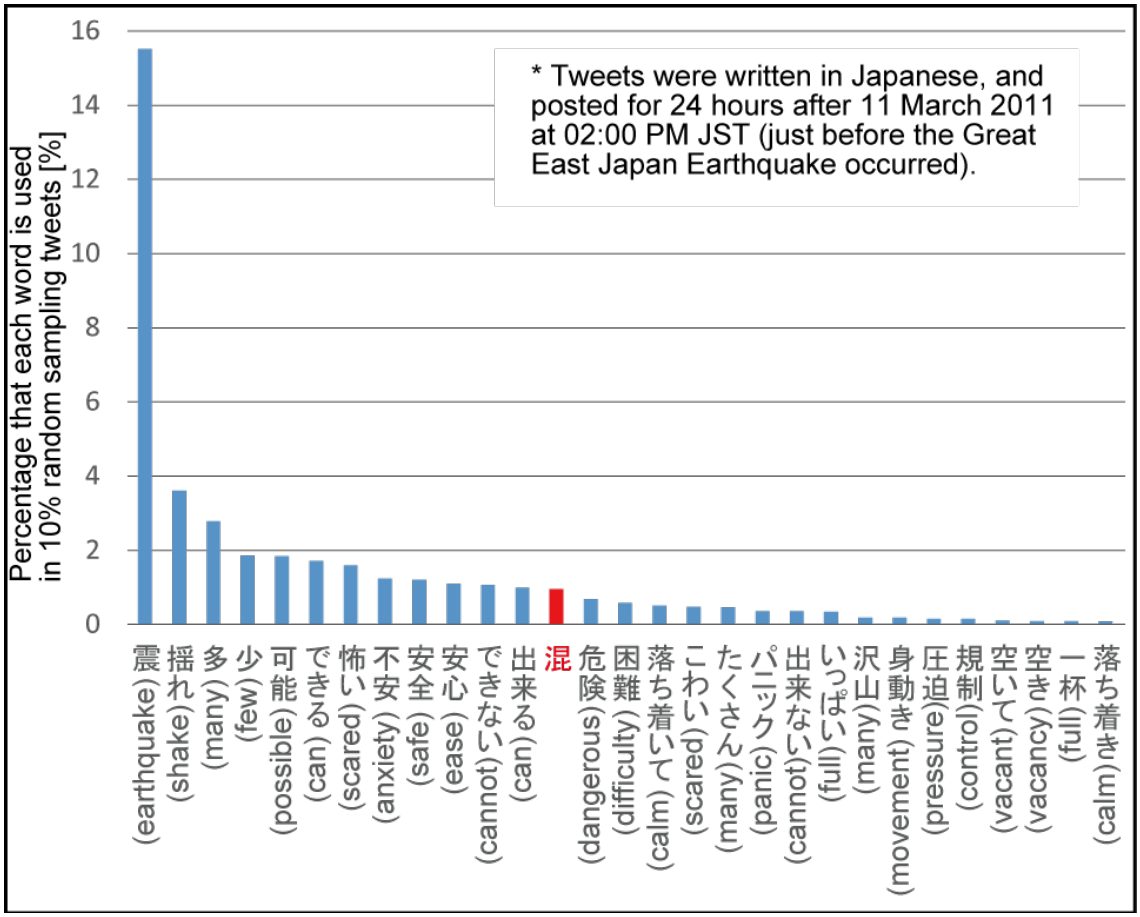

Figure 1. Frequency of Words Related to Crowd Congestion in 10% Tweets

CHARACTERISTICS OF TWEETS ABOUT CONGESTION

Time Transition of Tweets about Congestion

Looking at the time transition of the number of tweets about congestion (Figure 2), it is found that the total number of the 10% tweets rapidly increased more than five times immediately after the occurrence of the main shock (11 March 2011 at 02:46 PM JST), and then gradually decreased. On the other hand, we can see that the number of tweets about congestion was particularly large after 6:00 pm on 11th (Friday) and after 8:00 am on 12th (Saturday). These time periods corresponded to those when a large number of people tried to go home from places where they were going out. This result suggests that these tweets may well represent the time transition of the congestion.

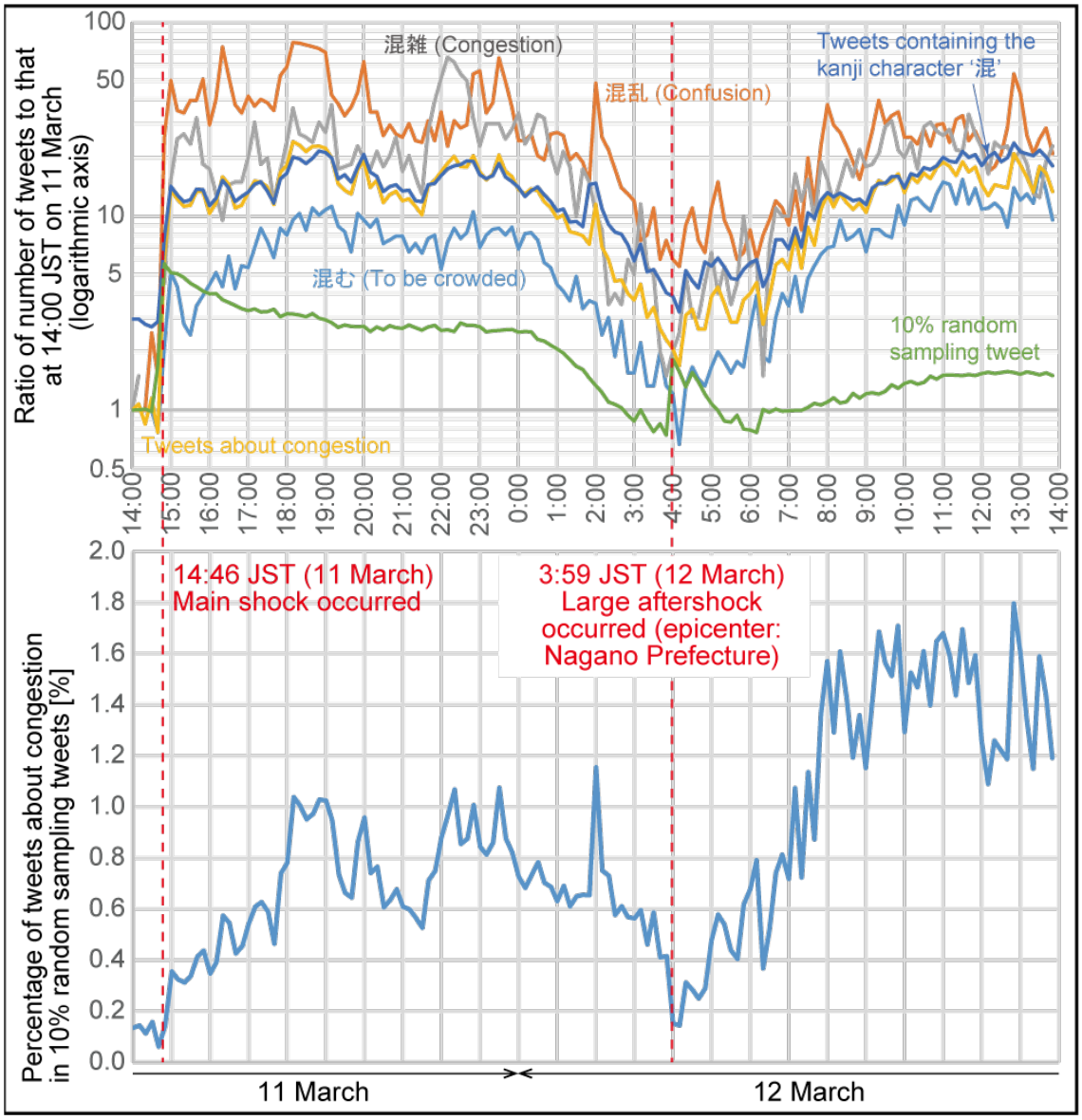

Figure 2. Time Transition of Number of Tweets (every 10 minutes)

Spatial Distribution of Tweets about Congestion

As the percentage of geotagged tweets (with information on the location where users posted tweets) is only about 0.2% of the whole tweets, it is not suitable to use only geotagged tweets for grasping the spatial characteristics of tweets about congestion. Therefore, we extract proper nouns and place names in tweets about congestion by using KH Coder[6], and attempt to complement location information based on the extracted words (totally 929 words) (Table 1). The word '混雑' tends to co-occur with words related to railway stations and railway lines in the TMA, whereas the word '混乱' tends to co-occur with names of a wide range of area.

These results suggest that: (1) the method to complement location information by proper nouns and place names in the 10% tweets is mainly useful for congestion on public transportation in the TMA; (2) the word '混乱' is not useful for complementing location information.

Table 1. List of Proper Nouns and Place Names in Tweets about Congestion

	‘混む (*Komu*)’		‘混乱 (*Konran*)’		‘混雑 (*Konzatsu*)’	
	Number of unique extracted words = 615		Number of unique extracted words = 353		Number of unique extracted words = 595	
	Extracted Word	Ratio[%]	Extracted Word	Ratio[%]	Extracted Word	Ratio[%]
1	日本 (Japan)	2.6 (3.1)	淡路 (Awaji)	2.7 (6.5)	銀座線 (Ginza line)	3.2 (11.3)
2	東北 (Tohoku)	1.8 (2.4)	東京 (Tokyo)	5.7 (6.1)	東京 (Tokyo)	5.7 (10.4)
3	愛知 (Aichi)	0.9 (2.2)	日本 (Japan)	2.6 (3.5)	渋谷 (Shibuya)	3.0 (6.9)
4	横浜 (Yokohama)	0.9 (1.1)	東北 (Tohoku)	1.8 (1.8)	新宿 (Shinjuku)	2.5 (4.6)
5	京王線 (Keio line)	0.6 (0.8)	千葉 (Chiba)	1.1 (1.7)	半蔵門線 (Hanzomon line)	0.7 (2.2)
6	東西線 (Tozai line)	0.7 (0.7)	関東 (Kanto)	0.8 (1.6)	池袋 (Ikebukuro)	0.8 (2.1)
7	山手線 (Yamanote line)	0.6 (0.7)	宮城 (Miyagi)	0.6 (1.2)	東西線 (Tozai line)	0.7 (1.8)
8	東横線 (Toyoko line)	0.5 (0.7)	仙台 (Sendai)	0.5 (0.8)	南北線 (Namboku line)	0.6 (1.6)
9	バレ (?)	0.3 (0.7)	茨城 (Ibaraki)	0.4 (0.8)	品川 (Shinagawa)	0.8 (1.6)
10	京浜東北線 (Keihin-tohoku line)	0.4 (0.5)	福島 (Fukushima)	0.4 (0.7)	東海道線 (Tokaido line)	0.5 (1.4)
11	総武線 (Sobu line)	0.5 (0.5)	太平洋 (Pacific ocean)	0.3 (0.7)	横浜 (Yokohama)	0.9 (1.4)
12	新宿線 (Shinjuku line)	0.3 (0.4)	田端 (Tabata)	0.2 (0.6)	千代田線 (Chiyoda line)	0.4 (1.3)
13	マック (McDonald’s)	0.3 (0.4)	田端新 (?)	0.2 (0.6)	北千住 (Kita-senju)	0.4 (1.3)
14	田園都市線 (Den’en-toshi line)	0.3 (0.4)	北 (North)	0.2 (0.6)	山手線 (Yamanote line)	0.6 (1.2)
15	寄 (?)	0.2 (0.4)	気仙沼 (Kesen’numa)	0.3 (0.4)	上野 (Ueno)	0.5 (1.2)
16	甲州 (Koshu)	0.3 (0.4)	大阪 (Osaka)	0.2 (0.4)	銀座 (Ginza)	0.4 (1.1)
17	埼京線 (Saikyo line)	0.2 (0.4)	東日本 (East Japan)	0.3 (0.4)	有楽町線 (Yurakucho line)	0.3 (1.1)
18	井の頭線 (Inogashira line)	0.3 (0.3)	新潟 (Niigata)	0.3 (0.4)	荒川線 (Arakawa line)	0.3 (1.0)
19	六本木 (Roppongi)	0.2 (0.3)	枝野 (Edano)	0.2 (0.3)	京王線 (Keio line)	0.6 (1.0)
20	中央線 (Chuo Line)	0.2 (0.3)	日 (?)	0.2 (0.3)	吉祥寺 (Kichijoji)	0.3 (0.9)
21	秋葉原 (Akihabara)	0.2 (0.3)	中 (?)	0.2 (0.3)	三鷹 (Mitaka)	0.3 (0.9)
22	新潟 (Niigata)	0.3 (0.3)	名古屋 (Nagoya)	0.2 (0.3)	日比谷線 (Hibiya line)	0.3 (0.9)
23	目黒 (Meguro)	0.2 (0.2)	近畿 (Kinki)	0.1 (0.2)	東横線 (Toyoko line)	0.5 (0.9)
24	朝 (morning)	0.2 (0.2)	台東 (Taito)	0.1 (0.2)	築地 (Tsukiji)	0.2 (0.9)
25	山手 (Yamanote)	0.1 (0.2)	関西 (Kansai)	0.1 (0.2)	浅草線 (Asakusa line)	0.3 (0.8)

Notes for Table 1

* Extracted words are arranged in the decreasing order of proportion that each word is co-occurring with '混む', '混乱' or '混雑'.

* Left-side value in each column "Ratio" is the composition ratio (%) of each extracted word in the whole tweets about congestion. Right-side value (in parentheses) in each column "Ratio" is the proportion (%) that each extracted word is used in tweets including the words '混む', '混乱' or '混雑'.

* The extracted words which can be considered as the name of railway stations [lines] existing in the TMA are indicated in red [blue] color.

Figure 3 shows the spatial distribution of 588 words existing in the database of names of railway stations/lines[8] out of 929 words extracted above. Among railway lines, there are overwhelmingly many tweets about congestion related to the subway lines (such as the Ginza line, the Tozai line, and the Hanzomon line of Tokyo Metro) and the Yamanote line. Among railway stations, the number of tweets about congestion is large at the major railway terminal stations like Shibuya station, Shinjuku station, and so on.

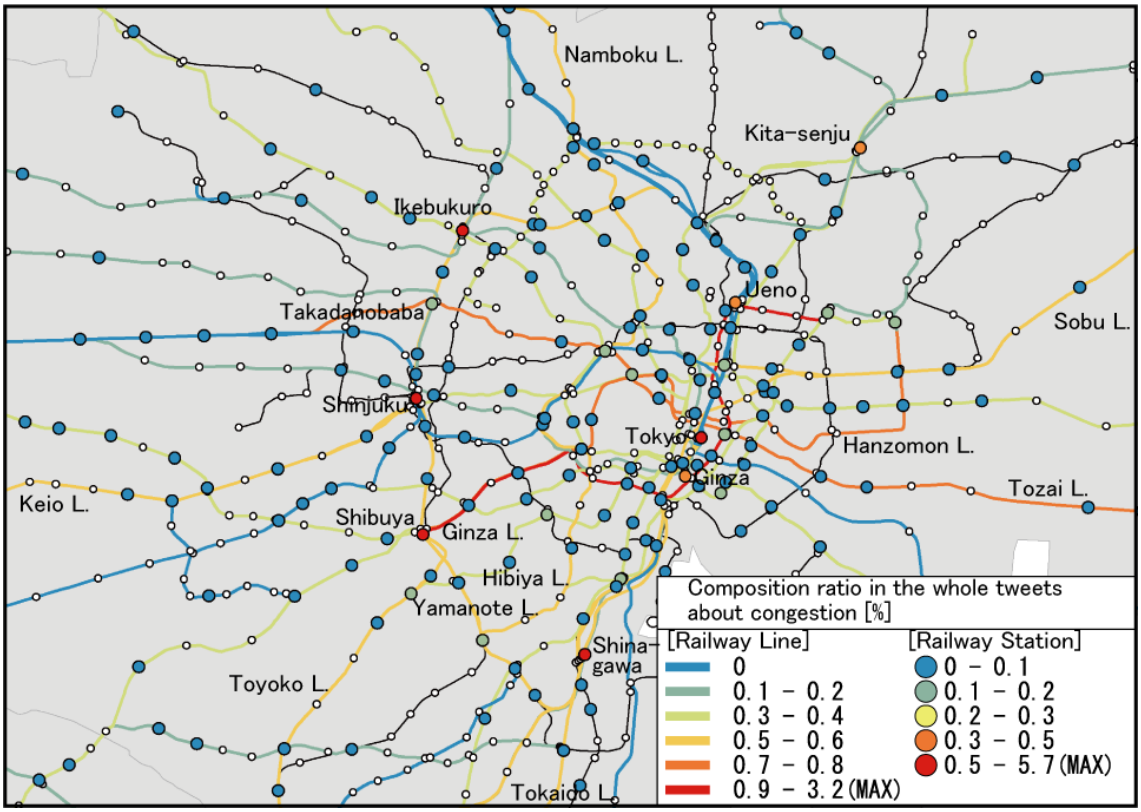

Figure 3. Spatial Distribution of Number of Tweets about Congestion (around the Main Part of Tokyo)

The timing when the number of tweets about congestion increases corresponds well with the operation resumption time of railway lines, which suggests the usefulness of such tweets for quick grasp of congestion (Figure 4(a)). Furthermore, paying attention to the trend of increase in the number of these tweets, the number of tweets about the Ginza line drastically increases after 8:00 pm on the 11th, but since then it gradually decreases. It suggests that the congestion on the Ginza line was temporary. By contrast, in Shinjuku, Shibuya, and Yokohama, where the number of tweets about congestion gradually increases from the aftermath of the earthquake occurrence to the next day, there is a possibility that the congestion state lasted for a long time (Figure 4(b)).

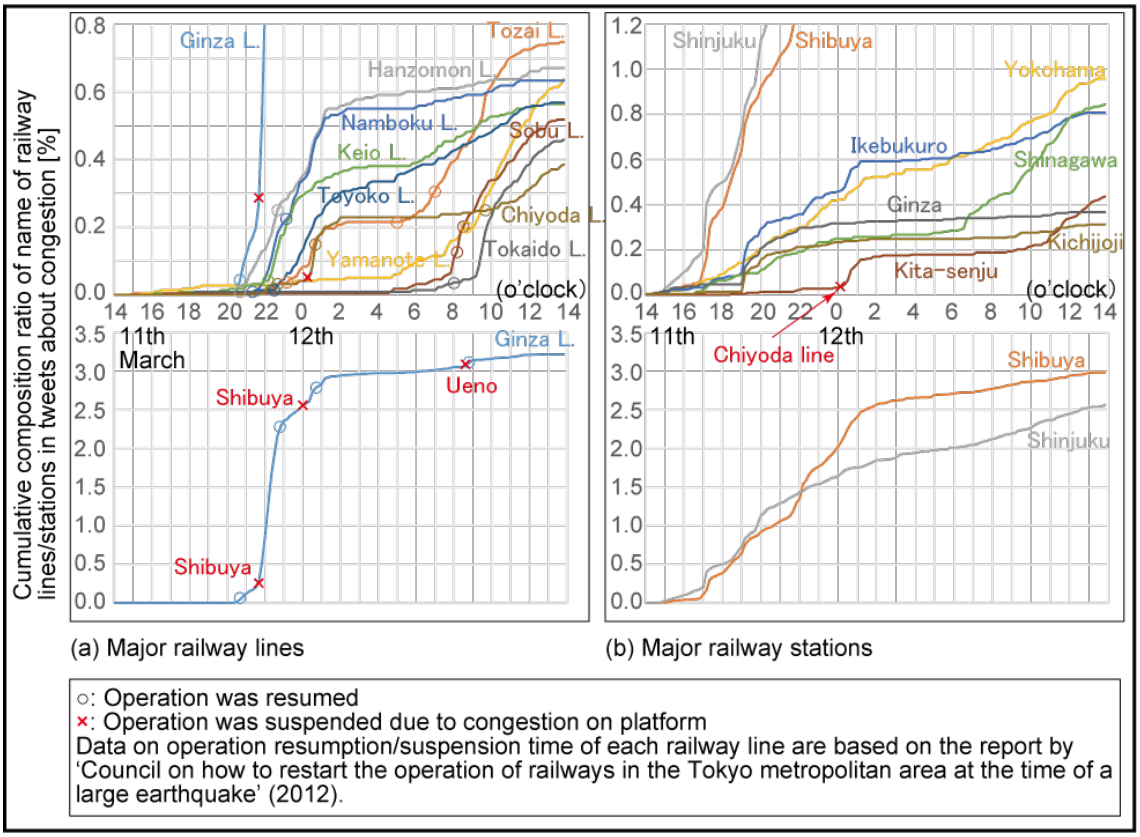

Figure 4. Time Transition of Number of Name of Main Railway Lines/Stations in Tweets about Congestion

Problems in Complementing Location Information with Proper Nouns and Place Names

The number of tweets about congestion seems to correspond to the amount of concern in congestion at a certain time/spot. However, to grasp the degree of congestion, it is necessary to analyze the whole text of tweets in more detail. Moreover, in order to grasp the congestion more densely, it is necessary to: (1) increase the sampling rate of tweets about congestion; (2) utilize useful information such as the name of main roads and landmarks (McDonald's, Disneyland, etc.) out of 341 words (36.7% of all 929 words) other than the names of railway stations/lines extracted by KH Coder[6]. In addition, we will take into account how to deal with the name of places used for various purposes (such as '東京 (Tokyo)') and the name of multiple candidates existing all over Japan (such as '東西線 (Tozai line)').

EXTRACTION OF CONGESTION LEVEL EXPRESSION

Problems in Extraction of Congestion Level Expression

To extract linguistic expressions related to congestion, we focus on words co-occurring with the words '混む [7)]', '混乱', or '混雑' same as the 'Extraction of Tweets about Congestion' section. We use KH Coder[6)] to extract co-occurrence words. In using the extracted co-occurrence words, it is necessary to solve the following problems:

(1) Discrimination of positive/negative and congestion level

It is an important issue directly related to estimation accuracy of congestion.

(2) Confirmation of dependency relations

An extracted co-occurrence word is not necessarily directly related to one of three words '混む', '混乱', and '混雑'. Therefore, dependency analysis (syntax analysis) is required. In general, it is considered that the verb '混む' is modified by adverbs and the nouns '混乱' and '混雑' are modified by adjectives. However, as a result of trying dependency analysis using CaboCha[9)], many modification examples other than mentioned above were seen. This is a problem specific to using tweets in Japanese, where the flexible usage of dependency relations is often seen.

Training Data on Congestion Level Expression

It is difficult to solve the aforementioned problems by only performing dependency analysis. Therefore, in this paper, we randomly extract 1000 tweets from the tweets about congestion defined in the previous section and attempt to analyze the characteristics of congestion level expressions visually detected from these 1000 tweets. The number of tweets judged as without congestion level expressions is 625 in 1000 tweets, and it is found that a majority of tweets about congestion is not co-occurring with congestion level expression. We will verify whether the number of samples of congestion level expressions is sufficient or not in the future.

Next, we classify the extracted congestion level expressions into two groups: (i) expressions in which he/she wanted to tweet that he/she was facing the congestion (Table 2); and conversely (ii) expressions in which he/she wanted to tweet that it was NOT crowded there (Table 3). Based on the classification result, expressions in Group (i) are more frequently used both in terms of variety and number than expressions in Group (ii). It suggests that crowd congestion can easily urge Twitter users to post the situation of congestion in front of them to Twitter.

In addition to the words that directly modify '混む', '混乱', and '混雑' as mentioned above, there are some expressions by which the degree of congestion is expressed using metaphor or comparison. For instance, expressions related to traffic (such as "difficult to take on/off", "a last train", "rush hour", "crowded train", "commuter hours", etc.), expressions likened to a specific date and time (such as "past 11:00 PM on Friday", "not look like Saturday morning", etc.), expressions compared with the situations in normal times (e.g., "as usual", "not ever", "a usual evening", etc.), expressions related to action/behavior (e.g., "hard to move", "entry restriction", "go down like ninepins", "a long line", etc.). Besides, there are unique expressions such as "there is almost no shopping cart", "like a movie", "over 200 m", and so on.

If we use the knowledge obtained in this section as training data, there is a possibility that congestion level expressions can be automatically and accurately extracted. In future, we are planning to verify the accuracy in extracting congestion level expressions by applying to other tweet data.

Table 2. Expressions in Which He/She Wanted to Tweet That He/She Was Facing Congestion

Expression in Japanese	Meaning	Frequency (Composition ratio)	Expression in Japanese	Meaning	Frequency (Composition ratio)
大 (*Dai*)	Heavy	68 (22.6%)	ごった返す (*Gottagaesu*)	Crowded	2 (0.7%)
大変 (*Taihen*)	Heavy/Very	33 (22.0%)	少し (*Sukoshi*)	A bit	2 (0.7%)
かなり (*Kanari*)	Rather/ Considerably/ Comparatively	31 (10.3%)	あふれる (*Afureru*)	Full	2 (0.7%)
すごい (*Sugoi*)	Awesome	29 (9.6%)	結構 (*Kekkō*)	Pretty/ Quite	2 (0.7%)
激 (*Geki*)	Extremely/ Terrifically	21 (7.0%)	尋常ではない (*Jinjōde wanai*)	Extraordinary	2 (0.7%)
めちゃ (*Mecha*)	Very/Extremely /Excessively	20 (6.6%)	こんな (*Kon'na*)	Such	1 (0.3%)
すぎる (*Sugiru*)	Too	14 (4.7%)	とんでもない (*Tondemonai*)	Tremendous	1 (0.3%)
半端ない (*Hanpa nai*)	Immense/ Enormous/ Tremendous/ Awful/Terrible	10 (3.3%)	ハイパー (*Haipā*)	Hyper-	1 (0.3%)
ひどい (*Hidoi*)	Heavy/Awful	10 (3.3%)	恐ろしく (*Osoroshiku*)	Terribly	1 (0.3%)
ものすごい (*Monosugoi*)	Tremendous	6 (2.0%)	あんなに (*An'nani*)	So	1 (0.3%)
超 (*Chō*)	Super	6 (2.0%)	ビッシリ (*Bisshiri*)	Tightly	1 (0.3%)
やばい (*Yabai*)	Dangerous	5 (1.7%)	非常に (*Hijōni*)	Extremely	1 (0.3%)
激しい (*Hageshī*)	Heavy	4 (1.3%)	さらに (*Sarani*)	Further	1 (0.3%)
相当 (*Sōtō*)	Considerable	4 (1.3%)	何気に (*Nanigeni*)	Surprisingly	1 (0.3%)
劇 (*Geki*)	Extremely	3 (1.0%)	まくる (*Makuru*)	Too much	1 (0.3%)
ちょっと (*Chotto*)	A bit	3 (1.0%)	ほどほどの (*Hodohodono*)	Moderate	1 (0.3%)
マジ (*Maji*)	Seriously	3 (1.0%)	やや (*Yaya*)	A little/Slight/ Rather	1 (0.3%)
あまりの (*Amari no*)	Too much	2 (0.7%)	ありえない (*Arienai*)	Unbelievable	1 (0.3%)
鬼 (*Oni*)	Very/Extremely /Super	2 (0.7%)	若干 (*Jakkan*)	A bit/ A little	1 (0.3%)
異常 (*Ijō*)	Unusual/ Abnormal	2 (0.7%)	えらい (*Erai*)	Serious/Awful / Terrible	1 (0.3%)

* Total: 301 (100.0%)

Notes for Table 2

* In summarizing Table 2, we visually and manually unified the words with notation fluctuation. Some examples are shown below:

(1) Fluctuation of *kanji* notation

(2) Fluctuation of *hiragana* / *katakana* notation

(3) Fluctuation in colloquialism

Table 3. Expressions in Which He/She Wanted to Tweet That It Was NOT Crowded There

Expression in Japanese	Meaning	Frequency (Composition ratio)	Expression in Japanese	Meaning	Frequency (Composition ratio)
そんなに...ない (*Son'nani … nai*)	Not so …	4 (13.8%)	全然...ない (*Zenzen … nai*)	Not … at all	2 (6.9%)
それほど...ない (*Sorehodo … nai*)	Not too …	4 (13.8%)	そこまで...ない (*Sokomade … nai*)	Not … so far	1 (3.4%)
大きな...ない (*Ōkina … nai*)	Without any …	4 (13.8%)	大して...ない (*Taishite … nai*)	Not too …	1 (3.4%)
あまり...ない (*Amari … nai*)	Not too …	4 (13.8%)	さほど...ない (*Sahodo … nai*)	Not too …	1 (3.4%)
特に...ない (*Tokuni … nai*)	Not particularly …	3 (10.3%)	驚くほどではない (*Odorokuhododewanai*)	Not surprising	1 (3.4%)
...ない (*… Nai*)	Not …	3 (10.3%)	ゼロ (*Zero*)	Zero	1 (0.3%)

* Total: 29 (100.0%)

DISCUSSION ON QUANTIFICATION METHOD OF CONGESTION LEVEL EXPRESSION

It is an important subject in various research fields how to quantify linguistic expressions about the degree, and there are many previous studies on quantifying level expression. For instance, Shibata et al. (2011) analyzed how much the test subjects adjust the speed of the machine in response to speed adjustment instructions using degree adverbs (such as "just a little", "a little", "quite", and "very"). Based on the experiment results, the authors constructed a model which determines the amount of adjusting speed corresponding to degree adverbs for intelligent machines. Kumamoto (2004) conducted a subject experiment to determine the relation of strength and weakness of 119 words used for strengthening/weakening the impression expressions of music. Furthermore, the author scored each degree word based on the experiment results and evaluated the influence on impression words by using the impression scale. Besides, there are some studies focused on the relationship between words expressing the degree of noise and the actual types of noise (e.g., Yano et al., 2002; Miyagawa and Aono, 2002).

As a method of associating the actual degree of congestion with linguistic expressions, it also can be considered to use the image information posted together with the text to Twitter. It is highly likely that images posted with tweets related to congestion were taken of crowded situations. However, it is found that the percentage of tweets including the URL[10)] of the image posted to "TwitPic", which was one of the main external image posting services as of March 2011[11)], was only about 0.5% of the whole tweets. If it is limited to tweets including any congestion level expression, the percentage will further decrease.

Considering the above background, we are planning to conduct a Web questionnaire survey aiming at ranking congestion level expressions and grasping the expressions selected under crowd congestion. The congestion will be virtually set by showing the test subjects photographs of crowded situations collected in advance. Here, it can be expected to quantify the selection tendency of congestion level expressions according to crowded situation, personal attribute, and individual by requesting the cooperation of test subjects with various personal attributes (such as gender and age) as much as possible (Table 4).

Table 4. Image of Correspondence Table between Congestion Level Expressions and Actual Degree of Congestion

Congestion Level Expression in Japanese	Meaning	Actual Degree of Congestion [person/m^2]
非常に (*Hijō'ni*)	Very / Extremely / Exceedingly	2.0 –
すごく (*Sugoku*)	Very / Mighty	1.5 – 2.0
とても (*Totemo*)	Very / Extremely / Exceedingly	1.3 – 2.5
だいぶ (*Daibu*)	Rather	1.0 – 1.2
多少 (*Tashō*)	More or less / Somewhat / A little / A bit / Slightly	0.5 – 1.0
…	…	…

SUMMARY AND CONCLUSIONS

Focusing on the tweets about congestion just before and after the occurrence of the Great East Japan Earthquake, we demonstrated the effectiveness for grasping the time transition of congestion. During the time periods when a large number of people tried to go home, the number of tweets about congestion was also significantly large. This result suggests that Twitter users can play an important role as the social sensors to detect local/sudden congestion by crowds in real time.

Although most of the related studies in the past used the geotag information to identify the location of user's post, the percentage of posts with geotag is considerably small. To overcome this problem, we tried to complement the location information by using proper nouns and place names co-occurring with the tweets. As a result, we showed the possibilities of grasping the spatiotemporal distribution of tweets about congestion by incorporating the proposed method without geotag information into methods in prior work. In the example of the aftermath of the Great East Japan Earthquake, the proper nouns and place names co-occurring with the tweets were mostly related to railway stations/lines in the TMA because many people rushed there after the operation of trains was resumed. Our future work will need to evaluate the applicability of the proposed method to other situations and countries.

Furthermore, we focused on linguistic expressions describing the degree of congestion extracted from tweets because the number of tweets is not necessarily correlated with the actual number of people there. Based on the analysis results of the 'Extraction of Congestion Level Expression' section, there are a certain number of tweets that contain congestion level expressions in the tweets about congestion, and it can be said that the ways of expressing congestion level are diverse. In this paper, the linguistic expressions in the actual tweets written in Japanese were used for analyses, and there were some difficulties specific to Japanese. Although the procedure of analyses in this paper can be easily generalized to tweets written in English or other languages than Japanese, it is necessary to investigate the frequency distribution of expressions similar to Table 2 and Table 3.

If it is possible to quantify congestion level expressions included in tweets, it is expected that it will be possible to estimate the degree of congestion in situations: (i) where/when it is difficult to secure a certain number of mobile terminal users for estimating the degree of congestion at each point; or (ii) where the radio waves are unstable such as in buildings or underground spaces. For that purpose, it is necessary to grasp beforehand to what extent congestion is expressed by each congestion level expression. Therefore, in the 'Discussion on Quantification Method of Congestion Level Expression' section, we discussed various methods for quantifying the extracted congestion level expressions. Of course, it is also important to examine the credibility of information in posted tweets separately. In the future, we will conduct a Web questionnaire survey on the relationship between the actual congestion levels and linguistic expressions, and report the survey results.

ACKNOWLEDGMENTS

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NOTES

1) https://www.nttdocomo.co.jp/corporate/disclosure/mobile_spatial_statistics/ [accessed Mar. 28, 2016]

2) http://lab.its-mo.com/densitymap/ [accessed Mar. 28, 2016]

3) http://map.yahoo.co.jp/maps?layer=crowd&v=3&lat=35.681277 & lon = 139.766266 & z = 15 [accessed Mar. 28, 2016]

4) https://nazuki-oto.com/twitter/ [accessed Mar. 24, 2018]

5) http://tangorin.com/kanji/%E6%B7%B7 [accessed Dec. 10, 2017]

6) http://khc.sourceforge.net/en/ [accessed Dec. 10, 2017]

7) Include conjugations.

8) The database of names of railway stations/lines and Figure 3 were processed by the author based on the National Land Numerical Information (Railways data) as of 2011, which were provided by Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

http://nlftp.mlit.go.jp/ksj-e/gml/datalist/KsjTmplt-N02.html [accessed Dec. 10, 2017]

9) CaboCha: https://taku910.github.io/cabocha/ [accessed Dec. 10, 2017]

10) The URL which starts with “http://twitpic.com/”.

11) Before August 2011, the official image posting service was not supported by Twitter, Inc.

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Crisis Event Extraction Service (CREES) – Automatic Detection and Classification of Crisis-related Content on Social Media

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ABSTRACT

Social media posts tend to provide valuable reports during crises. However, this information can be hidden in large amounts of unrelated documents. Providing tools that automatically identify relevant posts, event types (e.g., *hurricane*, *floods*, etc.) and information categories (e.g., *reports on affected individuals*, *donations and volunteering*, etc.) in social media posts is vital for their efficient handling and consumption. We introduce the Crisis Event Extraction Service (CREES), an open-source web API that automatically classifies posts during crisis situations. The API provides annotations for crisis-related documents, event types and information categories through an easily deployable and accessible web API that can be integrated into multiple platform and tools. The annotation service is backed by Convolutional Neural Networks (CNNs) and validated against traditional machine learning models. Results show that the CNN-based API results can be relied upon when dealing with specific crises with the benefits associated with the usage word embeddings.

Keywords

Event Detection, Word Embeddings, Deep Learning, Convolutional Neural Networks, API.

INTRODUCTION

Social media has emerged as a dominant channel for communities to gather and spread information during crises. Such media has proven itself as an invaluable information source in several recent natural and social crisis situations, such as floods (Starbird et al. 2010), earthquakes (Qu et al. 2011), wildfires (Vieweg et al. 2010), nuclear disasters (Thomson et al. 2012), and civil wars (Bercovici 2012).

A survey by the American Red Cross showed that 40% of the population would use social media during a crisis, and 76% of them expect their help requests to be answered within three hours. Doing this through manual analysis, however, is far from trivial, due to the sheer data volume generated during crisis events. For example, in a single day during the 2011 Japan earthquake, 177 million tweets related to the crisis were sent (Campanella 2006).

Although information is paramount during major crises, it is almost impossible for organisations and communities to manually absorb, process, and turn the volume of social media data during crisis into sensible, actionable information (Gao et al. 2011). Tools to automatically identify the type of emergency events reported by citizens (e.g., need shelter, trapped in building) are largely unavailable. Genuine help requests are often difficult to spot, group and validate and many urgent aid requests by individual citizens can go unnoticed.

Current works for event identification from social media data make use of supervised and unsupervised Machine Learning (ML) methods, such as classifiers, clustering and language models (Atefeh and Khreich 2015). Lately, deep learning has emerged as a promising ML technique able to capture high level abstractions in the data, providing significant improvement for various tasks over more traditional ML methods, such as text classification (Kim 2014),

machine translation (Bahdanau et al. 2014; Cho et al. 2014) or sentiment analysis (Tang et al. 2015; Dos Santos and Gatti 2014). Deep learning, in particular, Convolutional Neural Networks (CNNs) have been recently applied with success to social media during crises situations (Caragea et al. 2016; D. T. Nguyen et al. 2017; Burel, Saif, Fernandez, et al. 2017; Burel, Saif, and Alani 2017). However, these approaches have been mostly pursued in academic contexts and have not been made available to the public and social organisations through easily accessible and integrable tools.

Even though creating models for identifying relevant documents, event types and information categories is a major step in the right direction and show the potential of automatic approaches for dealing with a large amount of social media posts during crisis events, its adoption by practitioners is conditioned on their availability and accessibility to the general public.

In this paper, we create three different CNN-based classifiers that allow the identification of crisis-related documents (i.e., *related* vs *unrelated*), event types (e.g., *hurricane*, *floods*, etc.) and information categories (e.g., *reports on affected individuals*, *donations and volunteers*, etc.) using data from the CrisisLexT26 dataset (Olteanu, Castillo, et al. 2014) and make those models available through an easily accessible web service called CREES (Crisis Event Extraction Service).[1] The API and codebase is designed to be easily deployed and integrated into existing tools and has been already integrated into the Ushahidi platform[2] and Google Sheets.[3]

The contribution of this paper can be summarised as follows: 1) The generation of three CNN models that target the problem of event identification in crisis situations (event relatedness, event types and information categories), and; 2) The creation of an easily deployable web API that exposes the previously trained CNN classifiers and its integration into the Ushahidi platform and Google Sheets.

RELATED WORK

Recently, several works have introduced the use of deep learning for event detection (Chen et al. 2015; Feng et al. 2016; T. H. Nguyen and Grishman 2015; Ghaeini et al. 2016; Zeng et al. 2016). Unlike traditional ML feature-based methods, deep learning models do not generally require heavy feature engineering and are therefore less prone to error propagation, caused by using external NLP and text processing tools. Also, deep learning models are more generic and tolerant to domain and context variations than feature-based models, as the former use word embeddings as a more general and richer representation of words (T. H. Nguyen and Grishman 2015).

Pioneer works in this vein include (Chen et al. 2015; Feng et al. 2016; T. H. Nguyen and Grishman 2015). These works address the problem of event detection at the sentence and/or phrase level by first identifying the event triggers in a given sentence (which could be a verb or nominalisation) and classifying them into specific types. For example, the word *"release"* in *"The European Unit will release 20 million euros to Iraq"* is a trigger for the event *"Transfer-Money"*.

Multiple deep learning models have been proposed. For example, Nguyen and Grishman (T. H. Nguyen and Grishman 2015) use a Convolutional Neural Network (CNN) (LeCun et al. 1998) with three input channels, corresponding to word embeddings, word position embeddings and entity type embeddings, to learn a word representation and use it to infer whether a word is an event trigger or not. Chen et al. (Chen et al. 2015) argue that a sentence may contain two or more events and that using a traditional CNN model with a max-pooling layer[4] often leads to the capture of clues of one event in a sentence but to miss the rest. To address this issue, the authors propose using a CNN with a dynamic multi-pooling layer to obtain a maximum value for each part of a sentence and therefore cover more valuable clues of the events within it.

Feng et al. (Feng et al. 2016) use a hybrid neural network model for cross-language event detection. The proposed model incorporates both, a bidirectional LSTM (Bi-LSTM) (Schuster and Paliwal 1997) and CNN component. Bi-LSTM captures the contextual semantics of a given word by means of the preceding and the following information in the text, while CNN is used to capture structure information from the local contexts (e.g., sentence chunks). Results show that the proposed model achieves relatively high and robust performance when applied to data of multiple languages including English, Chinese and Spanish, in comparison with traditional feature-based approaches.

Other works (Caragea et al. 2016; D. T. Nguyen et al. 2017; Burel, Saif, Fernandez, et al. 2017; Burel, Saif, and Alani 2017) have explored directly the application of CNN models to the identification of crisis-related content. Although Caragea et al. (Caragea et al. 2016) explored the dataset used in this paper, they focused on floods event

[1]CREES, http://evhart.github.io/crees.
[2]Ushahidi, http://www.ushahidi.com.
[3]CREES Add-on, https://goo.gl/t73SNY.
[4]In a CNN, a max-pooling layer applies a max operation over the representation of an entire sentence to capture the most useful information.

types and on the informativeness classification rather than event relatedness, event types and information categories. D. T. Nguyen et al.'s work (D. T. Nguyen et al. 2017) investigated information types, they focused only on one of the three tasks investigated in this paper. Nevertheless, their results showed that CNN models can be used successfully for social media classification in crisis situations. Burel, Saif, Fernandez, et al. (Burel, Saif, Fernandez, et al. 2017; Burel, Saif, and Alani 2017) investigated the same dataset as the one investigated in this paper and proposed multiple extension to CNN using semantics. Their results showed some small improvement over conventional CNN. Unfortunately, the proposed approach requires concept extraction tools which tend to not scale well making this approach unsuitable for the development of a web API.

Few works have explicitly targeted the development of automatic machine learning tools and APIs that can be used for automatically labelling social media documents during crises. In general, most tools do not have any automatic classification abilities and rely on simple algorithms or manual work. AIDR (Imran, Castillo, et al. 2014), is one of the very few tools that is explicitly designed for automatically classifying social media documents by providing a platform for training and serving annotation models during crisis situations. Although AIDR shares many similarities to the CREES API presented in this paper and even provide advanced features for retraining machine learning models, contrary to CREES, AIDR relies on traditional machine learning models and requires more effort to be integrated into existing tools and workflows. Finally. it appears that AIDR does not provide any default models whereas CREES is designed to be deployed without any re-training requirements. CrisisNET[5] is another tool and API designed for extracting information in social media document. However, the project has not been updated since 2014 and does not give much information concerning its set of features and the models used.

APPLICATION SCENARIO

During crises, a very large number, sometimes in the millions, of messages are often posted on various social media platforms by using the hashtags dedicated to the crises at hand. However, a good percentage of those messages are irrelevant or uninformative.

Olteanu, Vieweg, et al. observed that crises reports could be classified into three main categories of informativeness; related and informative, related but not informative, and not related (Olteanu, Vieweg, et al. 2015). The percentage of relevant and informative social reports during crises varies a great deal, ranging from 10% in some cases[6] to 65% in others (Sinnappan et al. 2010). However, buried under very many mundane and irrelevant tweets, sometimes one post emerges that needs an urgent response.

In this paper, our goal is to create an automatic tool and the corresponding API that efficiently identifies crisis-related social media messages of sufficient relevance and value. For this purpose, and based on the event types identified by Olteanu, Vieweg, et al. (Olteanu, Vieweg, et al. 2015) and later on investigated by Burel, Saif, Fernandez, et al. (Burel, Saif, Fernandez, et al. 2017), we consider the following three tasks when developing our API:

- *Task1 - Crisis vs. non-crisis related messages*: The goal of this task is to differentiate those posts that are *related to a crisis situation vs. those posts that are not*.
- *Task2 - Type of crisis*: The goal of this task is to identify the different types of crises the message is related to and the potential sub-event linked to a particular crisis. Following the work of (Olteanu, Vieweg, et al. 2015) we consider the following types of natural and human-induced types of crises: *shooting, explosion, building collapse, fires, floods, meteorite fall, haze, bombing, typhoon, crash, earthquake and derailment*.
- *Task3 - Type of information*: the goal of this task is to provide a fine-grained information detection in crises situations. Following the work of (Olteanu, Vieweg, et al. 2015) we consider the following categories of crisis-related information: *affected individuals, infrastructures and utilities, donations and volunteer, caution and advice, sympathy and emotional support, useful information, other*.

The API resulting from training the models on the three previous tasks provides means for: 1) filtering crisis-related content on social media; 2) the identification of event types, and; 3) the identification of information categories. In a real-world use case, such services can be used sequentially in order to gain deep insights concerning a crisis situation.

[5]CrisisNet, http://crisis.net.

[6]Behavioral & Linguistic Analysis of Disaster Tweets, http://irevolution.net/2012/07/18/disaster-tweets-for-situational-awareness.

AUTOMATIC CLASSIFICATION OF CRISIS-RELATED CONTENT ON SOCIAL MEDIA

The first step required for creating the crisis annotation API is to train document classifiers that automatically identify event-related posts, crisis types and information categories. The following sections discuss the CNN model used for training the API models and evaluate the models against multiple baselines in order to validate the accuracy of the API.

Classification of Crisis-related Content using Convolutional Neural Networks (CNN)

Event detection in the context of Twitter is a text classification task where the aim is to identify if a given document (post) describes or is related to an event. In this section, we describe the Convolutional Neural Networks (CNN) model used for performing event detection on Twitter. Similarly to previous work (D. T. Nguyen et al. 2017; Burel, Saif, Fernandez, et al. 2017), the model relies on word embeddings in order to better represent the implicit semantics of the documents and consequently better identify crisis-related documents.

The pipeline of the model consists of three main phases as depicted in Figure 1:

1. *Text Processing*: A collection of input tweets are cleaned and tokenised for later stages;
2. *Word Vector Initialisation*: Given the word tokens produced in the previous stage and pre-trained word embeddings, a matrix of word embedding is constructed to be used for model training;
3. *CNN Training*: In this phase, the CNN model is trained using the word embeddings matrix.

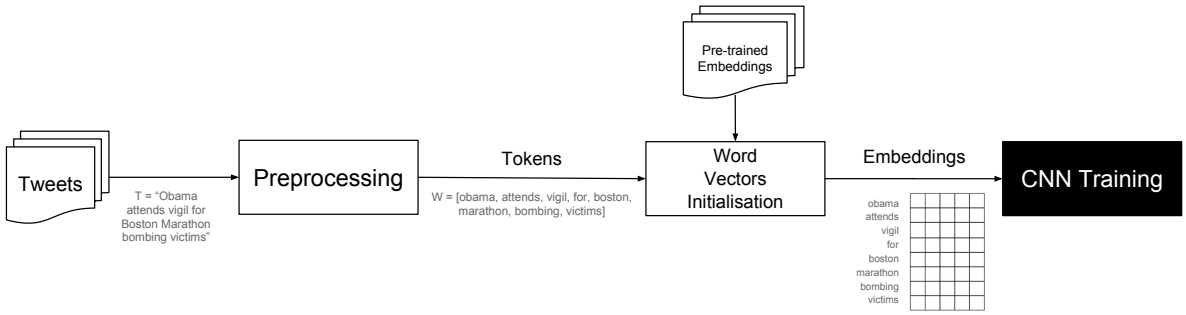

Figure 1. Pipeline of the CNN deep learning model event detection model.

In the following subsections, we describe each of the phases of the pipeline in more detail.

Text Preprocessing

Tweets are usually composed of incomplete, noisy and poorly structured sentences due to the frequent presence of abbreviations, irregular expressions, ill-formed words and non-dictionary terms. This phase, therefore, applies a series of preprocessing steps to reduce the amount of noise in tweets including, for example, the removal of URLs, and all non-ASCII and non-English characters. After that, the processed tweets are tokenized into words that are consequently passed as input to the *word embeddings* phase. Although different methods can be used for preprocessing the input data, in this paper we follow the same approach as Kim (Kim 2014) since it is scalable and does not require any complex algorithms.

Word Vector Initialisation

An important part of applying deep neural networks to text classification is to use word embeddings. As such, this phase aims to initialise a matrix of word embeddings for training the event classification model.

Word embeddings is a general name that refers to a vectorised representation of words, where words are mapped to vectors instead of a one dimension space (Bengio et al. 2003). The main idea is that semantically close words should have a similar vector representation instead of a distinct representation. Different methods have been proposed for generating embeddings such has Word2Vec (Mikolov et al. 2013) and GloVe (Pennington et al. 2014) and they have shown to improve the performance of multiple NLP tasks. Hence, in this work, we choose to bootstrap our model with Google's pre-trained Word2Vec model (Mikolov et al. 2013) to construct our word embeddings matrix, where rows in the matrix represent embeddings vectors of the words in the Twitter dataset. We decide to use this model since it is a commonly used embedding model. In future work, we are planning to experiment with Twitter and crisis-specific embedding models such as the model proposed by Imran, Mitra, et al. (Imran, Mitra, et al. 2016).

CNN Model for Text Classification

This phase aims to train the CNN model from the word embeddings matrix. Below we describe the CNN model along with the proposed training procedure.

As previously discussed, CNN can be used for classifying sentences or documents (Kim 2014). The main idea is to use word embeddings coupled with multiple convolutions of varying sizes that extract important information from a set of words in a given sentence, or a document, and then apply a softmax function that predicts its class.

The proposed CNN model is based on Kim's model (Kim 2014), a CNN model widely used for text classification. It consists of a convolution layer (with three region sizes and multiple filters per region) followed by a max-pooling phase and a fully connected layer where the softmax function is applied for predicting the document classes.

For example, the document D = '*Obama attends vigil for Boston Marathon bombing victims.*' may be tokenised as T_w = ['*obama*', '*attends*', '*vigil*', '*for*', '*boston*', '*marathon*', '*bombing*', '*victims*'] by a word tokeniser. Then, the embedding D_w is created using the previous document representation T_w and convolutional layers are used followed by a max-pooling step before applying the softmax step that classifies individual documents as depicted in Figure 2.

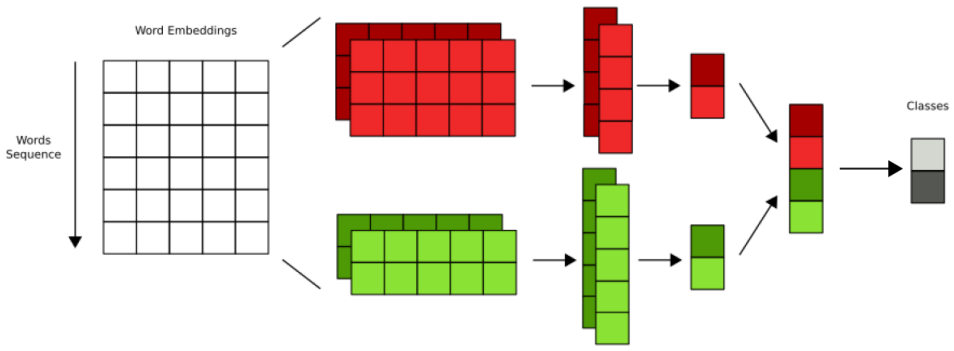

Figure 2. Convolutional Neural Network (CNN) for text classification using word embeddings.

Experimental Setup

Here we present the experimental setup used to assess the event detection model used in the classification API. As previously mentioned, we aim to design an API that supports three different tasks. As such, our evaluation setup requires the selection of (i) Twitter datasets, (ii) the semantic extraction tool, and (iii) baseline models for cross-comparison.

Dataset

To assess the performance of the event detection model we require the use of datasets where each tweet is annotated with: whether or not it relates to a crisis event, the type of crisis (e.g., *earthquake*, *flood*, etc.) and the type of information (e.g., *affected individuals*, *infrastructures*, etc.). For the purpose of this work, we use the CrisisLexT26 dataset (Olteanu, Castillo, et al. 2014).

CrisisLexT26 includes tweets collected during 26 crisis events in 2012 and 2013. Each crisis contains around 1,000 annotated tweets for a total of around 28,000 tweets with labels that indicate if a tweet is related or unrelated to a crisis event (i.e. *related/unrelated*, Task 1)

For the second task, we need a list of crisis types. In order to obtain such information, we consider that the annotated tweets that are from the same sub-collection belong to the same type of event. Using this approach we obtain 12 different crisis types (*shooting, explosion, building collapse, fires, floods, meteorite fall, haze, bombing, typhoon, crash, earthquake and derailment*) (Task 2).

The CrisisLextT26 tweets are also annotated with additional labels indicating the type of information present in the tweet (*affected individuals, infrastructures and utilities, donations and volunteer, caution and advice, sympathy and emotional support, and useful information and unknown*, Task 3). More information about the CrisisLexT26 dataset can be found on the CrisisLex website.[7]

[7]CrisisLex T26 Dataset, http://www.crisislex.org/data-collections.html#CrisisLexT26.

Table 1. Event detection performance of baselines and the CNN model under the three evaluation tasks on the full and undersampled datasets (PT-Embed: Pre-trained word embeddings).

			Related/Unrelated			Event Types			Information Types		
Model	Data	Features	*P*	*R*	*F*1	*P*	*R*	*F*1	*P*	*R*	*F*1
Naive Bayes	*Full*	TF-IDF	0.846	0.684	0.733	0.941	0.927	0.933	0.600	0.570	0.579
CART	*Full*	TF-IDF	0.742	0.707	0.723	0.992	0.992	0.992	0.506	0.491	0.497
SVM	*Full*	TF-IDF	0.870	0.738	0.785	0.997	0.996	0.997	0.642	0.604	0.616
CNN	*Full*	PT-Embed	0.861	0.744	0.797	0.991	0.986	0.988	0.634	0.590	0.609
Naive Bayes	*Sample*	TF-IDF	0.795	0.787	0.785	0.929	0.928	0.928	0.558	0.563	0.556
CART	*Sample*	TF-IDF	0.770	0.769	0.769	0.988	0.988	0.988	0.471	0.464	0.464
SVM	*Sample*	TF-IDF	0.833	0.830	0.829	0.995	0.995	0.995	0.606	0.609	0.605
CNN	*Sample*	PT-Embed	0.839	0.838	0.838	0.983	0.983	0.983	0.610	0.610	0.610

Since the annotations tend to be unbalanced, we also create a balanced version of the dataset for each task by performing biased random undersampling using tweets from each sub-collection. As a result, the first task dataset is reduced to 6703 tweets (24%), the second task to 12997 tweets (46.5%) and the final task to 9105 tweets (32.6%). The balanced datasets are created in order to avoid an overfitted model that does not generalise well in future event predictions where the data distribution can differ from the datasets used for training the models.

Evaluation

In this section, we report the results obtained from using the CNN model for crisis event detection of tweets under three evaluation tasks: (Task1) Crisis vs. non-crisis related tweets, (Task2) type of crisis, and (Task3) information categories. Our baselines of comparison are three traditional machine learning classifiers: Naive Bayes, Classification and Regression Trees (CART), and SVM with RBF kernels trained from words unigrams. We initialise the CNN models with the Google News 3 million words and phrases pre-trained word embeddings data.[8] Results for all experiments are computed using 5-fold cross-validation. For each task, we perform the evaluation on the full and undersampled versions of the dataset.

We train the CNN model using 300 long word embeddings vectors with $F_n = 128$ convolutional filter of sizes $F_s = [3, 4, 5]$. For avoiding over-fitting, we use a dropout of 0.5 during training and use the ADAM gradient descent algorithm (Kingma and Ba 2014). We perform 400 iterations with a batch size of 256.

Table 1 shows the results of our event detection classifiers for the three evaluation tasks on the full and undersampled versions of the dataset. In particular, the table reports the precision (P), recall (R), and F1-measure (F1) for each evaluation task and model. The table also reports the types of features and embeddings used to train the different classifiers.

Baselines Results

As seen in Table 1, the results for each task and each baseline show that the first two tasks are relatively easy to predict whereas predicting information types is much more complex. In general, we also observe that SVM is the best performing algorithm followed by CART and Naive Bayes. For the first two tasks with the full data, each method achieve *precision*, *recall* and $F_1 > 0.72$ and SVM appears to be the best model with $F_1 = 0.785$ for identifying crisis related tweets and $F_1 = 0.997$ for identifying event types. The task of identifying information types show much lower F_1 across the board. This is probably due to the fact that compared to the previous tasks, information types probably contain much more general terms in each class. Similarly to the previous tasks, SVM performs the best with $F_1 = 0.616$.

With the balanced datasets, the results are similar. However, the predictions for the first task increase by around +4.8%. This result is likely due to the fact that the first task was the most imbalanced task and benefits the most from the undersampling process.

The high precision and recall results observed for the second task ($F_1 = 0.997$) suggests that the different models overfit the data. The issue is not resolved by undersampling the data with an F_1 of 0.995. Looking at the data in more details, we observe that each category contains very clear category indicators. For instance, 77% of the tweets about *meteorite falls* contain the word *meteor*, whereas 76.2% of the tweets about *explosions* contains the word *Boston*. In order to reduce such issue, we could, for instance, remove some of these words from the dataset so the models become less tied to practical event instances (e.g the Boston bombings).

[8]Google Word2Vec, https://code.google.com/archive/p/word2vec

CNN Results

In general, applying CNNs with pre-trained word embeddings (*PT-Embed*) for both the full and undersampled data does not improve significantly over SVM. Using the full dataset, we obtain an F_1 of 0.797 for the crises related tweets and full dataset, 0.988 for event types detection and 0.616 for information type identification.

When using the undersampled datasets, the results are similar to the previous observations with an increase of +3.7% in F_1 for the first task. There is also a slight improvement for the last task with +0.6% in F_1.

Even though CNN models marginally improve over the baselines, word embeddings have the advantage to be less strict than the bag of words model. This means that when new vocabulary is added, the CNN model may be less affected by out of vocabulary words (e.g., by using pre-trained embeddings).

Discussion

Similar to previous work (D. T. Nguyen et al. 2017; Burel, Saif, Fernandez, et al. 2017; Burel, Saif, and Alani 2017), we used deep learning CNN models for detecting events on Twitter. This section discusses the limitations of the presented work as well as different areas of future investigations.

We experimented with three event detection tasks and observed that identifying crisis-related events and event types in tweets (i.e., Task 1 and Task 2) with high accuracy appears to be a relatively easy task that can be fulfilled well with both traditional models such as SVM and CNN models. Identifying the types of information provided in crisis related tweets (Task 3) is much more challenging as tweets mentioning event information types tend to contain much more general terms in each class than the tweets that are related or unrelated to crises or are discussing different types of events.

Looking into the details of the second task, we observed that for this task, the models were generally overfitted even after balancing the data. The reason seems to be associated with the presence of very clear category indicators (e.g., place names). In order to reduce such an issue, we could remove place names from training instances or try to collect additional data so that the associations between event types and locations is reduced.For instance we could consider the CrisisNLP datasets [9].

Although comparing our results with existing works is not straightforward due to differences in the used datasets and experimental setup, our results appear to be similar to previous observations (D. T. Nguyen et al. 2017; Burel, Saif, Fernandez, et al. 2017; Burel, Saif, and Alani 2017). As future work, we are considering using more complex preprocessing methods as well as augmenting the CrisisLexT26 dataset with the CrisisNLP datasets similarly to the work done by D. T. Nguyen et al. (D. T. Nguyen et al. 2017). We also plan to improve the CNN model by adding additional convolutional layers and performing parameter optimisation. For instance, we could try to improve the results by modifying the size of the model filters as well as the number of filters. We could also increase and optimise the number of training steps in order to obtain better results. Besides CNN, other more suitable models such as recurrent neural networks (RNN) (Graves 2012) may be also considered as future work due to their ability to capture textual relations more accurately.

THE CRISIS EVENT EXTRACTION SERVICE (CREES)

In order to be able to use the previous models, it is necessary to create an easily deployable API that can be integrated into multiple tools and software. In this section we introduce the Crisis Event Extraction Service (CREES)[10] as a simple REST API for automatically identifying crisis-related documents.

The CREES API Server

The CREES server provides a simple web API that can be queried using standard HTTP POST and GET queries. The API accepts textual documents as input and returns standardised JSON objects that contain the annotations returned by the CNN model presented in the previous section. The following subsections describe the API in more details and show how the API design choices help its integration into third-party tools.

[9] CrisisNLP, http://crisisnlp.qcri.org/.
[10] CREES API, http://evhart.github.io/crees.

API Description and Services

The CREES API exposes three different services that follow the tasks described in the previous sections. Each method can be accessed using a GET query with a text parameter that contains the document that needs to be labelled. CREES also provide POST queries that can be used for annotating more than one document by submitting a JSON array that contains multiple textual documents to the endpoint. The methods are the following:

- */events/eventRelated*: Determines if a document is related to a crisis situation. The following labels are returned: *non-related*, *related* (Task 1).
- */events/eventType*: Determines the type of crisis discussed in a document. The following labels are returned: *bombings*, *collapse*, *crash*, *derailment*, *earthquake*, *explosion*, *fire*, *floods*, *haze*, *meteorite*, *none*, *shootings*, *typhoon* and *wildfire* (Task 2).
- */events/infoType*: Determines the type of information discussed in a document. The following labels are returned: *affected_individuals*, *caution_and_advice*, *donations_and_volunteering*, *infrastructure_and_utilities*, *not_applicable*, *not_labeled*, *other_useful_information* and *sympathy_and_support* (Task 3).

Each method returns a similar JSON object. For example the following CURL[11] query:

```
curl -G http://127.0.0.1/events/infoType  \
--data-urlencode 'text=If you are evacuating please dont wait, \
take your pets when you evacuate'
```

Returns the following JSON object:

```
{
    "classifier": "CNN",
    "input": "if you are evacuating please dont wait, take your pets when you evacuate ",
    "label": "caution_and_advice",
    "version": 0.3
}
```

Although the GET method only accepts one document as input, the API also allows POST queries that can be used in order to annotate more than one document by submitting a JSON array containing a list of documents to annotate. Each method returns a similar JSON object. For example:

```
curl -X POST http://127.0.0.1/events/eventRelated  --header \
'Content-Type: application/json' -d '["If you are evacuating, \
"take your pets when you evacuate", "AAPL, NBA playoffs 2013, \
New York Post, West Texas, ..."]'
```

Returns the following JSON object:

```
{
    "labels": [
    {
        "input": "If you are evacuating, take your pets when you evacuate",
        "label": "related"
    },
    {
        "input": "AAPL, NBA playoffs 2013, New York Post, West Texas, ...",
        "label": "non-related"
    }
    ],
    "classifier": "CNN",
    "version": 0.3
}
```

[11] CURL, http://curl.haxx.se.

CREES is built on top of Flask[12] and Tensorflow[13] and exposes an OpenAPI v2[14] compliant endpoint that can be used for helping the automatic consumption of the CREES services. The API serves the aforementioned CNN models and integrates Swagger UI[15] so the API can be used directly in a web browser.

Installation and Integration

Besides the ability to handle multiple classification tasks concurrently, the development of the CREES server was driven by two key requirements. First, the API needed to be easy to understand and integrate into existing tools. Second, the CREES server needed to be easy to download install and deploy.

CREES has been integrated into the Ushahidi platform[16] as part of the COMRADES[17] project using the Ushahidi webhooks API. Ushahidi is a crowd-sourcing platform designed for collecting data from multiple resources such as social media, SMS and email. The platform helps the visualisation and classification of posts in order to better understand crisis situations by allowing users to manually map, annotate and classify documents. The CREES integration allows the automatic categorisation of Ushahidi posts as soon as they are added to the platform and as result reduces the human resources required for classifying incoming documents.

We also created a Google Sheets add-on[18] that exposes the CREES classifiers to Google Spreadsheet users since spreadsheet software is often used by volunteers during crises. The add-on exposes each of the three classifiers as a spreadsheet function (i.e., `CREES_RELATED`, `CREES_EVENT` and `CREES_INFO`) that can be used for annotating individual table cells or columns.

In order to allow the fast deployment of the CREES server during crises, the CNN models and code are both available online and can be deployed in a few minutes using Docker and a step-by-step documentation. Another specificity of CREES is that it is not deeply integrated into a specific ecosystem. This simplifies the integration of the annotation services into multiple products as the Ushahidi and Google Sheets integrations demonstrate.

Load Testing

Although the current version of CREES is not explicitly optimised for scalability, the API is built on top of Flask so multiple servers can be used for distributing user load when a large amount of data needs to be analysed concurrently. Nevertheless, we load test the CREES API in order to better understand the current strengths and limitations of the deployed server implementation. We conduct a traditional load balancing test by progressively increasing the number of API users and observing how the server handles the requests.

Although in principle, more than 6000 tweets are created every second, the standard (*free*) Twitter API only allows for the access of at most 20 tweets per second (180 queries that returns 100 tweets per 15 minutes windows). As a consequence, a realistic usage of the CREES API is to consider that each user will submit at most 12 GET query per second to each CREES annotation service every second (i.e., 12 queries per second to CREES). In this context, we decide to load test the CREES API by considering that each user performs 12 queries per second.

We load test CREES using Locust[19] by increasing the number of users every second by 10 until we have 1000 users that perform simultaneous server queries using the previously mentioned 12 GET queries per second. We report the number of average requests performed per second on the endpoint as well as the number of failed requests. We also report the server latency in order to evaluate the responsiveness of the API. In order to have a fairer evaluation, we perform the evaluation outside the network domain where the server is hosted.

Results

The evaluation results are listed in Table 2. In general, we can observe that each model performs roughly similarly and is able to perform between 77 and 82 queries per second with a median latency of 700 milliseconds. Out of the 1698 requests submitted to the CREES API, less than 5% of the calls fail. When performing the same test with at most 500 users, we observe no failing requests.

In general, the results show that the CREES API is able to serve 500 users concurrently without any issues and to some extent 1000 users successfully when each user perform more than 12 queries every second to the CREES API.

[12]Flask, http://flask.pocoo.org.
[13]Tensorflow, http://www.tensorflow.org.
[14]Open API, http://www.openapis.org.
[15]Swagger UI, https://swagger.io/swagger-ui/.
[16]Ushahidi, http://www.ushahidi.com.
[17]COMRADES, http://www.comrades-project.eu.
[18]CREES Add-on, https://goo.gl/t73SNY.
[19]Locust, http://locust.io.

Table 2. Load test of the CREES API using 1000 users performing 12 API calls per second with an hatching rate of 20 users per second.

Query	Nb Reqs	Nb Fails	Avg	Min	Max	Median	Req/S
GET /events/eventRelated	573	32 (5.29%)	1159	361	63845	700	82.60
GET /events/eventType	559	22 (3.79%)	1041	372	63210	690	79.40
GET /events/infoType	566	22 (3.74%)	1024	392	58950	700	77.80
Total	1698	76 (4.48%)					239.80

It is important to note that it is relatively unlikely that in a real use case more than 500 users or organisation will be accessing CREES concurrently. Moreover, if the users use the batch CREES API (POST), they need to only make 0.6 query per seconds to the API since they can submit multiple posts to the API using only one call. In this context, the CREES API can potentially handle much more connections if the clients use less aggressive methods for querying the API.

Discussion

Although the current CREES API requirements are principally focused on providing a simple API that can be integrated into existing tools and workflows, we showed that the CREES API can already support realistic query loads (i.e. 500 users performing 12 query per second on the API endpoint concurrently). Moreover, if necessary, the API efficiency can be easily improved by using multiple CREES servers together. Finally, we also showed that CREES can be easily integrated into third-party tools such as Ushahidi and Google Sheets.

Compared to other tools that use machine learning methods for helping the analysis of social media documents during crises, CREES is designed to be lightweight in order to easily integrate to already existing platforms and workflows such as the Ushahidi platform or Spreadsheet software. This approach can be directly contrasted to more integrated tools such as AIDR (Imran, Castillo, et al. 2014) that provide end-to-end annotation heavyweight features. Compared to AIDR, CREES models are also backed by CNN models making them potentially more accurate compared to the classifiers used by AIDR.

Even though improving the underlying CNN models can lead to better predictions, the CREES API can be improved in multiple ways in order to make it more robust and scalable. At the moment, CREES does not support rate-limiting and user authentication as well as advance caching features. Adding those features would allow for a more robust API. Another line of research could be the integration of methods for updating the trained CNN models through the API. However, adding such feature may increase the integration complexity of CREES.

CONCLUSIONS AND FUTURE WORK

In this paper, we introduced CREES (Crisis Event Extraction Service), a web API that allows the automatic classification of crisis-related social media documents. The API provides services for identifying crisis-related documents, event types and information categories. Compared to existing tools, CREES is a lightweight API that can be easily integrated into existing tools and workflows. In order to demonstrate the versatility of CREES, we integrated the API into the Ushahidi platform and exposed its features as a Google Sheet add-on.

CREES annotation features are backed-up by CNN models trained on a Twitter dataset consisting of 26 different crisis events. The models were tested evaluated. Results show that CNNs are able to successfully identify the existence of events, and event types with > 79% F-measure, but the performance of CNN significantly drops (61% F-measure) when identifying fine-grained event-related information. These results are competitive with more traditional Machine Learning models, such as SVM.

Although multiple improvements can be done in order to improve the CNN models used by CREES such as using additional training datasets (e.g., CrisisNLP) or alternative deep learning models (e.g., RNN). We plan to focus future work on adding more features to the CREES API such as user authentication mechanisms, rate-limiting features and better caching support. We are also working on evaluating the Ushahidi and Google Sheets integration with users as part of a crisis response exercise.

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Community coordination: Aligning social media use in community emergency management

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ABSTRACT

Emergency managers continue to struggle with a lack of staff, information processing tools, and sufficient trust in citizen-reported information to coordinate the use of social media in their communities. To understand possibilities for overcoming these barriers, we conduct interviews with emergency managers using scenarios describing the projective activities of community volunteers disseminating and monitoring social media. We find that coordinating social media use in communities requires alignments with local incident management systems and, in particular, existing sociotechnical infrastructure for managing citizen-reported information. These alignments open limited roles for community volunteers, notably coordinating the redistribution of official information; and stand to reshape the workflows and infrastructures of incident management systems by pushing emergency dispatchers to proactively process indirect reports of incidents obtained on social media, and integrate tools that can access hyperlocal data, curate incident and situational reports, and facilitate sensemaking among officials confronted with multiple information sources.

Keywords

social media, emergency management, community informatics

INTRODUCTION

Studies of social media (SM) use during crisis have arrived at two general conclusions. First, by circulating information resources, SM can support cooperation among crisis responders, and directly and indirectly-affected citizens during disasters (Palen et al., 2010; Reuter et al., 2018; Starbird et al., 2010). When someone uses SM to send warnings and updates, request or provide aid, or describe the situation around them, they contribute to information flows that both citizens and crisis responders depend on during disaster. As a result, the nature of these flows shapes the possibilities and requirements for cooperation among citizens and officials during disaster response.

Second, due to the volume, variety, and velocity of information flows, cooperation among distributed citizens and crisis responders using SM requires coordination (Dailey and Starbird, 2017; Starbird and Palen, 2011; Ludwig et al., 2015; Kaufhold and Reuter, 2016; Reuter et al., 2013). For the tweet of an affected citizen to reach a crisis responder, or vice versa, requires articulation work performed by assembled technologies and, increasingly, digital volunteers who disseminate official notices and curate information resources that support situational awareness and decision-making (Cobb et al., 2014; St Denis et al., 2012). This "articulation space" in which digital volunteers use SM to align the situated actions of citizens and crisis responders, represents a primary focus for Crisis Informatics research motivated by the evolving coordinative requirements for cooperation among crisis responders and citizens in disaster response (Hughes and Tapia, 2015).

Yet while Crisis Informatics continues to explore how digital volunteers can coordinate disaster response, the corresponding articulation space of Community Emergency Management (CEM)- ongoing incident and emergency management work that takes place in geographic communities during periods of stability *intervening* crises- remains relatively unexplored (FEMA, 2011; Schafer et al., 2008). In contrast, prior studies observe that community emergency managers struggle to make use of SM at all, finding they lack staff, tools, and trust to effectively utilize SM (Hiltz et al., 2014; McCormick, 2016; Plotnick et al., 2015; Reuter et al., 2016). On one hand, these barriers resemble those crisis responders encounter during disaster yet now engage digital volunteers to overcome, raising the possibility that emergency managers might similarly engage citizen, "community volunteers" to coordinate the use of SM in their communities.

On the other hand, community officials working within local Incident Command Systems (ICS), remain wary of citizen participation in highly-structured workflows designed to centralized authority and accountability in incident and emergency management work (Hughes, 2014; Hughes and Palen, 2012). CEM involves cooperation among emergency services (police, fire, medical); citizens who experience and report incidents using emergency numbers (e.g. 9-1-1) monitored by local call centers or Public Safety Answering Points (PSAP); and county or municipal-level emergency management agencies (EMA) responsible for emergency operations planning and risk mitigation surrounding large-scale community events (i.e. festivals, parades, and sporting events), and local response operations during natural (i.e. flooding) and man-made (i.e. protests) emergencies (Quarantelli, 2000). Importantly, CEM workflows centralize monitoring and dispatch of citizen-reported information across municipal agencies, typically within the PSAP, and strictly control the dissemination of public information. In this respect, the nature of cooperative work in CEM, organized around the single organizational and operational structure of the ICS, suggests existing barriers to the use of SM— a lack of staff, tools, and trust— result from coordinative requirements that differ from those observed in disaster response, and require aligning within existing incident management systems.

Through scenario-based interviews with community emergency managers, this paper builds on the aforementioned literature by examining the coordinative requirements for SM use in CEM, and the extent to which community volunteers might fulfill these requirements by disseminating and monitoring SM in communities.

COORDINATING COMMUNITY SOCIAL MEDIA USE

During a disaster, cooperation among people who have information and people who need information can be coordinated by digital volunteers disseminating and monitoring SM. Social Media Dissemination (SMD) involves distributing information resources (e.g. warnings, procedures, updates, etc.) to guide the situated actions of crisis responders and citizens preparing for, responding to, and recovering from crisis. SMD also includes redistributing (e.g. sharing, retweeting) information to facilitate the accessibility, and visibility of information during disaster (Chauhan and Hughes, 2017; Hughes and Palen, 2012; Starbird et al., 2010; Starbird and Palen, 2010; Starbird and Palen, 2012; Sutton, 2010).

Social Media Monitoring (SMM) involves collecting, processing, and curating information reported on SM to support situational awareness and decision-making (Hughes and Shah, 2016; Starbird, 2013; Starbird and Palen, 2011). Remotely-located digital volunteers, sometimes organized as regional Volunteer Operations Support Teams (VOST), can provide crisis responders with needed human and technical resources to cope with the volume of SM generated during a crisis (Cobb et al., 2014; St Denis et al., 2012). As the relationship between digital volunteers and crisis responders evolves, crisis response organizations increasingly institutionalize workflows around open-source platforms and information anticipated from digital volunteer communities (Soden and Palen, 2016). Taken together, the use of SM during a crisis involves a) distributed and interdependent activities— or cooperation; and b) requires dissemination and monitoring work, often performed by digital volunteers, to align— or coordinate— the distributed activities of officials and citizens engaged in disaster response (Schmidt and Simonee, 1996).

Whereas the coordination work of digital volunteers disseminating and monitoring SM has long been recognized to enable cooperation among crisis responders and citizens during times of disaster (Cobb et al., 2014; Starbird, 2013; St Denis et al., 2012), the forms of cooperative work and associated coordination requirements characterizing SM use during intervening periods of stability, the context of CEM, remain relatively unknown. While prior research finds that emergency managers serving county and municipal-level jurisdictions often lack the staff, tools, and trust necessary to make effective use of SM (Hiltz et al., 2014; Plotnick et al., 2015), the cooperative tasks and activities these barriers impede, or how they might be overcome by coordinating community actors and resources, require exploration.

Lack of Staff

In a survey of over 200 emergency managers, Plotnick et al. (2015) found that only half made any use of SM, with a lack of personnel and time most often reported as the primary obstacle to adoption and use. As Zhang et al. (2015) observed among county emergency managers preparing for Hurricane Sandy: "limited SM usage at this stage was due to the fact that staff, resources, and first responders were doing all they could to stay on top of the more traditional forms of communication" (p. 4). Complicating staffing challenges is the lack of experience, training, and policy and procedures for utilizing SM among EMA staff (Hiltz et al., 2014; Plotnick and Hiltz, 2016).

Lack of Tools and Information Overload

In addition, the volume, velocity, and variety of SM data provides additional challenges for officials seeking to utilize SM for situational awareness and decision-making (Cobb et al., 2014). A lack of technical tools to prevent information overload, or the inability of humans to effectively make sense of large quantities of data, persists as barrier to the use of SM (Hiltz and Plotnick, 2013; Plotnick and Hiltz, 2016). Despite needs for technologies to assist resource-strapped agencies collect and filter SM data, technical tools remain scarce or unaffordable for most community EMAs (Plotnick et al., 2015).

Lack of Trust

While community officials do monitor SM for needed information in certain situations (Dailey and Starbird, 2017), many emergency managers approach SM as an untrustworthy source of information, to the extent that trust represents "a barrier that… prevent[s] the use of SM for information collection at this time" (Plotnick and Hiltz, 2016, p. 267). Concern arises over the credibility of people using SM, and the accuracy of information they post, such that many officials view SM as unfit for use in decision-making processes (McCormick, 2016). Consequently, research seeking to facilitate trust in SM has identified "trustworthy" content features as a basis for automated filtering techniques (Halse et al., 2018). Tapia and Moore (2014), however, find that officials utilize SM when provided by trusted sources, observing that "trust in people trumps trust in information" (p. 508). In this regard, trust rests on the credibility of the information source: "trust in a person, trust in an organization and trust in a network, all of which produce data that can be seen as more accurate because of the human agents involve" (p. 504). An important corollary is noted by Dailey and Starbird (2017), who observe that officials will utilize information reported on SM when it has been corroborated by information obtained from trusted sources (p. 1283).

Research Questions

The lack of staff, tools, and trust among community emergency managers, points to breakdowns in the coordination of SM use in CEM that might be overcome through the articulation work of community volunteers disseminating and monitoring SM. We therefore address the following questions:

What tasks guide emergency managers' use of social media? While SMD and SMM have been generally understood to support situated action and situational awareness (Palen et al., 2010; Vieweg et al., 2010), respectively, the particular tasks that SMD and SMM might be deployed to accomplish remain poorly understood in the context of CEM.

What cooperative activities and resources must be coordinated to effectively utilize social media? With respect to accomplishing tasks guiding the deployment of SM, we examine the coordinative requirements for the distributed activities of officials and citizens, and the social and technical resources they employ for these activities.

How can communities coordinate the use of social media in emergency management? Understanding the coordinative requirements for SMD/M, we examine how communities might (re-)align the use of SM around available actors, including community volunteers, and technical infrastructures in the community to overcome barriers of staffing, information overload, and trust now facing emergency managers.

RESEARCH DESIGN

As the focus of our study concerns how emergency managers employ SM in CEM, we sought interviews with U.S. county-level emergency managers as they direct the operations of local EMAs in cooperation with PSAPs, emergency services, and various community services and citizens' organizations within a geographic jurisdiction. Participants were solicited by contacting EMAs in the state of Pennsylvania to arrange phone or in-person interviews with emergency management staff. Altogether we interviewed 26 participants representing 16 county EMAs, including 14 EMA directors, 6 EMA planning and operations managers, four PIOs, and two

PSAP supervisors.

Populations served by each EMA represented vary widely. In Pennsylvania, counties are classified from 1-8 based on population size, with Class 1 and 2 counties located in urban centers with populations over 1.5m and 500k respectively, while Class 8 counties feature less than 20k people living in very rural areas (Table 1). In their survey of U.S. county-level emergency managers, Plotnick and Hiltz find "few differences in SM use or perceived barriers associated with county characteristics of population size or urban vs. rural composition," to include the size of EMA staff (Hiltz and Plotnick, 2016). However, as we explain in the following analysis, we only observed officials of more populous jurisdictions (Class 2-3) employing SMM.

Table 1. Emergency Management Officials Interviewed by Jurisdiction Population

County Class	Participants	Total
1 (>1.5m)	-	-
2 (>500k)	P11	1
3 (>210k)	P5, 12, 13, 16, 17, 21	6
4 (>145k)	P4, 6-8, 18, 19, 22-26	11
5 (>90k)	P3	1
6 (>45k)	P1, 2, 10, 14, 15, 20	7
7 (>20k)	-	-
8 (<20k)	P9	1
		26

Scenario-based Interviews

Interviews were conducted around use-case scenarios, "short stories about hypothetical characters in specified circumstances, to whose situation the interviewee is invited to respond" (Finch, 1987). Through the use of scenarios, we wanted emergency management officials to consider possibilities of SM use involving community volunteers in concrete situations of use (Carroll, 2000). Before each phone interview we forwarded written scenarios to participants by email. These served as the basis for exploratory, semi-structured interviews that followed emergent topics participants brought up as they reflected on the situations, actors, and activities described in each scenario. Interview data was collected either through written notes or audio recordings that were later transcribed and analyzed.

To construct each scenario, we began with actual situations of SM use described by emergency managers and coordinators serving a Class 3 county that was the site of an early, pilot study, and extrapolated these accounts by integrating activities and technologies observed among digital volunteers in disaster response (Cobb et al., 2014; St Denis et al., 2012; Starbird and Palen, 2011). As an exploratory study, we iteratively modified the three constructed scenarios across our interviews with emergency managers, in order to make each both plausible to interviewees and critical from a design perspective (Carroll, 2000). Each scenario was constructed and modified to facilitate insight into the purposes, cooperative arrangements, resources, and associated coordinative requirements of SM use in CEM. In this sense, we sought to use the constructed scenarios as a form of probe, "a design-oriented way to acquire inspirational glimpses of communities targeted for design" (Boehner et al., 2007).

The three scenarios begin with the prompt: "The following scenarios are set in fictional Laurel County. They imagine how an established group of community volunteers - the "Laurel Watch" (LW) - might support an emergency manager by monitoring and disseminating information on social media." Each scenario (1-3) then proceeds with a statement introducing a potential emergency event: 1. A rally for a national political candidate will be held in Laurel county; 2. Rumors are spreading of contamination to the county water supply; 3. Weather forecasts warn of a severe winter storm. Following Schmidt and Simonee (1996), we analyzed emergency managers' perceptions of these scenarios by coding and analyzing the tasks, activities, and roles defining cooperative work arrangements of SMD/M, as well as the sociotechnical resources (conceptual, informational, and technical) that support the common field of work of these arrangements.

ANALYSIS: SOCIAL MEDIA DISSEMINATION

As prior research observes (Plotnick and Hiltz, 2016), the emergency managers and PIOs we interviewed (n=20) use SM primarily to disseminate information to the public. However, as a task, emergency managers look to SMD to direct and coordinate public action before, during, and after emergencies: "What it comes down to is

being able to get them the information when they need it, make it valuable to them to make decisions, and be self-sufficient for a certain period of time" (P13). SMD involves sending the right message, to the right people, who can then take the right actions. This requires aligning three interdependent activities: gatekeeping, redistribution, and public response.

Gatekeeping, or the process by which municipal agencies control what information reaches the public (Hughes and Palen, 2012), guides officials' use of SM and constrains the possible roles for community volunteers in SMD. Scenario three begins by suggesting volunteers might disseminate messages to the public:

> Scenario 3a. Before the storm, volunteers disseminate weather warnings, emergency and non-emergency contact information, and preparation advice on SM.

Every official we interviewed rejected this idea out of hand: "We can't have outside people putting out information for us that has not gone through our vetting process" (P14). This gatekeeping process involves coordinating activities often distributed among staff across municipal agencies— information gathering, verification, inter-agency coordination, and message approval— to control what official information reaches the public. Conversely, *public action* involves the situated actions of citizens using official information. This information and the activities they inform can, of course, vary widely: severe weather notifications, traffic advisories, preparation advice (e.g. storm kits), etc. Crucially, however, the possibility of public action hinges on aligning official gatekeepers with the citizens who stand to use official information.

Redistribution

After releasing information to the public, EMA control over SMD- and the role of gatekeeper- effectively ends: "If we would put something on our social media, on Facebook and Twitter, and they take that and retweet it or tell their neighbors, of course we have no control over that" (P18). Here the articulation space of redistribution opens around the activities (i.e. retweeting and sharing) of community volunteers who coordinate information flows between gatekeepers and citizens situated to use official information.

Scenario one describes a local emergency manager directing the distribution of event-related information with volunteers of the "Laurel Watch" during a political rally:

> Scenario 1c. Traffic congestion and police efforts to manage the rival demonstrations have led to significant delays on the main road leading to the rally. You ask LW volunteers to identify and use relevant hashtags to retweet official traffic and safety advisories.

As the scenario illustrates, reaching the right people (e.g. people at the rally) with the right message (e.g. detours to take), likely requires deliberate coordination. For many officials (n=9), SMD can be used to reach more or particular citizens than possible with existing dissemination channels. Considering the role of redistribution, these emergency managers readily acknowledge the role of citizens: "we depend on, at that point… people to go ahead and grab hold of that information and continue to push it out" (P7). However, when considering the role community volunteers might play in redistributing official messages, as suggested in scenario one, emergency managers and Public Information Officers (PIO) often highlight experiences coordinating press releases with local television and radio stations. Officials readily describe the "great relationships" they develop with local media in the community, to whom they can call directly in order to arrange public notifications (P9). In contrast to these traditional activities of PIO work, most emergency managers found the idea of working with volunteer "influencers"- citizens who can voluntarily redistribute official messages to a large or specific group of people in the community- difficult or inaccessible.

While the majority of officials we interviewed actively utilize SMD (n=20), these officials typically neither know who uses SM in the community or take deliberate efforts to reach them. At the same time, however, these officials employ SMD to quickly reach more or particular segments of the population in their communities. Through SMD, for instance, an emergency manager can communicate with the majority of people who do not subscribe to the county's mass notification system: "even with this new system [Everbridge] we have probably less than 5% of the county enrolled in it" (P13). For other officials, SMD provides access to a unique audience: "kids who don't even use email anymore" (P18). "We utilize it for reaching that demographic, because it's a certain demographic that utilizes social media...," explains another, "it is usually the younger generation that is constantly on it, and that is our way of reaching them" (P10).

At the same time, emergency managers understand SMD as a poor way to reach other populations in the community. Among these are people especially vulnerable during emergencies:

> A lot of times the people that need assistance are not the ones on social media because you don't find a lot of the elderly folks on Twitter, you don't find people with access and functional needs on Twitter, and economically depressed people cannot go out and buy a $600 iPhone… (P11)

Yet beyond anecdotal evidence, the emergency managers we interviewed rely on assumptions of who actually uses SM in their jurisdictions. Importantly, these assumptions motivate the adoption and use of SMD among the emergency managers in their efforts to reach particular populations in their community.

ANALYSIS: SOCIAL MEDIA MONITORING

What do community emergency managers seek to accomplish through SMM? Prior research describes SMM as a source for situational awareness (Vieweg et al., 2010), however, our scenarios sought further insight into tasks that SMM supports in CEM. Scenario one, for instance, reads:

> Scenario 1b. On the day of the rally, volunteers curate important social media posts for you, including: posts detailing traffic jams surrounding the event; pictures at the rally that show and describe the developing protest; and campaign posts suggesting that the candidate- and the rally- will be delayed multiple hours.

While emergency managers we interviewed appreciated the general usefulness of situational information— "if people have information like that or tell us they are going to send us photos that is fantastic because the more information that we can get the better we can help somebody" (P15)— officials (n=12) often expressed difficulty imagining how community volunteers could support the routine operations of EMAs. Some expressed interest in deploying SMM to identify rumors circulating in the community (n=4), or, in the event of disaster, for rapid damage assessment using information (especially images) citizens post (P7, 24).

However, when generally considering CEM work, several officials (n=8) highlighted the experienced or assumed usefulness of SMM for early warning of incidents before they are reported to 9-1-1, and for situational information that could provide additional details or context to information provided by 9-1-1 callers. These emergency managers approached SMM as a distributed, indirect reporting system for coordinating incident management work, that could be deployed to more quickly report and dispatch emergency services (i.e. fire, medical, police) to the scene of an incident, and provide emergency responders with enhanced situational awareness to plan and conduct a response.

Incident Management: Report, Dispatch, and Response

These emergency managers see SMM as an "immediate source of information" where citizens can report incidents they observe in the community, potentially in advance of reports to 9-1-1 or inter-agency communications (P3). "We know that people will share things on SM and, in some cases, put things up before calling 9-1-1 or calling the power company," explains an emergency manager with SMM experience (P13). Officials observe that citizens often use SM alongside existing reporting channels as people will call 9-1-1 to report incidents they observe on SM (P3), or "put something on Twitter or Facebook and assume that someone has already called it in" (P18). Moreover, officials noted that as multiple people can report information on the same incident at the same time, SM provides a distributed source of situational information that can supplement sparse or incomplete information obtained from individual 9-1-1 callers and on-site emergency responders.

Rather than wait for citizens to report an emergency by calling 9-1-1, these officials seek to proactively *dispatch* emergency services by using indirect reports of incidents- information citizens post on SM surrounding events but not directly communicated to officials. "We are essentially utilizing a resource that we don't have direct access to for information gathering," explains the emergency manager of a Class 3 county:

> Right now, we are dependent on somebody else initiating the share of information with us, whether it's a responder in the street using a radio, a civilian calling 9-1-1 or a posted point of contact number, unless someone sees something and says something there is a delay in us gaining the information. Every second that we are unaware of an event or situation delays, correspondingly, any response that we can provide to whoever is in need in whatever capacity. (P12)

Nearly half of the emergency managers we interviewed, most of whom serve in Class 4 counties or higher, addressed SMM as a way to extend existing incident reporting systems such as 9-1-1 by processing indirect reports for early warning of incidents and situational awareness in order to more quickly dispatch emergency services.

Approaching SMM as an indirect incident reporting system for incident management work carries significant consequences for the progressive potential adoption of SMM in CEM. First, incident management consists of distributed activities: citizens indirectly reporting incidents on SM, officials dispatching appropriate emergency services, and officials responding with on-site fire suppression, medical assistance, security, etc. In the context of CEM, responsibility for coordinating these activities by processing citizen-reported information and dispatching emergency services does not rest immediately with emergency managers, but the staff of Public

Safety Answering Points (PSAP). As will be discussed, integrating SMM within a PSAP requires two additional activities- detection and verification- that allow SM to become useful for incident management work by overcoming barriers to staffing, information overload, and trust that have so far hampered SMM when performed among emergency managers.

PSAP Integration: Detection and Verification

Integrating SMM within PSAPs, remains, to our best understanding, extremely rare. Only two emergency managers we interviewed experienced this arrangement as a result of the unique organizational alignments present in their communities. Both were the directors of Public Safety Departments in urban, class three counties that administratively unified the county EMA and PSAP. In most jurisdictions, the EMA and PSAP operate along distinct administrative and operational divisions.

Integrating SM within a PSAP, rather than an EMA, allows distinct opportunities for aligning SMM within existing cooperative work arrangements and technical infrastructures for processing citizen-reported information in incident management. First, the demand for staff to continuously monitor SM has posed a persistent barrier to emergency managers seeking to employ SMM. However, integrating SMM (and SMD) within PSAPs avoids this barrier. PSAP integration proves, "absolutely, beneficial for the emergency management side here, of course during a disaster we are here, but the [9-1-1] dispatch is there around the clock, 24/7, and bodes well for us to get out anything we need to" (P18). Unlike all EMA offices, and most EOCs, PSAPs are continuously staffed and can provide around-the-clock monitoring of incidents detected on SM, as well as the dissemination of official information.

Second, the PSAP already coordinates information flows information between citizens and emergency response and management officials. In most communities, the EMA is often removed from this information: "When those two operations are split [EMA and PSAP], at least in my experience, what I take for granted as information coming out of the 9-1-1 center, there is also sometimes a significant delay in that knowledge rising to the level of EMA operations." (P12). This delay reflects the different operational mandate of the two agencies, with PSAPs primarily responsible for translating citizen-reported information into intra-agency dispatches for all emergency services and EMA personnel.

Detection

Integrating SMM within a PSAP, however, creates new challenges for 9-1-1 dispatchers and supervisors. Foremost among these becomes a shift in posture from reactively processing direct reports of emergencies made by citizens calling 9-1-1, to proactively *detecting* indirect reports of incidents. The emergency managers we interviewed recognize the need for technologies that can access information reported on SM and detect incidents in the community: "The idea was to mine information using keywords for things like power outages, flooded [areas], road closures, that kind of thing would really benefit us greatly," explained another emergency managers (P13). Requirements for detection in SMM follow existing protocols of 9-1-1 dispatch:

> Our primary thing is to not gather as much information from additional sources as we can. Our primary mission is to get as much information from the caller as you can, and as soon as you have the location and incident type, dispatch help, and continue to take information and push it to the help en route through a mobile data terminal. So by the time an officer or firefighter pulls up, if there is anything that would change their posture, upon entry to that event, they have that information before they get there. (P12)

The motivation for an early warning system suggests that useful SMM technologies would support existing protocols of emergency dispatch by prioritizing incident alerts, consisting of incident type and location, for the rapid dispatch of emergency services, and, second, curating relevant situational reports for use by emergency responders.

Detection, however, first requires technologies that can collect and filter hyperlocal SM data: information content (i.e. social media posts) and activity traces (e.g. likes, retweets) created by people using SM within a geographic jurisdiction. One PSAP utilized Geofeedia, a commercial platform for collecting and mapping geolocated information, to monitor SM alongside 9-1-1 calls:

> We would have it running in the background of the 9-1-1 center, and across Twitter and Facebook we had a list of approaching 75-100 keywords…surprisingly a lot of times SM gets posted on an event, particularly a fire or a law enforcement occurrence, and it would hit SM before a 9-1-1 call was made. (P12)

The PSAP was only able to use Geofeedia until October 2016, when Twitter, Facebook, and Instagram denied

the platform commercial access to data after reports described its use by law enforcement agencies during the 2014 and 2015 protests in Ferguson, Missouri and Baltimore, Maryland, respectively (Cagle, 2016). As the unified EMA/PSAP director explained, without this access the platform became "no use to us" (P12). Lacking a replacement, the PSAP no longer monitors SM.

Verification

In addition to detection, integrating SMM within PSAPs requires verifying the accuracy of citizen-reported information on SM. As mistrust of SM remains a primary barrier to its use, verifying the accuracy and relevance of information reported on SM becomes essential. The officials we interviewed sought to verify reports of incidents by following, often informal, protocols for corroborating information obtained from SM with information obtained from trusted sources, namely on-site officials and and 9-1-1 callers, or, in some cases, other social media users.

PSAPs provide the sociotechnical infrastructure for verification. "We get the information [SM], we will… vet it and investigate…," one emergency manager explains:

> Let's say they [9-1-1 dispatcher] gets something that someone puts out [on SM], "I just drove by John Doe warehouse and I see smoke and flames shooting out of the roof." They get that information and, hopefully that person has also called 9-1-1, but what they would do is let the supervisor know, they would probably yell it in the room, "hey, I just saw this." They would then send, law enforcement-wise, someone there to verify as soon as possible that there was an issue there (P18).

As infrastructure, the PSAP draws together, in the same room, the personnel and resources needed for verifying incidents reported on SM. These include dispatchers who monitor for incidents detected on SM, supervisors authorized to dispatch officials to investigate incident reports, and on-site emergency responders communicating (non-)corroborating information; as well as the information systems (i.e. radios, CAD) for receiving 9-1-1 calls, dispatching emergency services, and communicating with on-site first emergency responders. The other emergency manager observes the same:

> If we get a report that there are shots fired, and nobody can confirm it, generally most municipalities will send an actual patrol out to check the area, and once they're on the street, because we are a unified operation here- we handle 9-1-1, emergency management, and emergency dispatch- there is no entity in [Pennsylvania] County that we don't have direct, two-way communications with through a secured radio system. So once an officer, patrolman, fireman, regardless, is asked to check a report that has not been verified, we rely on our two-way radio communication… (P12)

This unique sociotechnical infrastructure for detecting and verifying incidents reported on SM enables the PSAP to coordinate the situated actions of citizens and officials during emergencies.

Occasions arise, however, when officials act on SM information before it can be corroborated and verified using official sources. In the case of multiple, original citizen reports or visual evidence of an incident on SM, officials might immediately dispatch aid before verifying the accuracy of the information. In these cases, emergency managers are sometimes willing to corroborate a reported incident on SM using only other citizen-reported information on SM. As an emergency manager explains:

> I'm going to try and validate the source. Is this the only one [tweet] that says this or is there someone else saying it too? I'm going to look to see if people are just retweeting the same thing that I just saw, or are they getting it from someone else? Or, are they all the originators of this information? (P8)

For certain types of incidents, and in the hope of dispatching a response more quickly, emergency managers are willing to substitute "crowd" measures for information obtained from trusted sources as provisional corroboration and verification of information accuracy. "If you get one report you'll probably send one person out there to check it," describes another emergency manager, "If you get ten people, you might start rolling out the fire company." (P18)

REVISITING BARRIERS TO SOCIAL MEDIA USE IN CEM

Our interviews with community emergency managers reveal that using SM is not a simple task. Rather, using SM in CEM involves cooperative arrangements among distributed officials, community volunteers, and citizens. Simply put, we find that to use SM in CEM requires community cooperation and, therefore, community coordination. By approaching the use of SM during periods of stability intervening crises, and as community-based, cooperative work, rather than the work of a single agency (Schafer et al., 2008), we reinterpret barriers impeding SM use among emergency managers- a lack of staff, tools, and trust- as community coordination

challenges that can be overcome by aligning SM use among municipal agencies, volunteers, and citizens in a community.

The Right Staff for the Right Task

Our interviews reveal that, taken alone, the availability, experience, and motivation of staff are insufficient for effective uses of SM (Hiltz et al., 2014; Plotnick and Hiltz, 2016): each task requires unique sociotechnical infrastructure to coordinate the use of SM in a community. It is insufficient, for example, for an experienced, full-time PIO working in an EMA to monitor SM, if that information can only be verified and dispatched by PSAP officials. Similarly, the availability of a PIO to distribute official notices on SM remains insufficient if community "influencers" in the community do not redistribute these messages to reach their multiple, intended publics. Overcoming staffing barriers requires aligning the distributed activities of SMD/M among community actors who are not only available and capable to take on SM duties, but appropriately positioned with respect to the sociotechnical infrastructures required for coordinating these tasks.

Consequently, to align tasks of SM use during periods of stability with their required sociotechnical infrastructures, our interviews suggest that the primary users and use context for SMD/M shift from emergency managers and the EMA, to emergency dispatchers and the PSAP, respectively. While EMAs lack staff to regularly monitor SM activity, PSAPs are continuously staffed to disseminate and monitor SM, while also positioned to verify and dispatch information reported on SM using trusted protocols and information sources. Similarly, while the lack of available EMA staff continues to impede SM tasks, community volunteers might not be able to perform them on officials' behalf. While for SMD we find immediate opportunities for community volunteers redistributing messages to the public, coordinative requirements for SMM during periods of stability often preclude volunteer participation.

Tools for Information Access and Overload

While prior research has observed a lack of tools among emergency managers capable of managing high volumes of SM data (Plotnick and Hiltz, 2016), our interviews reveal that barriers of information access often precede those of information overload. Primarily due to a continued lack of SMM tools, officials lack, the ability to collect hyperlocal SM originating from a geographic jurisdiction. As the case of Geofeedia illustrates, access to hyperlocal SM remains controversial and closely moderated by SM platforms, with some providing more opportunities for access (e.g. Twitter) than others (e.g. Facebook). Our interviews find that officials lack tools to even access available information, as well as tools that might expand access beyond the 2% of tweets geotagged within a geographic community (Morstatter, Pfeffer, Liu, and Carley, 2013). Thus, in addition to SMM tools for event detection (Imran, Castillo, Diaz, and Vieweg, 2015), systems that can extend access to hyperlocal SM are required. Grace et al. (2017), for example, infer Twitter accounts associated with a geographic community on the basis of community-associated social network ties. Such geographic inference methods could be leveraged by SMM technologies to access hyperlocal data.

In addition, despite using SM to provide timely information to the public, emergency managers lack access to information about the citizens they hope to inform. Consistent with Dailey and Starbird (2017), we observe that officials approach the use of SM with respect to "imagined audiences" they assume do or do not use SM. To coordinate SMD requires, first, access to community network visualizations that map publics of social media users and influencers who can reach them. Such information would allow officials to utilize the social network topography of a community to deliberately coordinate the diffusion of official information (Grace et al., 2017).

Second, to coordinate the redistribution of messages from officials to citizens vis-a-vis volunteers, as well as increase the speed of message diffusion, applications for automatically redistributing posts by official accounts could be voluntarily adopted by influencers in the community. This suggests a translation of traditional PIO practices: just as officials now develop relationships with local media to broadcast press releases, relationships could be developed with community influencers to automatically redistribute official SM posts in emergency situations.

Trust in Protocol, Not Information and People

Lastly, our findings provide further perspective on how emergency management and response officials come to trust information reported on SM. Rather than characteristics of information content (Halse et al., 2018), or the source of information (Moore & Tapia, 2014), we find trust to be based in protocol, to the extent that information reported on SM becomes trustworthy when officials follow established procedures for verification and dispatch. Trust in protocol is highlighted in PSAP use of SMM, where incidents reported on SM *initiate processes of verification and dispatch without preconditions for trust in the content or source of information*.

Our interviews reveal that the accuracy and salience of information reported on SM can be verified when corroborated with trusted sources and, under certain conditions, information posted by unknown SM users. Crucially, whether trusted or alternative sources of corroborating information suffice for verifying and, in turn, using information reported on SM remain situated determinations guided by formal or informal protocols established among PSAP officials.

While citizens play a necessary role in these cooperative arrangements by indirectly reporting information that officials seek to monitor and use, roles for community volunteers remain less apparent during periods of stability than those celebrated for digital volunteers in disaster response. Through our scenario-based interviews, we find that emergency managers look to SM as an early warning system for incidents that have not yet been reported to 9-1-1 and, secondarily, for situational information that can supplement 9-1-1 caller information to provide emergency responders with enhanced situational awareness. In view of such an early warning system, the work processes of digital volunteers processing SM data for use by officials becomes simply too slow; as previously highlighted, SMM technologies for event detection and curation become required.

CONCLUSION

Extending the findings of previous research (Hughes, 2014; McCormick, 2016; Plotnick and Hiltz, 2016), we detail the coordinative requirements for SM use in Community Emergency Management (CEM). The primary contribution of this work is an exploration of the articulation space of CEM to understand how community volunteers can disseminate and monitor social media (SM) to coordinate community activities during periods of stability intervening crises. In this unique context, and in contrast to activities performed by digital volunteers and VOSTs (Cobb et al., 2014; St Denis, et al., 2012; Starbird and Palen, 2011), coordinative roles for community volunteers transform and become less apparent in CEM, when emergency managers prioritize mechanisms for rapid and targeted information dissemination and event detection systems that can be integrated into existing incident management systems.

However, by addressing SM use in CEM as a form of cooperative, community work, our interviews also reinterpret barriers to SM use previously observed among emergency managers- a lack of staff, tools, and trust (Plotnick and Hiltz, 2016)- as breakdowns in community coordination. We suggest that these barriers can be overcome by aligning SM use within existing incident management systems. In particular, our findings recommend integrating SM capabilities within Public Service Answering Points (PSAP), 9-1-1 call centers that already process citizen-reported information and coordinate inter-agency and public incident notification and emergency dispatch. PSAPs are continually staffed and, via trusted protocols, can uniquely detect, verify, and dispatch information reported on SM using existing sources of official and citizen-reported information.

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Does Flight Path Context Matter? Impact on Worker Performance in Crowdsourced Aerial Imagery Analysis

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ABSTRACT

Natural disasters result in billions of dollars in damages annually and communities left struggling with the difficult task of response and recovery. To this end, small private aircraft and drones have been deployed to gather images along flight paths over the affected areas, for analyzing aerial photography through crowdsourcing. However, due to the volume of raw data, the context and order of these images is often lost when reaching workers. In this work, we explored the effect of contextualizing a labeling task on Amazon Mechanical Turk, by serving workers images in the order they were collected on the flight and showing them the location of the current image on a map. We did not find a negative impact from the loss of contextual information, and found map context had a negative impact on worker performance. This may indicate that ordering images based on other criteria may be more effective.

Keywords

crowdsourcing; Amazon Mechanical Turk; context

INTRODUCTION

In the aftermath of a natural disaster, swift and efficient coverage of the area for accurate status reports is critical, given the small time window that response and recovery efforts must organize and effectively operate. One popular and cost effective approach which is often deployed is using aerial photography (e.g. drones or small piloted aircraft) for post-disaster image collection. These images must then be analyzed in order to identify locations in need of immediate assistance, using visualization techniques such as cartography and heatmaps. Crowdsourcing has proven an efficient approach to aerial imagery analysis and map generation in scenarios where automated image analysis can be difficult, with systems targeted towards the crowd deployed in numerous disaster events around the world in recent years (Liu 2014; Munro et al. 2013; Barrington et al. 2012).

When dealing with aerial images taken using unmanned aerial vehicles, such as drones, control over captured content may be minimal. Meaningful content can be spread among numerous images, creating a potentially useful context for image analysis. However, in crowdsourcing settings, datasets are often presented randomly to participants, to ensure adequate coverage of the area and an even distribution of labels. This results in a loss of context, as participants enter the process through a series of unrelated images, having no way of situating themselves on the area in view, causing useful information to dissipate. This may lead to user frustration and loss of label quality, in situations where context is necessary to accurately categorize images.

In this work we explored providing two specific types of context to participants: first, varying the *order* in which they encountered images, and second, varying the presence of *map context* during the task. Showing images in their original sequence offered visual overlap to participants, creating a context continuity. We also considered map context, by visualizing the path of the images on a map, along with the current image location, with previously

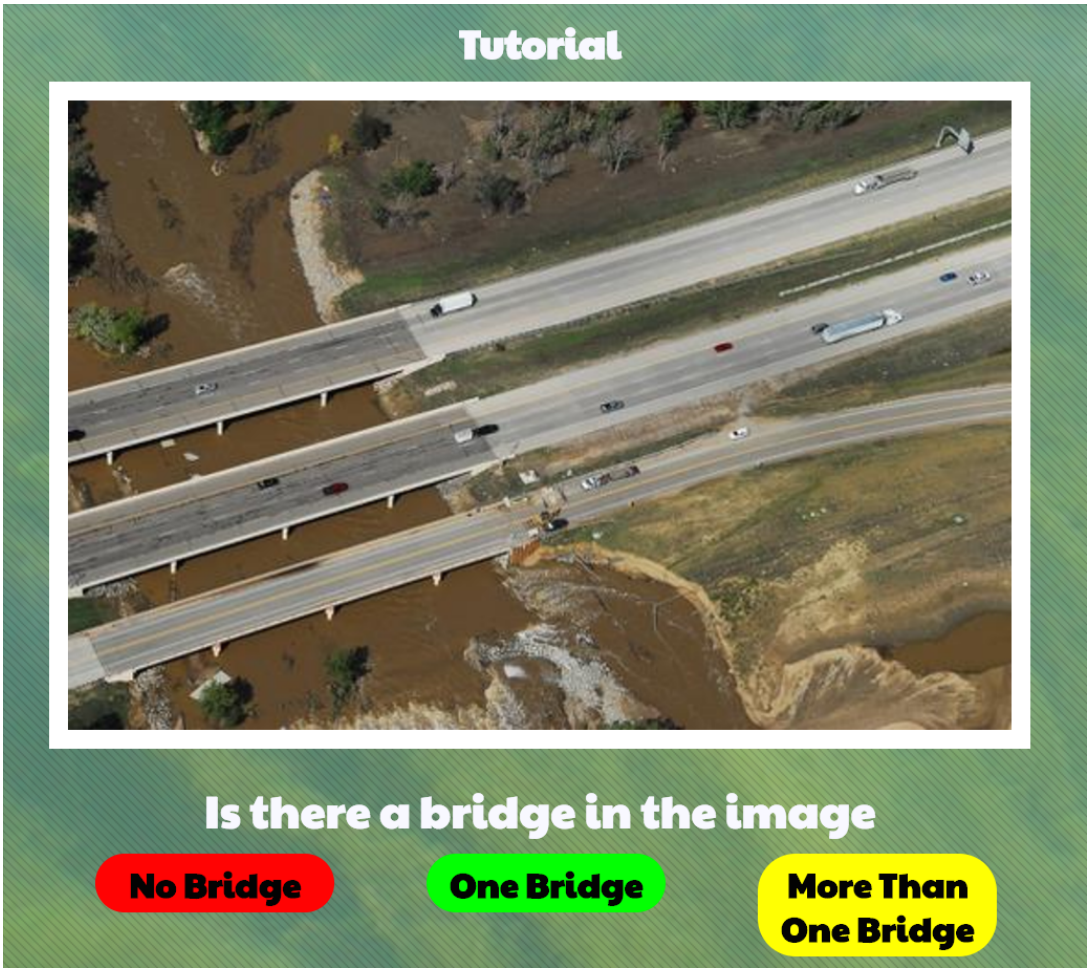


Figure 1. The training page of the task, showing the core interface of the labeling task, with an image, a question and a set of possible labels for workers to choose. The image shows an example for "More Than One Bridge".

submitted labels annotated accordingly, creating a progress context. We were interested in whether the loss of context would have a negative impact on performance in a crowdsourcing setting. To this end, we posted a Human Intelligence Task (HIT) on Amazon Mechanical Turk, asking workers to label a series of images taken from a disaster scenario involving floods in the State of Colorado.

We found that removing context from the task interface did not negatively impact worker performance, including output rate, number of labels provided, and label quality (in terms of accuracy with ground truth). Showing images at random was as effective as preserving order and context, which indicates that other types of ordering, such as decision-theoretic means (Dai et al. 2010) may be better suited when designing a task for disaster response. Further, we found that including a map showing image locations and progress had a negative impact on worker completion of the task. This work contributes an empirical study of how designing a task to include context may impact behavior and performance in crowdsourced aerial imagery analysis, with a focus on disaster response applications.

RELATED WORK

Crowdsourcing has long been used as a means of analyzing significantly sized image datasets for label and characteristics extraction, across multiple domains. In the domain of image labeling for web search, the ESP Game was a multiplayer game designed to allow participants to succeed in labeling an image by submitting the same label at the same time, using required agreement to improve label quality (von Ahn and Dabbish 2004). Cropland Capture was also developed as a crowdsourcing game to monitor cropland from satellite imagery (Sturn et al. 2015). However, Sturn et al. observed a significant drop in classifications in the weeks following press releases about the game.

Galaxy Zoo is viewed as a successful example of crowdsourcing classifications, in the domain of astronomy, attracting more than 200,000 volunteers for classifying images of galaxies from the Sloan Digital Sky Survey

(Raddick et al. 2010). Crowdsourcing image analysis is also used in "space archaeology", with projects such as Global Xplorer, a platform for analyzing satellite images (Global Xplorer 2016), as well as retinal photography (Mitry et al. 2013).

Crowds have often been called upon to aid during severe weather and natural disaster events, by providing information or assisting in analyzing existing data collected through various means. During the Santa Barbara wildfires that took place between 2007 and 2009, volunteers assisted in analyzing and submitting geographic information with the goal of creating a map of the area, using tools like Google Maps, to maintain up to date status reports of the event (Goodchild and Glennon 2010).

After the earthquake that struck Haiti in 2010, a short number code was set up where people could communicate their needs via SMS text messaging. These text messages where in turn translated, geo-coded and categorized by volunteers using a tool developed by Ushahidi, to allow better organization for humanitarian response (Liu 2014).

Satellite imagery, among other types of inputs, was used in analyzing the effects of another earthquake event that affected New Zealand in 2011, using a crowdsourcing tool developed by Tomnod (Barrington et al. 2012). Volunteers were asked to identify affected buildings and rate the level of damage. In a project closely related to our work, MapMill was originally developed in response to the Deepwater Horizon Oil Spill (Warren 2010), but was then adapted and used for assessing damage from aerial photographs after Hurricane Sandy affected over eight countries in the Atlantic region in 2012 (Munro et al. 2013). AIDR (Artificial Intelligence for Disaster Response) was initially designed to classify Twitter posts created during disasters using crowdsourcing (Imran et al. 2014) and was later extended to support aerial data captured via unmanned aerial vehicles (UAVs) (Ofli et al. 2016).

A growing body of work has pointed out the negative effects of context loss when performing tasks on crowdsourcing platforms. Contextual interruptions, which are caused by switching between tasks of different types, were shown to cause a significant delay in performance (Lasecki, Marcus, et al. 2014), while the negative impact of long delays between tasks has also been highlighted (Lasecki, Rzeszotarski, et al. 2015). Another example of context enhancing performance can be found in conversations with the crowd in the Chorus and Chorus:View projects, as well as VizWiz, a mobile application developed to assist blind users in providing labels and answering questions using the crowd (Bigham et al. 2010; Lasecki, Thiha, et al. 2013; Lasecki, Wesley, et al. 2013). Allowing users to engage in conversations with the crowd offered more context on the task, which improved crowd response.

Context loss was also explored in Dai et al.'s work (2015), where inserting micro-diversions in long running tasks on Amazon Mechanical Turk was found to lead to increased worker retention without compromising quality. However, none of the types of micro-diversions were relevant to the main task and the main purpose was to offer relief to workers engaging in monotonous tasks.

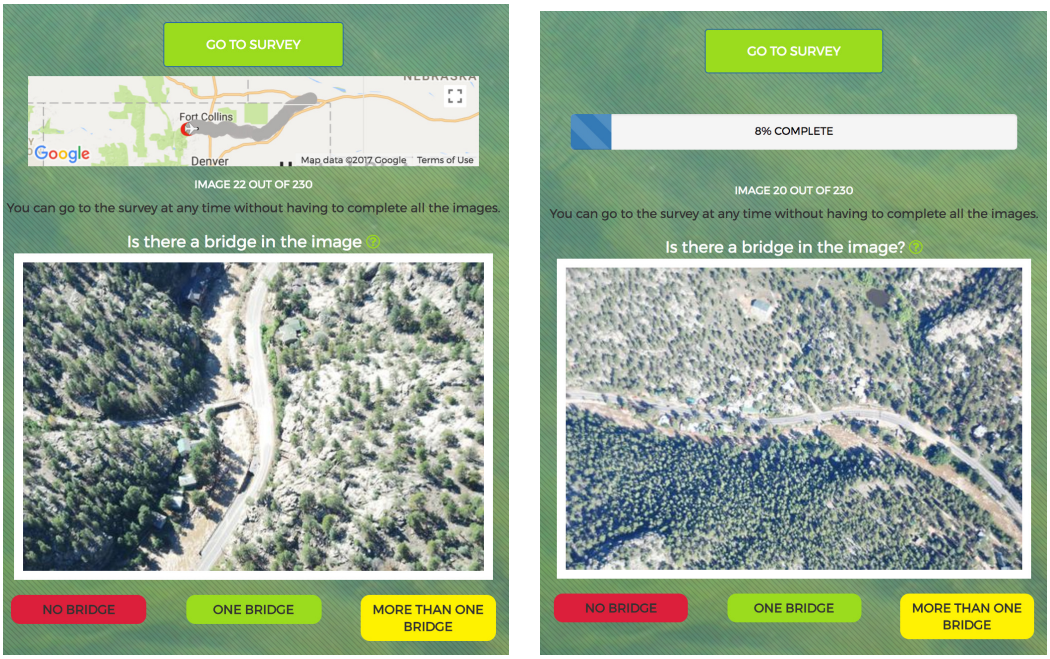
Other examples of ordering crowdsourcing tasks to improve worker performance include Cai et al. (2016), where writing tasks were presented in different sets of orders to optimize worker behavior. However, the criteria for order were based on complexity and not content overlap, as is the case for our work. Moreover, none of the previously mentioned work on context involved disaster response applications. Specifically in the domain of crowdsourcing for disaster response, recent work has shown that switching between tasks of similar context but different types may also lead to increased worker performance (Spatharioti and Cooper 2017).

STUDY SETUP

The type of natural disaster that was investigated in this study concerned floods, as they occur due to various reasons in different geographical locations around the world all year round. We focused on the 2013 Colorado Floods that were caused due to heavy rain that affected areas from Colorado Springs, to Fort Collins. Participants were asked to assist in labeling aerial imagery captured by Civil Air Patrol, which is publicly available through the Hazards Data Distribution System (HDDS), provided by the U.S. Geological Survey (Hazards Data Distribution System Explorer 2016).

After the event, a sizable number of bridges were affected, with local news stating that around 120 structures in the state of Colorado were in need of repairs (Hendrick 2013). We were interested in assessing whether the crowd would be able to identify these structures through analyzing aerial photography. A first step towards this process was to sort through the available images to identify ones that contained bridges. To this end, we designed a simple labeling task where workers would view an image and answer the question "Is there a bridge in the image?", with possible options being "No Bridge", "One Bridge", and "More Than One Bridge". A screenshot of the training page with the core interface of the task can be seen in Figure 1.

The flow of the experiment was straightforward; participants would first have to consent to the purpose of the experiment, based on IRB guidelines. They would then go through a small training session of example images, to



Flight Path Bar Ordered / Bar Random

Figure 2. Comparison of interfaces among conditions, showcasing the differences in progress feedback. The interface on the left was used for the *Flight Path* condition and the interface on the right for the *Bar Random* and *Bar Ordered* conditions. Workers in the *Bar Ordered* condition would be presented with the second interface, but the images would be in the order of the flight path, similar to the *Flight Path* order of images.

familiarize themselves with the question and the answers, after which they would proceed to the task. At the end of the task, a small survey was presented.

To generate context, we selected a subset of our image dataset than ran along a clear path geographically on the state of Colorado. These images were then ordered according to the path and selected in a way that created some visual overlap among images, similar to how a dataset of images captured from the air, via drones or small piloted aircraft, would appear. This resulted in an image set of 230 images. The density of images was a bit higher in the beginning, but contextual overlaps occurred consistently across the entire path, as we focused on eliminating gaps between points. We then considered the following three conditions, which can be viewed in Figure 2:

- **Flight Path**: Images were shown in the order of the path of the flight. Progress was shown as a map, with dots indicating the available images in the set and an airplane icon denoting the current location on the task. Dots of previously labeled images were colored according to the participant's vote, mirroring the answer color schema.
- **Bar Ordered**: Images were shown in the order of the path of the flight, but progress was shown in the form of a progress bar.
- **Bar Random**: Images were shown in random order. Progress was shown in the form of a progress bar indicating the percentage of available images completed.

An example illustrating overlap between images in the *Flight Path* and *Bar Ordered* conditions, in contrast to the lack of overlap in the *Bar Random* condition, is shown in Figure 3.

Participants were recruited using Amazon Mechanical Turk. We set up a Human Intelligence Task (HIT) on the crowdsourcing platform titled "Disaster Area Map Image Tasks". The description of the HIT informed workers that they would be performing image related tasks such as image labeling and answering a short survey. The HIT region was the United States. Although the HIT title suggested that workers would be working on images from a disaster event, the actual event was not revealed to workers. We chose a fixed payment scheme of 50 cents, regardless of the amount of images that were submitted and offered no further incentive through bonuses for accuracy or volume of contributions. Previous crowdsourcing work that has used fixed payments include the domains of games (Khajah et al. 2016) and writing tasks (Cai et al. 2016), as well as the domain of disaster response (Spatharioti, Govoni, et al. 2017). In addition, no lower bound on the number of images provided was present; workers could proceed at any time to the post-task survey. As evidenced in the work of Ho et al. (2015), workers carry different beliefs in what is considered acceptable performance in crowdsourcing tasks. In order to counteract fears of rejection, we explicitly mention in the instructions of the task that any submission will be accepted as long as the post-task survey

Figure 3. Example of a sequence of images in the task for the different conditions. In the conditions where aerial imagery is shown in order, a visual overlap of content is present.

is completed. The instructions were always available to workers for the entire duration of the image labeling part of the task.

Findings

We collected and analyzed responses from 909 Amazon Mechanical Turk workers, randomly assigned to one of the aforementioned conditions. The setup of the HIT guaranteed that no duplicate submissions were allowed. We also chose to exclude workers who had taken previous iterations of the task that were deemed too similar.

Worker actions on the interface were logged for the entire duration of the task. In order to examine worker behavior, we recorded the following variables for each worker:

- *N_Labels*: The total number of labels provided. Workers could provide one label for each image encountered, and no edits were allowed.
- *Time per Image*: The average amount of time spent labeling each image, in seconds.
- *Total Time*: The total time spent labeling images, in seconds. When analyzing Total Time and Time per Image, we identified and capped breaks over five minutes from our analysis.
- *Accuracy*: The percentage of labels provided agreeing with the ground truth. To determine ground truth, all images were cross-referenced by one of the project team members based on geo-location, extracted from EXIF tags, and content, with a list containing bridge structures monitored by the state of Colorado, provided by the Colorado Department of Transportation.
- *Set Completion*: A boolean indicating whether or not labels were provided for all available images in the set.

Workers were required to complete a survey at the end of the labeling task, in order to complete the HIT and get compensated. To gauge how the task was perceived by workers, we used the NASA Task Load Index (NASA-TLX) which is widely used to gain subjective system assessments in a variety of domains (Hart and Staveland 1988). In particular, we used the raw NASA-TLX, which consists of the six sub-scales of total workload, namely *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Performance*, *Effort* and *Frustration*, separated in 5-point steps from 0 to 100. Workers were required to complete all six sub-scales, which were afterwards combined for the Task Load Index (TLX). We also provided small descriptions of each sub-scale, to facilitate comprehension of what was required. Workers could also communicate their thoughts through the optional *Additional Feedback* field provided.

Our statistical analysis consisted of two types of tests. We initially determined that numerical variables (such as *N_Labels*, *Total Time*, etc.), were not normally distributed, using a Shapiro-Wilk test. Thus we used the Kruskal-Wallis test to determine any differences in numerical variables. We used Pearson's chi-squared test to examine differences in the boolean variable *Set Completion*. We report median values for all numerical variables, unless otherwise noted, in Table 1. Accuracy, although presented as percentage, should be considered a numerical variable.

	Conditions		
Metric	*Flight Path*	*Bar Ordered*	*Bar Random*
N	327	285	297
N_Labels	47	70	55
Time per Image	3.742	3.762	3.959
Total Time	163	249	265
Accuracy	67.5%	66.7%	60.0%
Set Completion (*)	25.7%	34.7%	36.0%
TLX	130	134	127

Table 1. Summary of performance and survey metrics for workers per condition. Results represent median values, unless otherwise noted. (*) denotes $p < 0.05$.

Our statistical analysis did not reveal any significant differences among the three conditions, when viewing numerical variables. Although workers submitted fewer labels and spent less time overall on the task in the **Flight Path** condition, this performance was not deemed significantly different from the other conditions. We did however notice a significant difference in Set Completion, that is the percentage of workers who ended up submitting labels for all available images in the dataset, with 25.7% of workers in the **Flight Path** condition, compared to 34.7% and 36% in the **Bar Ordered** an **Bar Random** conditions. Our post-hoc pairwise comparison analysis, using Pearson's chi-squared test with the Bonferroni correction, revealed a significant difference between the *Flight Path* and *Bar Random* conditions ($p < 0.05$).

DISCUSSION & FUTURE WORK

Our results indicate that stripping workers of provided order and map context when performing the task did not negatively impact performance by an observable amount. It is possible that there were effects, but the sizes were smaller that could be determined by our study; though we did include nearly a thousand subjects.

We observed similar levels of worker accuracy, when measured as agreement with the ground truth acquired for the dataset. Workers in the condition where no type of context was available (*Bar Random* condition) were able to perform similarly to both conditions with context, whether that was in the form of order (*Bar Ordered*), or in the form of map progress context and order (*Flight Path*). The highest median number of labels provided was recorded in the *Bar Ordered* condition, though not significantly.

When focusing on time spent labeling per image, workers recorded little variance among conditions. As the *Flight Path* condition contained a new visual element not present in the no context condition (*Bar Random*), this result suggests that workers chose to pay limited attention to the flight path progress element, or to ignore it completely. However, this context path element was not explicitly required for the completion of the task; workers could still choose to label the image based on the question shown without having to perform any action on the map at all, whose purpose was more of an optional aid for the task. We believe that lack of map utilization suggests that workers chose to complete the task by optimizing time and minimizing the amount of steps taken to reach payment. This result is supported by previous work on task design and on worker motivation on Amazon Mechanical Turk (Paolacci et al. 2010; Ross et al. 2010).

While not significant, the Task Load Index measure was lowest in the no-context condition *Bar Random*. Although special care was given to the design of the core interface to minimize distractions and unnecessary elements from the task, the increased TLX measures may hint to cognitive load due to the addition of the flight path progress map. Cognitive load on task design has been shown to negatively impact quality of work on crowdsourcing platforms (Finnerty et al. 2013; Kittur et al. 2013; Rahmanian and Davis 2013).

We did observe a significant difference in the percentage of workers completing the entire set of available images between the condition with both types of context (*Flight Path*) and the no context condition (*Bar Random*), which may also suggest some level of cognitive load presence in the first condition. Nevertheless, none of the workers commented on the presence of the map in the survey.

Our work was primarily based on recruiting workers from Amazon Mechanical Turk. We would like to explore the effects of context in other paid crowdsourcing platforms, as well as in pure volunteer work systems. We were also focused on one specific type of task, image analysis. Other types of tasks relevant to disaster response include structure identification on maps as well as emergency text transcription and analysis. It also remains to be seen if

similar observations can be made in non-disaster response settings on crowdsourcing platforms such as Amazon Mechanical Turk.

The selected task of this work was characterized by an increased level of complexity, as it requires meticulous image analysis for object extraction, in our case bridge structure identification and quantification. The level of complexity is validated both by the levels of accuracy posted by workers, as well as direct comments on the Additional Feedback optional field in the post-task survey. This also offers a new direction towards exploring better training concepts as well as breaking down the task into smaller, less complex subtasks to achieve our goal.

Other approaches to integrating flight path information may offer more promising directions for future work in motivating engagement in crowdsourcing aerial imagery analysis. We are particularly interested in extracting diverging flight paths from image datasets and allowing participants to branch out from the main path and explore alternative directions, as part of a larger research project focused on exploring task variety. We believe that worker flexibility during the task can contribute to the growing work on how task variety can positively impact worker performance on crowdsourcing platforms.

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November 2015 Paris Terrorist Attacks and Social Media Use: Preliminary Findings from Authorities, Critical Infrastructure Operators and Journalists

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ABSTRACT

Crisis communication is a key component of an effective emergency response. Social media has evolved as a prominent crisis communication tool. This paper reports how social media was used by authorities, critical infrastructure operators and journalists during the terrorist attacks that hit Paris on 13th November 2015. A qualitative study was conducted between January and February 2017 employing semi-structured interviews with seven relevant stakeholders involved in this communication process. The preliminary critical thematic analysis revealed four main themes which are reported in the results section: (1) social media is used in crisis times; (2) authorities gained situational awareness via social media; (3) citizens used social media to help one another; and (4) communication procedures changed after these critical events. In conclusion, authorities, citizens and journalists all turned to social media during the attack, both for crisis communication and for increasing situational awareness.

Keywords

Social media, crisis communication, situational awareness, Paris terrorist attacks, terrorism.

INTRODUCTION

On the night of Friday 13th November 2015, Islamic State in Iraq and Syria (ISIS) gunmen and suicide bombers attacked almost simultaneously a major stadium, restaurants and bars, and a concert hall in Paris. The atrocities left 130 people dead and 368 wounded. The first of three explosions occurred outside the Stade de France stadium on the northern fringe of Paris where the national football teams of France and Germany were playing a

friendly match. A man wearing a suicide belt was reportedly prevented from entering the stadium after a routine security check detected the explosives. The man backed away from security guards and detonated the explosives. The game, attended by then President François Hollande, was being broadcast on television. After a second man detonated his suicide vest outside a different stadium entrance at 21:30, the president was rushed to safety. A third suicide bomber blew himself up at a fast-food outlet near the stadium at 21:53. The attackers all wore identical explosive vests. Meanwhile, other attacks were unfolding nearer to the centre of town around popular nightlife spots. The first took place at about 21:25 in the 10th district, not far from the Place de la Republique, where driveby shootings aimed at people sitting on restaurant terraces occurred. Then, three heavily armed gunmen broke into the Bataclan, a concert venue, during a rock group performance at 21:40. They killed 90 people at the venue and critically injured many others. A map of the events is presented in Figure 1. (BBC, 2015).

Figure 1 Map of the Paris Terrorist Attacks from the BBC (http://www.bbc.co.uk/news/world-europe-34818994)

Responses to the attacks happened in real time on social media platforms, especially Twitter. Authorities, citizens and journalists all turned to social media during the event. The French National Audio-visual Institute (INA), which is one of two French bodies that have the legal authority and responsibility to archive the Internet, started an emergency collect, amassing 11 million URLs and, starting at 23:00, over 20 million tweets with related hashtags (Shaefer, 2016). For the 13th of November, there is no main hashtag as had been the case for previous events and several are used: #parisattacks #paris #bataclan #fusillade #prayforparis #porteouverte #jesuisparis #FluctuatNecMergitur #NousSommesUnis, among others (Truc, 2016). Sense making for the attacks appears to happen on social media instead of on live TV, as was the case for previous terrorist attacks. This could be due to the fact that some of the events, like for example the drive by shootings, were first reported on Twitter. Furthermore, the French emergency phone lines were quickly overwhelmed by the number of callers, and so citizens turned to social media to communicate.

Paris firefighters (@PompiersParis) also used social media, for example to encourage people to only call the authorities if there is a real need in order to avoid saturating the network as seen in this tweet (Figure 2). The city of Paris (@Paris) published on their Twitter information pertaining to the shooting (Figure 2), and in the early hours of the morning changed their background and profile picture to black to demonstrate mourning (Leclere, 2015).

Figure 2 Tweets from Parisian Firefighters and the city of Paris. Translates as, on right, "Due to recent events going on in Paris, please do not saturate the emergency lines," and on left, "shootings in Paris, we invite you to stay indoors and await instructions from the authorities cc @prefpolice."

Institutions were also active on Twitter after the event, with the German government among others using #NousSommesUnis and Anne Hildalgo, the mayor of Paris, using #FluctuatNecMergitur (Truc, 2016). Following the events, institutions official Twitter accounts saw a huge increase in followers. For example, the Préfecture de police (@prefpolice) saw an increase in 200,000 followers in the week following the events (AFP, 2015). The use of Facebook during the 13 November 2015 terrorist attack has been studied less by researchers, mainly due to the more private nature of the platform. However, it was also heavily used during the attack; with 4.1 million Facebook users activating the SafetyCheck feature.

This paper aims to study how social media was used by authorities, journalists and critical infrastructure (CI) operators during the November 2015 Paris terror attacks. In order to achieve this objective, a qualitative study was conducted employing semi-structured interviews with relevant stakeholders involved in this communication process. The study was designed to reveal the in-depth processes, as well as the lessons learnt and the communication barriers during this case study. In the following part of the paper we clarify the theoretical concepts used, describe the method and the preliminary results of the qualitative analysis, and finally we discuss the main themes revealed by our analysis.

Social Media and Crisis Communication

Crisis communication is a key component of an effective emergency response. The main aims of crisis communication are to explain to the public the event and the effects, whilst also providing information to mitigate harm (Reynolds & Seeger, 2005). Information and communication technologies (ICTs) have played an increasingly prominent role in disaster information flows over the past decade (Procter et al., 2013; Simon et al., 2015). One of the main reasons for this is that compared to traditional media (television, newspaper and radio) and other means of communication (telephone landlines, face-to-face) the use of the Internet and social media allows easy and instantaneous access to real time information (Bossu et al., 2018; Reuter & Spielhofer, 2017; Bossu et al., 2015; Gupta et al., 2013; Lerman & Ghosh, 2010). Furthermore, the ability of social media to push and pull information differentiates it from traditional media. Despite the potential use of these platforms to share disinformation and rumours, it is generally recognised that blue light organisations can leverage the connective affordances of social media to enhance emergency response.

Social media can also be seen as an amplifier for crisis information. Messages that are deemed useful to an online community can be retweeted or reposted by members and many official authorities retweet one another. For example, during the 2013 Westgate Mall Terror Attack in Kenya, all emergency related organisations and officials actively used Twitter to retweet one another (Simon et al., 2014). Indeed, studies have shown that repetition of crisis information via different channels is more likely to both reach a wider audience and convince people to take appropriate action to protect themselves and their communities from harm (Tierney, 2009; New Zealand, the Ministry of Civil Defense & Emergency Management, 2010; Stephens et al., 2013).

There is already significant evidence that citizens are turning to the social media channels of emergency services to obtain information during crisis situations (Lindsay, 2011). The authorities are responding to the public's expectation that they use social media to disseminate crisis information, and many official guidelines[1] exist. Indeed, when surveying emergency services, Reuter and Spielhofer (2017) found that 60% of respondents felt

[1] See for example, Belgium Federal Interior Minister White Paper (http://centredecrise.be/sites/default/files/brochure_sociale_media_fr.pdf) or the French Ministry of Interior's crisis communication kits destined for Prefectures (http://www.interieur.gouv.fr/Actualites/L-actu-du-Ministere/Votre-prefecture-presente-sur-les-reseaux-sociaux).

that social media is important for their organisation, with sharing information to the public being an important use case. During the 2013 Boston Marathon Bombing in the USA, local, State and Federal agencies successfully used Twitter to share information with the public about the hazard impact, guidance on how to protect oneself, and public safety advisories (Sutton et al., 2014).

Twitter in particular has also been increasingly used by emergency managers as a tool for crowdsourcing crisis information that helps build situational awareness during such incidents (Latonero and Shvlovski, 2010; Potts, 2014). It was used by authorities to crowdsource information about the identity and whereabouts of the terrorist who committed the Boston Marathon Bombing (Sutton et al., 2014) and it was also used by authorities to crowdsource information related to potential hostages during the Westgate Mall Terror Attack (Simon et al., 2014). Recent studies on citizens' expectations towards infrastructure operators and crisis communication show that they expect operators to provide crisis-related information to the public via both traditional and social media (Petersen et al., 2017a, 2017b, 2017c, 2017d).

Another way citizens are finding information and authorities are providing it is via disaster applications for smart phones. Indeed, disaster related apps have multiplied over the past five years and meet the public's timely information, alert and safety tip needs (Bachmann et al., 2015). Some examples include the *LastQuake* app by the European Mediterranean Seismological Centre (EMSC) that provides real-time earthquake information based on crowdsourcing (for more, see Bossu et al., 2018), and the French government's alert app, SAIP (acronym for Public Alert and Information System), which was launched following the 13 November 2015 terrorist attacks for the 2016 UEFA European Championship.

METHOD

This study set out to add to the limited empirical data on the role of social media in the information flows that emerged during the Paris terror attacks by exploring the perspectives of key stakeholders including critical infrastructure operators, blue light organisations and journalists. Semi-structured interviews were conducted with seven relevant stakeholders between January and February 2017 in order to explore these issues. The interview guide was developed during the EU Horizon 2020 project IMPROVER (Improved risk evaluation and implementation of resilience concepts to critical infrastructure; http://improverproject.eu) and included 10 open questions. The participants were contacted by email or phone and invited to participate in this study. All interviews were conducted at the International Union of Railways Headquarters, in Paris, either face-to-face or by phone. Interviews were conducted in French and translated into English for data analysis by a certified bilingual speaker. According to the participants' availability, two different interview schedules were developed and used to explore the perspectives of CI and emergency management professionals, and journalists in relation to disaster information flows during the attacks, and how social media might be used during future such incidents. CI and emergency management professionals were also asked about how traditional and social media were used in tandem during crisis situations, what feedback is collected, and what audiences they hoped to reach using different platforms. Sylvain Lapoix (hereafter SL), the journalist widely credited with creating #PorteOuverte, was interviewed as part of the study in order to explore the inspiration behind this hashtag and how it intersected with the crisis communication strategies of other key stakeholders during the attacks. Marina Tymen (hereafter MT) works with VISOV (Volontaires Internationaux en Soutien Opérationnel Virtuel), a French VOST (virtual operations support team) association that gathered and analysed social media for the authorities during the attacks. Also interviewed were a representative from DGSCGC / COGIC (Direction générale pour la sécurité civile et la gestion des crises - general directorat for civil security and crisis management/ Le centre opérationnel de gestion interministérielle des crises - the operational centre for interministry crisis management), a representative from the Crisis Communication Unit at the Minister of Interior, a firefighter captain representing the operational side of SDIS (Service départemental d'incendie et de secours - departmental firefighting and rescue service), and a crisis communication representative of a critical infrastructure operator.

Our study focused on three research questions:

RQ1: What role did social media play in the crisis communication practices of key stakeholders during the November 2015 Paris Terrorist Attacks?

RQ2: What role did these organisations play in the creation and promotion of #PorteOuverte?

RQ3: How, if at all, did procedures change following the Attacks?

Ethics approval was sought and obtained from the host institution prior to data being collected and it was agreed that those participants who wished to remain anonymous would not be identified in subsequent publications. Themes that emerged from the data were identified and explored using the six phases of critical thematic analysis proposed by Braun and Clarke (2006). Two coders read each transcript and compared notes in order to

identify the communication practices that these interviewees believed would help build critical infrastructure resilience.

It should be acknowledged that the data presented below is based upon a self-selected sample and could not be considered representative of how every organisation involved in the response to the terrorist attacks used social media for crisis communication during this incident. However, the participants helped us build the overall picture of how social media responses emerged and developed during and immediately after the Paris terrorist attacks. They were also able to draw on their experiences of working with other organisations in order to explore the lessons that could be drawn from the attacks.

RESULTS

The critical thematic analysis revealed four themes which are presented below.

How Interviewees Use Social Media in Crisis Times

All interviewees shared that social media is used in crisis times by their organisation, to varying degrees.

The Ministry of Interior (MoI) is responsible for crisis communication with the public and the media, and for them, social media is seen as just another channel for crisis communication.

Originally, in order for social media monitoring to even be used at COGIC, one person had to, unknowingly, break the rules by creating a twitter account in order to communicate with the people stuck in the March 2013 snowstorm crisis. By doing so, this person demonstrated that the existing procedures prohibiting social media use were not compatible with the fast paced, citizen response to crisis. However, by the time of the 13th of November terrorist attacks, social media monitoring had been more or less established. COGIC does not communicate directly with the public, and instead it is the MoI that uses their social media monitoring in order to then communicate crisis information via social media (among other channels).

While in France crisis communication must come from the Préfet and other official channels, certain firefighting stations do have a social media presence. They use it not only to promote prevention, but also to communicate about their ongoing actions. The interviewee from SDIS provided an example that certain firefighting stations might use, “Don't go in a certain zone because currently we are there on the ground intervening.” SDIS does not have official social media accounts. While they also try to keep an eye on social media, their strategy is always to intervene first, and check social media after. The official stance of both the MoI and firefighters is to encourage the public to continue to use the emergency number 18 to contact the authorities. However, the interviewees recognized that if people can’t get through on the telephone, they will use social media and are already doing so.

MT explained that while VISOV has a twitter account, when something happens they “are the last to share the information,” choosing instead to perform social media monitoring expressly for the authorities; “[our work] is not aimed to go public, because we do our work, let's say, in a private way, to go to the authorities first.” As explained by MT, “We do have a sort of methodology. But one must also tell people to not just look at Twitter and Facebook. That there are also Instagram, YouTube, Dailymotion. One must also try to see what is happening elsewhere.” They use Google sheets to document the social media messages. There, they put the name of the person who found the information, from where and at what time they accessed the information, what the information consists of (if there is a photo, what it looks like, etc.), and whether or not the information appears credible. As information on social media evolves very quickly and may become invisible (i.e. deleted) equally fast, the methodology insists on traceability. When they do use Twitter for crisis communication, they use it to amplify official channels by retweeting.

The interviewee representing the critical infrastructure operator shared that their crisis communication team also uses social media, especially Twitter, to communicate about ongoing events. “There really is, just by how things are, a crisis management system that is really well developed, able to be used at all times, and that relies on social media on the one hand to listen and also to spread information, because… [people] need information and that we understand.”

SL hadn’t used Twitter for crisis communication before the 13th of November attacks, but upon seeing some of the reactions on social media, decided to take action on Twitter and share best practices. “So I started a series of tweets… trying to bring something resembling reasonable precaution to the situation that was completely absurd and unusual… typically, don't expose yourself to danger, stay inside rather than going outside… Stuff that comes from, well I wouldn't say common sense but more from the basis of rescue services…The basics.” This also led him to the creation of the #PorteOuverte hashtag, which will be discussed in more detail later on.

How Situational Awareness Was Gained for Authorities via Social Media

The interview analysis revealed how the authorities work together with VISOV to increase situational awareness during crisis events, including the 13th of November terrorist attacks. The head of COGIC asked the interviewee from COGIC if he could find information on social media about what was going on, as well as if it was possible to do a summary of the victims. As such, the interviewee used his personal contact with VISOV to see if they would be willing to help. While originally intended to be a group that focuses on natural disasters, the immediate human reaction of the VISOV volunteers was to also help out emergency services in the case of a terrorist attack. As the representative from VISOV explained, "The 13th November, the Friday at 21:30 we were 43 in five minutes in our WhatsApp chatroom… but it wasn't specifically in our charter to go and look where is there shooting? Where are they being shot at? etc." Thus, they decided to implement their methodology to follow the events on social media. About an hour after VISOV had started collecting social media data, the COGIC interviewee contacted them, only to discover that "they had already made a spreadsheet, line by line, minute by minute, the trustworthy information, less trustworthy, underlined in red, with question marks, is this a rumour?" But instead of simply collecting all the relevant social media posts, as did INA, VISOV does a preliminary analysis and sorts the information. "Out of the 1 million tweets from 13 November, our Google doc, after about four hours, there were only 500 tweets. Because, us, our interest is to funnel the information." According to our interviewee from COGIC, the VISOV analysis provided them with "90% of the interesting tweets." COGIC then shared the information that they had received and verified from VISOV with the Ministry of Interior.

How Citizens Used Social Media to Help One Another: #PorteOuverte

The hashtag #PorteOuverte, which means "OpenDoor" in English and was first used during this attack (and subsequently reemployed for other attacks), enabled people to either ask for a shelter if they were in an unsecured area, or offer shelter, providing it to people in the streets (McHugh, 2015). Journalist SL used his understanding of the functionality of Twitter to create the #PorteOverte hashtag in order to help people who were offering shelter and needing shelter in the wake of the terrorist attack to connect (Figure 3). In his own words, "What happened is after a bit I saw two tweets on my [Twitter] feed, just by chance on my timeline, almost one on top of the other, with just seconds between them. So the first tweet was something like, 'if you are on the street Rue de Chemin Vert, I can put you up, provide shelter'… And then just below that, but really just below, someone who said 'I'm currently at the doorway of a restaurant at Square Maurice Gardette, I am outside, can you help me?' It was something like that… And so then I told myself, well actually these two people could [help each other], well really there just wasn't any matchmaking… [I did a] tweet straight away where I said, well I no longer remember the exact words, but it was something like, 'if you are looking for or offering shelter due to the Paris attacks, add the hashtag PorteOuverte.' And that's where it all started."

Figure 3 Tweet from Sylvain Lapoix about #PorteOuverte. Translates as: Those who can open their doors, geolocate your tweets + #OpenDoor to indicate safe places. #shooting #Paris

According to SL, there were mainly three types of users of his hashtag: retransmission or relay tweets that consisted of people recommending to use the hashtag or simply retweeting him; use-tweets that consisted of people actually using the hashtag to find/give shelter; and collective reassurance tweets that consisted of people expressing what a good idea it was. As SL said, "well it was someone who said that in such a moment, the fact to see the movement, to have something like #PorteOuverte, and to have so many people latch onto it and use it to really take action, well for him it was a light in the darkness." Furthermore, SL believes that the use tweets were in the minority, if for nothing else than out of 300,000 tweets with the hashtag, there were not 300,000 people "with their mobile phones on Twitter looking for shelter." Instead, not only was the hashtag useful to people who needed shelter, but it also provided a means to become an actor in the crisis and "pass on something positive." When asked about how the tweet became so viral, SL explained that "I just wrote the right hashtag in maybe the right quarter hour" and at first wasn't even sure if he really was the person who came up with the

idea (however this was later verified). His understanding of twitter as a journalist also helped him spread the hashtag, as he asked people with lots of followers (known as influencers) to retweet his #PorteOuverte tweet. He also insisted on Twitter as being the appropriate medium for such kind of communication among citizens, especially considering the fact that the phone lines were overwhelmed and the emergency lines were saturated. Lastly, he acknowledged that the authorities cannot be expected to ask people to potentially put themselves in a dangerous situation, as may be the case by using this hashtag, and thus it needed to come from the citizens themselves.

How Procedures Changed Following the Attacks

Following the attacks, the firefighters updated the calling system for the main emergency telephone number 18 in order to ensure redundancy and attempt to eliminate call centres being overwhelmed with callers, as was the case during the 13 November Attacks. As put by our interviewee, "the, I don't know how many, millions of calls that were lost, now they will come through, whether that be in Marseille or Toulon. And there will be someone to answer, and say, 'don't worry, we're sending people.'" SDIS is currently reviewing best practices of social media use by firefighters and hopes to be able to use social media for crisis communication shortly. Furthermore, COGIC got the authorisation to start work on a social media monitoring tool that uses keywords to detect crisis. As our interviewee put it, "Actually, it's been four years that I've been asking for this tool and we had to have the 13th of November in order for us to have access to it."

The #PorteOuverte hashtag was subsequently used in following incidents of terrorist attacks, for both the Brussels and Nice Attacks. As SL said, "today, when we see a situation where people are stuck in an unusual and dangerous situation elsewhere than where they are from and they don't have any resources…well, we've seen that some people have relaunched #PorteOuverte." When asked about the future use of the hashtag, MT explained "It's part of history now." While citizens have continued to use the hashtag, according to SL there remains a personification of the hashtag. "During Nice [someone] sent me a message saying, 'go go go Sylvain!' … So in other words, my position as an influencer was still expected."

The interviewee from the MoI brought up the SAIP app, which was created following the attacks and is supposed to send alerts notifications on all smartphones on which the app is currently running. While there have been some critiques of the app (especially following the 14th of July 2016 Nice terrorist attack where the alert was sent out very late) (Fallou, 2017), the MoI representative informed us that "we have had a peak of downloads that was higher than the uninstalls after the events."

DISCUSION AND CONCLUSION

This study investigated the perspectives of CI and emergency management professionals, and journalists in relation to disaster information flows during the 13 November Paris terrorist attacks, and explored how social media might be better used during future such incidents.

Our analysis revealed that authorities, citizens and journalists all turned to social media during the 13th November 2015 Paris terrorist attacks, both for crisis communication and for increasing situational awareness via monitoring. Authorities such as the Prefecture of Police, the Paris firefighters and the city of Paris used social media for crisis communication, as did the Ministry of Interior. COGIC partnered with VISOV in order to do social media monitoring of the events, increasing situational awareness and sharing this information with the Ministry of Interior. Journalist Sylvain Lapoix used his knowledge of social media in order to create the #PorteOuverte hashtag, which enabled citizens offering shelter and needing shelter to connect. The fact that the hashtag propagated so quickly could be explained not only by its usefulness, but also by its positive nature. Indeed, most tweets with #PorteOuverte were not use-tweets, and previous research about the 2013 Woolwich, London terrorist attack found that members of the public using twitter chose to mostly distribute positive and supporting content (Burnap et al., 2014). While the hashtag was not promoted by authorities, SL pointed out that as the hashtag could potentially lead citizens to danger, the authorities couldn't endorse it. However, he was critical of the fact that the hashtag was not promoted by the media during the events (and only afterwards was it talked about as a 'phenomenon'). That said, the media engagement with the hashtag as a phenomenon could explain why it remained in collective memory and was reemployed in subsequent terror attacks. More research is needed to confirm this. Since the attack, interviewees have changed their procedures in order to better respond to any future crisis.

While social media was heavily used during the 13th November attacks, a recent survey by the French Research Institute for the Study and Monitoring of Living Standards (CREDOC) found that only 6% of respondents found out about the events via social media, compared to 81% via traditional media (Ory, 2017). One explanation for this finding might relate to the large television audience for the international football friendly being played at the

Stade de France that evening (an estimated 5.75 million people were said to be watching). Moreover, according to the Standard Eurobarometer 84 survey, radio and television remain the most popular and trusted media in France, with 100 percent of participants stating they had access to at least one television set. That said, studies show that people tend to use a combination of both traditional and social media to obtain information about crisis situations (Petersen et al., 2017a). Thus it is important to keep in mind that social media was neither the only information source nor the only channel for crisis communication for this event.

In summary, crisis communication on the 13th of November can be seen as a matter of cooperation between different types of actors, who have different means of actions and different constraints.

The results reported above have a number of limitations that should be acknowledged. Most of the limitations are inherent to the qualitative methods used. Semi-structured interviews can leave room for subjective answers and the critical thematic analysis for subjective interpretations. Furthermore, the self-selecting sample is made up of a low number of interviewees that did not include all possible stakeholders. While the findings may be relevant for recent terrorist attacks in France, they are difficult to generalize to other critical events or contexts. However, this paper does showcase the big picture of how social media was used during the Paris terrorist attacks for both crisis communication and increasing situational awareness of authorities and to the best of our knowledge is the first paper to do so. Previous research on social media use during terrorist attacks has also tended to focus on the tweets themselves instead of the perspectives of social media users and this paper attempts to help fill that gap.

Future work will continue to apply the critical thematic analysis proposed by Braun and Clarke (2006) on this corpus of data in order to analyse the latent level of the content (e.g. the underlying ideas, assumptions, and conceptualizations). Future work should also include further interviews. Other studies could further compare the results of this study with how social media was used during other critical events in France or other European terror attacks, or how social media was used in tandem with other crisis communication channels during this event.

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Social Media in Citizen-Led Disaster Response: Rescuer Roles, Coordination Challenges, and Untapped Potential

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ABSTRACT

Widespread disasters can overload official agencies' capacity to provide assistance, and often citizen-led groups emerge to assist with disaster response. As social media platforms have expanded, emergent rescue groups have many ways to harness network and mobile tools to coordinate actions and help fellow citizens. This study used semi-structured interviews and photo elicitation techniques to better understand how wide-scale rescues occurred during the 2017 Hurricane Harvey flooding in the Greater Houston, Texas USA area. We found that citizens used diverse apps and social media-related platforms during these rescues and that they played one of three roles: rescuer, dispatcher, or information compiler. The key social media coordination challenges these rescuers faced were incomplete feedback loops, unclear prioritization, and communication overload. This work-in-progress paper contributes to the field of crisis and disaster response research by sharing the nuances in how citizens use social media to respond to calls for help from flooding victims.

Keywords

Crisis communication, social media, emergent groups, volunteerism, mobile technology, emergency management

INTRODUCTION

Natural disasters often pose an overwhelming demand on first-responders—a demand that cannot always be met by official organizations. Aside from simply not having enough staff to meet the response need, local organizations often find their equipment, structures, and supplies damaged, flooded, or otherwise inaccessible or inoperable. Although some "disaster myths" (Perry & Lindell, 2003) stereotype citizens as helpless victims or prone to panic, disaster evaluations reveal that most victims are saved by fellow citizens (Helsloot & Ruitenberg, 2004). Citizens also form groups to collectively coordinate and help those in need. Whether using the label of "emergent response groups" (Drabek & McEntire, 2003), "emergent citizen groups" (Stallings & Quarantelli, 1985) or the moniker of "informal volunteerism" (Whittaker et al., 2015) citizen-led groups play a clear role in disaster response. Prior research indicates that these groups tend to emerge when citizens feel that demands are not being met by existing organizations (Auf der Heide, 1989). For example, ham radio operators served to transmit information, dispatch ambulances, and coordinate rescues in the wake of the Hurricane Katrina disaster (Majchrzak et al., 2007). During

Hurricane Sandy, citizens used Twitter to alert others to gas shortages, electricity outages, and road closures (Murthy & Gross, 2017).

The citizen-led rescues of flood victims in the aftermath of Hurricane Harvey in Houston, Texas are a recent example of emergent volunteer response. In August 2017 Hurricane Harvey hovered above Houston, TX, dumping record levels of rain on the region. Flood control aqueducts spilled over their banks and flooded 30-40,000 homes in Houston and the surrounding suburbs. This level of flooding was unprecedented, official response varied throughout the area, and thousands of families were trapped in their flooded homes. Multiple city officials and the Federal Emergency Management Agency (FEMA) called for citizens with boats to help rescue people trapped in their homes (Quinn, 2017; Raja, 2017).

Citizens and community groups responded to officials' requests to bring boats and help with the rescue effort. Some citizens operated independently to conduct rescues, while others acted as members of groups like the 'Cajun Navy'—boat owners who travel from surrounding regions to flooded areas and conduct water rescues and/or deliver supplies. The Cajun Navy is not a singular organization. Rather, there are multiple groups operating under the Cajun Navy umbrella. As scholars have noted with similar emergent response groups (see Majchrzak et al., 2007), official membership or affiliation with the Cajun Navy is fleeting. Some individuals may claim membership in the group whereas other individuals are assumed as Cajun Navy because they own a boat and helped conduct rescues. Structures present in The Cajun Navy also mirror findings of previous emergent-response-group research (Drabek & McEntire, 2003) in that leadership is fluid and dispersed, boundaries are unclear, task definitions and assignments are unstable, and contributors are often geographically dispersed. Although membership and boundaries are fuzzy, one thing became clear during the Hurricane Harvey response: mobile communication technologies played a key role in both independent citizens and 'members' of the Cajun Navy's ability to rescue flood victims.

The use of social media and mobile technologies during disasters is not a new phenomenon (Hiltz et al., 2014, Murthy & Longwell, 2013, Reuter & Kaufhold, 2017). A plethora of prior research examines official, top down (Giacobe & Soule, 2014; Hughes & Palen, 2012; Hughes, St. Denis, Palen, & Anderson, 2014; Kavanaugh et al., 2012; Ruggiero & Vos, 2014) and public, bottom up (Starbird & Palen, 2011; White at al., 2014) use of social media during all phases of a disaster life cycle. A majority of the bottom up research focuses on Twitter—a publicly-available data source (David et al., 2016; Hughes & Palen, 2010; Starbird & Palen, 2011; Starbird et al., 2012) and concerns information gathering and dissemination functions.

While Twitter indeed plays an important role during many disasters, the standout social media platforms used to *coordinate* citizen dispatchers with citizen rescuers during the Hurricane Harvey floods in Houston, TX were the Zello walkie talkie app, some new apps developed specifically for Harvey (e.g., CrowdSourceRescue, see Figure 2), Facebook (see Figure 1 of Cajun Navy using Facebook), and a host of other ad hoc platforms.

Figure 1: Cajun Navy Facebook (available publicly)

Figure 2: CrowdSourceRescue (available publicly)

Whereas research has examined social media use by officials and the public during disaster, we know less about how emergent groups use mobile communication technologies and social media to coordinate actions during disasters (see Fritze & Kray, 2015 for a notable exception), particularly during flooding. Considering citizens are often the first on scene during disaster, it is important to study how they utilize mobile technologies and social media tools to facilitate response. Thus, our first research question:

> RQ1: How do emergent groups use mobile communication technologies and social media to coordinate actions during a wide-scale flood disaster?

Furthermore, it is important to learn the challenges they faced using mobile tools and social media, so those can be addressed in future disasters. Therefore, our second research question is:

> RQ2: When social media and mobile communication technologies were used to coordinate actions among volunteer rescuers, what communication challenges emerged?

METHOD

This study on social media use in citizen-led disaster response groups was conducted as part of a larger project examining the role of social media in posting calls for help during Hurricane Harvey. Eriksson and Olson (2016) claim that, "social media is not a homogenous phenomenon with one coherent role in crisis management and communication research and practice" (p. 205). To that end, we did not focus on one particular social media platform. Instead, we examined the social media technologies used in practice by citizens during the Hurricane Harvey response.

Data Collection

Participant recruitment started by contacting relief organizations operating in the wake of Hurricane Harvey. Using snowball sampling techniques, our initial respondents referred us to individuals who participated in the rescue effort. These responders were either working on their own, or they were part of a group. One set of our respondents were members of the various 'Cajun Navy' groups. Other respondents were part of groups representing religious organizations, non-profit festival groups, and community groups that sprang up in direct response to Hurricane Harvey. A semi-structured interview guide was used to elicit responses related to the individuals' roles and involvement in volunteer rescues. Questions asked about the participants' motivation for contributing, memorable rescues, decisions to use social media, emotions experienced during rescue, and communication successes/challenges during rescue.

We completed 20 interviews for this analysis of our work-in-progress study (see Table 1 for participant information) that ranged from 31 minutes to over two hours. All interviews were audio recorded for later transcription. The data were analyzed by listening to audio recordings, reviewing field notes, and engaging in team discussions where we followed Owen's (1984) criteria of recurrence, repetition, and forcefulness. Both research questions were answered using this inductive analysis and for research question one, we identified types of social media and the roles rescuers played. Our three core themes and one overarching theme emerged inductively and represent our conceptual categories as we addressed research question two.

Table 1. Study Participants

Pseudonym	Age	Role	Association
Barbara	56	Dispatcher*	Individual
Bill	51	Rescuer*	Individual
Brock	20	Rescuer	Community Group
Carol	42	Dispatcher	Community Group
Diana	44	Dispatcher	Community Group
Harry	33	Information Compiler*	Community Group
Genevieve	34	Information Compiler	Community Group
Harriett	46	Dispatcher	Cajun Navy
Ilene	62	Information Complier	Community Group
Jade	31	Dispatcher	Individual
Jake	47	Rescuer	Cajun Navy
Julie	40	Dispatcher & Rescuer	Community Group
Kathryn	47	Information Compiler	Community Group
Mike	44	Rescuer	Cajun Navy
Olga	59	Dispatcher	Individual
Rachel	48	Rescuer	Community Group
Ripkin	33	Rescuer	Community Group
Sarge	50	Rescuer	Cajun Navy
Susan	68	Dispatcher	Community Group
Tucker	48	Dispatcher	Cajun Navy

**Note: The three roles emerged through addressing RQ1*

FINDINGS

Research Question 1: How did citizens use mobile tools and social media?

To address this research question, we first identified the host of specific tools people used during the rescue efforts, but we also found that how they used these tools varied depending on the rescue role they played.

Specific Social Media Tools

Using a combination of research on publicly available news and social media sources, as well as through our interviews, these dominant platforms emerged to coordinate citizen response: Zello walkie talkie app—a push-to-talk smartphone application that mimics the functions of a walkie-talkie, Facebook—both public pages and private group sites, NextDoor—a private neighborhood-specific social media platform, and a host of related technologies that were repurposed to organize disaster responses. For example, Brock, who was involved in volunteer rescues in the greater Houston area and provided clean-up after the flood, stated, "We started a Google Doc where people could post 'I need help' or 'I can help." We also found that the specific tools groups used were defined by their group and that many new apps emerged during the rescue effort.

Rescue Roles

Citizens joined the rescue effort by falling into three different types of roles: *rescuer, dispatcher*, or *information compiler*. The visible role that some citizens played was the *rescuer*; these were the people in the water who often were interviewed by the media. These volunteers came with their boats, found a way to launch their crafts, and physically rescued flooding victims. The rescuers often had mobile phones with them on their boats. Their use of mobile phones to communicate or access social media varied depending on how busy they were and how much rain was present during the rescue. Many of these volunteers reported having to purchase new mobile phones after the rescues because their devices were damaged by the rain and flood waters.

The next role, vital for the success of the rescues, was what we call the *dispatcher*. These people stayed behind the

scenes, often by choice, but still wanted to help the rescue effort. They sat behind computers, and/or mobile devices, in dispersed locations and physically used rescue-related platforms. These behind-the-scenes rescuers performed valuable activities: managing a fairly organized rescue-system platform, searching multiple social media platforms for people who said they needed help, taking phone calls from rescuers in the field, finding updated weather and road conditions online, and trying to update information that could help other people in the rescue effort. For example, one volunteer rescuer, not affiliated with a specific organized rescue group, Bill, recounted how family members back in Austin, TX 'dispatched' him around Houston:

> "They were on Facebook getting all the information, um, they had Facebook on one screen they had Google maps on the other with road closures and then they started mapping it out and um, so they had information I didn't in the car so they told me where to be."

Jake, also a volunteer rescuer, working with the Cajun Navy, had his wife monitor the Cajun Navy social media page while he conducted rescues in the field.

The third role people played was a behind-the-scenes *information compiler* not directly involved with the rescue effort, but they saw themselves as vital links to information. These information compilers often had neighborhood maps that they shared through private social media platforms like NextDoor or community Facebook pages, and they were adept at finding relevant information like road closures, predicted flooding levels, and statements from officials about the flooding. The more influential information sources had large networks of community members who followed their Facebook pages, or they were regular contributors to NextDoor before the extensive flooding happened. They were not necessarily social media or technology experts, but they could find the valuable information that others needed during the rescue efforts.

RQ2: Emerging communication challenges when using social media to coordinate actions among volunteer rescuers.

While it is broadly understood that citizen rescues saved many lives in the Greater Houston, Texas area, there were three technological communication challenges that emerged from interviews: *incomplete feedback loops*, *unclear prioritization*, and *communication overload*. Together, these three themes led the volunteer rescuers to feel dissatisfied, but also hopeful for the future. We discuss each of the themes next and end explaining this overarching finding.

Incomplete feedback loops

The main feature all the mobile apps used to track rescue status was through the mechanism of marking. For example, a common way this is accomplished on broad social media platforms, like Facebook, is marking one's self as safe. In theory, the marking mechanism was much more sophisticated in the rescue platforms, but a person had to manually update the system and close the feedback loop.

Harriett commented:

> "There were so many rescues happening and so many requests coming in that it was hard for people to know, hard for the rescuers to know if anyone had already gotten to a certain address or not and so there was a lot of repeat. Ya know someone would get rescued but there was no way to know that and so then a different rescuer would go and that person would already be gone."

With a high volume of information coming in it was difficult for both volunteer rescuers and the people being rescued to remember and report back that they were no longer in need of rescue. While conducting rescues from his boat, Mike utilized a particular Facebook feature:

> "Facebook has this thing where they can tag themselves safe or not safe or whatever and uh, we were using that app thing a lot. It would show you several potential locations and we would try to pick an area with a bunch of pins and go to that area and try to hit all those addresses and make sure everybody was out but we found most of em were already gone."

Harriett explained that there were processes in place to close the feedback loop, but they were not always followed. As a dispatcher using the Zello app, Harriett provided the flood victims with a case number to give to the rescuers once on the boat. Once the rescuer had the case number they could mark that particular case as closed. But, in the hustle and bustle of rescues, many flood victims forgot the number entirely, or did not remember to tell the rescuer their case number. Many flood victims and volunteer rescuers' phones were also destroyed by rain or flood water, leaving them no way to contact the dispatcher and close the feedback loop. Or, as Susan noted, "You never knew which boat was gonna pick them up because somebody else could drive by and pick them up too. So it wasn't the best organization." If a boat other than the one dispatched for that specific case number reached the flood victim first, then the feedback loop was often left open.

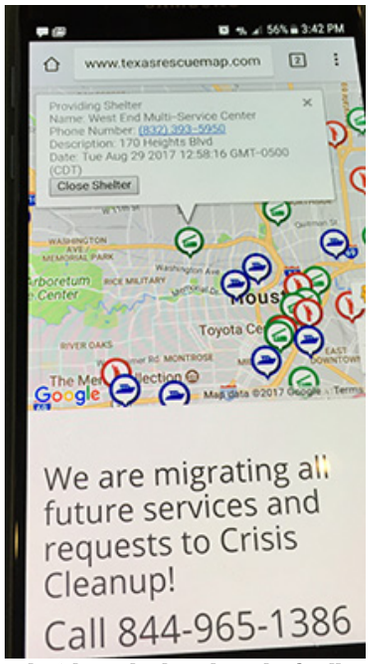

Figure 3. Screenshot of mobile app created with method to close the feedback loops (shared publicly during the disaster).

Unclear Prioritization

A common problem cited by citizen dispatchers and rescuers alike was that there needed to be a way to prioritize certain calls for help. These criteria are established in official response and rescue systems that focus on whether the call is deemed to be life-threatening (Nordberg, 1995) but citizen groups found themselves knowing intuitively that prioritization was needed, but then feeling awkward about enforcing these mushy rules. Indeed, 9-1-1 operators face similarly blurred lines (Nordberg, 1995). For instance, if someone was elderly or injured there needed to be a way for the technology to help the citizen dispatcher indicate the priority of that rescue call:

> "I definitely think that is a point that needs to be addressed if this happens again with this kind of social media rescue kind of thing somebody needs to be in, . . . [short pause] people that are trained to do that need to be in charge of prioritizing calls and assigning." – Harriett

In one case, Harriett needed a rescuer to reach an elderly man who could not easily navigate through the floodwaters. Because Harriett did not have a way to prioritize this call for help, she had to manually cut into conversations on the Zello walkie-talkie app and continually remind the rescuers that the rescue was urgent. This is a clear example of it taking redundant messages to capture the attention of the already overloaded rescuers.

Gary recalled a mother who made an urgent call for help, "she posted, I think on Facebook and Nextdoor, 'water's four feet in our house, we lost power, we moved to the second floor and my son is on a ventilator can someone get us?' and they were rescued finally." There were literally so many messages posted through diverse social media platforms that people were missed, and at times three boats showed up at the same time to rescue the same family.

To overcome the prioritization problems, Brock's group setup a Google Document to collect information:

> "We set up like name, phone number, what you need, and is it immediate?, kind of thing um, and so it gave us a chance to get the information we needed rather than someone just saying 'hey we need help.'"

Although the Google Document allowed Brock's group to indicate priority levels, they were only able to gather this information from flood victims that they spoke to on the phone. Then, there was still the issue of closing the feedback loop when people were actually rescued.

Communication Overload

It is not surprising that citizens—many not trained to handle the chaos that is normal in an emergency—expressed feelings of being overwhelmed. However, our findings allowed us to identify three primary reasons that volunteer responders felt communication overload: (1) they received too many calls for help at once, (2) when using the Zello app, there was excess radio chatter, and (3) concerned family members called and texted them directly to stay top of their mind.

Too many to help them all

While Bill was driving his boat rescuing people in the pouring down rain, his family member, acting as a dispatcher,

would text him about urgent messages he found on social media, "I would get endless streams of texts of 'okay there's another person over here that needs help' . . . honestly, they gave me a lot of addresses; I only got to maybe two of them." In addition to the large quantity of information becoming a burden, Bill went on to say that he could not carry out many of the rescues due to flood conditions. His boat needed about two feet of water to float and some neighborhoods had shallow spots preventing him from reaching the other addresses.

Gary recalled, "it became overwhelming just trying to keep track of who was going out who was coming back who was out on a boat, can we account for everyone, and who's in their house and it was a mess."

Jake, a leader of one of the Cajun Navy groups that also helped conduct rescues in Louisiana's 2016 floods, compared the volume of calls for help between the two situations: "it was so many [in Louisiana] you couldn't um, you couldn't answer all of them and during Harvey it was even tenfold that, it was just amazing." The calls for help reached Jake through posts on the Cajun Navy Facebook page wall and private messages sent to the Cajun Navy page. Jake claimed, "the personal messages, there were so many coming in at one time I might click on a message to read it and by the time I read that message I'd done had 15 or 20 more pop up."

Radio chatter

In addition to the quantity of calls for help, the Zello App became overloaded with radio chatter. As Jake put it, "there was just so much chatter online that you couldn't keep up with what somebody started information wise giving somebody, ya know, they'd get bombarded with other people ya know maybe giving addresses of another rescue."

It is important to note that the Zello App was available for download by the public; official emergency responders use private channels and trained dispatchers to streamline their communication. However, it is equally relevant that by being publicly available, anyone who knew about Zello could make requests, something not possible through official radio channels.

In some instances, citizens who needed to be rescued discovered the Zello App and began using the rescue communication Zello channels to call for help:

> "A lot of civilians that were needing to be rescued they'd go straight to the Zello channel that our rescuers were on and, once again, you had about 40 or 50 of them trying to make rescue requests on there, it kind of hampered our efforts out in the field . . . it was pretty much chaos at that point" - Jake

This overload of data meant that the information was not always received and translated into actionable knowledge.

Eventually, the overload of communications on Zello was partly relieved by dividing up communication channels:

> "There was so much traffic [radio traffic] in Houston they split the Zello group into two different groups, one in Houston, the original one, and one in West Houston" – Bill

> "We learned to make several groups so it would kind of clear some of that up and we wouldn't have so much traffic on each channel." - Jake

Requests by concerned family members

Communication overload was not only in the form of direct calls for help initiated by people who were trapped or needed rescue, but many volunteer rescuers were constantly being asked for updates by concerned family members:

> "My parents are very like 'tell me what's going on now' and so like my phone was constantly blowing up from them and it was just like 'we're here, bye, I'll talk to ya'll later' and so that was, I think that was what was hard was some of the responders, they were coming and their families were like 'are you okay, are you okay, are you okay.'"

As Brock's quote illustrates, citizen dispatchers and rescuers responding to disaster are often overloaded with messages from concerned family members. In Brock's case, his parents concerns were likely exacerbated after he used his mobile phone for Zello so much that the battery died. This may be a particular type of communication overload that official sources are not often faced with. For instance, if family members of Police officers, EMS workers, or firefighters are accustomed to their loved ones helping in times of crisis, then the family members may not check in as often.

The communication overload finding also represents a culmination of the two other key themes.

Untapped Potential & Hope for the Future

These three themes describing the key social media challenges, *incomplete feedback loops*, *unclear prioritization*, and *communication overload*, led to an overarching finding: interviewees painted a picture of the disaster response as one of *untapped potential*. While the informal individual volunteers and groups rescued thousands of flooded residents, many interviewees expressed regret that they could not rescue more people. Mike, a member of the Cajun

Navy put it succinctly:

> "There was a lot more volunteers could've done, but there just was not enough resources to direct us where we needed to go so what you ended up with was the end of the day was a thousand guys riding around trying to find people to help."

Similarly, Brock commented how the ad hoc nature of the response made some boats redundant:

> "I think that was the hardest part was explaining, okay, if you four boats go in that neighborhood and you three go into that neighborhood rather than 20 of us going to here and there's only three families that need it."

Susan also noted the extra boats:

> "We had so many boats in the neighborhood they actually had to be sent away because there were too many."

Even though they may not have accomplished as much as they would have liked, some expressed amazement at the collective effort. For instance, Harriett acted as a behind the scenes dispatcher using the Zello App and commented:

> "To know how much was done without official organization is just mind boggling to me. That many thousands of volunteers with no official organization or no one really telling them what to do just kind of coming together and making it happen."

DISCUSSION & CONCLUSIONS

Previous disaster research confirms that individuals and groups have a tendency to become more cohesive, improvisational, and prosocial when faced with disaster (Helsloot & Ruitenberg, 2004; Murthy, 2013; Stallings & Quarantelli, 1985). In other words, people *want* to help. This study provides additional insight into the roles that citizens can play in the rescue effort and what we can learn from how social media was used to coordinate and respond during Hurricane Harvey. While official responders have used a response-dispatch model for decades, official communication channels are private and not accessible to the public. While some privacy is certainly needed, we find that the only way citizen rescuers can share information about rescues with official rescuers is by leveraging the information compiler role.

Furthermore, the separate groups of citizen rescuers have a similar challenge: they use different social media platforms. One of the few shared systems was Zello, and it was not used by all groups. For instance, Jake, a leader of one of the Cajun Navy groups commented, "They'd [rescuers] never heard of Zello or didn't know how to work it, didn't even have the app on their phone, so what I'm getting at is they weren't real tech savvy." But that particular group had their own system they used to coordinate rescues. Figure 4 displays this coordination challenge, but also illustrates how dispersed citizens who want to help can jump into the response process and serve in valuable behind-the-scenes roles.

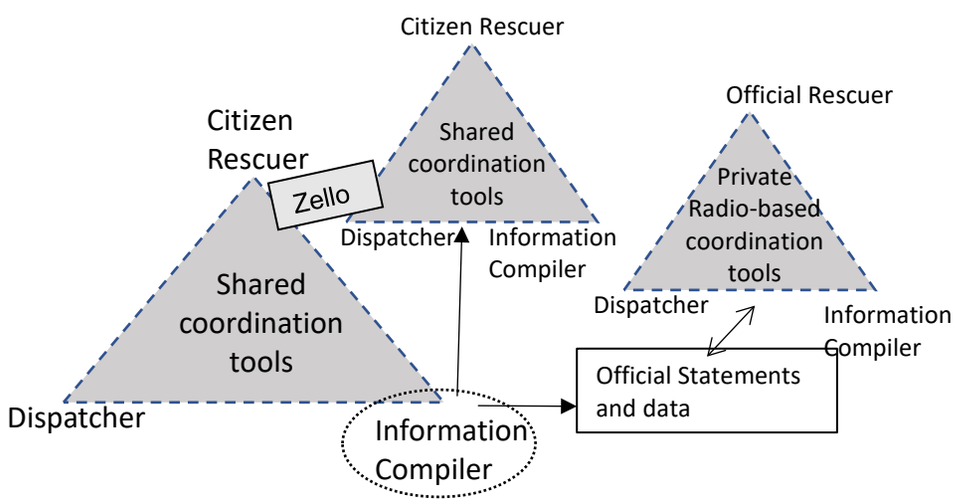

Figure 4. Information Compiler Role

Figure 4 is a simplification of what actually occurred during Hurricane Harvey. Our data show that there were at least 20 different groups, and between them, there was no way to seamlessly share information and coordinate activity. The information compilers would often look between the disparate groups and try to share that information to close

feedback loops, but they could not do much about prioritization or overload. The dispatchers were often making the decisions on prioritization, but they felt uncomfortable having that much responsibility unless they had been trained in a similar job role prior to the emergent dispatch system.

Communication overload was a challenge faced primarily by the citizen rescuers and dispatchers. As previous research has indicated communication overload encompasses multiple dimensions and can lead to frustration, poor decision making, and burnout (Burchell, 2015; Stephens et al., 2017). Brock, a rescuer with a community group, communicated with his team of other boats using his own 2-way radio system but he also kept an earpiece in his ear tuned to the Zello App; that was how he learned where to go and who needed to be rescued. Brock commented, "by far I think [Zello] was what made the impact because the setting up of that was just incredible. By the time we got there it was all over social media 'get on Zello!'" Zello functioned as a way for disparate groups to share some rescue information, but in the process, so many people jumped on Zello that communication overload became a reality. These are clearly real problems, but Harriett, a dispatcher, still found the social media tools useful: "I do feel like without that app and social media and obviously of course without the volunteer rescuers who were out on the boats I think lots more people would have died."

The challenges facing citizen-led disaster response are not simply technological. While technology designers should take into account affordances of the social media platform (e.g., prioritization, feedback loop) that will help disaster response, attention should be paid to the design of intuitive systems that can quickly be mastered by the novice social media user.

This study is limited by a small number of interviews concerning one specific disaster response. However, we are in the early stages of this 'work in progress' and plan on further developing our findings for future studies. The findings presented here represent an early look at the communication technology challenges and opportunities facing citizen-led disaster response coordination.

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Helping Crisis Responders Find the Informative Needle in the Tweet Haystack

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ABSTRACT

Crisis responders are increasingly using social media, data and other digital sources of information to build a situational understanding of a crisis situation in order to design an effective response. However with the increased availability of such data, the challenge of identifying relevant information from it also increases. This paper presents a successful automatic approach to handling this problem. Messages are filtered for informativeness based on a definition of the concept drawn from prior research and crisis response experts. Informative messages are tagged for actionable data – for example, people in need, threats to rescue efforts, changes in environment, and so on. In all, eight categories of actionability are identified. The two components – informativeness and actionability classification – are packaged together as an openly-available tool called Emina (Emergent Informativeness and Actionability).

Keywords

informativeness, twitter, social media, actionability, information filtering

INTRODUCTION

A key aspect of dealing with the aftermath of disasters and critical events is to get a quick situational understanding of the situation. This situational understanding enables responders to not only understand the gravity of the situation and the needs of the affected community, but also the operational circumstances and the availability of resources. However, during a crisis situation getting a coherent understanding of the situation can prove challenging, due to its chaotic nature. Therefore crisis responders are continuously looking for key pieces of information to build, implement and improve their response (Harrald 2006).

In recent years, the advent of information technology has provided crisis responders with new tools and systems to collect information directly from the communities affected by crisis. At the same time, with the rise of social media and the profusion of mobile technology the same communities are also increasingly empowered – and at times incentivized – to share their data through an increased number of channels. These developments provide crisis responders with access to more data than ever before, directly from the communities affected by the crisis (S. Vieweg et al. 2010).

However, this data surge has given rise to new challenges. Where before the key challenges were to gather sufficient data to build a situational understanding, the main challenges now are to identify the relevant messages (Comes, Meesters, et al. 2017). While many responding agencies have confirmed the usefulness of social media and other

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forms of electronic information gathering, it remains challenging to integrate an effective workflow in short-burning crisis situations (Meesters et al. 2016). Currently, organizations often rely on external volunteers, such as the Standby Task Force in the wake of the 2010 Haiti Earthquake (Patrick et al. 2011; Rencoret et al. 2010). However, not all organizations have the capacities or knowledge to process the large amounts of data available to them in the search for relevant messages.

Information filtering is critical to crisis workers dealing with streams of information related to emerging and ongoing situations (S. E. Vieweg 2012; Temnikova et al. 2015). Today, messages in many forms arrive constantly in volumes too large for humans to effectively prioritize in real-time. In this research, we aim to provide automated methods for filtering this information so that crisis workers can effectively find potentially important messages and perform information triage.

Crisis worker flow typically begins with defining selectors that determine what information is retrieved; these could be keywords, particular sources, GPS coordinates, and so on. For example, to get content about hurricane Irma, one could capture just messages that contain “irma" and originate within the monitored area. This is the first pass at reducing the volume of information, but even with this, the volume of information balloons rapidly as events progress; data for Typhoon Yolanda in 2013 goes from 182 tweets in the first three days to 1778 on the fifth day and 4385 a week later; the west Texas explosion generated 10K tweets on the first day, going from 128 tweets in hour 1 to 2456 in hour 4.[1] And indeed these selectors do not guarantee that the incoming data is good; many messages can be irrelevant (Homberg et al. 2014).

These challenges are however not only related to natural disasters, but also extend to other disruptions and incidents faced by communities around the world. For example, in a recent iHub project exercise monitoring elections in Kenya, workers found roughly 90% of the messages captured in the message monitoring Ushahidi platform were irrelevant[2] – not only due to their content, but also due to missing content, repetitive messages, and so on. In this case the messages were deliberately solicited: people were encouraged to post their own observations (via various channels). Despite this ’top-down’ approach, the collected data still resulted in the high percentage of irrelevant messages. In sudden onset disasters, the number of messages and noise is potentially much higher. Methods to ease the impact of high data volume are therefore still pressing.

These developments and trends show that a tool to reduce the amount of data seen by humans and filter to just the relevant messages is not only necessary but would improve the usefulness of the data available to responders. The development of auto-assessment of informativeness is the first challenge that needs to be addressed towards a system of automated identification of relevant messages for crisis responders.

In this paper, we describe the openly-available Emina (Emergent Informativeness and Actionability) tool, which we have developed to address these issues as part of the EU COMRADES project.[3]

RELATED WORK

The problem of assessing informativeness automatically, or of extracting salient posts from intense social media streams, is not unfamiliar. Prior work has addressed informativeness extraction and coarse classification using DNNs (Nguyen et al. 2016). Over this, we add many categories of actionability, while also refining the informativeness decision using a new dataset and training target. Other efforts have addressed the data scarcity problem by recycling prior data (Imran, Mitra, and Srivastava 2016) over a two types of event (earthquakes and floods), or focused on extracting individual self-contained documents that are highly relevant, as exemplars of the ongoing crises or high-quality messages that should be responded to (Imran, Elbassuoni, et al. 2013).

DEVELOPMENT APPROACH

Our approach began by developing a definition for informativeness. With this, we can gather and annotate data for its informativeness, using a crowdsourcing task, where readily-available workers are drawn from a pool over the internet to quickly process the kinds of tasks that require human intelligence. This produces our training set. This training set is used to train a machine learning system, which learns mathematical rules about the text in the training set that help it predict the informativeness of future, previously-unseen messages, mimicking a deployed situation. The same general approach is taken to learning actionability.

[1] From CrisisLex data (Olteanu, Castillo, et al. 2014)

[2] See https://www.ushahidi.com/blog/2017/08/10/ushahidis-global-uchaguzi-partnership-crowdsourcing-kenyan-election-incidents-shows-a-mostly-orderly-election

[3] See http://comrades-project.eu

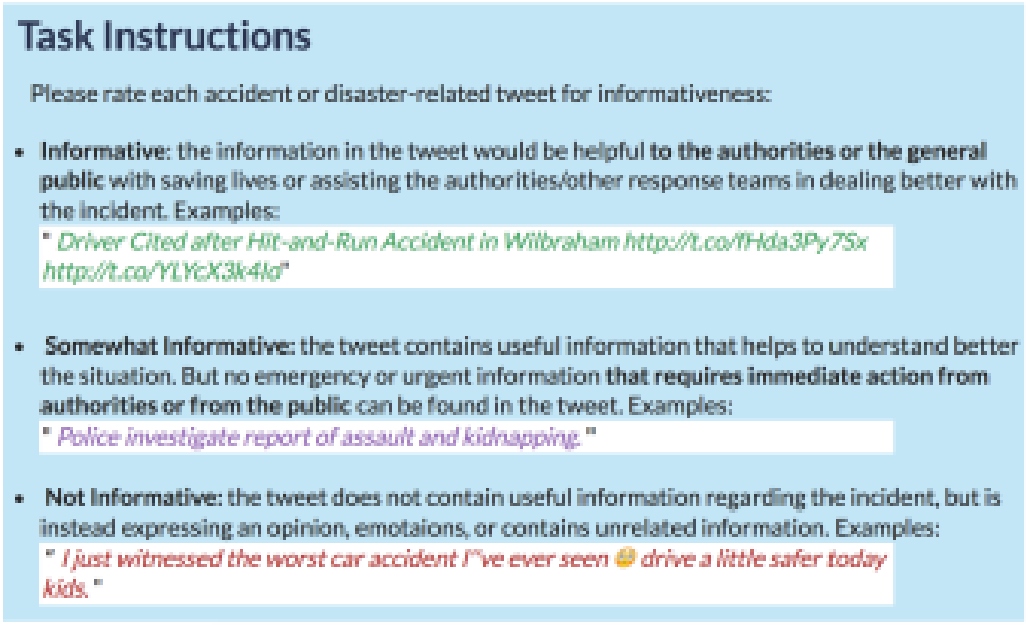

Figure 1. How the informativeness task is presented to crowd workers

The developed method for assessing the informativeness and filtering the messages is divided into two stages. Firstly, incoming messages are labelled for informativeness by a machine learning system. Messages deemed to be uninformative are discarded. The sensitivity of this system can be tuned. For example, in situations where it is critical to process every potentially important message, this can be achieved, at the cost of some irrelevant messages coming in. In other situations, where it's most important to keep up to date, and only summary information is required, then all irrelevant messages can be discarded at the risk of some potentially relevant ones being missed.

The second stage is to determine what kind of action can be taken based on the message. This is termed *actionability classification*. This paper describes a novel schema for actionability classification. The schema is prototyped, updated, and then used to construct a dataset. A machine learning system is then trained to classify incoming messages according to their actionability, based on this dataset.

PREDICTING INFORMATIVENESS

Discarding uninformative data is critical when one aims to process crisis-relevant messages in real time. Typically, when capturing messages related to a crisis, any potential selector (e.g. geographical area, hashtag) yields a high volume of available content, via e.g. Tweets or SMS. However, only a limited part of this will in fact be relevant to the crisis and also informative.

Therefore, the first step in dealing with any information stream related to a crisis is to differentiate between informative and non-informative content. The two major technical challenges here are first in developing a computationally operationalised definition of informativeness in crisis situations, and secondly in creating a technical solution that can discriminate based on informativeness in the extraordinarily broad range of not only crisis situations but also the social and other message media used around them.

Defining Informativeness

A key challenge in developing an automated approach for identifying relevant messages is to describe 'relevant' in a manner that enables it to be transformed into an automated process. However, identifying messages which are relevant, or informative (having an information value), is often both heavily context-dependent and also subjective. Furthermore, informativeness patterns (and associated relevancy of information) may differ from one type of crisis to another (Olteanu, S. Vieweg, et al. 2015). Because we rely partially on human-annotated data to train our system, the definition of informativeness must additionally both provide useful distinctions for the end users of the tool (the crisis workers) and be as easy as possible for human annotators to understand and apply to the data they are given. Previous work has shown that the quality of crowdsourced data is heavily dependent on both the simplicity and clarity of the task and definition (Sabou et al. 2014), and this data is critical for the development of the tool.

These issues makes it challenging both to capture good examples of informativeness, and to develop a definition for it that can be used for crisis analysis. For this scenario, the notion of informativeness ideally needs to reflect the extent to which information captured during a crisis is useful to responders; or at least whether or not a message is related to the crisis. Rather than build a definition from first principles, we instead took a top-down approach, considering what kinds of messages in practice would be useful, and generalising from that. To arrive at a definition, we drew on a range of existing sources and efforts. These included third-party resources from established authorities in the field of information management for crisis response, such as CrisisLex (Olteanu, Castillo, et al. 2014), the OCHA Guiding Principles (Van de Walle et al. 2008), and the World Disaster report, as well as academic sources such as the DERMIS principles (Turoff et al. 2004), and field research in Nepal (Baharmand et al. 2016). Finally, we included research carried out within the COMRADES project, including monitoring exercises from iHub and input from Delft University of Technology (Comes, Toerjesen, et al. 2016).

From these resources, and after some trial and error testing different definitions on a number of volunteer annotators and getting feedback, we created a three-level definition of informativeness. It became clear that informativeness often hinges on how urgent information is, so this concept is reflected in the levels:

- **Informative:** the information in the message would be helpful with saving lives or assisting the authorities/other response teams in dealing better with the incident.
- **Somewhat Informative:** the message contains useful information that helps to understand better the situation. But no emergency or urgent information can be found in the tweet.
- **Not Informative:** the message does not contain useful information regarding the incident, but is instead expressing an opinion or contains unrelated information

Because we crowdsource the work to human annotators, we were mindful of how task design and framing could affect results: taking care of cognitive biases is paramount to achieving good results (Sabou et al. 2014; Derczynski, Bontcheva, et al. 2016; Eickhoff 2018). Specifically, we wanted annotators to think carefully about mid-cases. Our initial tests showed that a binary decision (informative or not) was too rigid; on the other hand, giving annotators too many categories made it hard to find the boundaries between them. A sample task is shown in Figure 1.

Data Collection

The text data used in this stage of the project was part of the dataset released in (Schulz et al. 2017). This dataset includes over 10K tweets that were selected and labelled for the domain of incident detection of 10 different cities. The tweets were already labelled by crowdsourced annotators, and classified. The first dataset has two classes (related and not related to the incident); the second has four classes (crash, fire, shooting, and not related). Note that there is a distinction between related and informative: related messages are not necessarily informative, but unrelated messages are definitely not informative. We thus retrieved 600 tweets from the first dataset taking only those labelled as related. Following this, we filtered our dataset to remove all retweets, as well as tweets with redundant content (i.e. subjectively carrying the same information or describing the same fine-grained event).

Annotators on CrowdFlower[4] were then instructed to label these documents according to the three informativeness categories listed above. Five crowd worker judgments were collected for each tweet. Crowd responses were then adjudicated taking the most popular category. In general, total agreement was higher than 70% in all three groups, and over 80% for the “not informative" category. The resulting annotated data has been made publicly available as the COMRADES Crowdsourced Informativeness Dataset (CCSID) (Qarout et al. 2018).

Supplemental Data

At least a few thousand examples are required to train most machine learning systems. For extra data, we used CrisisLex (Olteanu, Castillo, et al. 2014), which contains around 60,000 tweets. These are labelled for informativeness, though not as stringently as CCSID; messages are coded as either “Informative", corresponding to the union of CCSID’s first two options, or “Non-informative", corresponding to the third. In any event, it comprises 32K positive and 28K negative examples. While this dataset is not as reliable (for example, there are anecdotal cases of useless “informative" tweets in it), the effect of this is diminished by balancing data and exploiting loss functions during training. This helps us to get high quality from the CCSID while leveraging the bulk of the CrisisLex annotations, as described below.

[4]http://www.crowdflower.com/

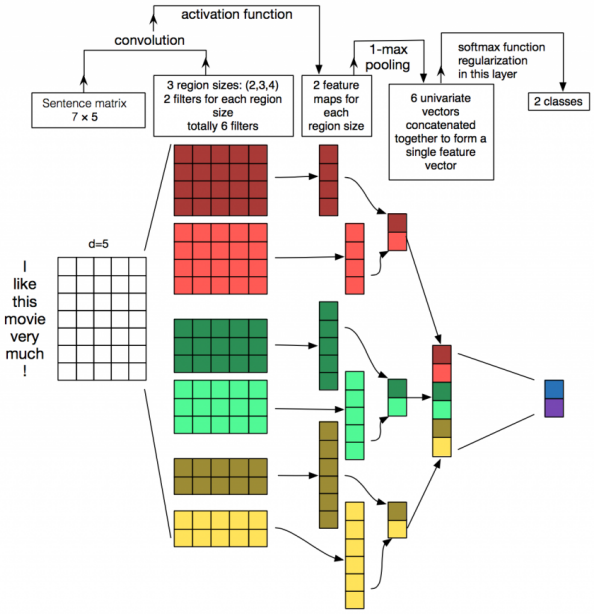

Figure 2. The convolutional neural network architecture used (from Zhang et al. 2015)

Machine Learning Approach

Having the data, the next step is to learn what informative messages generally look like. A machine learning algorithm will pick up patterns in the data we present it with, and try to generalise from that what signals an informative message. Then, when applied to new messages, it should be able to make some decision about what is and is not informative. In this instance, because we are dealing with highly diverse text and have a reasonable amount of data, we choose a convolutional neural network, which ought to be able to infer directly from text without additional feature extraction.

Because we need to leverage the data from CrisisLex as well as CCSID, we can label a maximum of two classes, as CrisisLex does not have the middle “informative but not urgent" label. Therefore, for this system, we reduce the CCSID categories from three to two by combining “informative and urgent" with “informative but not urgent".

Convolutional networks work by repeatedly applying a “window" to a numerical representation, and combining all the values under that window. For text, those numbers come from a word embedding. We followed the convolutional text classification network of Zhang et al. 2015 to determine informativeness (Figure 2).

It is important to know how good a machine learning model is, so that we know when to stop training. Sometimes, training for more time does not give a better result. This is because some systems match the training examples too closely, and so will not operate well in a new environment. For example, if our training set only took examples from shootings, and the term “AK47" occurred often in this data, then a system might end up thinking that highly specific mentions of “AK47" indicate informativeness, instead of phrases like “wounded". This is called overfitting.

The quality of a machine learning model is judged in two ways. First, we can measure how well the trained model works on the data that is used to train it (the “training set"). This is like measuring how well the system has learned the data to which it has been exposed. The metric used for this is “training loss", and lower is better. The second way is to measure the model’s performance on some other, held-out data (a “validation set"). A good score on this indicates that the model is learning to predict things beyond the data it has already seen, i.e. the model is generalising. This is called “validation loss", and again, a lower value is better.

Typically, one takes a dataset, and splits off a part which becomes the validation set. During training, training loss decreases, as does validation loss. When training loss becomes lower than the validation loss, the model has started to predict the training data better than other data, meaning it has started overfitting. So, the model selected is the one just before this crossover of validation and training loss, with a minimum validation loss.

In the instance of our informativeness classifier, we have a somewhat limited dataset (large scale machine learning text datasets typically comprise millions of examples). In addition, some of the training data (ie. from CrisisLex) is not a precise match for the kinds of scenarios we envisage COMRADES outputs being deployed in. This means that

measuring loss against CrisisLex alone might gives a system that is very good for the kind of scenarios contained in this dataset, but does not generalise well across crises.

To remedy this, we use part of the CCSID in the validation set, and give it a much larger proportion in the validation set than the test set. Specifically, the validation set is comprised of 300 CCSID instances and 300 drawn from CrisisLex (150 each of informative and non-informative). The remainder of the data, some 60,000 examples, forms the training data. This means that scoring well on the more-varied CCSID, which matched COMRADES goals well, is very important, despite it only comprising a smaller proportion of the training data. In this way, we can select a model for informativeness classification that uses all the data we have available and is optimally likely to score well in real-world deployment.

Evaluation

This training and validation partition were used with the configuration specified above. The final scores in this case are an accuracy of 92% and an F1 of 91%. This is over the validation dataset, which represented both the definition of informativeness we wanted to capture and also the diversity present in social media. The F1 indicates that we achieve an excellent balance in errors between false positives (i.e. uninformative messages slipping through) and false negatives (informative messages being missed). We attribute the high performance of this system to the careful annotation process, as well as the volume and range of documents available for training. Additionally, we purposefully created a system aimed at high performance on this data type.

ACTIONABILITY

Having filtered out uninformative content, the next stage is to assist crisis workers in information processing by categorizing the remaining messages. This could be used to select individual messages and hand them over to a specialist team, as well as to get a good overview of the crisis situation or detect emerging events.

Some former work has addressed this. Recently, the CREES system (Burel et al. 2017) used the CrisisLex categories and large amount of data there to do some filtering of information into different categories. However, not all these were actionable, and while there is some overlap, the categories are either not directly useful when determining actionability, or do not provide a sufficient amount of granularity. Nevertheless, with its large amount of data, CREES achieves good performance. Earlier work on determining actionability in crises was effective though studied over a single crisis (Munro 2011). We go further and train on multiple crises, allowing a more general impression of how actionability can look over a broad range of contexts.

Defining Actionability

Our requirements were that a relatively small number of categories should be selected, and all of these at a single, top level. A hierarchical system is complex and hard to build; the added complexity here incurs cost and quality risk, and for a real-time prototype system, it is better to provide something that works. Further subcategorization could always be efficiently provided later if necessary.

Additionally, the categories should correspond to issues relevant to the type of crisis tracked by COMRADES and envisaged for use by project stakeholders. This means some categories in other datasets feature less in our work. For example, media opinion of the crisis response is less important in our use cases than trapped and injured people. The source categories are given here; firstly, for the MIT Humanitarian Response Lab's schema, as in Figure 3.[5]

[5]See https://humanitarian.mit.edu/ (MIT HR is also the source of the schema diagram)

Figure 3. A schema from the MIT Humanitarian Response Lab for prioritising hurricane response

Secondly, from CrisisNLP (Imran, Mitra, and Castillo 2016):

1. Injured or dead people: Reports of casualties and/or injured people due to the crisis
2. Missing, trapped, or found people: Reports and/or questions about missing or found people
3. Displaced people and evacuations: People who have relocated due to the crisis, even for a short time (includes evacuations)
4. Infrastructure and utilities damage: Reports of damaged buildings, roads, bridges, or utilities/services interrupted or restored
5. Donation needs or offers or volunteering services: Reports of urgent needs or donations of shelter and/or supplies such as food, water, clothing, money, medical supplies or blood; and volunteering services
6. Caution and advice: Reports of warnings issued or lifted, guidance and tips
7. Sympathy and emotional support: Prayers, thoughts, and emotional support
8. Other useful information: Other useful information that helps understand the situation
9. Not related or irrelevant: Unrelated to the situation or irrelevant

We settled on a blended prototype set of top-level actionable information types. Unlike CrisisNLP, this set imposes no specific ordering or prioritization on the data. This ordering is not applicable in all crises, nor indeed over time in the same crisis. For example, dead bodies are not a priority compared with the trapped and injured, on day zero; but on day 3-4, they may well be.

To avoid colouring user judgments, we took a conscious decision to make all tools as agnostic as possible, cutting out any biases that we noticed. This has the goal of placing all decisions about response and action on the analyst, instead of providing nudges about what has higher or lower rankings (as one implicitly does by ordering actionability types).

- A specific resource, where the kind of need is given explicitly.
- Mentions of some group that's responding or aiding (e.g. volunteers, military, government, businesses, aid agencies).
- Threats to the general crisis response. Weather warnings, fires, military action etc.
- Changes in accessibility - limits to access, or other changes in how much transport can get through.
- Damage to infrastructure, livelihoods etc.
- Mention by name of the geographic areas affected
- Changes in the local environment (weather, hazards, etc.); e.g., a storm is intensifying
- General reporting about the rescue effort (from the media or the public)
- Opinion or individual message.

Note that some categories, such as those around Needs, are collapsed into one. Following this example, we first should identify content about needs, and analysis of the exact type of information – for example, the resource required, or the location – can be postponed (Munro 2011).

Category	Count
Needs	22
Response groups	99
Threats to response	195
Changes in accessibility	19
Damage to livelihoods	62
Mention of affected areas	400
Changes in environment	40
General reporting	83
Personal opinion	423

Table 1. Actionability data

Gathering Actionability Data

Labelling qualitative data with quantitative, hard categories is a difficult process, with some margin of error. The standard of this process directly reflects the quality of the resulting dataset and the performance of machine learning systems trained on them.

Humans typically perform rather poorly in data labelling when faced with more than seven labels, and best when faced with two (Sabou et al. 2014). As we have nine categories, the set must be decomposed somehow. As with the informativeness task, we trialled various different combinations and setups using in-house volunteer annotators. We had best results from splitting types into two groups, and providing the “personal opinion" option alongside both.

To maintain quality in crowdsourcing, a first portion of the data was annotated by experts who had experience in the goals of the data, crisis response, and linguistic annotation. After settling discrepancies, this pilot part of the data was converted to 118 “gold" messages which would be used as test examples for crowd workers; for each gold example, the correct answers are pre-filled, and then used to give feedback on the job as crowd workers proceed. The test data gives crowd workers a safe environment in which to learn how to annotate, while seeing real examples of correctly-labelled data. This follows best practices in crowdsourced annotation of corpora (Sabou et al. 2014).

We combined tweets from all days of Hurricane Irma[6] with data from CrisisLex, taking from the latter only crises of natural origin, in order to filter out short-term anthropogenic events like shootings. These were then filtered for informativeness based on the system introduced above, so that only informative tweets were scanned for actionable information. In total, 1350 tweets were labelled according to the actionability criteria indicated above, distributed as shown in Table 1.

Note that an individual tweet can contain more than one kind of information (or no relevant information at all). Therefore, the totals above do not sum to the dataset size. This comprises our dataset of actionable messages, annotated by a mixture of experts and crowd workers that have been trained with expert data.

Extracting Actionable Content

Having now a set of examples of actionable and non-actionable data, it is possible to train a system to triage messages according to actionability.

Deep learning requires large amounts of data; its advantage lies in a better ability to leverage better data. In this situation, however, we are faced with a paucity of examples from each actionability class, which is tough for deep learning. Indeed, applying a convolutional text kernel as with earlier informativeness analyses led to very poor results, with a F-score under 0.1 in almost every case. We attribute this to the extreme data sparsity.

Further, data where there is a strong imbalance is harder for most machine learning algorithms to learn to predict. In this case, our dataset of over 1000 instances often contains only a minority of positive examples, complemented by an overwhelming majority of negative examples. This is a difficult learning environment: for effective learning the number of positive and negative examples should be roughly equal.

We cast actionability extraction as a multi-class labeling problem. That is, a message can have more than one kind of actionable information at a time. For example,

There are people camped out between Lincoln and fifth who need water

[6]Kindly provided by PushShift – http://pushshift.io

Class	Accuracy	F1	Recall	Baseline F1
Needs	66.83%	57.50%	63.01%	45.21%
Response groups	63.13%	62.94%	62.63%	40.18%
Threats to response	57.18%	57.72%	58.46%	33.70%
Change in accessiblity	57.89%	57.89%	57.89%	18.18%
Damage to infrastructure, livelihoods	56.45%	54.24%	51.61%	20.16%
Geographic names	56.63%	57.84%	59.50%	45.23%
Changes in environment	50.00%	47.37%	45.00%	23.58%
Reporting about the rescue	57.83%	58.82%	60.24%	13.95%
Personal opinions	66.59%	63.43%	57.94%	42.27%

Table 2. Performance of actionability detectors

contains both a need (type A) and a geographic location mentioned by name (type J) – so it's labeled [A,J]; hence, multi-class. We construct a solution based on many binary classifiers, one for each actionability type. Each classifier will attempt to predict whether or not the message contains a single type of actionability data, and a single classifier is dedicated to each kind of actionable information. Finally, the results are pooled to form an aggregate labeling of the message.

For feature extraction, following Aker et al. 2017, we extracted from the data a set of keywords for each actionable information type, and also induced word embeddings over recent social media data as a continuous representation of individual word types. These were taken from 20 million tweets from 2016, filtered for English with langid.py (Lui and Baldwin 2012) randomly selected for variation in time (across seasons and across time of day), processed with GloVe (Pennington et al. 2014), and having 25 dimensions (a low dimensionality is less prone to errors with this relatively sparse training data). Documents are converted to data by splitting them into words using a social media tokenizer (O'Connor et al. 2010) and then, for each word in the keyword list, measuring the proportion of words in the document that are similar to the keyword. Similarity is defined by cosine vector proximity, with a cut-off of 0.45. That is to say, document words whose vectors have a cosine with the keyword under 0.45 are disregarded. Additionally, each document word is scaled by its score; so, if a ten-word document has one similar keyword, and the similarity is 0.6, the overall value for this keyword is 0.06 (10% × 0.6). This feature extraction converts documents into a one-dimensional vector with a value for each keyword.

Sample keywords for two of the actionability types are:[7]

Personal opinion: `[i people us all me please good will trump your pray praying toll concerned omg worried god]`

Changes in accessibility: `[G accessibility street bridge blocked derailment collapse close flooded closed careful cancel cancelled canceled avoid alert affect advised]`

These terms are those likely to be indicative of a particular class. They are extracted by finding the most discriminative words for each class through a simple Bayesian analysis. The full set of keywords and actionability types are downloadable from the Emina distribution and can be edited to suit new situations.

We needed a classifier that was rapid, could learn with with a low amount of data, and that did not select a liner decision boundary. To this end, the RBF SVM fit our needs. In addition, we reduced the "negative" data (i.e. the non-actionable cases) down to match the number of positive examples for each class, randomly removing examples.

Evaluation

We measured both the accuracy of the system (i.e. the proportion of examples it got right) as well as its F1 score and its recall (i.e. the proportion of known actionable messages that were retrieved by the classifier). Recall was particularly important here as precise systems (i.e. those that return only actionable information) were not considered as useful as those with good recall; for us to correctly pick up two instances of people in need and ignore four hundred would still have high precision – when no false need messages were returned (i.e. those where there is no need expressed) – but poor impact on crisis analysis and response.

[7] The full set is provided with the Emina toolkit

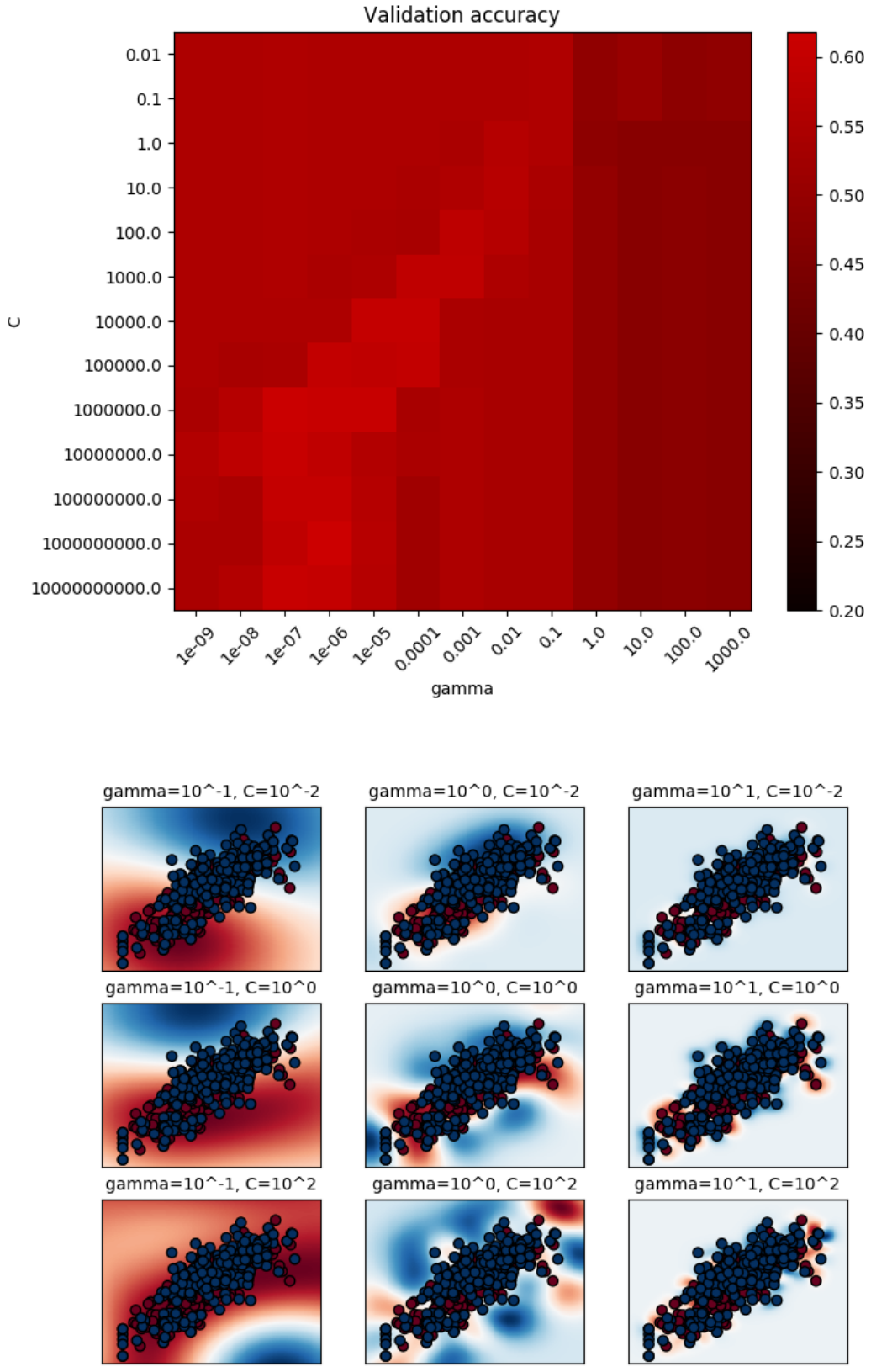

Figure 4. Tuning parameters for the RBF SVM

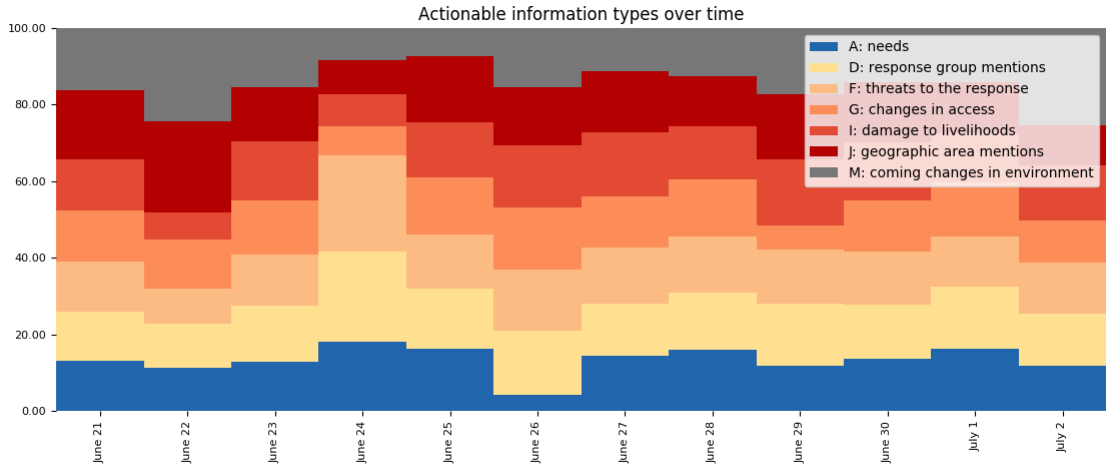

Figure 5. Types of actionable data during the 2013 Alberta floods

Radial Basis Function (RBF) SVM had excellent performance in some categories and good performance in others. Other classifiers did best in some areas but much worse in others. RBF SVM's overall performance indicates it is stable for this task especially given that we have relatively small datasets and the way messages are written varies very wildly across crises, even more so than to be expected in social media (Derczynski, Maynard, et al. 2013).

The RBF SVM works by exploring the space out from each example, to see where boundaries lie. This effectively tells us the impact or sensitivity of each keyword, in the context of other keywords. It seems that such an approach is more effective than finding linear separators in such a data-imbalanced, high-variance environment.

RBF is tuned with two parameters, C and gamma. The gamma parameter defines the influence that a single data point has. C trades off error against simplicity – a very complex system might make few errors, but may be fragile, having very poor performance on new data. The behavior of an RBF SVM can be highly sensitive to gamma; large values give individual examples power to distort the system's behavior. To best tune our system, we searched for parameters (Figure 4. Results are for category G, access to infrastructure, though simplified for visualization to the first two keyword parameters.

The plots show that performance is best with a high C and a low gamma – that is, we should not fit the data too tightly to either of these points. In the end, C=20 and gamma=3 worked for the general case. Overall results for RBF SVM are given in Table 2. These are compared with a keyword-match baseline, which matches texts if any of the keywords for a given actionability type are present.

This actionability extraction, coupled with the informativeness filtering, is released as an open source tool Emina at https://github.com/GateNLP/emina.

PROFILE OF A CRISIS

Using both informativeness filtering and actionability classification, we are able to see how the kind of actionable information in a crisis situation develops over time. To this end, we applied informativeness filtering and then actionability extraction to messages around individual crises in prior datasets.

Visualization

To measure the balance of actionable information over time, we bucketed messages according to their timestamps and then calculated the proportion of each actionability type. The results are shown in a proportional stacked bar chart. That is to say, for each time slot, the chart shows the proportion of actionable information during that period. If the dominant information type is "needs", then this second will have a larger proportion than the others, regardless of volume. An example for the 2013 Alberta floods is shown in Figure 5. This kind of visualization is an accessible summary of the profile of the crisis over time.

CONCLUSION

Filtering out uninformative messages is crucial to effective use of human monitors of electronic messages during a crisis. The majority of inputs in recent crises are irrelevant, and systems that preprocess and reduce the volume

of irrelevant messages become invaluable. We developed a pair of techniques that first remove the bulk of irrelevant messages, and then attempt to select particular kinds of actionable messages, according to some top-level actionability categories.

We were able to extract informative messages at over 90% accuracy, incorporating both the accurate selection of informative content and also avoiding extraction of non-informative content. Furthermore, we were able to recall between 50% and 70% of actionable information over eight individual information classes. The results presented in this paper are a first step to examine the feasibility of automatically identifying informative, and actionable messages such as those present from social media sources during a crisis event. While the results in this paper are promising, further research is needed to improve this approach. More importantly, given the importance of data and responsibilities of crisis responders, additional research is needed into the risks and ethics associated with automatic data processing. With automated services and tools, like Emina presented in this paper, we gain the potential to support crisis responders, digital volunteers and communities themselves in processing large volumes of data.

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Leveraging Elasticsearch and Botometer to Explore Volunteered Geographic Information

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ABSTRACT

In the past year, numerous weather-related disasters have continued to display the critical importance of crisis management and response. Volunteered geographic information (VGI) has been previously shown to provide illumination during all parts of the disaster timeline. Alas, for a geospatial area, the amount of data provided can cause information overload, and be difficult to process/visualize. This work presents a set of open-source tools that can be easily configured, deployed and maintained, to leverage data from Twitter's streaming service. The user interface presents data in near real-time, and allows for dynamic queries, visualizations, maps and dashboards. Another VGI challenge is quantifying trustworthiness of the data. The presented work shows integration of a Twitter-bot assessment service, which uses several heuristics to determine the bot-ness of a Twitter account. Architecture is described, Twitter data from a major metropolitan area is explored using the tools, and conclusions/follow-on work are discussed.

Keywords

Crisis Management and Response, Elasticsearch, Social Media, Volunteered Geographic Information, Botometer.

INTRODUCTION

Situational awareness is a critical component in the field of crisis management and response. Knowledge of a disaster space with high spatiotemporal resolution is necessary for directing supplies/responders, monitoring for further disaster, and responding to needs as they arise. Unfortunately, an area that has recently suffered a disaster usually faces compounding challenges including loss of power/water/environmental services, inaccessible roadways, limited communications channels, etc. With the recent modern proliferation of Internet-connected, robust, low-power smart devices, individual humans in a disaster space can provide a wealth of information (Goodchild, 2007). Online social media communities also enable the rapid distribution of information for an area. Provided the data is geospatially annotated with latitude/longitude, volunteered geographic information (VGI) (Zook et al., 2010) can be found in multiple forms, e.g. text messages from Twitter, images/videos from Instagram, Facebook stories, etc.

One of the difficulties of using social media data is processing the massive quantity of VGI and creating a cohesive product that can be used by managers and responders. This work will show an inexpensive enterprise architecture, comprised of open-source technologies, that can process streaming Twitter data from multiple geospatial areas in near real-time, and provide a flexible, web-based interface for data exploration. The entire environment is made from industry standard tools/software/infrastructure and can be readily replicated for new geographic areas, with limited human and financial cost.

VGI requires the user to be aware of trustworthiness (Halse et al., 2016) issues, as the producers cannot always be verified, leading to current decision-making models being resistant to its integration (Tapia et al., 2011). Inaccurate data, especially published by automated accounts called bots (Chu et al., 2010), can misrepresent the status of a geospatial area. This work will leverage a web-based service that processes information about a Twitter account and returns an assessment as to the account's bot-ness. Using this value, the aforementioned web-based interface can dynamically filter Tweets from accounts that have bot-like characteristics. This process

greatly increases the trustworthiness of the social media data and provides a higher quality picture to responders for a disaster area.

BACKGROUND

Understanding a geographic space has long been of importance to human communities; during a disaster, managing dynamic knowledge of a space is even more challenging. Social media is a relatively new concept and has been shown to support many steps in the lifecycle of a disaster, from pre-planning to recovery (Veil et al., 2011). Use cases are numerous, from community members sending images during the Deepwater Horizon oil spill (Merchant et al., 2011), to using wikis and text messages to affect response for the 2010 Haiti Earthquake (Yates et al., 2011) (Caragea et al., 2011), to processing Tweets from the New York City area during Hurricane Sandy in 2012 (Shelton et al., 2014).

Social media data, which can be explicitly collected by motive, or implicitly collected from ongoing streams (Aubrecht et al., 2017) can be challenging to obtain programmatically. Some social media services provide Application Programming Interfaces (APIs) which allow modern programming languages to communicate with them via web services. Consuming social media data via code allows for complex analysis and creation of interfaces. GNIP, a social media aggregator combines and delivers streams from many social media services, but the cost is out of scope for this work. GNIP sources include Facebook, Flickr, Instagram, Panaramio, Stack Overflow, YouTube, etc. (Sources, n.d.).

Once the data has been consumed, stored and processed, cohesive presentation to an end user is necessary. The data must provide some value, or meet a need, and be easily accessible technically and visually. Previous work has shown a web application that can display Twitter-sourced population estimations as a heatmap overlaid on a Google Map for a day of the week, and hour of day (Toepke et al., 2015). The application showed illumination into population movements for an area, but was slow, inflexible, and difficult to replicate. The Digital OnLine Life and You (DOLLY) (floatingsheep: DOLLY, n.d.) project utilizes a custom, enterprise grade Twitter aggregator and viewing interface; allowing for numerous publications, and easy insight into Twitter data. The Sahana Foundation publishes open-source software that can be used for social collaboration during a disaster situation (Li et al., 2013); the information management system supports preparedness, response and recovery.

While large/complex Twitter consumption projects exist, they require a large technical skill-set if a new researcher intends to replicate and/or extend the work. Twitter API access tools e.g. Twitter4j/Tweepy are well known and can be leveraged with online examples and custom glue-code; however, authoring a multi-user enterprise application to securely visualize the data while affecting rapid ad-hoc queries is non-trivial. This work shows the utilization of easily repeatable free and open source analytics tools, adapted to Twitter aggregation and visualization.

Also challenging is programmatically integrating trustworthiness assessments for each Twitter account, which can create a higher quality product and remove noise generated by Twitter bots. This work shows integration with the Botometer (Davis et al., 2016) service, previously known as Botornot, which was created by the Observatory on Social Media, a joint project between the Indiana University Network Science Institute and the Center for Complex Networks and Systems Research (OSoMe: Home, n.d.). Botometer is designed to take input about a Twitter account, including user information, Tweet timeline and Tweet mentions; after running the data through custom algorithms, bot-ness information on the Twitter account is returned.

The heuristics consider several factors for each account (Varol et al., 2017):

- Friends, investigates followers, follows, etc.
- Sentiment, analyzes mood/emoticons/etc. in the textual content of the Tweets.
- Temporal, considers times/dates/frequencies of the account's Twitter activity.
- User, evaluates metadata pertinent to the account, e.g. how built-out is the profile, the account's age, etc.
- Network, processes information diffusion patterns focusing on retweets, mentions, hashtags, etc.
- Content, invokes natural language processing to inspect the textual content of Tweets.

The analytics tools and Botometer are leveraged to process Twitter data, with the downtown area of San Diego, California in the United States of America being the geospatial area of interest. The coverage area is approximately 3 kilometers square and encompasses the downtown core. Data was collected from five cities in the United States, and one metropolitan area in Portugal; the selection of San Diego for this discussion was arbitrary.

ARCHITECTURE

During the recent massive growth/adoption of cloud technologies, a need has arisen to glean insights from disparate servers and applications in near real-time. This is difficult across security layers, during dynamic deployments of environments, with different applications logging different metrics, etc. To address this need, a set of tools has been developed: Logstash, Elasticsearch and Kibana (the ELK stack) (Gormley et al., 2015). The ELK stack products are open-source and maintained by Elasticsearch Global BV in Amsterdam, Netherlands, which has undergone rapid growth and expansion in the past several years.

Logstash is a small, Java based log shipping application (Logstash, n.d.). It is meant to be installed alongside any application, or inside any server/environment that needs introspection. Logstash is then configured to include the locations of logfiles on the system to ship to an Elasticsearch instance, security/connection data for the target Elasticsearch location, and any transformations that need done to the logfiles before shipping occurs. The flexibility of the transformations allows almost any software product or environment to provide meaningful data without changing the product itself. E.g. a log file for the Apache Web Server can have each line read into Logstash, the timestamp, user, log level, message etc., extracted, and then wrapped as JavaScript Object Notation (JSON) for sending to the Elasticsearch instance.

Logstash does have the native ability to directly attach to the Twitter Streaming API, which creates a low barrier to entry for a new researcher. The Twitter input plugin takes security values for Twitter, automatically makes the connections, and starts shipping Tweets. Since this work performs the intermediate step of attaining Botometer data for each account, this functionality isn't directly pertinent.

Elasticsearch is a schema-less, distributed, JSON based search engine (Elasticsearch, n.d.). The product is meant to be deployed to the cloud, accessible through secure connections, and it can concurrently absorb many large streams of data. A custom query language exists for Elasticsearch called Querydsl, which allows an end user to create powerful, low latency, ad-hoc queries.

Kibana is the user interface component of the ELK Stack and functions as a portal into an Elasticsearch installation (Kibana, n.d.). A user can login, and navigate to several pages, which allow for exploration of the underlying data. Kibana components include:

- Query terminal to directly explore the raw data.
- Charts that show trends over time, which can be filtered/populated based on keywords/queries.
- Map visualizations that display geospatial data, heatmaps, clustered information, and external layers from compliant Open Geospatial Consortium Web Map Services (WMS).
- Mashups of visualizations can be combined for a near real-time dashboard.
- A full enterprise solution with active user-management. Many users can login to one Kibana instance for data exploration using web browsers, e.g. Firefox, Chrome, Internet Explorer, Safari, etc.

This work leverages three freely available web services:

1. The Twitter Streaming API (Consuming streaming data --- Twitter Developers, n.d.).
2. The Twitter Representational State Transfer (REST) API (Standard search API --- Twitter Developers, n.d.).
3. The Botometer service via Mashape (Botometer API Documentation, n.d.).

To implement the reliable consumption of data from the Twitter Streaming API, a solution is created using Java, Docker and Amazon Web Services (AWS). The code is repeatable, resilient to failure, and is highly available via the cloud.

The primary data processing and visualization toolset is an implementation of the ELK stack. Elasticsearch and Kibana as-a-service is implemented via Elastic's Elastic Cloud (Elastic Cloud: Hosted and Managed Elasticsearch | Elastic, n.d.). Full architecture can be visualized in Figure 1.

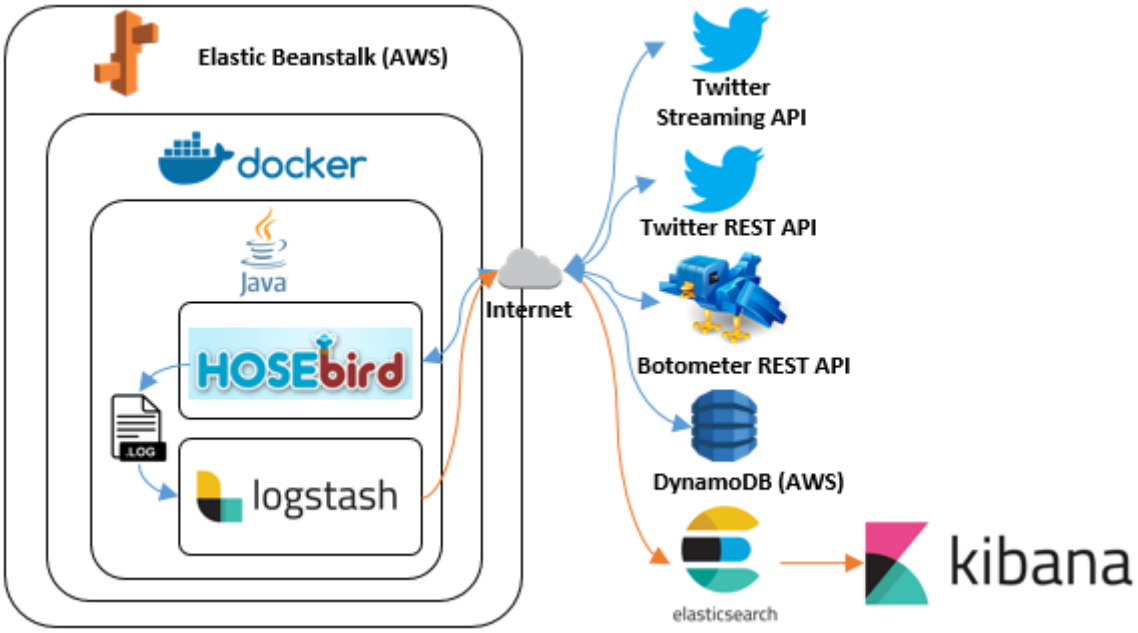

Figure 1. Architecture Diagram

Twitter APIs and the Botometer Service

Twitter provides two primary APIs for developers, the Streaming API, and the REST API. While the REST API is convenient to query, it has limitations on the number of queries, and the number of Tweets that can be returned for a time frame. While useful for testing and prototyping, the request/return model is not suited for large geographic areas.

The Streaming API operates on a different principle: if a connection can be made/maintained over the Internet, the API will constantly stream Tweets back to the consumer. This requires a different architecture from the REST API, where issues with processing/connections/streaming need to be resilient and handled gracefully such that the connection is maintained. In this case, before the streaming connection is made, quadrangular geographic boundaries are set for each metropolitan area of interest.

The Twitter REST API is used during the Botometer query process to populate the information passed to the service. Botometer requires two queries per new account to the Twitter REST API; to get information about the user's Tweet timeline, with up to 200 Tweets, and to get information about the user's Tweet mentions, with up to 100 mentions. This process is non-trivial, and a Java library was created to abstract this functionality (GitHub - samueltoepke/Botometer4J, 2018).

Due to current Twitter REST API constraints, only 180 requests are allowed per 15-minute window (Rate Limiting --- Twitter Developers, n.d.), thus limiting the number of actual Botometer queries to 90 per 15-minute interval. The collection code makes use of a cloud data table as a cache for Botometer values per account, which helps limit calls to Botometer. Nonetheless, if the Twitter API reaches its rate-limit, then a 15-minute rest occurs, and any Tweets with account names that haven't been previously loaded into the cache are shipped to Elasticsearch with "null" Botometer values. The consumer code immediately starts querying the Botometer API, populated from Twitter REST calls, as soon as the rest is over.

The Mashape Marketplace is an online service that allows authors to host their APIs. Botometer is deployed via Mashape and is also constrained by rate-limiting rules. Botometer allows 17,280 free requests per day, per authenticated user; if a customer needs more, they can register for a "Pro" account, and pay for more requests. Since two Twitter REST API queries are required per each Twitter username, this architecture is throttled to the Twitter REST rate limit, and the Mashape free limits will not be reached.

When the Botometer service is queried for a Twitter user name, a JSON string is returned with a score for each of the aforementioned categories. Also returned is an average score for all categories for English Tweets, and a universal score for non-English Tweets, which removes the content and sentiment scores. Each unique Tweet contains a language field which can be accessed to programmatically decide whether to utilize the English or

universal score. Each score is a decimal value from 0 to 1.0, with values towards 0 being less bot-like and values toward 1.0 being more bot-like. An example response from Botometer can be seen below.


```
{
  "categories": {
    "friend": 0.45,
    "sentiment": 0.34,
    "temporal": 0.55,
    "user": 0.29,
    "network": 0.43,
    "content": 0.41
  },
  "user": {
    "screen_name": "IUNetSci",
    "id": "2375509748"
  },
  "scores": {
    "english": 0.34,
    "universal": 0.36
  }
}
```


The score breakdown per the Botometer documentation is as follows.

- 0.0-0.39, likely not a bot.
- 0.40-0.60, unable to tell if account is a bot or not.
- 0.61-1.00, likely a bot.

The Botometer documentation clarifies that these classifications are difficult, and while they provide insight to an account, can be incorrect.

Amazon Web Services

AWS provides a variety of cloud-based computational services, that are well documented, inexpensive and offer high uptime and reliability. The code that connects to the various APIs and the Elastic Cloud is implemented using the following AWS products.

- Elastic Beanstalk (ELB), an orchestration service that provides an execution environment; essentially an application server as-a-service. The Docker execution environment is utilized, where a custom Linux based container hosting the Java consumer code resides. The container is designed to be secure, repeatable and ephemeral. If anything goes wrong with the underlying virtual machine, ELB will terminate it, and immediately create a new machine with identical functionality.
- DynamoDB, which functions as a datastore as-a-service. A single table is used as a cache for the Botometer data where each row contains information for a single Twitter account. This table is queried before Botometer is called, with the idea being mostly the same people are Tweeting in mostly the same geographic boundaries. Over time, the table is loaded such that far fewer calls to Botometer are required. Each row also has a flag containing a timestamp for most-recent-update. As a Twitter user's facets are continually dynamic, if the Botometer data for a user is over a week old, the data is discarded and updated via a new call to Botometer.

The Twitter Streaming API consumer code consists of the following components.

- A standalone Java (Arnold et al., 2005) application that begins running when the Docker container is started. A combination of Cron/flock manage the Java process and will restart the process if it is down. The Java code uses Hosebird Client (HBC) (GitHub - twitter/hbc, 2014), a 3rd party Java library for managing the connection to the Twitter Streaming API. HBC handles security, making connections to the API, acting on received Tweets, re-enabling failed web connections, etc. The Java application is multi-threaded, spawning a new thread for each received Tweet. Populating a request for, and reaching out to Botometer can take time (between 5 and 10 seconds on average). Threading the application prevents the web service calls from blocking the processing of incoming Tweets. Apache Log4j 2 is used for configuring and rotating the log files. Each new thread takes the Tweet and checks the DynamoDB cache for Botometer information. If data for that Tweet's account is not there, or is there and over a week old, then the Botometer library is used to get the data from the Botometer service, assuming a global rate limit break is not in place. If the rate limit break is active, then the Botometer data remains null. The local Tweet is updated with retrieved Botometer data, and the data is also added

to the DynamoDB cache. Finally, the Tweet is printed to the log in JSON format. The main program flow for the Java application can be found as pseudocode in Appendix A.

- A Logstash installation, which ships logs to the Elasticsearch/Kibana stack. Logstash is Java based and is run when the Docker container is started. Cron/flock also manage this process and will restart Logstash if it fails.

The above describes an enterprise solution for Tweet consumption and log shipping to an Elasticsearch/Kibana stack, though is not entirely necessary. Crisis management and response is fluid, and the overhead needed to leverage AWS may be a blocker. The consumer code and Logstash are both Java based, which has an implementation for many modern operating systems. Any user with a laptop and Internet connection could easily run the two products from the command line in a time-constrained situation. The setup would not be as resilient and require human over-watch; but would reasonably attain and ship Tweets in a crisis.

The ELK Stack

This work uses the Elastic Cloud, a fully managed Elastic/Kibana as-a-service product, which greatly abstracts the configuration, deployment and management of the underlying servers, for low cost. Once setup, web endpoints and security values are provided, which are used in the consumer code's Logstash configuration. AWS does provide Elasticsearch/Kibana as-a-service, though configuration is non-trivial.

The described architecture is deployed in cloud environments, uses a fusion of open-source products, and deploys an interface such that a multi-user application is available for a minimally trained user to make powerful queries/visualizations on near real-time, textual data.

RESULTS

Once the entire stack is deployed and shipping log files, Kibana's user interface can be used for active inspection of the data. Figure 2 shows the main Kibana screen in the Firefox web browser. Points of note as follows.

- The top right of the screen shows "Last 5 Days"; clicking here allows the user to dynamically select any custom time period, which quickly repopulates the graph, and list of Tweets.
- The main portion of the screen shows a running list of the most recent Tweets, and all pertinent data. Refreshing the page will display Tweets that have been received since the last page load.
- At the top of the screen, there's a query field, which allows the user to explore the data using the Lucene query syntax (McCandless et al., 2010).
- The left side of the page is a menu for visualizations, dashboards, management, etc.

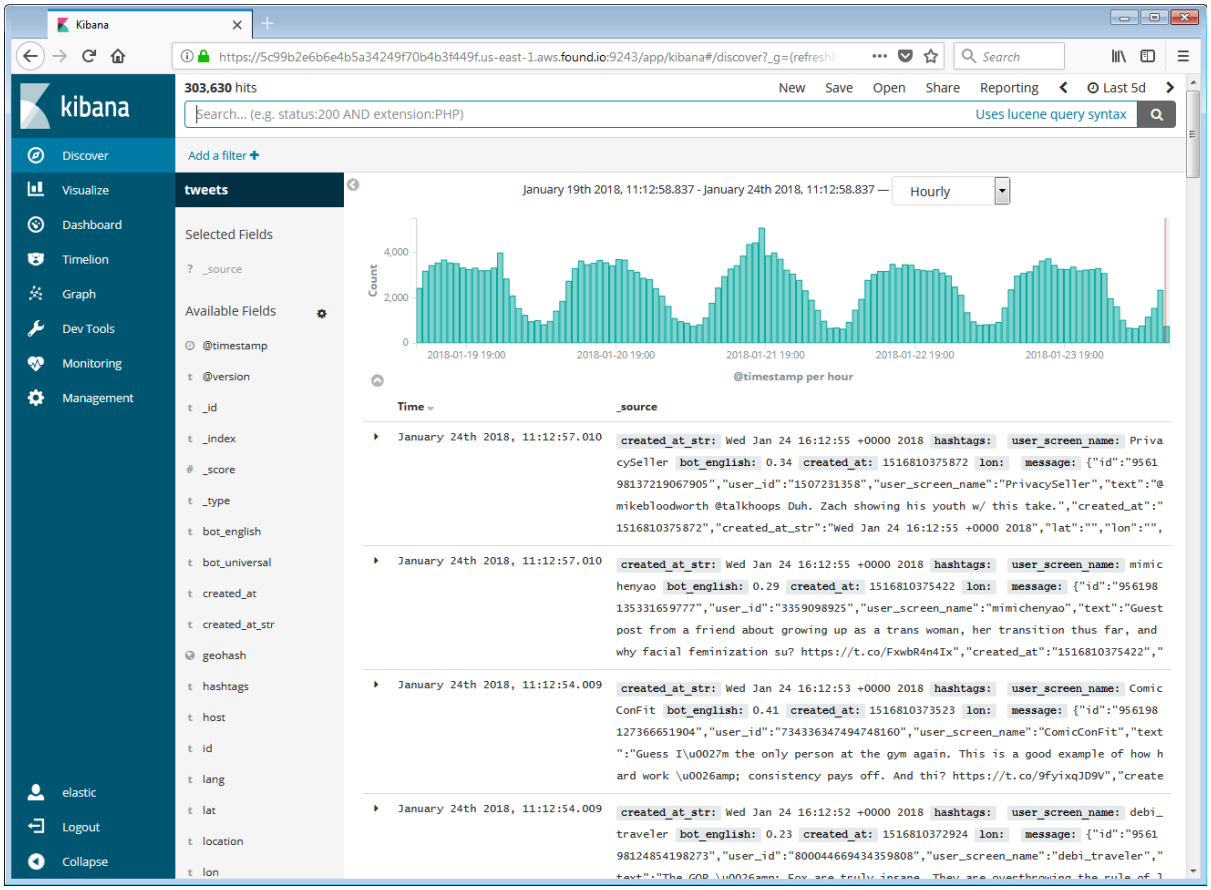

Figure 2. Kibana Main User Interface

During the development process, it was apparent that unexpected Tweets were being returned from the Twitter Streaming API. The only inputs passed during initialization are six latitude/longitude bounded, quadrangular, geospatial query areas corresponding to the metropolitan areas of interest. Nonetheless, many Tweets are returned that do not have corresponding latitude/longitude values but do have a pseudo-location populated. E.g. Tweet with id "952263569093025792" has no coordinates, but has "location: San Diego, CA". It appears that the Twitter Streaming API is not hard-lining the returned Tweets based on the requested geospatial borders but is returning all Tweets that are approximately in that area. For trend watching and sentiment analysis, these Tweets are useful; but if one is using the data to generate heatmaps representing population, these Tweets should be pre-emptively filtered (Standard Stream Parameters – Twitter Developers, n.d.). This can be accomplished by adjusting the query when creating the heatmap visualization to remove Tweets from outside of the bounding area of investigation.

For example, in the last 5 days from time of querying, 303,630 Tweets have been shipped to Elasticsearch/Kibana; using Query 1, only 48,004 of the Tweets have lat/lon populated; all queries can be found in Appendix B. It is also necessary to ensure that all the Tweets that have lat/lon populated are inside of the requested query areas. Per Query 2, only 14,873 Tweets are inside of the areas of interest. All further discussion will assume that the bounding filters for San Diego are applied to the data, unless otherwise specified.

Kibana offers the ability to create many types of visualizations: charts, data tables, gauges, coordinate maps, region maps, etc. In Figure 3, a panable/zoomable coordinate map, with Twitter data overlaid as a heatmap can be seen. Creation of this map is simple, essentially selecting which field in each Tweet is the 'geospatial' field. Note in the top right, the time period selector is still present for dynamic time period changes. Also, notice the filter for San Diego does not have negatives for the longitude values. Elasticsearch organizes the data lexicographically and does not understand negative numeric values as configured. There are workarounds, including padding numeric fields to a fixed width, and adding n/p symbol to delineate negative/positive respectively, but such functionality was unnecessary for this prototype (Numeric Range Searches in Lucene, 2009).

Kibana also offers integration to modern geospatial information systems (GIS) using a WMS interface. WMS is a standard for sending/displaying raster based geospatial data across different platforms, and is a common

functionality for popular GIS products, e.g. ESRI ArcGIS Server, GeoServer, MapServer, etc. A user can add their own geospatial data to a WMS server, then configure Kibana to leverage the layers. Many government and

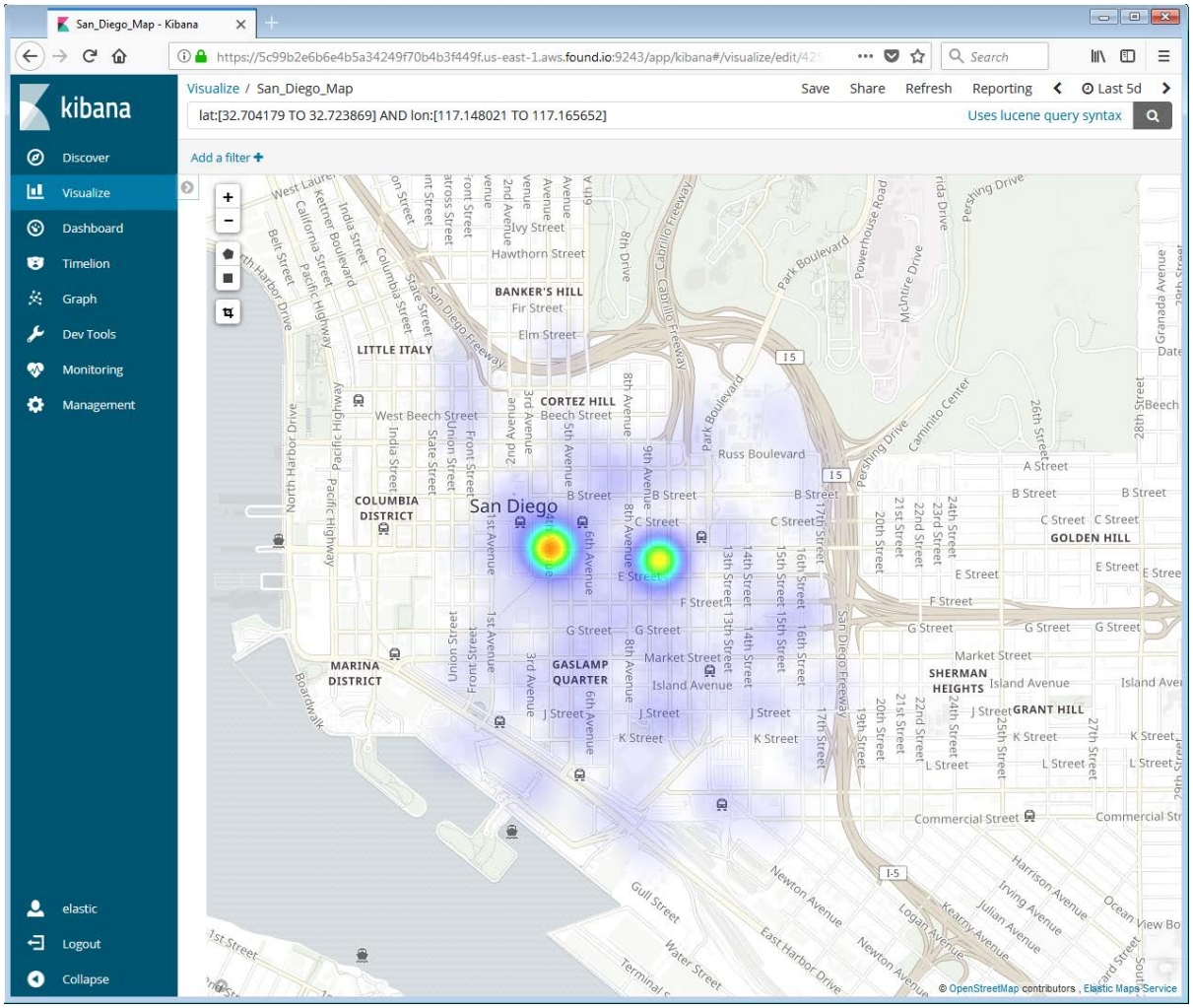

Figure 3. Kibana, Coordinate Map for San Diego, CA.

independent groups also publish GIS data for public consumption. In Figure 4, the San Diego heatmap is shown, overlaid on the National Flood Hazard Layer from the United States Federal Emergency Management Agency (FEMA). One can see that the bottom right of the map includes Twitter hotspots that are over a flood hazard zone.

The different charts and visualizations can be combined to create dashboards. Figure 5 shows a dashboard for San Diego with visualizations convenient for crisis management emergency responders.

- The heatmap of Tweets over the downtown area, allows a user to visualize groups of people, and where they are congregating.
- A chart of Tweet quantity over time provides insight into the social media patterns throughout the time period in question.
- A pie graph to show most popular users, who could be contacted to assist in providing information from “the ground”, or to directly distribute information to others.
- A pie graph to show most popular hashtags, provides insight into the content of what is being Tweeted about. A rise in crisis-related hashtags can warn about an impending/developing emergency in a geographic area.
- A hashtag cloud which allows immediate visual inspection of the popular hashtags in each Tweet.

An emergency responder could also leverage the Lucene query box and the time period selector to draw precise spatiotemporal constraints, e.g. over a city block in the last 3 hours, and have the dashboard immediately re-

populate with pertinent data. This functionality can support fluid and dynamic resource/response allocation (Shamoug et al., 2014) to where they are needed most. Kibana also implements responsive design (Gardner, 2011) in its interface, so it will automatically optimize for the physical device being leveraged, e.g. laptop, tablet, phone, etc.

Immediate inspection of the dashboard in Figure 5 shows many posts from "tmj*" with the hashtag cloud and pie graph showing many of the Tweets being pertinent to job seekers; direct inspection of the Twitter accounts shows they are likely automated. Using Query 3, the Botometer data is leveraged to remove bot-like data, and only display

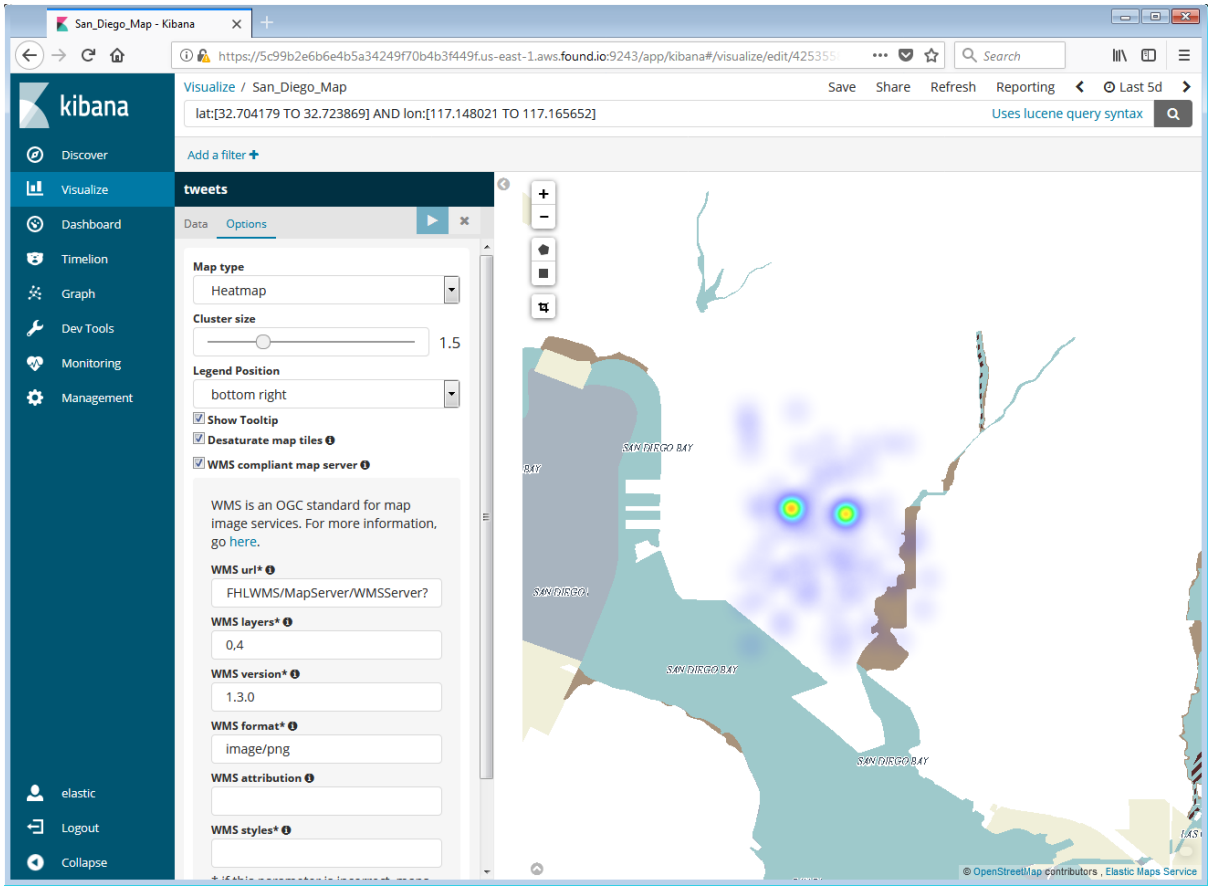

Figure 4. Kibana, Coordinate Map for San Diego, CA. with FEMA's National Flood Hazard Layer as WMS

Tweets that have corresponding bot-data of between 0.0 and 0.4. The interface immediately updates after entering the query, reflecting a decidedly more 'human' representation, which can be seen in Figure 6.

- Upon direct inspection, the Twitter usernames mostly correlate to real humans.
- Hashtags represent events that are occurring in the city from the play Hamilton visiting the San Diego Civic Center, to Monster Jam at Petco Park.
- One of the heatmap hotspots disappeared, the bot-created Tweets were likely using that location as a standard San Diego latitude and longitude. Filtering out this data can greatly improve human representation in the heatmaps.

This full dashboard for San Diego, using a Lucene query and Botometer data to remove Tweets from bot-like accounts, provides a flexible environment. As a crisis management and response actor, using the dashboard on any Internet-connected pervasive computing device can provide powerful near real-time insight into Twitter data, for a geographic space.

FOLLOW-ON WORK

This work presents a proof of concept and has many avenues for follow-on work.

- Actual deployment and use by a federal/state/tribal/local entity for the purposes of crisis preparation, management and/or response. Functional use will provide objective and necessary feedback about pain-points, utility and desired features.
- The current prototype only leverages the Twitter Streaming API for social media data. Integration with other services e.g. Panaramio, Facebook, etc. would provide ample opportunity for data fusion. The architecture of the system makes the Kibana interface amenable to integrating disparate data types. Once code is created to consume from a new service, a properly configured deployment of Logstash is all that is required to start shipping logfiles to an existing Elasticsearch/Kibana installation. Queries like the ones used here can be used to glean information and/or create visualizations.
- Investigation/creation/deployment of a service like Botometer for other social media services, using similar bot-detection heuristics. With a large percentage of Twitter accounts showing bot-like characteristics in this work's dataset, the necessity of filtering bots from VGI is apparent.

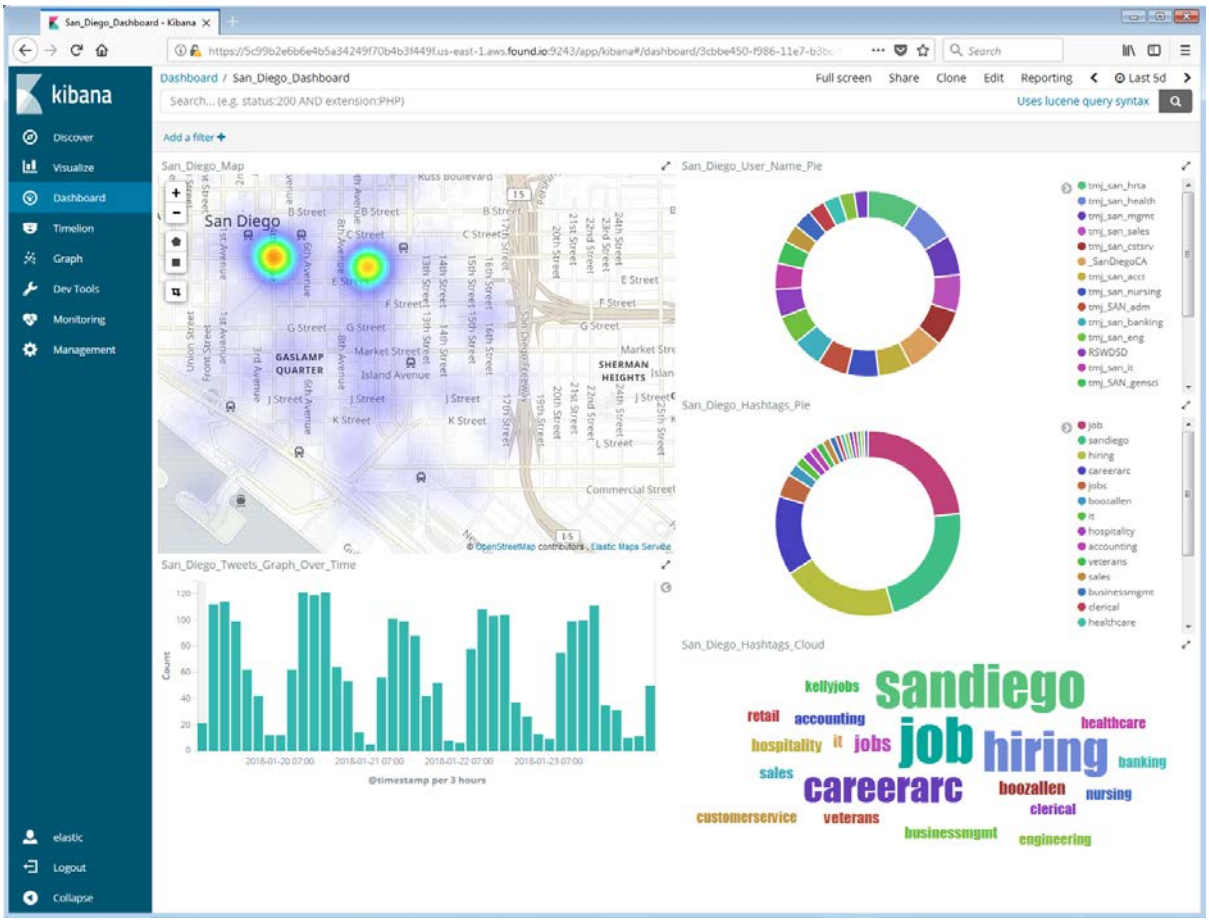

Figure 5. Kibana, Dashboard for San Diego, CA.

CONCLUSION

This work has shown an inexpensive, flexible, open-source software stack that can ingest Twitter API data and provide illumination into a population for a geographic location. The visualizations, dashboards and graphs are especially useful for supporting the full crisis lifecycle for emergency management, and can be deployed to the cloud, or run locally. Results are shown/discussed with full data, and again after filtering data from bot-like accounts, showing the importance of considering trustworthiness when using social media to represent a human population in near real-time. While the prototype does show promise, use by an existing emergency management entity (team/laboratory/agency/etc.) would be highly beneficial to understanding and improving its true utility.

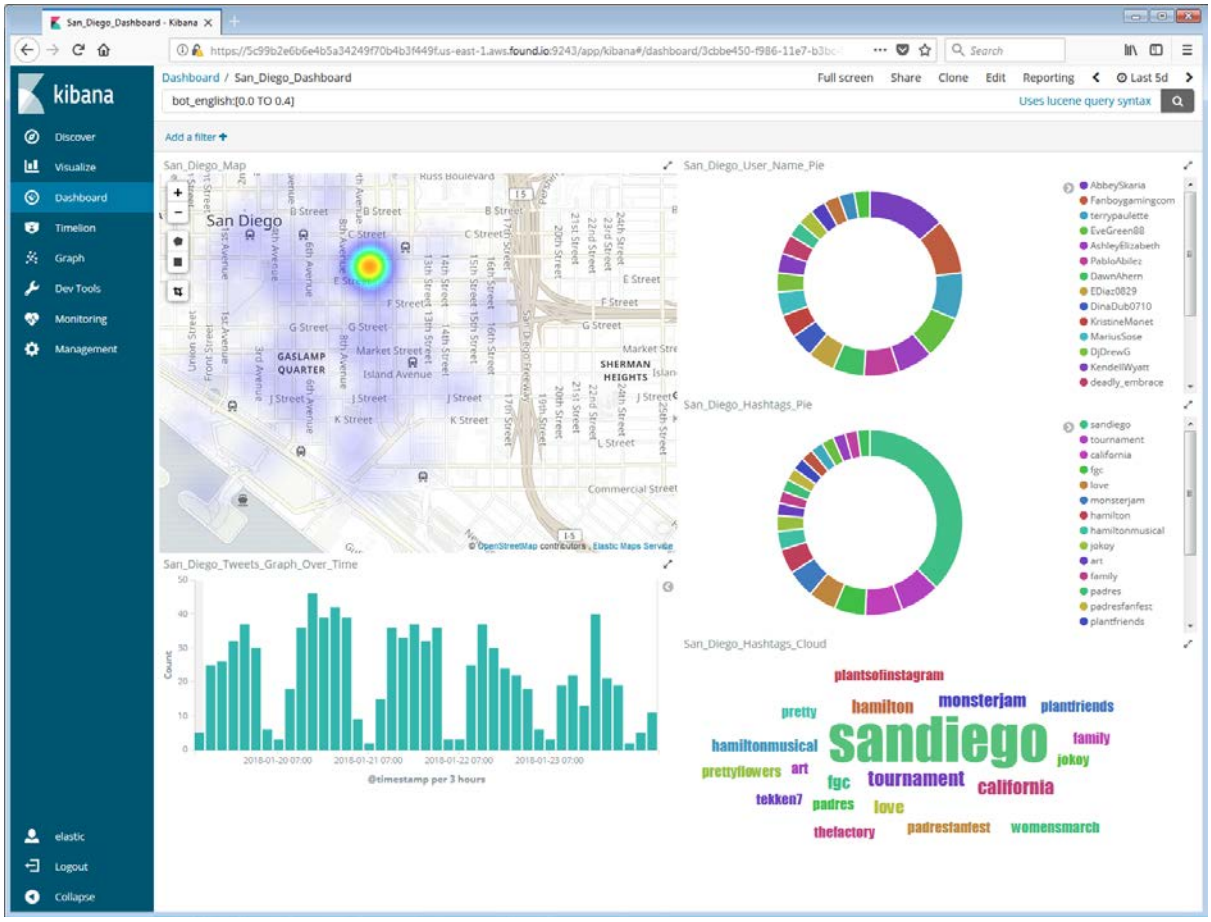

Figure 6. Kibana, Dashboard for San Diego, CA. with Bot-Like Tweets Removed

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APPENDIX A, PSEUDOCODE FOR THE JAVA CONSUMER

Algorithm 1 Twitter Streaming API Consumer Java Code

```
1: global waitFifteenMinutes ← false;
2: global dynamoDbTable;
3:
4: procedure MAIN
5:     queue localQueue;
6:     Create Connection to Twitter Streaming API with Geo Filters;
7:     Continually Place Tweets from Twitter Streaming API on localQueue;
8:     while 1 = 1 do
9:         if localQueue.size() > 0 then
10:            Tweet t ← localQueue.dequeue();
11:            NEWTHREAD(t);
12:
13: procedure NEWTHREAD(Tweet t)
14:    t.botData ← GETBOTDATAFROMDYNAMODB(t.accountId);
15:    if t.botData = NULL then
16:        if waitFifteenMinutes = true then
17:            if Now > 15 Minutes since (waitFifteenMinutes ← true) then
18:                waitFifteenMinutes ← false;
19:        else
20:            Timeline tL ← GETTIMELINEFROMTWITTER(t.accountId);
21:            Mentions m ← GETMENTIONSFROMTWITTER(t.accountId);
22:            BotData b ← MAKEBOTDATAREQTOBOTOMETER(t.userInfo, tL, m);
23:            t.botData ← b;
24:            UPDATEBOTDATAINDYNAMODB(t.accountId, t.botData);
25:    PRINTTOLOGASJSON(t);
26:
27: procedure GETBOTDATAFROMDYNAMODB(t.accountId)
28:    BotData b ← NULL;
29:    if dynamoDbTable.contains(t.accountId) then
30:        b ← dynamoDbTable.getBotData(t.accountId);
31:        if dynamoDbTable.getBotData(t.accountId).age() > 1 Week then
32:            dynamoDbTable.delete(t.accountId);
33:    return b;
34:
35: procedure UPDATEBOTDATAINDYNAMODB(t.accountId, t.botData)
36:    dynamoDbTable.insertOrOverwrite(t.accountId, t.botData, Now);
37:
38: procedure GETTIMELINEFROMTWITTER(t.accountId)
39:    Timeline tL ← MAKETIMELINEREQTOTWITTER(t.accountId);
40:    if Rate Limit Error = true then
41:        waitFifteenMinutes ← true;
42:    return tL;
43:
44: procedure GETMENTIONSFROMTWITTER(t.accountId)
45:    Mentions m ← MAKEMENTIONSREQTOTWITTER(t.accountId);
46:    if Rate Limit Error = true then
47:        waitFifteenMinutes ← true;
48:    return m;
49:
50: procedure PRINTTOLOGASJSON(t)
51:    JSON j ← t.toJSON();
52:    print(j);
```

APPENDIX B, QUERY STRINGS FOR ELASTICSEARCH/KIBANA

1. lat:[* TO *] AND lon:[* TO *]
2. (lat:[38.659419 TO 38.935678] AND lon:[8.993235 TO 9.253356]) OR (lat:[47.570555 TO 47.656297] AND lon:[122.269366 TO 122.423584]) OR (lat:[45.515404 TO 45.535094] AND lon:[122.6675029 TO 122.6851339]) OR (lat:[32.704179 TO 32.723869] AND lon:[117.148021 TO 117.165652]) OR (lat:[37.777479 TO 37.797169] AND lon:[122.387043 TO 122.404674]) OR (lat:[37.322802 TO 37.342492] AND lon:[121.876213 TO 121.893844])
3. bot_english:[0.0 TO 0.4]

Deep Neural Networks versus Naïve Bayes Classifiers for Identifying Informative Tweets during Disasters

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ABSTRACT

Traditional machine learning techniques have shown promising results in automating the process of identifying useful information in crisis-related data posted through micro-blogging services such as Twitter. More recently, deep learning techniques have also shown promise in the area of disaster response. In this paper, we focus on understanding the effectiveness of deep neural networks by comparison with the effectiveness of standard classifiers that use carefully engineered features. Specifically, we design various feature sets (based on tweet content, user details and polarity clues) and use these feature sets individually or in various combinations, with Naïve Bayes classifiers. Furthermore, we develop neural models based on Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) with handcrafted architectures. We compare the two types of approaches in the context of identifying informative tweets posted during disasters, and show that the deep neural networks, in particular the CNN networks, are more effective for the task considered.

Keywords

Machine Learning, Deep Learning, Naïve Bayes, Feature Engineering, Identifying Informative Tweets.

INTRODUCTION

In recent years, micro-blogging services such as Twitter have emerged as effective tools for broadcasting messages worldwide during disaster events. For example, over 20 million tweets were posted in less than a week during Hurricane Sandy, whereas five thousand tweets were posted every second during the earthquake and subsequent tsunami in Japan in 2011, resulting in 1.5 million tweets every 5 minutes. A quarter of Americans looked for information about the Boston bombings, and followed the updates regarding the hunt for bombers on social media such as Facebook and Twitter (Bullock et al. 2012). With millions of messages posted through micro-blogging services during disaster events, it has become imperative to identify valuable information that can help the emergency responders to develop efficient relief efforts and aid victims (Watson et al. 2017). Manually sifting through voluminous streaming data to filter useful information in real time is inherently impossible (Meier 2013).

Traditional machine learning techniques have shown promising results in automating the process of identifying useful, relevant and trustworthy information in big crisis data (Qadir et al. 2016), However, these techniques usually require carefully engineered features to represent the data (e.g., tweets), and produce accurate classifiers (Imran, Castillo, et al. 2015). Such features include standard bag-of-word features, part-of-speech tags, or other more sophisticated content-based features. Generally, the more comprehensive the set of features used and the more it captures the domain knowledge, the more accurate the classifier that it produces. Thus, accurate classifiers are produced at the cost of constructing (often expensive) features.

No.	Tweet	Class
1.	*"Boston police: At least 3 people killed in Boston marathon bombing http://t.co/duv2iiwmrz #bostonmarathon"*	Informative
2.	*"RT abcnews: Breaking: Flood maps for Brisbane River are now available http://t.co/2ExK39rY #bigwet"*	Informative
3.	*"#walangpasok because of a holiday in the philippines. hoping that the weather is much better. #floodph #maringph"*	Non-informative
4.	*"@user really sad about the tragedy:(,may they rest in peace #santamaria"*	Non-informative

Table 1. Examples of tweets from disaster events with class labels.

More recently, researchers have started to investigate the use of deep learning in the area of disaster response (Nguyen et al. 2017; C. Caragea, Silvescu, et al. 2016; Ben Lazreg et al. 2016). Deep learning approaches (LeCun et al. 2015) have significantly improved the performance on many tasks, such as speech and visual object recognition (LeCun et al. 2015), and tweet classification (Yuan et al. 2016), among others. They can make use of pretrained distributed representations (Mikolov et al. 2013), and have the ability to identify higher-level hierarchical data representations, eliminating the need for carefully engineered features (LeCun et al. 2015), at the cost of engineering the network architecture and learning the network weights based on larger amounts of labeled data than are generally needed by traditional machine learning algorithms.

However, in disaster events, which unfold rapidly, the amounts of *labeled data* are limited. Hence, one research question that can be raised is: *Given a limited amount of labeled crisis-related data, how does the effectiveness of deep learning models that use pretrained distributed representations, compare with that of standard machine learning classifiers that use carefully designed feature representations?* In particular, we compare Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) trained on distributed representations with Naïve Bayes classifiers trained on handcrafted features. These features include standard bag-of-word features, content-based features (e.g., URLs, hashtags, emoticons, slang), user-based features (e.g., number of friends and number of followers) and polarity-based features (e.g., positive and negative words).

We address the research question above by training classifiers for identifying informative tweets during disasters using the CrisisLexT26 dataset constructed by Olteanu et al. (2014). This dataset comprises of tweets from 26 disasters that occurred during 2012 and 2013. "Informative" tweets are defined as tweets that provide valuable information to anyone in the scene of a disaster (as a victim, supporter, responder, etc.), and non-informative tweets are defined as tweets which do not convey any useful content in the scene of a disaster. Examples of informative and non-informative tweets are shown in Table 1.

In summary, our contributions are:

- We engineer a set of features that combines "bag-of-word" features with features extracted from tweet content, user details, and polarity clues, and use those features with Naïve Bayes, as an effective representative of standard machine learning classifiers for text data. We show experimentally that models trained using the combination of all features perform better than models trained on each feature type independently (i.e., either "bag-of-word" features or features extracted from the tweet content, etc.).
- We engineer and train deep neural network models, specifically CNN and RNN models, with various architectures. We show that the deep neural network models are more effective in identifying informative tweets for both natural and non-natural disasters, as compared to the Naïve Bayes models.
- Furthermore, we show that the deep neural network models generalize better than Naïve Bayes across disasters of different nature (e.g., natural and non-natural disasters). We achieve this by comparing models trained on natural disasters and evaluated on non-natural disasters, and vice-versa.

Our study provides additional evidence to the claim that proper analysis of streaming data may lead to applications able to help not only the disaster response providers to allocate resources more efficiently, but also the victims who are in need and seeking support, by filtering out necessary informative messages for immediate availability. The problem of finding relevant information as a disaster evolves faces many challenges since extracting informative tweets and filtering out those that are non-informative has to be done in real time and with high accuracy. In particular, deep learning networks, such as CNN and RNN networks, can address this task more effectively than standard machine learning methods that require more extensive feature engineer.

The remaining of this paper is organized as follows: We first discuss the related work and challenges of using microblogging data in disaster events. Next, we describe the Twitter dataset in the DATASET section. We present the features used for identifying informative tweets from a stream of messages, and the deep neural networks used in the APPROACHES section. We discuss the results of our experiments in the RESULTS section. Finally, we conclude the paper and provide several directions for future work.

BACKGROUND AND RELATED WORK

Castillo et al. (2011) developed automatic machine learning techniques to assess the credibility of tweets related to specific topics or events (however, not restricted to emergency events). Using a comprehensive set of features extracted from user's posting behavior and tweet text and context (specifically, message-based, user-based, topic-based, and propagation-based), newsworthy events were classified as credible or not credible.

Subsets of the features introduced by Castillo et al. (2011), together with other specific features, have been used with traditional machine learning approaches for disaster tweet classification, as described in the following surveys (Imran, Castillo, et al. 2015; Beigi et al. 2016). For example, C. Caragea, Squicciarini, et al. (2014) used features such as unigrams, polarity clues, emoticons, punctuation and acronyms to identify the sentiment of tweets posted during Hurricane Sandy. Verma et al. (2011) used unigrams and bigrams, together with part-of-speech (POS) tags, subjectivity of tweet, tone of tweet (personal/impersonal), etc., to identify tweets that contain information useful for situational awareness. Rudra et al. (2015) used features such as count of personal pronouns, count of wh-words, fraction of subjective words, to classify tweets as situational or non-situational. Sen et al. (2015) have also focused on identifying situational awareness tweets using low level syntactic features, including POS tags, tweet formality, word subjectivity, emoticons and exclamations, personal pronouns, etc. Imran, Elbassuoni, et al. (2013) classified tweets according to several situational awareness categories, such as caution and advice, casualties and damage, donations, people missing, etc. using unigrams, bigrams, POS tags, presence of URL/hashtags, tweet length, etc. Yin et al. (2012) used similar features to identify tweets related to a disaster, identify disaster type and assess the impact of a disaster. Neppalli et al. (2017) used features such as presence of hashtags, number of hashtags, tweet length to predict tweet retweetability. Other works (C. Caragea, McNeese, et al. 2011; Ashktorab et al. 2014; Imran, Chawla, et al. 2016; Huang and Xiao 2015) have simply used the standard bag-of-word (BOW) features based on unigrams and/or bigrams, with accurate results.

More recently, research has started to investigate the use of deep learning (LeCun et al. 2015) in the area of disaster response (C. Caragea, Silvescu, et al. 2016; Nguyen et al. 2017; Ben Lazreg et al. 2016). For example, C. Caragea, Silvescu, et al. (2016) used convolutional neural networks (CNN) to identify informative messages in data from flooding disasters and reported significant improvements in performance over Support Vector Machines and fully connected Artificial Neural Networks. Similarly, Nguyen et al. (2017) used CNNs on situational awareness crisis data and noted improvements over traditional algorithms. Ben Lazreg et al. (2016) used a different deep learning approach, specifically a Long Short-Term Memory (LSTM) network, to learn a model from crisis tweets and used this model to generate snippets of information summarizing the tweets.

Inspired by the above-mentioned works, we compare several sets of features extracted from the tweet content, user details and polarity clues, to understand what features are the best-performing ones for the problem of identifying informative tweets posted during a crisis event. Moreover, we compare traditional machine learning algorithms, specifically Naïve Bayes classifiers, that use the most comprehensive set of features for identifying informative tweets, with deep learning networks that use pre-trained embeddings of the tweet words to understand what type of approach gives better results. Despite that the deep learning approaches often provide improved results over traditional models, they are not interpretable, whereas our handcrafted features could yield interpretable models. We focus on Naïve Bayes as a traditional machine learning algorithm, given that Naïve Bayes has no parameters that need to be tuned, and has shown good performance in the context of disaster tweet classification, when compared with other machine learning algorithms, such as Support Vector Machines (SVM) or Random Forests (RF) - see, for example, (Li, D. Caragea, C. Caragea, and Herndon 2018; Li, D. Caragea, and C. Caragea 2017). We evaluate the performance of the models trained on natural disasters (e.g., earthquakes and floods), as well as non-natural disasters (e.g., fire accidents and train crashes). Furthermore, we investigate what type of models, Naïve Bayes classifiers or deep neural networks, have the capability to generalize from one type of disaster to another (e.g., from natural to non-natural disasters).

DATASET

We used the CrisisLexT26 dataset constructed by (Olteanu et al. 2014). This collection contains tweets from 26 disasters that occurred during 2012 and 2013, which are manually annotated by crowd-sourced workers with the

No.	Non-natural Disasters	Natural Disasters
1.	Colorado Wildfires (2012)	Costa Rica Earthquake (2012)
2.	Australia Bushfires (2012)	Gautemala Earthquake (2012)
3.	Venezuela Refinery (2012)	Italy Earthquake (2012)
4.	Boston Marathon Bombings (2013)	Bohol Earthquake (2013)
5.	Brazil Night Club Fire (2013)	Typhoon Pablo (2012)
6.	Glasgow Helicopter Crash (2013)	Typhoon Yolanda (2013)
7.	LA Airport Shootings (2013)	Alberta Floods (2013)
8.	Lac Megantic Train Crash (2013)	Colorado Floods (2013)
9.	NY Train Crash (2013)	Philipinnes Floods (2012)
10.	Savar Building Collapse (2013)	Manila Floods (2013)
11	Spain Train Crash (2013)	Queensland Floods (2013)
12.	Singapore Haze (2013)	Sardinia Floods (2013)
13.	West Texas Explosion (2013)	Russia Meteor (2013)

Table 2. Summary of disasters used in the experiments.

following informativeness labels: "*related and informative*", "*related - but not informative*", "*not related*", and "*not applicable*." There are about 1000 tweets manually annotated in each of the 26 disasters. Among the 26 disasters, there are 13 non-natural disasters and 13 natural disasters. We classify as a natural disaster any catastrophic event caused by nature, or a natural process of the earth (e.g., cyclones, earthquakes, floods). We classify as a non-natural disaster any event caused by human actions, which may be intentional actions (e.g., gun shootings, bombings), or unintentional actions that lead to technological failures (e.g., industrial accidents, train crash). Table 2 shows the 26 disasters used in this study and their types. Using the language attribute available from Twitter, we found that some of the tweets in the dataset are in languages other than English. Furthermore, some tweets are labeled as *not-related* or *not applicable* to the disaster in question. We removed from the dataset the not-related and non-English tweets, and were left with 7200 tweets related to non-natural disasters and 6480 tweets related to natural disasters.

APPROACHES TO INFORMATIONAL TWEET CLASSIFICATION

Informational Tweet Classification as Supervised Learning

We formulate the problem of informational tweet classification as a supervised learning problem. Specifically, given an independent and identically distributed (iid) set of labeled tweets posted during various disasters, a hypothesis class (e.g., Naïve Bayes classifiers), and a performance criterion (e.g., accuracy), a supervised learning algorithm identifies a hypothesis (i.e., a classifier) that optimizes the given performance criterion. The identified classifier is used to classify tweets as informative or non-informative during the testing phase.

Feature Engineering for Traditional Learning Algorithms

Next, we describe the features that we use as input to the Naïve Bayes classifier. We divide them into four sets, namely bag-of-words (BOW), tweet content features (TC), user-based features (UF) and polarity-based (PF) features.

Bag-of-Words (BOW)

A vocabulary is first constructed, which contains all unique words from the collection of training tweets. Using this vocabulary, we use a binary representation to represent tweets as vectors. Specifically, we assign 1 for each word in the vocabulary if the word is found in the tweet, otherwise we assign 0.

Tweet Content Features (TC)

We designed these features based on the content of a tweet, as follows:

- Presence of URLs: True if at least one URL is present in the tweet, false otherwise.
- Presence of hashtags: True if at least one "#hashtag' is present in the tweet, false otherwise.
- Hashtag count: Number of occurrences of hashtags in the tweet.
- Presence of emoticons: True if at least one emoticon is present in the tweet, false otherwise. Intuitively, this feature is indicative of conversational tweets.

- Instructional keywords: True if the tweet contains instructional words, such as "text," "call," and "donate," otherwise false.
- Phone numbers: True if the tweet contains a phone number, otherwise false. Phone numbers are identified using regular expressions (e.g., `\\d{3}-\\d{3}-\\d{4}`identifies numbers of the form xxx-xxx-xxxx).
- Internet slang:[1] True if the tweet contains abbreviations or slang, such as "OMG" (Oh My God), otherwise false. Abbreviations/slang are indicative of informalities, and occur mostly in conversational tweets.
- Retweet (RT): True is the tweet contains retweet patterns, such as "RT @" or "RT@," otherwise false.
- Profanity - True is the tweet contains informal/cuss words, otherwise false.
- Sentence structure: We use OpenNLP[2] Java Libraries to check whether the tweet contains a one-word sentence. We assign a value of 1 for the presence of one-word sentences, otherwise 0. Likewise, we also check for the presence of multiple sentences, and assign value 1 for multiple sentences, and otherwise 0.

User-based Features (UF)

The following attributes, provided by Twitter, are used as the set of user-based features.

- Followers count: Total number of followers of a user.
- Friends count: Total number of friends of a user.
- Favorites count: Total number of favorite tweets in the user account.
- Listed communities count: Total number of communities that the user is listed in.
- Statuses count: Total number of tweets posted by the user.
- Verified account: Twitter follows a procedure to verify the authenticity of the users who are famous personalities, brands, etc. Each user account is assigned with a special emblem, if the user meets the verification criteria. The possible value for this feature is 1 (if verified account) and 0 (if not verified).

Polarity-based Features (PF)

These features are formulated based on the polarity (positive or negative) of the words in a tweet. We identify the polarity words using lexicons of positive and negative words created by Hu and Liu (2004), and extract the following features:

- Positive word count: Number of positive words in a tweet.
- Negative word count: Number of negative words in a tweet.
- Positive Score: Positive score returned by the SentiStrength algorithm.
- Negative Score: Negative score returned by the SentiStrength algorithm.
- Emotional Divergence: We adopt the definition of "emotional divergence" (ED) from Pfitzner et al. (2012). ED is defined as "the (normalized) absolute difference between the positive and the negative sentiment score delivered by SentiStrength." It is calculated as $ED = \frac{(p-n)}{10}$, where p is a positive score and n is a negative score output by the SentiStrength algorithm. This feature is an aggregate of the above four polarity features.

Models

In this work, we evaluate the performance of several models for identifying informative tweets posted during disaster events. First, we evaluate the performance of models based on bag-of-words (BOW) and custom features (namely, TC, UF & PF), and use them as our baselines. Then, we evaluate the performance of Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN), which take as input pre-trained embeddings.

[1]https://www.lifewire.com/urban-internet-slang-dictionary-3486341
[2]https://opennlp.apache.org/

Naïve Bayes Models

In the category of traditional supervised machine learning algorithms, we use the Naïve Bayes algorithm, as Naïve Bayes has been shown to be an effective classifier in crisis-related tweet classification (Li, D. Caragea, C. Caragea, and Herndon 2018). Furthermore, our own preliminary examination with Support Vector Machine and Random Forest classifiers confirmed that the Naïve Bayes classifier gives results competitive and sometimes better than the results given by other classifiers (results not shown due to space constraints). We used the following features and feature combinations with Naïve Bayes: individual feature types (namely, Only TC, Only UF, and Only PF), BOW (0/1 representation of tweets), and the combination of BOW with the other feature sets.

Deep Neural Network Models

CNN Model: Convolutional Neural Networks can be seen as a special category of Deep Neural Networks, based on the concepts of *local receptive field* and *weight replication*. CNNs consist of combinations of convolution and sub-sampling layers, which help extract meaningful representations of the input data. We use a model similar to the one described in (Kim 2014). Our model has a single convolution layer followed by max-over-time pooling layer and a fully connected layer. The input to convolution layer is a matrix, where each row is a vector representation of a word in the tweet, specifically an embedding trained using crisis-related tweets. Multiple filter of different sizes are used to convolve this matrix and detect local features. The output of each filter is fed to a pooling layer that scans for the maximum value. The output feature maps corresponding to the filters used are finally concatenated to get the feature representation of input. For regularization, we implement the dropout technique to the fully connected layer. Finally, a softmax layer calculates the probability distribution over the two classes, and also the loss function.

RNN Model: Recurrent Neural Networks represent another category of Deep Neural Networks. RNNs have a recurrent hidden state whose activation is controlled by the output from the current step as well as previous time steps. They keep track of contextual information from each time step in the past and are suitable for modeling sequences such as sentences, which are sequences of words. We create a Recurrent Neural Network Model with Gated Recurrent Unit (Cho et al. 2014). GRU has gating units to modulate the flow of information. The inputs to our RNN are word embeddings as for the CNN model.

EXPERIMENTS AND RESULTS

We used tweets from 26 disasters available from CrisisLexT26 (Olteanu et al. 2014), and separated them in two subsets based on the disaster type: one consisting of 7200 tweets from non-natural disasters and another one consisting of 6480 tweets from natural disasters. To have an equal amount of data for training in each subset and remove the sample size bias, we randomly sampled a subset of 6400 tweets from each subset. Each sample consists of 5000 informative tweets and 1400 non-informative tweets. Table 3 shows the results of the comparison between the Naïve Bayes models obtained using different feature sets and the deep neural network models, specifically CNN and RNN models, that take as input word embeddings. We evaluate the models using the 10-fold cross-validation strategy. We report the F1-scores of the classifiers on the informative and non-informative classes, and also the average scores over the two classes.

Naïve Bayes Models

We trained several Naïve Bayes models using bag-of-words, custom features and their combinations. For the bag-of-words, we removed stop words and words occurring in less than three tweets. As can be seen from Table 3, among our custom feature sets (TC, UF, PF), the classifiers trained using only TC perform better than using only UF and only PF, on both disaster types. For example, the average F1-score of only TC for non-natural is 0.776, which is much better than 0.583 (the average F1-score for only UF) and 0.742 (the average F1-score for only PF). When user features (UF) are added to any feature set, the performance does not improve for any disaster type, which indicates that the informativeness of a tweet is independent of the user features, given the other features used. Overall, we observe the best performance for TC+PF among our feature set combinations. When polarity features are added to TC, we observe that the classifiers' performance improves, implying that these two feature sets are mutually assisting each other to boost the classifier's performance. For example, for the non-natural disaster type, the average F1-score increases from 0.776 (for only TC) to 0.789 (for TC+PF), which represents a 1.68% increase. When TC features are combined with BOW features, the classifier's performance is similar to that obtain with Only BOW. By adding UF to BOW+TC, the classifier's performance is degraded. However, by adding PF features to BOW+TC, the performance improves slightly by comparison to only BOW features. Overall, by comparing Naïve Bayes models trained with different features, we observe that UF features are not useful for identifying the informative tweets, while TC and PF are slightly improving the results obtained with BOW only on this classification task.

Model Type	Feature/Model	Non-natural			Natural		
		Info.	Non-Info.	Avg.	Info.	Non-info.	Avg.
Naïve Bayes	Only TC	0.841	0.555	0.778	0.835	0.435	0.748
	Only UF	0.656	0.323	0.583	0.195	0.369	0.233
	Only PF	0.867	0.297	0.742	0.855	0.341	0.743
	TC+UF	0.808	0.539	0.749	0.679	0.470	0.633
	TC+PF	0.870	0.500	0.789	0.865	0.457	0.776
	UF+PF	0.801	0.390	0.711	0.279	0.375	0.300
	TC+UF+PF	0.837	0.577	0.781	0.718	0.494	0.669
	Only BOW	0.903	0.704	0.859	0.900	0.681	0.852
	BOW+TC	0.902	0.703	0.858	0.901	0.688	0.855
	BOW+TC+UF	0.894	0.696	0.850	0.880	0.670	0.834
	BOW+TC+PF	**0.905**	**0.710**	**0.862**	**0.902**	**0.688**	**0.855**
DNN	**CNN**	**0.937**	**0.747**	**0.895**	**0.928**	**0.687**	**0.875**
	RNN	0.927	0.714	0.880	0.918	0.676	0.865

Table 3. The performance (F1-score) of the Naïve Bayes (NB) models with various feature sets, by comparison with the performance of the deep neural network (DNN) models, specifically CNN and RNN. Experiments are performed using 10-fold cross-validation on the sets of *Non-natural* and *Natural* disasters, respectively. Among the Naïve Bayes models, the model that uses BOW+TC+PF gives the best results (values highlighted in blue), while the best results overall are obtained with the CNN model (values highlighted in red).

Deep Neural Network Models

We train two neural network models: CNN and RNN. For the CNN model, we trained several architectures and tuned different sets of parameters on a separate validation set. The best overall parameters, which were used in the final CNN model, are described in what follows. We used a word2vec (Mikolov et al. 2013) model trained using crisis-related messages from a collection of disaster tweets (i.e., tweets crawled from Hurricane Sandy and Boston bombing disasters, which consist of $\approx$ 30 million tweets). The dimension of each word vector is 150. We used three convolution filter sizes: $3 * 150$, $4 * 150$ and $5 * 150$. The number of feature maps for each filter size is 256 and the dropout ratio is 0.5 in all cases. For the RNN model, we used a single GRU cell with 32 hidden units, and maximum sequence length of 20 words. The results of deep neural networks are shown in the last two rows in Table 3. As can be seen from the table, the CNN model outperforms the other models. For instance, on non-natural disasters, the CNN shows approximately 3% better F1-score as compared to the Naïve Bayes model trained using the combination of BOW+TC+PF features. Furthermore, the CNN model performs better than the RNN model by approximately 1.5%.

Cross-Domain Experiments

Next, we investigate how the Naïve Bayes and the DNN models will generalize from one type of disaster to another (e.g., from natural to non-natural disasters). We use data from one type of disaster for training and data from the other type of disaster for testing. Table 4 shows the results of these experiments. As can be seen from Table 4, the best cross-domain results are also obtained with the DNN models, and the CNN model performs better than the RNN model. Among the Naïve Bayes models (Only BOW, Only TC, BOW+TC, BOW+TC+PF) trained and tested in the cross-domain setting, we observe that classifiers trained using feature sets TC and PF, in conjunction with BOW features, are performing better than the classifiers trained on Only BOW, for example in Train-*Non-natural*/Test-*Natural* experiment, the average F1-score is 0.707 for Only BOW and is 0.725 for BOW+TC+PF, which represents a 2.55% increase.

We also compare the cross-domain results with the 10-fold cross-validation results (Table 3), which were obtained when training and testing on the same type of disaster (this is a fair comparison as in the cross-validation each example is used exactly once in testing). As can be seen from Tables 3 and 4, generally, the cross-domain models trained using data from natural disasters and tested on data from non-natural disasters show similar performance to that of the classifiers evaluated using 10-fold cross-validation on the non-natural disaster data. The same trend is observed for the DNN models, when training on data from non-natural disasters and testing on data from natural disasters. However, in this cross-domain case, the Naïve Bayes models have significantly worse performance than that of the models trained and tested using 10-fold cross-validation.

These results suggest that the features extracted from natural disasters can be used for developing Naïve Bayes models that could predict both disaster types (non-natural or natural), whereas features extracted from non-natural

Model Type	Features/Model	Train-*Natural*/Test-*Non-natural*			Train-*Non-natural*/Test-*Natural*		
		Info.	Non-Info.	Avg.	Info.	Non-Info.	Avg.
Naive Bayes	Only BOW	0.891	0.656	0.839	0.753	0.540	0.707
	Only TC	0.871	0.446	0.778	0.817	0.497	0.74
	BOW+TC	0.894	0.666	0.844	0.768	0.546	0.719
	BOW+TC+PF	0.897	0.669	0.847	0.773	0.555	0.725
DNN	**CNN**	**0.929**	**0.676**	**0.874**	**0.912**	**0.682**	**0.862**
	RNN	0.918	0.685	0.867	0.911	0.66	0.856

Table 4. Summary of results for cross-domain experiments with Train-on-all/Test-on-all strategy

disasters do not generalize well for natural disasters. We further investigated this aspect by analyzing several patterns in natural versus non-natural disasters. Our analysis revealed some variation in terms of hashtags usage: the usage seems to be greater in natural disaster tweets as compared to the usage in non-natural disaster tweets. Specifically, in our natural disaster subset, there are 204 unique hashtags with a total of 6174 occurrences, while in the non-natural disaster subset, there are 154 unique hashtags with a total of 3758 occurrences. Another observation we made was that the non-natural disaster tweets have a lot of slang words, whereas a more limited slang usage can be seen in natural disaster tweets. Therefore, the fact that the models trained on non-natural disasters do not generalize to natural disasters can be explained through variations in usage of hashtags and slang, but more analysis is needed to confirm this hypothesis, which will be interesting to explore in future.

CONCLUSIONS

Previous research suggests that data gleaned from social media contributions have both significant value to emergency responders and are difficult to use. Responders seek an enhanced operational picture during any disaster, which grants them better situational awareness. In this paper, we designed several feature sets for identifying informative tweets using CrisisLexT26 dataset. We experimented with BOW and various combinations of our designed feature sets - TC, UF, and PF to obtain the best performing model. Among our feature set combinations, TC+PF is performing better than other feature set combinations and adding BOW to TC+PF show improved classifier performance over TC+PF. We find that using user features is not useful for this classification task, that is, in general, the informativeness of a tweet is independent of user characteristics. From all the experiments, it is evident that CNN outperformed the other models. We also explored how the models developed for natural disasters are useful for non-natural disasters and vice-versa. For the traditional machine learning (non-neutral) models, we found that the natural disasters generalize well on both natual and non-natural disasters, but non-natural disasters do not. In contrast, neural models generalize well across both types of disasters.

In future, it would be interesting to explore a combination of DNNs with hand-crafted features. One more interesting direction would be to identify the tweets which convey actionable information and particularly those that ask for help, which will make it easier for the first responders to find those victims who are seeking help.

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Understanding Eyewitness Reports on Twitter During Disasters

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ABSTRACT

Social media platforms such as Twitter provide convenient ways to share and consume important information during disasters and emergencies. Information from bystanders and eyewitnesses can be useful for law enforcement agencies and humanitarian organizations to get firsthand and credible information about an ongoing situation to gain situational awareness among other uses. However, identification of eyewitness reports on Twitter is challenging for many reasons. This work investigates the sources of tweets and classifies them into three types (i) direct eyewitnesses, (ii) indirect eyewitness, and (iii) vulnerable accounts. Moreover, we investigate various characteristics associated with each kind of eyewitness account. We observe that words related to perceptual senses (feeling, seeing, hearing) tend to be present in direct eyewitness messages, whereas emotions, thoughts, and prayers are more common in indirect witnesses. We believe these characteristics can help make more efficient computational methods and systems in the future for automatic identification of eyewitness accounts.

Keywords

social media, disaster response, eyewitness accounts

INTRODUCTION

At times of natural and anthropogenic disasters, people use social media platforms such as Twitter and Facebook to share information (Vieweg et al. 2010) that potentially can support the disaster response. This information includes reports of injured and dead people, urgent needs of affected people, reports of missing and found people, and reports of bank robberies, among others (Imran, Castillo, Diaz, et al. 2015). Social media not only contains useful information, it also breaks stories and events faster than many other traditional information or news sources such as TV. For instance, the first report of the Westgate Mall attack[1] in Nairobi, Kenya in 2013 was published on Twitter, almost 33 minutes before a local TV channel reported the event. Similarly, the news about the Boston bombing incident[2] appeared on Twitter before any other news channel reported the event. Likewise, in the case of the California earthquake[3] it was observed that the first half dozen tweets were recorded by Twitter about a minute earlier than the recorded time of the event according to the USGS.

At the onset of a disaster event, people share massive amounts of data, but much of that data has redundant information, sharing the same news article, or same video. For instance, millions of messages were posted on Twitter during Hurricane Harvey in 2017.[4] However, studies have revealed that sources of this online information include

[1] https://en.wikipedia.org/wiki/Westgate_shopping_mall_attack
[2] https://en.wikipedia.org/wiki/Boston_Marathon_bombing
[3] http://latimesblogs.latimes.com/technology/2008/07/twitter-earthqu.html
[4] https://crisiscomputing.qcri.org/2017/09/27/hurricane_harvey_and_the_role_ai/

many local citizens, bystanders, and eyewitnesses, i.e. people who directly observe the occurrence of an event (Diakopoulos et al. 2012). From the perspective of an information seeker (affected citizen or institutional response agency), information from eyewitness accounts is preferred over other types of information sources (e.g., people outside the disaster area). For instance, law enforcement agencies look for firsthand and credible information for decision-making. Humanitarian organizations look for timely and trustworthy information that is directly observed from the disaster-hit areas to better estimate the severity of a disaster event, the scale of damage done by the disaster, and the amount of aid required to help save lives and fulfill the urgent needs of affected people.

Gaining rapid access to the information shared by eyewitness accounts, especially during an ongoing disaster event, is useful but challenging for many reasons (Imran, Mitra, et al. 2016). One solution is to identify local residents in disaster-hit areas through Twitter provided geo-information along with tweets. However, given only 1% to 3% of Twitter messages are geotagged, and relying solely on geotagged tweets to identify local residents does not provide enough data. Moreover, not all the tweets from local people can be considered as posted by eyewitness accounts. The location mentioned in the user profile is another opportunity, but research has shown that it is very noisy and inaccurate, and it does not indicate location of the source at the time when a Tweet is made.

Given the above issues, it remains a challenge to process millions of tweets to filter out those belonging to people outside disaster-hit areas followed by the identification of eyewitness accounts from local residents. Doggett and Cantarero 2016 identified a set of eyewitness and non-eyewitness linguistic features to categorize eyewitness news-worthy events by conducting their research on human-induced disasters such as protests, shooting, and police activities. Likewise, Fang et al. 2016 highlighted another similar set of linguistic and meta-features to identify witness accounts on various natural and human-induced disasters. They also used the topic of tweets as a feature to automatically classify tweets as witness accounts. Tanev et al. 2017 also identified a set of eyewitness features from several dimensions and categorized stylistic, lexical Twitter metadata and semantic features. Truelove et al. 2014 developed a generalized conceptual model of different types of eyewitness accounts for several events such as concerts, shark sightings, cyclones, and protests. However, most of the works do not differentiate between different types of eyewitnesses particular to natural disasters, and do not identify different characteristics associated with those types.

This paper aims to address this research gap by categorizing eyewitness characteristics for different types of disasters, and prepare the ground for including geographic location when possible to determine whether a particular piece of information is from an eyewitness source, and whether that source is vulnerable and at risk. The paper presents analyses of Twitter data related to different natural disasters and makes the following contributions: We first manually analyze the collected data to identify which tweets are posted by eyewitnesses. Next, we identify different types of eyewitness accounts and defining characteristics associated with each kind of eyewitness account. Finally, we make the annotated dataset available on the CrisisNLP repository[5] for research communities to further explore this area and develop computational methods to automatically identify eyewitness accounts from Twitter using the identified characteristics.

LITERATURE REVIEW

Twitter is a well established source to harvest opportunistically information during crisis events. Kwak et al. 2010 argue that Twitter serves also as news source and not only as social media platform. Their research reveals that over 85% of trending topics are news headlines. People are motivated to search for breaking news and real-time contents on Twitter (Teevan et al. 2011) as in case of disasters (Kryvasheyeu et al. 2016) ; (Schnebele et al. 2013) ; (Allen 2014) ; (Amaratunga 2014) . Oh et al. 2013 explore the use of Twitter during social crisis situations.

Tweets are micro-blogs, i.e. small packets of information which can be used by humanitarian and disaster relief organizations by developing real-time tweet crawler applications such as TweetTracker (Kumar, Barbier, et al. 2011), Artificial Intelligence for Disaster Response (AIDR) (Imran, Castillo, Lucas, et al. 2014), Twitcident (Abel et al. 2012), ScatterBlogs for situational awareness (Thom et al. 2015), cross-language aspects on Twitter (Imran, Mitra, et al. 2016), or using Twitter during a particular disaster such as Typhoon Haiyan in the Philippines (Takahashi et al. 2015). For more than a decade, Twitter has been used by researchers to study different aspects of social media because of its near real-time and free of cost nature. Academic research into Twitter and disaster management has mainly focussed on user contributed data in disaster response (Haworth and Bruce 2015) and relief phase (Landwehr and Carley 2014) such as the Haiti earthquake in 2010 (Meier 2012) or during forest fires (Ostermann and Spinsanti 2012).

According to Twitter usage statistics [6] , around 500 million tweets are posted per day. Research universally agrees on the noisy nature of Twitter due to this massive volume and the unstructured nature of tweets. In the case of

[5] http://crisisnlp.qcri.org/
[6] http://www.internetlivestats.com/twitter-statistics/

emergency events, extraction of relevant information from this noise is critical. Crowdsourced social media data generated by often anonymous users suffers from an absence of quality assurance (Goodchild and Li 2012) on the truthfulness, objectivity, and credibility of the information. Disaster response organizations search for eyewitness accounts as those are considered more credible (Truelove et al. 2015). Researchers have studied possibilities to identify eyewitness accounts out of millions of tweets for journalism (Diakopoulos et al. 2012), criminal justice and natural disasters (Olteanu et al. 2015). Morstatter et al. 2014 relate identification of eyewitness tweets to the use of language and linguistic patterns within the region during different crisis events. They also identified a set of features to automatically classify eyewitness accounts. Kumar, Morstatter, et al. 2013 relate location information of the users to assess local users and remote users on crisis reports.

However, both research strands have worked mostly in isolation until now, with the potential of location information not fully exploited for establishing whether a source is an eyewitnesses, who might be vulnerable and at risk. This paper aims to develop a holistic categorization of characteristics of eyewitness reports for different types of disasters.

DATA COLLECTION AND MANUAL ANALYSIS

Data collection

We followed the same data collection process as described in Zahra et al. 2017 from the Twitter streaming API to collect data related to three types of natural disasters: earthquakes, floods, and hurricanes. We used disaster type-specific keywords to collect data from 01-August-2017 to 28-August-2017. In total, we collected 243,194 tweets related to earthquakes using *"earthquake, foreshock, aftershock"* keywords. For hurricanes-related data, we collected 36,815 tweets using *"hurricane, cloud-burst"* keywords. And, for floods, we collected 671,503 tweets using *"flood, inundation, extensive rain, heavy rain"* keywords. The collected dataset contains multiple incidents of different earthquakes, floods, and hurricanes occurred around the world during the data collection period.

Manual analysis

To investigate different types of eyewitness accounts and their posting characteristics, next we perform a manual analysis of the collected data. For this purpose, we sampled 2,000 tweets from each disaster type. The sampled data do not contain any re-tweets. Two authors developed and tested the following annotation guidelines before applying these to the sampled Tweets:

- **Tweet source:** This task aims to determine the source of a given tweet. We only consider two types of sources: eyewitness account and non-eyewitness account.
- **Eyewitness account type:** If a tweet is an eyewitness account (identified by the previous task), then this task aims to further determine the type of eyewitness. If the author of a tweet claim to have directly seen or observed the incident, then he/she is considered as direct eyewitness. However, if the author of a tweet sourced a piece of information from his/her family or friends circle and has implicitly or explicitly mentioned the original sources, then the tweet is considered coming from an indirect eyewitness account. A further category of tweeters identified as vulnerable direct eyewitness who were reporting about an anticipated disaster and were present in the region.
- **Eyewitness characteristics:** Given a direct, indirect, or vulnerable direct eyewitness account tweet, this task aims to identify various characteristics and clues that help understand the source of a tweet.

Two authors of this paper used the above guidelines to annotate the sampled data. Table 1 shows the details of our data collection and the results of the manual analysis where both annotators agreed. Findings and discussion about these results are described in the next section.

Table 1. Data collection and manual analysis results

Event type	Total tweets	Sampled tweets	Direct eyewitness	Indirect eyewitness	Vulnerable direct witness	Non eyewitness	Don't know
Floods	671,503	2,000	62	2	84	113	1,739
Earthquakes	243,194	2,000	354	13	-	321	1,312
Hurricanes	36,815	2,000	95	16	185	100	1,604

FINDINGS AND DISCUSSION

Types of eyewitness accounts

Direct eyewitness

Our manual analysis has revealed that there are different ways in which direct eyewitness accounts report on events. Table 2 shows some examples of direct eyewitness reports taken from manually analyzed data from all three types of disaster events.

Table 2. Direct eyewitness reports from manual analysis

No.	**Floods direct eyewitness reports**
(1)	*I almost died driving home from work because it started to downpour and flood on the freeway and lightning and its 99 f**king degrees out*
(2)	*No one even notified me that this flood in our area has reached almost 3 feet. but atleast i was able to reach home safely.*
(3)	*Stuck in New Brunswick. High flood waters near Rutgers. Rt 1 south #Avoid*
(4)	*I just experienced a flash flood. they're intense*
	Earthquakes direct witnesses reports
(1)	*Most intense earthquake i've experienced in japan so far...that is*
(2)	*Big midnight earthquake and aftershocks now*
(3)	*Just felt the house shaking in Tokyo. Been awhile since I felt an earthquake. I hope it wasn't a bad one anywhere on the island.*
	Hurricanes direct eyewitness reports
(1)	*Please pray for us right now, the winds and rain is heavy and the hurricane hasn't even hit us yet. #hurricaneharvey2017*
(2)	*This hurricane ain't no joke, the rain and winds are heavy right now. #hurricaneharvey2017*
(3)	*It's starting to flood in our area (hurricane Harvey) so if I don't respond back within a 7++ days expect for the worse hope we'll be safe*
(4)	*first time is street is starting to flood and the power went out , hurricane harvey finally hit us*

The first tweet in the floods section reports the personal experience of the author about a flood situation. The second tweet is even more interesting since the author not only reports the event, he/she also complains that there were no notifications or flood warnings in his area. Similarly, in the third tweet the author reports about high flood waters and that he/ she has got stuck due to it. The fourth tweet is also about a personal experience of a flash flood situation.

Direct witnesses of earthquakes also report the event in different ways. All the earthquake-related tweets in Table 2 express personal experiences of the authors about some earthquake events. We observe that in most of the earthquake cases, people express or relate their messages to the sense of feeling such as "just felt" or "feeling shaking".

Regarding hurricane-related tweets, the first and second example tweet report about winds and heavy rain, which are obvious signs of a direct personal experience. Both authors experienced the situation and reported it, while the author of the third tweet not only reported a flood situation but also gave an indication that the situation could get worse. The last tweet is again a personal experience of an event where the author is also reporting a power outage.

One clear observation from the analysis of direct eyewitness accounts is that eyewitnesses often mention the severity of situation they are in. Moreover, people associate their messages to different senses like "seeing", "feeling", "hearing" or "smelling". For example, in case of an earthquake they relate it to the sense of "feeling" such as, *Just felt an earthquake...* Likewise, in case of a storm or floods, tweets are related to the sense of seeing or hearing such as; *I've never seen or heard such a violent thunder/hail/rain storm as the one we've just experienced.*

Indirect eyewitness

During our manual analysis, we found tweets where the author was not present in the disaster hit region. Hence, they were sharing valuable information received from direct witnesses (friends, relatives and social circle). However, we found a very small number of tweets from this category in our dataset. Table 3 shows some examples of indirect eyewitness reports taken from manually analyzed data from all three types of disaster events.

There were only two tweets found in the flood dataset where tweeters were reporting about disasters by referring to their family members, while for earthquakes, a tweeter was reporting about an ongoing earthquake with emotions of worry for his/ her family who are the direct witnesses of this earthquake. The second example shows a unique case where tweeter is reporting about an earthquake he/ she was experiencing live but distantly during a video call with one of their family members. The last tweet in this section is reporting about the safety of direct witnesses from a relative.

Finally, indirect eyewitness reports on hurricanes were rather interesting. The first and second examples are about tweeter's hometown conditions mixed with emotions of worry. The third example shows concern of tweeter about their relatives property due to the prospective hazard. In the last example, tweeter is sharing the witness account of his friend.

Table 3. Indirect eyewitness reports from manual analysis

No.	**Floods indirect eyewitness reports**
(1)	*Some days in Thailand has been insane, there has been massive flood on the road to the city (only have image on my dad's phone)*
(2)	*the hsm school and my uncles house are right behind eachother and they were ruined in the flash flood)):*
	Earthquakes indirect witnesses reports
(1)	*F*cking hell...my wife and kids are in Tokyo and they're in the middle of an earthquake Jesus Murphy just how crap can one day get?*
(2)	*Was Facetiming my brother in Tokyo when an earthquake . It wasn't strong but took a long time. Glad that he's ok. #tokyo #earthquake*
(3)	*Finally able to hear from my uncle and know that he and his daughters are safe, the earthquake did not affect them to much #bless #mexico*
	Hurricanes indirect eyewitness reports
(1)	*Texas has me going for a spin....my hometown was evacuated for the hurricane then an earthquake in Dallas where my entire family is*
(2)	*my city is getting a rain storm from the hurricane and hella winds but that's nothing compared to what's going on god i'm so worried*
(3)	*So this hurricane is heading for my brother and sister-in-law's brand new winery. Hope it doesn't get flooded before https://t.co/VBfAchRplM*
(4)	*Heard from friends in Houston, Austin and San Antonio. High winds and heavy rain last night. Everyone is safe. #hurricaneharvey*

Vulnerable direct eyewitness

During our manual analysis of sampled tweets we noticed tweets where users were anticipating a disaster and were reporting warnings and alerts they received from local authorities on their cell phones. This bunch of tweets was only found in floods and hurricanes dataset due to their predictable nature. Table 4 shows some examples of vulnerable direct eyewitness reports taken from manually analyzed data from all three types of disaster events.

The first tweet in the floods section reports the personal experience of the author about a flood warning where he relates the alert with the current weather situation. The second and third tweets depict emotions of fear created because of a hazard warnings. On the other hand, in fourth example tweeter is angry because of so many flood warnings. On the same note, in hurricane section the first, second and third examples are showing mixed emotions of hope and fear while reporting about an approaching hurricane. While in last example tweeter is relating their vulnerability to the intensity of approaching hazard.

In this particular category of tweets, we also noticed a mix of different types of emotions written in words (not emojis) such as hate, disgust, fear, anger, and humor.

Non-eyewitness and Don't know cases

In our dataset, tweets which do not possess explicit eyewitness characteristics, but either were re-tweets or were possessing non eyewitness characteristics (Doggett and Cantarero 2016) and were reporting about disasters were categorized as non eyewitness accounts. These accounts were sharing disaster related information primarily from news media sources. There were a number of tweets where users used disaster related keywords as metaphors,

Table 4. Vulnerable direct eyewitness reports from manual analysis

No.	**Floods vulnerable direct eyewitness reports**
(1)	*Flash flood warning yet it's not even raining*
(2)	*Why am I always napping when a flash flood warning comes on to my phone? #scared*
(3)	*Those flash flood alerts will kill me one day, they scare the f**k out of me*
(4)	*Ima throw my phone if I get another flood warning*
	Hurricanes vulnerable direct eyewitness reports
(1)	*Hurricane Harvey is approaching..Dun dun dun.. first hurricane I will experience in Texas in my new home omg I hope my area doesn't flood*
(2)	*Staying home for the hurricane,hopefully it doesn't flood*
(3)	*I'm so scared I hope this hurricane don't flood my apartment or my car*
(4)	*big hurricane is supposed to hit the area tonight and i live in one of the flood zones...*

such as, *Troll army will then flood social media with press cuttings, naughty headlines, whatsapp distortions to offset growing positive opinion*. Such tweets were categorized as "don't know" cases along with tweets which have disaster related keywords in URL's instead of tweet text.

Characteristics of different types of eyewitness accounts

This section describes different characteristics we observed in each type of eyewitness messages during our manual analysis. Posting information on social media platforms requires the following platform-specific constraints. For instance, Twitter previously had a 140 character limit, which is now increased to 280 characters. Such constraints force social media users to try different ways to, for example, shorten their messages while conveying their actual intent. A consequence of this makes social media communications different to our usual daily life communications such as conversations, email, etc. We believe identification of characteristics associated with each type of eyewitness accounts will help (i) differentiate among different types and (ii) to build automatic computational methods and systems to automatically identify and categorize eyewitness accounts.

Table 5. Direct eyewitness characteristics. EQ (earthquake), FLD (flood), HUR (hurricane). X indicates the presence of a characteristic

No.	Characteristic	Examples	EQ	FLD	HUR
(1)	Reporting small details of vicinity	window shaking, water in basement	X	X	X
(2)	Words indicating perceptual senses	seeing, hearing, feeling	X	X	X
(3)	Reporting impact of disaster	raining, school canceled, flight delayed	X	X	X
(4)	Words indicating intensity of disaster	intense, strong, dangerous, big	X	X	X
(5)	First person pronouns and adjectives	I, we, me	X	X	X
(6)	Personalized location markers	my office, our area	X	X	X
(7)	Exclamation and question marks	! , ?	X	X	X
(8)	Special/swear words	wtf, omg, s**t	X	X	X
(9)	Mention of a routine activity	sleeping, watching a movie	X	X	-
(10)	Time indicating words	now, at the moment, just	X	-	-
(11)	Short tweet length	one or two words	X	-	-
(12)	Caution and advices for others	watch out, be careful	-	X	X
(13)	Mention of disaster locations	area and street name, directions	-	X	X

Direct witness characteristics

Table 5 lists all the characteristics we have observed in direct eyewitness messages along with examples. We indicate the presence of a characteristic in a disaster type (e.g., flood) using an 'X' mark. As social media communications are short and to the point, users usually skip writing first person pronouns and adjectives. However, if a tweet has first person pronouns and adjectives, we observe that it is a strong indication of direct eyewitness account (Fang et al. 2016). Moreover, we observed that words related to perceptual senses such as seeing, hearing, feeling are another strong indication that a tweet belongs to a direct eyewitness.

Words indicating the intensity of a disaster situation such as intense, heavy, strong are extensively found in eyewitness messages posted during all three types of disasters. We suggest that the presence of intensity words is also a strong signal that the message is from an eyewitness, as a person far from the disaster area cannot describe the intensity of the situation. Eyewitnesses tend to mention more about their personalized locations such as my office, our area than non-eyewitnesses. Among other characteristics that are shared across all disaster types include use of exclamation and question marks and special/swear words like "wtf", "omg", and "s**t".

As shown in table 5 a number of characteristics, specifically from 1 to 8, are common across the three types of disasters. However, in our dataset characteristic 9 was not found in the hurricane dataset. This may be due to the predictable nature of the disaster as well as biased sampling. Characteristics 10 and 11 were only found in earthquake dataset due to sudden and somewhat unpredictable nature of the disaster. Similarly, the last two characteristics were only found in flood and hurricane datasets due to their predictable nature.

Indirect witness characteristics

Table 6 shows characteristics learnt from indirect witness messages for all three disasters. We observed that indirect witness accounts either mention a person or a place tweeters already know. The social circle of a user tends to be credible and so the indirect witness is also considered credible. If an indirect witness account is about the hometown of a user, then it is assumed that they know the geography of disaster hit region very well and can provide useful information if required. It was also observed that indirect witness accounts were reporting either emotions of worry or sense of relief. Indirect witness accounts were also reporting about damage, safety or missing people/property.

Table 6. Indirect eyewitness characteristics. EQ (earthquake), FLD (flood), HUR (hurricane). X indicates the presence of a characteristic

No.	Characteristic	Examples	EQ	FLD	HUR
(1)	Mention of locations or people the author knows	mom, dad, hometown	X	X	X
(2)	First person adjective	my, our	X	X	X
(3)	Expressing emotions	thoughts, worry, relief	X	X	X
(4)	Reporting safety, damage, missing	missing, safe	X	X	X

Vulnerable direct witness characteristics

Table 7 shows distinct characteristics of vulnerable direct witness accounts. This category was only found in flood and hurricane dataset due to their predictable nature. A number of characteristics, i.e., 5 to 9, and characteristic 14 in table 5 were common in both categories. Users were mostly found reporting about hazard warnings and associating it with current weather situations. As hazard alerts were sudden in nature, they provoked different types of emotions due to sudden disruptions in user's routine activities.

Table 7. vulnerable direct eyewitness characteristics. EQ (earthquake), FLD (flood), HUR (hurricane). X indicates the presence of a characteristic

No.	Characteristic	Examples	EQ	FLD	HUR
(1)	Warnings and alerts about expected disasters	flash flood warnings	-	X	X
(2)	Associating warnings with current weather situation	flash flood alert with rain	-	X	X
(3)	Expressing emotions	hate, disgust, anger, scare	-	X	X

CONCLUSIONS AND FUTURE WORK

Finding firsthand and credible information during disasters and emergencies is an important task for relief organizations and law enforcement agencies. The extensive use of social media platforms during disasters provides numerous opportunities for humanitarian organizations to enhance their response. Among them, identification of bystanders and eyewitnesses can help to get important information. In this work, we presented an analysis of tweets collected during three types of disasters to understand different types of eyewitness accounts. Our results show that we can categorize eyewitness accounts into direct, indirect, and vulnerable direct witnesses. Moreover, an important contribution of this work is to determine various characteristics associated with each type of eyewitness account. We

observed that direct eyewitnesses use words related to perceptual senses such as seeing, hearing, feeling. Whereas, indirect eyewitness mainly express emotions such as thoughts, prayers, worry. And, the vulnerable category mostly share warnings and alerts about an expected disaster situation.

Future work: We believe this work provides a conducive ground for future research work in the direction of automatic identification of eyewitnesses on social media, specifically on Twitter. The identified characteristics will help design more robust automatic computational methods using artificial intelligence and machine learning techniques for automatic identification of eyewitnesses during a disaster situation.

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The Sound of Silence: Exploring How Decreases in Tweets Contribute to Local Crisis Identification

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ABSTRACT

Recent research has identified a correlation between increasing Twitter activity and incurred damage in disasters. This research, however, fails to account for localized emergencies occurring in areas in which people have lost power, otherwise lack internet connectivity, or are uncompelled to Tweet during a disaster. In this paper, we analyze the correlation between daily Tweet counts and FEMA Building Level Damage Assessments during Hurricane Harvey. We find that the absolute deviation of Tweet counts from steady state is a potentially useful tool for the evolving information needs of emergency responders. Our results show this to be a more consistent and persistent metric for flood damage across the full temporal extent of the disaster. This shows that, when considering the varied information needs of emergency responders, social media tools that seek to identify emergencies need to consider both where Tweet counts are increasing and where they are dropping off.

Keywords

Crisis informatics, emergency response, flooding, hurricanes, social media, Twitter

INTRODUCTION

By the start of August 2017, natural disasters in 2017 had already cost the United States 15 billion dollars and the lives of almost 300 people. The yet-uncalculated costs of the three major hurricanes that hit the East Coast in August and September are expected to catapult that total cost into the hundreds of billions (Lam, 2017). The first of these three, Hurricane Harvey is expected to ultimately cost more than $183 billion dollars in federal relief (Amadeo, 2017). As the frequency and intensity of hurricanes are only expected to increase, understanding how to improve our crisis infrastructure is of critical importance. Our ability to both minimize initial damage and accelerate recovery is contingent on a wide variety of factors, including primarily the availability of emergency resources and how we structure our emergency response. We will need to improve the efficiency of both factors in order to mitigate future disaster-related costs.

The National Center for Environmental Information (NCEI) reports that tropical cyclones are, on average, the costliest of natural disasters in the United States (NCEI, 2017). This cost can be mitigated by an increase in the resilience of the community infrastructure (Coughlan De Perez et al., 2015), the availability of social, economic, and physical capital (Abramson et al., 2014), and the speed and efficiency of the emergency response network (Conrado, Neville, Woodworth, & O'Riordan, 2016). Much of crisis mitigation research has focused on understanding the importance of and strengthening of these resilience factors. Empowering emergency response organizations by increasing information availability has recently taken center stage in crisis research (Shklovski, Palen, & Sutton, 2008).

Information regarding disaster severity, human locations and mobility, and resource locations tends to be scarce immediately after disaster strikes and in the weeks following. Victims of disasters are one of the main providers

of crisis information, as they are the most intimately familiar with the aftermath. First responders are often operating on eye-witness accounts when they arrive at the scene of local emergencies, such as flooded houses or electrical fires, that comprise the larger disaster. However, it is difficult to acquire and accumulate victims' local knowledge during a massive crisis (Mason, Drew, & Weaver, 2017). There is an unmet need to facilitate the utilization of affected people's information in emergency response. In the past few years, a growing amount of research has sought to utilize humans as sensors—that is, using how victims "sense" damage and danger and how their behavior changes in response—to produce usable data for emergency responders (Hiltz et al., 2014; Kryvasheyeu, Chen, Moro, Van Hentenryck, & Cebrian, 2015; Sakaki, Okazaki, & Matsuo, 2010b; Tien et al., 2016). The conversion of human behavior data to empirical crisis data has been mainly performed through the use of social media; however, that crisis data is not currently in widespread use. We need to improve the accuracy and usability of social media tools before they can be implemented effectively.

LITERATURE REVIEW

Since the explosive increase in Twitter users in 2009 and the increasingly widespread use of other social platforms, researchers have been trying to utilize social media to characterize and improve community resilience to disaster. Initially, researchers used social media data to analyze the details of a specific prior event such as an earthquake (Sakaki, Okazaki, & Matsuo, 2010a); more recently, researchers have been trying to use the real-time flow of information from victims to advise responders during an emergency. The behavioral data recorded through social media has been examined for use in detecting emergencies (Kryvasheyeu et al., 2015), emergency types (Hiltz et al., 2014), damage severity (Kryvasheyeu et al., 2016), detecting resource availability and need (Choe, Park, Han, Park, & Yun, 2017), identifying human sentiment in real time (Caragea, Squicciarini, Stehle, Neppalli, & Tapia, 2014), and characterizing resilience and community recovery through mobility patterns (Wang & Taylor, 2014). Authors have utilized this information to create a variety of tools that are intended to assist professional emergency responders and citizen volunteerism in real time. These tools mainly utilize Twitter and Facebook, and primarily take the form of smart phone applications and websites, such as Ushahidi and XHELP (Reuter, Hughes, & Kaufhold, 2018).

Responders need to know, with high accuracy, the most time- and cost-effective areas in which to focus their efforts. Knowing where to go involves knowing where people and emergencies are. Knowing where to go *first* requires knowing where people are in the most danger relative to the people around them. Social media data is useful for the former, because geo-located Tweets show exactly when and where a single person is. Previous research has concerned itself with connecting social media to the latter. The current theory operates on the idea that people Tweet when they feel endangered, when they feel they can receive aid through social media, or, at the very least, when something abnormal is happening. More Tweets are thought to indicate abnormal occurrences and thus indicate when and where a disaster may be occurring.

In the search for a correlation between Tweeting and the presence of a disaster, Kryvasheyeu et al. performed a rigorous analysis of how well Twitter was able to predict infrastructure costs before, during, and after Hurricane Sandy (Kryvasheyeu et al., 2016). Large numbers of Tweets per day at the ZCTA-scale corresponded well with areas with higher insurance claims, and vice versa. This relationship was identified in twelve other emergency events in 2013 and 2014 at varying strengths. However, despite the strong correlation discovered in the above research, emergency identification and responder advisement systems do not currently have widespread use during disasters (Mason et al., 2017). Many of the inhibiting factors for tool usage are related to a perceived lack of accuracy (Imran, Castillo, Diaz, & Vieweg, 2015).

Accuracy in disaster informatics consists of rumor and completeness. The accuracy of Twitter data with respect to rumor has been addressed through studies that have sought to quantify rumors' propagation through networks (Starbird, Maddock, Orand, Achterman, & Mason, 2014) and to identify rumors in automatic Tweet filtration tools (Zeng, Starbird, & Spiro, 2016). Recent studies have been able to classify Tweets as rumors in emergencies, such as the 2013 Boston Marathon Bombing, with reasonable accuracy (Lu & Brelsford, 2015; Zeng et al., 2016). There is, however, another important aspect to accuracy: data completeness. A lack of data completeness can produce false negatives. A false positive such as a rumor would result in a waste of time and resources; a false negative could result in overlooked victims. Much of existing social media research assumes that if there is a disaster, people are Tweeting about it, but there is little research on the detriments of only using areas that are Tweeting in emergency identification and danger assessment (Reuter et al., 2018). There is also a lack of research on how we can potentially use the gaps in Twitter activity.

Emergency analysis tools that can only function in areas with high volumes of Tweets may be biased against underprivileged people in disasters that can heavily impact energy infrastructure, such as hurricanes. The Rutgers report on the impact of Superstorm Sandy showed that, although lower income families were hit by more than half of the costs of the storm, they received only 27% of the distributed aid. Wealthier communities

with more robust houses and energy infrastructures are also less likely to fear for their livelihoods or fear an extended loss of power, so they would be less likely to take precautions to conserve power. FEMA has encouraged people needing to conserve power to activate their phones' airplane mode (Fugate, 2017), which would remove the phones' data capabilities and the ability to Tweet.

Shelton et al. sought to demonstrate potential flaws in big data by looking at the relationship between Twitter activity and areas in the High-Impact Zone assessment produced by FEMA (Shelton, Poorthuis, Graham, & Zook, 2014). They normalized their data to a steady-state Tweet count value calculated from two weeks prior to the disaster instead of normalizing the activity to the number of active users. This normalization strategy reduces the possibility of areas without any active users during a disaster situation being ignored by the correlation analysis. Their results show that, while some areas' increase in Twitter activity did correlate with being in a High-Impact Zone, other areas lacked Tweets. These areas were termed "data shadows". A large data shadow was particularly evident in Staten Island, in which more than half of all Sandy-related deaths occurred. The majority of social media emergency identification tools developed to date would have been unable to help emergency responders prevent these deaths, as the silent areas would have been ignored.

In order to make social media analysis tools useful for emergency responders, we need to show that the data can be utilized in a way that does not overlook areas that do not Tweet during a disaster because of older demographics or lower socioeconomic status. We theorize that natural disasters can influence human behavior by causing some people to Tweet more, and others to Tweet far less. As such, strong deviations from steady state Twitter activity may be indicative of separate hazards and risks in addition to the spikes in Twitter activity utilized in the majority of social media crisis studies. By accounting for the data shadows identified by Shelton et al., we can increase the usability of social media data for emergency responders while reducing the risk of ignoring areas in need of assistance that do not have the ability or compulsion to Tweet.

In this paper, we seek to determine if there is a significant, useful correlation between hurricane damage and a decline in Twitter intensity that is missed in analyses focused on Twitter activity spikes. We chose to apply our analysis to Hurricane Harvey, which heavily impacted Houston, the fifth-biggest metropolis in the U.S.

RESEARCH DESIGN AND METHODS

Spatial Grid Creation

Based on our data distribution, the size of the Greater Houston Area, the layout of the city's roadway infrastructure, and the findings of Potter et al. (Potter, Koch, Oswalt, & Iannone, 2016), we used ArcGIS' Generate Tessellation function to generate a grid of 10 square kilometer (km^2) hexagons. In our grid, approximately 2,000 hexagons overlaid the Greater Houston Area, and approximately 500 of those contained more than three Tweets per day across the study period.

Twitter Data Acquisition

Because we wanted to find a metric of Twitter activity intensity that would consider both users' ability to Tweet *and* their inclination to Tweet, we decided to explore each area's deviation from a defined steady state of Twitter intensity. We defined our steady state using the period of August 7 to August 15, 2017, two weeks before Hurricane Harvey made landfall the night of August 25, 2017. Harvey developed into a tropical storm on August 17, 2017, so this time frame is distant enough from the storm's inception to not be impacted by the storm development and yet close enough to reflect an accurate steady state.

Our Lab has been continuously collecting Tweets through the Twitter Streaming Application Program Interface (API). We are accessing the Twitter API through the use of the python package tweepy. Twitter only provides 1% of real-time global Tweets; however, the 1% can be filtered by certain specifications. We filtered our streamed Tweets to only include geo-referenced data. From these Tweets, we downloaded the associated User ID, originating latitude and longitude, username, and the text of the Tweet. We used this data to extract Tweets generated within the Greater Houston Area during our determined steady state time frame. We then manually filtered out Tweets made by Twitter bots, which are accounts that Tweet pre-programmed messages at automated times throughout the day, through manual inspection of suspicious Tweets and Twitter Users. Identifying Tweets that do not originate with a real person is a continuing problem in crisis informatics; however, we believe that the bots will not change their behavior overtly from the steady state to the crisis, and their impact will be mitigated through our analytical methods.

We repeated this process for the days following August 21, which is two days prior to when Harvey developed into a hurricane. As such, Tweets from August 21 to August 31, 2017 were used to define our perturbed state.

Hazard Assessment Data

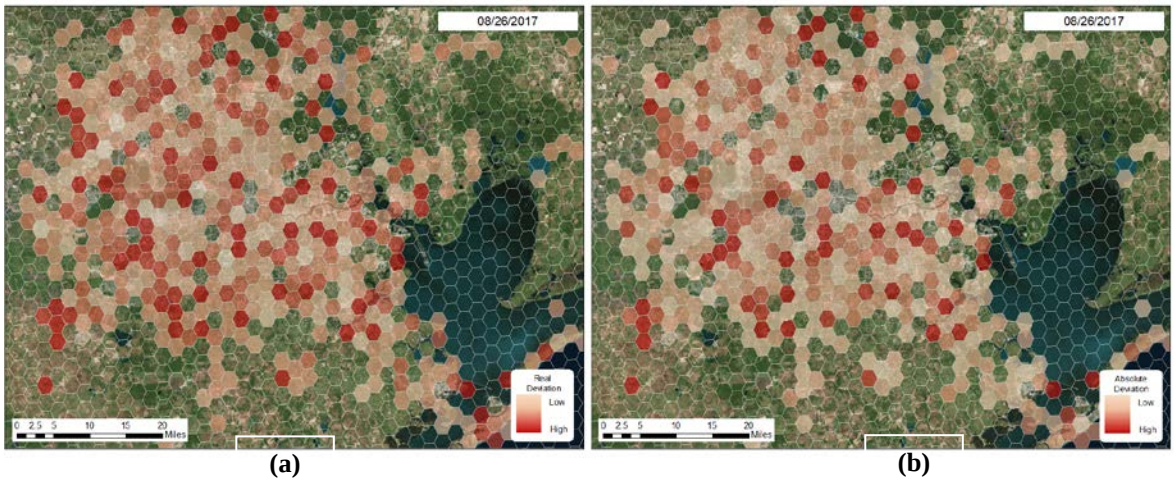
We analyzed five different metrics of hazard indicators related to weather and flooding phenomena in order to avoid the confounding factor of economic influences. Primarily, we used data from the FEMA Building Level Damage Assessments, referred to as FEMA Damage Assessments (The Federal Emergency Management Agency, 2017). These preliminary damage assessments were performed as soon as was safely possible following the hurricane and are available as point data that represent buildings that have been classified as having "No Damage", being "Affected", having "Minor Damage", having "Major Damage", and being "Destroyed" (The Federal Emergency Management Agency, 2016). We reinterpreted this range into a continuous numeric scale from 0, representing "No Damage", to 5, representing "Destroyed". This more subjective scale would represent the overall potential danger to a building's inhabitants during the hurricane more judiciously than a monetized scale, which might amplify damage to richer communities. Based on the threat to human life represented by flooding, we also used the interpreted flood risk from Risk Management Systems (RMS) for the Greater Houston Area. This flood risk was modeled using elevation, rainfall, and data from the National Oceanic and Atmospheric Administration (Young, 2017). This data was rasterized in ArcMap with a cell size of approximately 30 meters. In another interpretation of flood risk, we mapped historical high water mark data from previous floods provided by the USGS (United States Geological Survey, 2017). Lastly, as one of the greatest dangers with flooding is due to flooded roads, we downloaded the volunteered geographic information (VGI) from the most popular crowdsourced map that identified road closures during Hurricane Harvey (*Flooded streets due to #Harvey*, 2017). Hurricane Harvey was the wettest tropical cyclone in both Texas and US history, and the sudden, massive, unexpected rainfall flooded homes while simultaneously cutting off evacuation routes. We theorized that areas with damaged or blocked escape routes would have a much greater need of emergency rescue. Lastly, we determined whether or not each hexagon was mostly within or without the hurricane evacuation area defined by the Houston Emergency Operations Center (Houston-Galveston Area Council, 2017).

Hexagon Data Attribution

We developed a model in ArcMap that would summarize the Twitter activity statistics for each day within each hexagon. We used the sum total Tweet counts for each day of the steady state to determine the average Tweet count and the standard deviation of that Tweet count for each hexagon. We normalized the Tweet counts within each hexagon for each day of the perturbed state using the standard deviation and average of the Tweet counts in each hexagon across the defined steady state.

We then used ArcMap's Field Calculator to create two sets of normalized Twitter counts in the attribution field of each hexagon. The first was the real normalized data, which ranged from -1.8 (decreased Twitter activity) to 8.3 (greatly increased Twitter activity). The data is referred to as the real deviation because it preserves the direction, positive or negative, of the deviation. For the second set of Twitter counts, we took the absolute value of this normalized data, which ranged from 0 (no deviation from steady state) to 8.3 (the highest deviation from steady state). We show the difference in deviation spread between the real and absolute normalized Twitter activity data for the day following Hurricane Harvey's landfall in **Figures 1a and 1b**.

Figure 1. A map of the Greater Houston Area overlaid with a grid of 10 km^2 hexagons. Each hexagon is colored according to the real (Figure 1a) or absolute (Figure 1b) standard deviation of georeferenced Tweet counts recorded on August 26, 2017 when normalized to the steady state period.



(a) **(b)**

For the hazard assignation, we used a second ArcMap model to classify each hexagon based on:

1) The highest classification of any singular FEMA Damage Assessments located within the hexagon.
2) The average, maximum, and minimum of the RMS flood hazard cells in the hexagon;
3) The average, maximum, and minimum height of the high-water marks in the hexagon;
4) The presence (1) or absence (0) of a flooded road in the hexagon; and,
5) If the hexagon was mostly inside the evacuation zone (1) or mostly outside of it (0).

ANALYSIS

We determined the Kendall and Spearman rank correlation coefficients for two pairs of variables: 1) the correlation between the highest FEMA Damage Assessment in each hexagon and the real normalized deviation in Twitter intensity from steady state, and 2) the correlation between the highest FEMA Damage Assessment and the absolute normalized deviation in Twitter intensity. Following Kyryvasheyeu et al., we compare the Kendall and Spearman rank correlation coefficients for the damage assessments and the absolute and real Twitter activity deviations from steady state in **Table 1.**

Table 1. Kendall and Spearman Rank Correlation Coefficients for the maximum FEMA Assessment in each hexagon and the normalized Twitter Activity from August 21 to August 31, 2017.

		Absolute Deviation		Real Deviation	
Date	**Rainfall (in.)**	**Spearman's ρ**	**Kendall's τ**	**Spearman's ρ**	**Kendall's τ**
21-Aug	0	-0.02	-0.02	0.06	0.05
22-Aug	0	0.04	0.03	-0.03	-0.02
23-Aug	0	0.03	0.02	0.01	0.01
24-Aug	0	0.04	0.04	0.05	0.04
25-Aug	0.28	0.09*	0.07*	-0.03	-0.03
26-Aug	3.83	0.07*	0.05	-0.01	-0.01
27-Aug	11.82	0.08*	0.07*	0.13**	0.10**
28-Aug	1.74	0.10**	0.08*	0.08*	0.06*
29-Aug	2.4	0.09*	0.08*	0.09*	0.07*
30-Aug	0.15	0.13**	0.11**	-0.07	-0.05
31-Aug	0	0.01	0.01	0.07	0.05

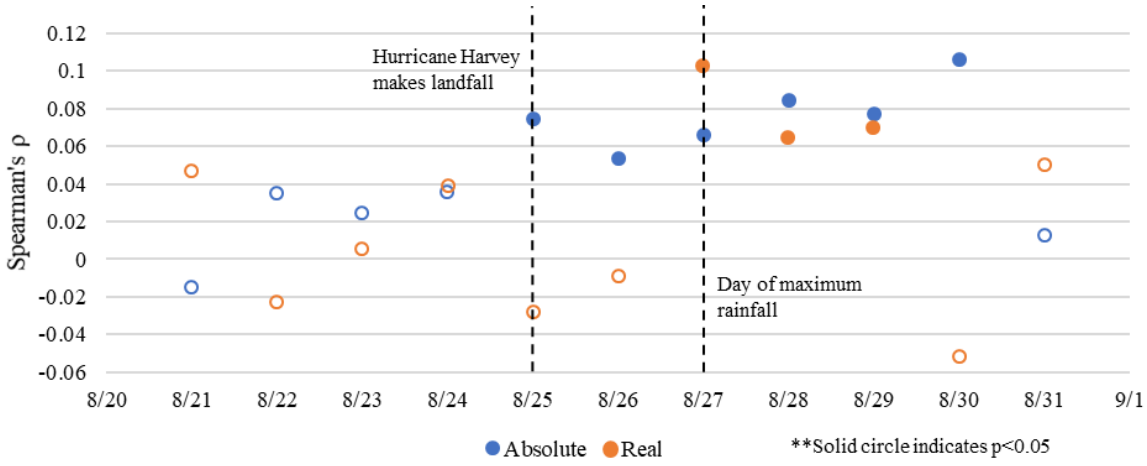
* indicates $p < 0.05$; ** indicates $p < 0.01$

FINDINGS

Our first research question concerned identifying the strength of correlation between Twitter data and hurricane hazard at a spatial scale smaller than ZCTAs. The correlation determined in our research is weaker than that found by Kryvasheyeu et al. during Hurricane Sandy, but comparable with the correlations found by Kryvasheyeu et al. during flooding events. We also used a much smaller spatial area, so a weaker correlation can be expected. Our correlation results are still significant and the real deviation results follow the same general trends seen in prior research. It should be noted that, although the hurricane made landfall the night of August 25th, the hurricane's movements resulted in the heaviest rainfall hitting Houston on August 27th. The fact that the correlations peak on that day—and that they more closely match the prior correlations found during flooding—are likely because the persistent flooding was the biggest danger for the city.

The spatiotemporal behavior of the correlation coefficients for each metric and their significance across the perturbed period is shown in **Figure 2.** The correlation between damage and Twitter activity is significant from August 27th to August 29th for both metrics, and the correlation between real deviation and damage is much stronger on the day of the greatest rainfall. However, the correlation between absolute deviation and damage is significant for the days after the hurricane made landfall (the 25th and the 26th), and for one additional day after (the 30th). Both relationships peak with a Spearman's ρ of 0.13 with a p-value of 0.001, but these peaks occur on disparate days: the real deviation peaks on the day of the most damage, and the absolute deviation peaks later. The absolute deviation is also the stronger relationship for every day except that of maximal flooding.

Figure 2. Spearman's ρ for Twitter Activity Deviation and FEMA Damage for the Perturbed Period



DISCUSSION AND CONTRIBUTIONS

We sought to assess the utility of social media in emergency response by correlating Twitter activity and the extent of infrastructural damage, and to define that correlation through a metric that can encompass areas that have lost the ability to Tweet. To our knowledge, this is the first analysis to supply a method for Twitter data analysis that utilizes a deviation from a steady state to address potential data shadows, as determined by Shelton et al (Shelton et al., 2014). Our results show that, in confirmation of prior literature, Twitter activity spikes are significantly correlated with damage on the day of maximal rainfall in Houston (Kryvasheyeu et al., 2016); they also show that absolute activity deviation is a more significant metric before and after that day. This shows that the absolute change in Twitter activity and the infrastructural damage can provide a secondary hazard indicator to address more persistent informational needs during an evolving natural disaster.

A potential flaw in this analysis is that the decrease in activity primarily indicates areas that people have evacuated, or commercial sectors of the city that have closed in anticipation of danger. In terms of evacuation, the distribution of hexagons that increased and decreased in Twitter activity does not appear to have any correlation with being inside the evacuation zone, and the city of Houston did not have mandatory evacuation orders prior to landfall. The hexagonal grid should minimize the partitioning of our study area by residential and commercial sectors. It is therefore likely that Tweeting behavior deviated from its steady state due to reasons beyond mobility. Future research needs to focus on determining at what spatial and temporal scales the identified relationship is strongest, and at which spatiotemporal scales the relationship breaks down. The effect of broad-scale, enforced evacuation on the correlation needs to be identified and removed such that emergency responders do not look for victims in rows of empty houses.

This analysis needs to be performed on other hurricanes and natural disasters. Based on preliminary further research and the theories identified above, we believe that the potential uses and relevance of our metrics could be dependent on the economic demographics and the severity of the hurricane. Hurricanes that do not heavily impact the energy infrastructure of the city may do very little to a population's ability and inclination to Tweet, and prior research has shown that, in some areas, even power outages do not heavily influence social media access (Jennex, 2012). The situations in which the absolute deviation would be useful needs to be identified through further disaster analysis.

Our research shows that the relationship between human behavior and damage across a disaster's duration is not only because people Tweet more in the face of danger; rather, people are changing their Twitter habits in different ways based on their inclination and their environment. Some are Tweeting more, sharing information with family members or trying to spread awareness about hurricane dangers; some are Tweeting less, saving their phone battery for 911 calls, or are without power. This modulation is the human behavior signal that should be additionally monitored when advising emergency response on an extended timeframe.

CONCLUSIONS AND IMPACTS

There is currently a lack of confirmation that the emergencies identified through Twitter are the most critical emergencies for responders to address, especially in terms of people who become unable to access their phones or are without power. In order for responders to triage the emergencies during a natural disaster, they need to

know the emergency's location, severity, and magnitude throughout the emergency. Existing social media emergency response tools fail this by neglecting the possibility of severe emergencies occurring in areas where Tweets are not occurring (Tapia & Moore, 2014). Through our research, we have shown that absolute Twitter activity deviation from a steady state can be used to identify areas that are experiencing more infrastructural damage during a hurricane. Our method does not ignore areas with fewer Tweets, but rather fully incorporates those areas into its hazard association, and is more particularly useful on days following landfall or after the biggest disaster event.

For emergency responders, the identification of the existence of an emergency through social media is not sufficient; 911 calls and aid requests already inundate emergency agencies with emergency identifications during a major disaster. To be truly useful to responders, social media must be able to point responders in the direction of the greatest and most urgent damage in near-real-time. For tools using only spikes in Twitter activity to identify areas of need, areas without the ability to Tweet are invisible. These tools may be stronger on the day of maximum perturbation, but as the emergency evolves, response information needs change and other populations are more at risk. We need to be able to "hear" distress among these populations as well. We show this is possible by ascertaining the value of listening to where Tweets have stopped occurring. Our paper highlights the importance of considering the presence and absence of data in social media analysis tools designed for use by emergency responders. Ultimately, we find that the most effective analysis tools using humans as sensors must be able to incorporate the sound of humans in danger—and the sound of silence.

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Deep Learning Approach towards Multi-label Classification of Crisis Related Tweets

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ABSTRACT

Micro-blogging sites like Twitter, over the last decade, have evolved into a proactive communication channel during mass convergence and emergency events, especially in crisis stricken scenarios. Extracting multiple levels of information associated with the overwhelming amount of social media data generated during such situations remains a great challenge to disaster-affected communities and professional emergency responders. This valuable data, segregated into different informative categories, can be leveraged by government agencies, humanitarian communities as well as citizens to bring about faster response in areas of necessity. In this paper, we address the above scenario by developing a deep Convolutional Neural Network (CNN) for multi-label classification of crisis related tweets. We augment the deep CNN with several linguistic features extracted from tweets, and investigate their usages in classification. Evaluation on a benchmark dataset shows that our proposed approach attains the state-of-the-art performance.

Keywords

Deep learning, Multi-label classification, Social media, Crisis response

INTRODUCTION

Emergency situations bring along with them innumerable challenges to professional humanitarian communities, various government agencies as well as the citizens, and demand fast and effective decision-making capabilities from the response authorities. There has been phenomenal growth in the social media information available during the last few years. Numerous platforms have been introduced, and many new ones are constantly being created. This has created an opportunity to build socially intelligent systems exploiting the large volume of textual contents generated through social media platforms. Effective communication at different layers, for e.g. from person to person, person to government agencies, and government to people etc. can be efficiently managed through these various information sources. Information gathered from Twitter, one of the most popular social media platforms, can be leveraged as an aid to improve overall situational awareness, thereby taking informed decisions (Castillo, 2016; Vieweg, Castillo, et al., 2014).

Extracting valuable insights from a large chunk of twitter data tends to be challenging and complex owing to the character limit and informality of the shared information. Users often employ abbreviations, spelling variations and colloquial words while using Twitter platform for sharing information (Han et al., 2013). Despite advances in natural language processing (NLP), interpreting the semantics of short informal texts remains itself a hard problem. Here we propose an efficient multi-label classification model, which can be generalized to multiple crisis situations. This would prove highly beneficial to various sectors (citizens, humanitarian communities, government agencies etc.) as an initial step towards harnessing the information flow during crisis situations. In recent times, deep

learning models have shown tremendous success in solving several problems in image processing, computer vision and natural language processing. In this paper we propose a deep learning model augmented with domain-specific features for classifying the crisis-specific twitter data.

Problem Definition

The main objective of this paper is to propose a scalable deep learning architecture for the multi-label classification of disaster specific tweets into discrete informative categories. As discussed in Dembczyński et al. (2012), a straightforward approach for multi-label classification is the Binary Relevance (BR) method. Here one binary classifier is trained for each label and used to predict whether, for a given test instance, this label is present (relevant) or not.

For better understanding, the goal, as mentioned above, can be modularized into a set of research questions. By combining qualitative, quantitative analysis and sleek architecture design, we seek to answer the following questions.

RQ1: Can we develop a deep binary relevance classifier for multi-label classification, which performs well in multiple crisis domains, using tweet text as the only input to the model?

RQ2: What kind of enhancements do twitter-centric features like hashtags, user-mentions and keywords extracted from embedded URLs bring to the model?

By answering the above mentioned questions, we intend to create a system which can classify a given crisis specific tweet into one or more informative categories. For example, "Death toll rises to 112. I pray for the affected families. #NapaEarthquake" should be classified into *Casualties category* as well as *Sympathy* and *Emotion* category. Hence, the problem is posed as a multi-label classification problem.

Motivation

Due to its growing ubiquity, rapidity of communication, and cross-platform accessibility, Twitter is increasingly being considered as a means for emergency communication during and after crisis related events. During a sudden outburst of emergency, the affected people tend to share information about personal whereabouts and the general conditions of their immediate environment, in anticipation of quick humanitarian response. Identification and classification of such tweets targeted at disaster events would help the crisis-response community in deep analysis of escalating situations and in efficient allocation of available resources, as discussed in Imran, Castillo, Diaz, et al. (2015). Classification enables more effective re-routing of necessary information to the concerned specialized units on a real-time basis without having to stroll through the huge collection.

Most of the existing research works carried out in this area treat the above mentioned problem as a binary or multi-class classification problem (Nguyen, S. R. Joty, et al., 2016; Imran, Mitra, and Castillo, 2016). Necessity for a multi-label classification model arises owing to the observation that a majority of tweet instances do actually belong to multiple classes of information. People often mix personal and informative contents pertaining to multiple categories while sharing messages over social media platforms. For example, "I would like to donate $100 to #NapaEarthquake relief fund. Around 1k casualties reported ☹" contains information regarding both *donation* and *reported casualties*. Thus, a multi-label classifier would assist in better and accurate information extraction as well. Finding relevant features that help in an online setting, and improving the model's ability to generalize to multiple crisis domains are of utmost importance. With the recent success of deep neural networks, we hypothesize that general relationships (e.g. lexical, syntactic as well semantic relationships) in this complex domain can be effectively captured by these models.

Contributions

In this paper, we propose a Convolutional Neural Network (CNN) based deep learning architecture for multi-label classification of disaster related tweets into seven distinct informative categories. To the best of our knowledge, no prior research work has dealt with deep neural network (DNN) based multi-label classifier in the crisis response domain. Therefore, we intend to open this niche with this paper. Another important characteristic of our proposed approach is that we investigate the effect of twitter specific linguistic knowledge to the deep CNN.

The proposed model is generic in the sense that we do not necessarily train and evaluate the model with the datasets of similar domains. Rather we train and evaluate our proposed approach over a single dataset containing tweets shared during crises belonging to multiple domains (for example, earthquakes, floods, typhoons etc.). Experimental results, recorded in subsequent sections, prove that the model generalizes satisfactorily to multiple disaster domains, which share the same information taxonomy. In an online setting, the model yileds as output an evolving set of hashtags and user-mentions, befitting the disaster, which can be fed back into the tweet collecting module (for example, AIDR(Imran, Castillo, Lucas, et al., 2014) to fetch disaster related tweets with higher accuracy.

RELATED WORKS

Classification of disaster related tweets and accurate Information Extraction from it have gained significant attention to the government and other stakeholders due to the growing need for building an automated crisis response system. The recent advancement in Natural Language Processing, Machine Learning and Data Mining techniques have facilitated this process.

Here we present a very brief summary of the most relevant research works carried out in this domain. Vieweg, Hughes, et al. (2010) proposed a methodology and disaster ontology to identify tweets that provide situational awareness. Kongthon et al. (2012) developed classifiers to analyze tweets from the Thailand floods in 2011. Purohit and Sheth (2013) developed Twitris with semantic enrichment, classification and geotagging as its main capabilities. Robinson et al. (2013) visualized heat-maps based on geotags in order to extract valuable information. Caragea, McNeese, et al. (2011) used twitter and SMS data generated during crisis events for the classification purpose. Shallow machine learning approaches towards multi-class classification of disaster-specific tweets were proposed in Imran, Mitra, and Castillo (2016) and Imran, Elbassuoni, et al. (2013). They trained three different models, namely Support Vector machine (SVM), Naive Bayes (NB) and Random Forest (RF), for the classification of tweets into 9 different informative categories, namely *Caution and Advice, Displaced people and evacuations, Donation needs or offers, Infrastructure and Utilities damage, Injured or dead people, Missing or trapped or found people, Sympathy or emotional support, Other useful information* and *Irrelevant case*. A naive Bayes classifier for cross-lingual crisis domain adaption was explored by Imran, Mitra, and Srivastava. (2016). A multi-label naive-Bayes classifier has been proposed in Imran, Elbassuoni, et al. (2013) to extract the most relevant information. The survey as presented in Imran, Castillo, Diaz, et al. (2015) provides a very informative description of various crisis response and analysis systems developed to address information flow during emergency situations.

Prior research work focusing on application of deep learning in NLP has shown that neural networks mimic biological information processing and thus outperform shallow ML models in grasping general and complex relationship existing in various datasets. A unified Deep Neural Network (DNN) architecture for solving various NLP tasks including part-of-speech tagging, chunking, named entity recognition and semantic role labeling was presented in Collobert et al. (2011) and S. Joty and Hoque (2016). In case of crisis domain, Caragea, Silvescu, et al. (2016) used convolutional neural network (CNN) to segregate informative and non-informative messages during disasters. A MLP-CNN based multi-class classification approach to classify tweets into different informative classes was proposed by Nguyen, S. R. Joty, et al. (2016) and Nguyen, Al-Mannai, et al. (2017). In our current work we propose a multi-label deep learning model for classifying disaster-specific tweets, and to the best of our knowledge this is the very first attempt in this direction.

PROPOSED METHOD

In this section we describe our proposed approach for multi-label classification of disaster specific tweets.

Deep CNN based Architecture

At first we describe the preliminary architecture for deep CNN based multi-label classification of disaster related tweets with respect to the 7-class taxonomy (as discussed in Section Crisis Information Taxonomy). This addresses our first research question (i.e. **RQ1** of Problem Definition Section). An elevated view of the overall architecture is shown in Figure 1. The overall system consists of seven similar classifiers (represented as B_i), each of which takes in a similar input and produces an unique binary output, predicting whether or not a particular label is relevant.

The seven binary outputs are independent to each other, and each output corresponds to one of the seven categories associated with the information taxonomy used in this paper. Moreover, inter-label dependency between the informative categories varies significantly with the type of crisis under consideration. For example, there is a very high inter-label dependency between 'Casualties and Public Impact' and 'Infrastructure Damage' in case of physical disasters like earthquakes while negligible dependency exists in case of biological crises like epidemics.

Our proposed architecture is more generic in the sense that rather than training our model on any specific type of disaster related tweets, we make use of a dataset containing tweets of multiple crises. We thereafter train seven separate neural network classifiers (for each category), rather than a single neural network with seven output neurons, so that each classifier learns features corresponding to only its category ignoring inter-label dependency.

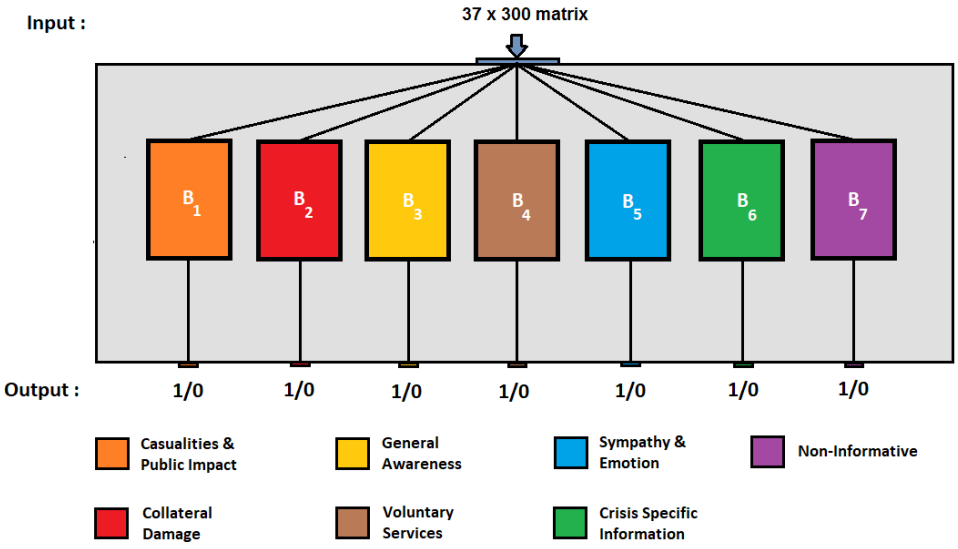

Figure 1. An overview of the proposed architecture

The seven classifiers, represented as B_i in Figure 1, have identical neural net design as shown in Figure 2, but vary in their hyper-parameter values. The CNN is chosen for this classification problem owing to its ability to use distributed representation of words as well as learn key features automatically at different levels of abstractions. The matrix representation of tweet text (as discussed in the Dataset and Experimental Setup Section), generated using pre-trained word2vec model (Mikolov et al., 2013), is fed into a convolutional layer generating 250 feature maps of kernel or filter sizes {2, 3, 4}. These feature maps are max-pooled, followed by global max-pooling and concatenation to be inputted into a fully connected dense layer which mimics auto-encoder neural net properties. All neurons until this level have Rectified Linear Unit (ReLU) as their activation function and corresponding weights are initialized using uniform random distribution. Output from the final layer neurons of auto-encoder network is then fed into a single neuron with sigmoid as activation function. In order to avoid overfitting, dropout probabilities are applied to the final three layers of the model.

Augmenting Twitter-Centric Linguistic Features to CNN

We propose a modified version of the baseline model (i.e. the CNN as described above) by augmenting twitter-centric features to the deep CNN. We closely analyze the influence of these features on the overall system performance. We explore the features based on hashtags, user-mentions and keywords extracted from the embedded URLs in the tweet message (addressing the research question **RQ2**). All these features are fed into the first fully connected layer as shown in *Figure 3*. It is found that integration of twitter-centric textual features, indeed, has a positive influence on the performance of the classifier (discussed in more details in Table 4). Hence, our final architecture comprises of seven classifiers, corresponding to the 7-class taxonomy, integrated with those combinations of twitter-centric features which resulted in the highest Area Under ROC curve (AUC) values during 5-fold cross validation evaluation.

Hashtags: A hashtag is a keyword or a phrase used in a Tweet message to describe a topic or a theme. This is denoted by a special character '#' at the beginning of a word. First, an unified set of hashtags collected from all the tweets belonging to a specific label from the training set is created (i.e., 7 sets, each pertaining to a specific label). Thereafter, we compute the Jaccard similarity between the set of hashtags present in each tweet and the set of hashtags contained in the category-specific unified set. This is then fed as an input to the first fully connected layer of the corresponding classifier as shown in Figure 3. The Jaccard Similarity J for any two sets A and B is given by the equation:

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|} \quad (1)$$

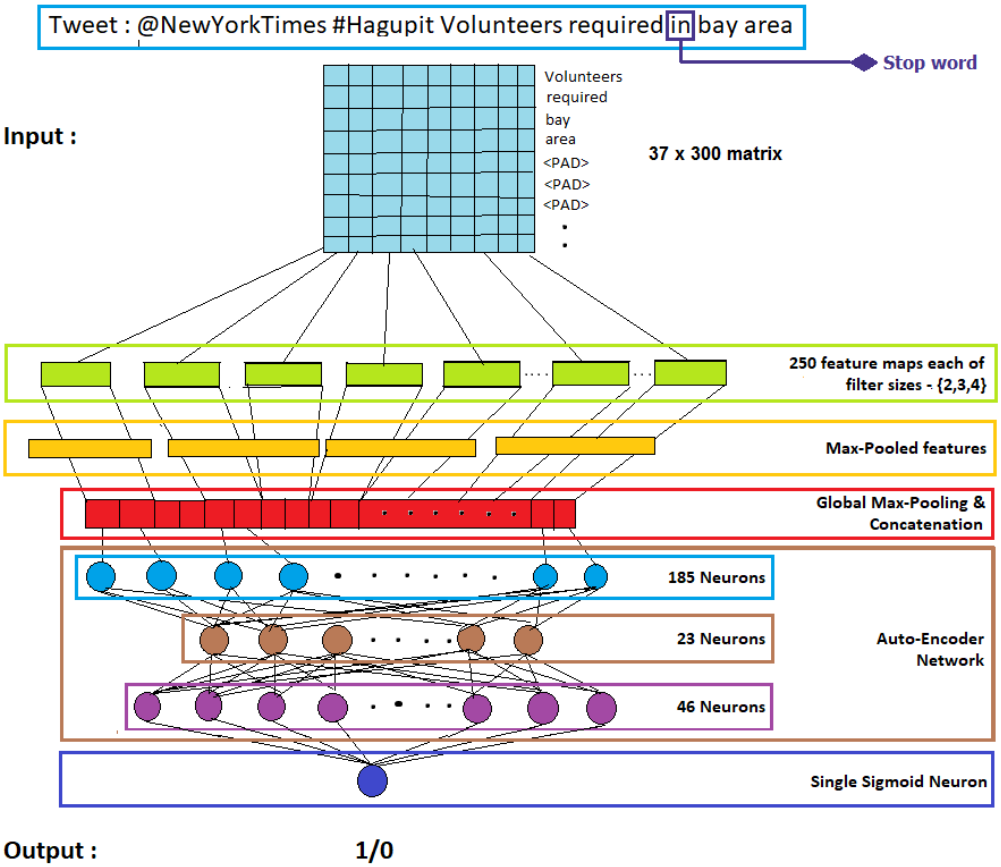

Figure 2. Deep CNN based architecture design (baseline) of classifier (B_i)

User-mentions: An user-mention corresponds to a word used to refer to a user account in a tweet, identified by the use of special character '@' at the beginning of the word. Like with hashtags, the Jaccard similarity between the set of user-mentions present in each tweet and the unified set of user-mentions for that particular label from the training data is fed as an input to the first fully connected layer as shown in Figure 3.

Keywords extracted from Embedded URLs: The top six keywords, having the highest Tf-Idf values, are extracted from the content of the webpage (Content refers to the text inside <p> tags, the webpage title and the meta description) pointed to by the embedded URLs in a tweet. Similar to the other features, Jaccard similarity between the set of extracted keywords and the global set corresponding to that particular label is fed into the first fully connected layer of the network as shown in Figure 3.

Online Setting: The proposed architecture, if deployed in an online setting, would generate an evolving set of hashtags, user-mentions and URL keywords over the time for each category. The union of all these can be fed back into the tweet collecting module for better efficiency of disaster-specific data retrieval.

DATASET AND EXPERIMENTAL SETUP

In this section we present the datasets, taxonomy and the various setups that we use for the evaluation.

Tweet Dataset

The dataset used for our research was obtained from CrisisNLP[1]. It consists of of 49,143 tweet IDs, each corresponding to a crisis-related message from Twitter posted during 14 different crises that occurred from 2013 to 2015. Each tweet was annotated by the paid CrowdFlower[2] workers or volunteers, with a label corresponding to a category belonging to the subset of annotations used by the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA). A category is assigned to a tweet if and only if at least three different annotators agree on that particular label. **Table 1** shows the distribution of tweet instances corresponding to each crisis type.

[1]http://crisisnlp.qcri.org/lrec2016/lrec2016.html
[2]https://www.crowdflower.com/

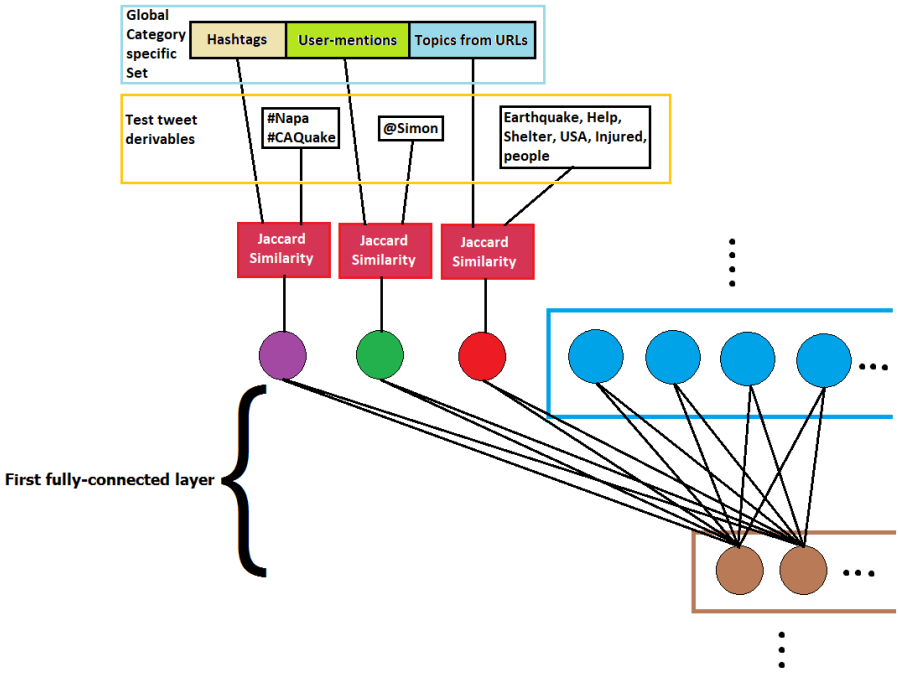

Figure 3. Proposed deep CNN Architecture with augmented twitter-centric features

Crisis Name	X	Y
California Earthquake	2014	184
Chile Earthquake	2014	441
Hurricane Odile	2014	184
Iceland Volcano Eruption	0	417
Airline MH370 crisis	0	135
MERS	2018	383
Typhoon Hagupit	2014	9676
Cyclone Pam	2014	601
Nepal Earthquake (2015)	3019	9472
Landslide Worldwide	0	4493
Pakistan Flood	2014	0
India Flood	2004	0
Ebola Virus Epidemic	2018	0
Pakistan Earthquake (2013)	2014	0
Total	**23157**	**25986**

Table 1. Number of Crowdflower annotated tweets (X) and Volunteer annotated tweets (Y), corresponding to 14 different disasters that happened between 2013 and 2015, present in the original single-label CrisisNLP dataset.

Crisis Information Taxonomy

Our analysis of the dataset provides us more insight about the type of information that flows during crisis situations. The labeling instructions for annotation of the tweets vary with respect to the crisis under consideration. This implies that the guidelines for a given category which is informative to one crisis may be insignificant to the another. For example, while the category *Infrastructure Damage* is significant in case of geophysical disasters like earthquakes or tsunamis it is insignificant to a biological crisis like an epidemic. Similarly, a category named *Disease Prevention* is significant in biological scenarios whereas it is not applicable to geophysical situations. The taxonomy that we use for classification of disaster tweets comprises of 7 classes which are largely derived from the one reported in Imran, Mitra, and Castillo (2016). All the classes from the CrisisNLP dataset are mapped to one of these seven labels. The crisis information taxonomy used in this paper is as follows:

- *Casualties and Public Impact*: This denotes to the reports of affected people in the form of death, injury, displacement etc. This is the class that we obtain by merging the classes *Injured or dead people*, *Missing*

trapped or found people and *Displaced people and evacuations* in the original dataset. These classes were merged as (i). the number of instances for the *Missing trapped or found people* classs were relatively low, and (ii). the ambiguity betwen these two classe was very high-with almost all containing the similar contents.
Example:- 25 people dead in the hurricane #latestReports #BBC

- *Collateral Damages*: This corresponds to the reports of indirect or utility damages caused by the crisis. This class is derived from *Infrastructure and utilities damage* in the original dataset.
Example:- Bridge collapses due to 7.2 richter scale #napaquake

- *General Awareness*: This class denotes the tweets regarding public notices or situational awareness. This is created from the *Caution and advice* class of the original dataset.
Example:- Rescue missions are continuing at the affected areas. Everyone is advised to stay calm.

- *Voluntary Services* : This class denotes to the tweets showing willingness to donate services like money, food, clothes, manpower etc. This class is derived from the *Donation needs or offers* of the original dataset.
Example:- I would like to donate $1000 to #NapaReliefFund.

- *Sympathy and Emotion*: This particular class denotes to the tweets showing emotional support.
Example:- My prayers are with families of ten fellow beings who lost their lives at bay area today.

- *Crisis-specific Information*: This class denotes the tweets corresponding to crisis-specific categories which cannot be included in any of above categories. This is derived from the *Other useful information* class of the original dataset.
Example:- Palmer Tech at the verge of launching medicine which can fight ebola #Epidemic

- *Non-informative* : Tweets which do not impart any significant information.
Example:- Chilling out in the hurricane stricken beach.. #GonnaEnjoyToday

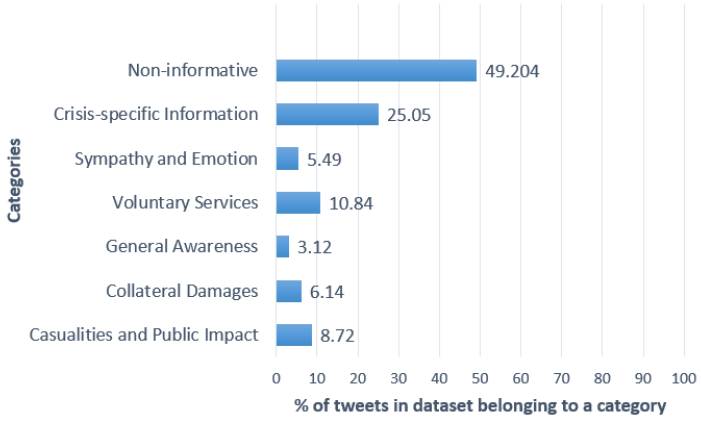

Figure 4. Class distribution of tweets in the original single label CrisisNLP dataset with respect to the 7-class taxonomy system.

We show the class-wise distribution of instances in Figure 4.

Word Embeddings

Capturing semantic similarity between target texts is an important step towards accurate classification. For this reason, word embeddings play a pivotal role. We use three different 300 dimensional pre-trained word2vec (Mikolov et al., 2013) word embeddings in our current work – CrisisNLP word embedding[1] trained over 52 million tweet messages provided by the CrisisNLP team, Google News word embedding[3] trained by the skip-gram model on part of Google news dataset containing about 100 billion words and Wiki fastText word embedding[4]. The methodology and rationale behind using three different word embeddings is further discussed in Tweet Vectorization.

[3]https://github.com/mmihaltz/word2vec-GoogleNews-vectors
[4]https://s3-us-west-1.amazonaws.com/fasttext-vectors/wiki.en.vec

Tweet Text Normalization

Use of colloquial and abbreviated forms of words while messaging in social media platforms, often poses a challenge in automated tex analysis. An Out-Of-Vocabulary (OOV) word dictionary contains the mapping between the OOV words and its corresponding normalized wordforms. We use the dictionary as reported in Imran, Mitra, and Castillo (2016), which contains 1,415 pairs of OOV wordforms.

Tools used for Experiments

The codebase, during experimentation, is written in Python (version 3.6) with external libraries – namely *keras*[5] for neural network design, *sklearn*[6] for evaluation of baseline and the proposed model, *pandas*[7] for easier access of data in the form of tables (or, data frames) during execution, *twython*[8] for fetching tweets corresponding to IDs in CrisisNLP dataset, *NLTK*[9] for textual analysis and *pickle*[10] for saving and retrieving input-output of different modules from the secondary storage devices.

Preprocessing

The class distribution of the collected data from the original CrisisNLP dataset mapped onto our 7-class taxonomy, is shown in *Figure 4*. The pre-processing phase comprises of the removal of non-ASCII characters, stop words and handling of non-alphanumeric characters followed by tokenization. Tokens of size (number of characters) less than 3 were removed with an intution that these do not contribute significantly in classification. Tweet text normalization was carried out using an OOV dictionary. Out-of-vocabulary terms such as slangs, place names, abbreviations, misspellings, etc. were replaced with their corrections or normalized forms, using the OOV dictionary. Tweets with identical tokens were combined together so as to form a multi-label k-hot encoding corresponding to each tweet. Many informative tweets were represented by re-tweets as well in the dataset, and had been labeled multiple times. It was observed that several of these tweets therefore contained multiple labels assigned to themall being the valid labels. This phase resulted in 27,150 data instances with the corresponding k-hot vector. Shrinkage of the number of data instances from 49,143 to 27,150 points to the dominance of multi-label instances in the dataset. Since the original dataset was a single label dataset, it is evident that a dataset prepared with multiple-labels in mind could potentially be a better indicator.

Tweet Vectorization

In order to feed the tokenized tweet into the proposed architecture, the corresponding 2-D matrix should be generated. Three pre-trained word2vec models as discussed earlier are used for this purpose. Each token is converted into a 300-dimensional vector using each of CrisisNLP, Google and Wiki trained word2vec models. Usage of these models ensured that 99.15% of the tokens are present in the combined vocabulary. The overall vector of every token is the weighted average of these three vectors in 4:2:1 ratio. For OOV words, we define a 300-dimensional zero vector. Vectors corresponding to all tokens of a given tweet are stacked together and zero-padded to form a 2-D matrix of the desired size (37 x 300). The number 37 was chosen, since it was the maximum number of tokens found in a preprocessed tweet from the training set.

EXPERIMENTS, RESULTS AND ANALYSIS

In this section we report the details of our experiments, show the evaluation results with necessary analysis.

Experiments: Training & Hyper-parameter Tuning

The baseline CNN as well as the modified architecture discussed in the previous section are trained on the instances obtained after preprocessing. The system is tuned using 5-fold cross validation. We report in *Table 2* the values of optimal hyper-parameters with respect to each component during the experiments. Batch size is set to 32. For training we use the various combinations of twitter-centric features, used along with the word embedding features (as discussed in the Section Augmenting Twitter-Centric Linguistic Features to CNN). We choose the final model architecture based on that particular configuration, which produces the best performance in terms of the AUC value.

Algorithm 1 Online Learning Evaluation

```
Initialize model by training on known crisis data except that of Nepal Earthquake (21750 data instances)
N is set to 1
for minibatch d_i = {d_1 ... d_{n-2}} do
    if i is not divisible by 10 then
        Continue model training on d_i
    else
        Train model on previously seen data (21750 + 10*N mini-batches)
        Increment N
    end if
    Evaluate model on d_{i+1} ∪ d_{i+2}
end for
```

Category	N	D		
Casualties and Public Impact	6	0.25	0.38	0.5
Collateral Damages	5	0.2	0.4	0.5
General Awareness	6	0.25	0.31	0.5
Voluntary Services	6	0.1	0.25	0.5
Sympathy and Emotion	5	0.25	0.38	0.5
Crisis-specific Information	7	0.25	0.38	0.5
Non-informative	3	0.0	0.25	0.5

Table 2. Optimal hyper-parameter values used during experiment. N denotes number of epochs for training and D corresponds to the set of dropout values to be applied to final three neural layers of each component

Online Learning Evaluation

We evaluated our model in an online environment with an algorithm similar to that discussed in Nguyen, S. R. Joty, et al. (2016), as shown in Algorithm 1. The model was initialized on the available CrisisNLP dataset except the Nepal Earthquake. We thereafter divide the incoming dataset D (containing around 5400 tweets) for the Nepal Earthquake into mini-batches d_i of equal size (set to 100). We trained our model on every d_i, and was evaluated on the next 2 mini-batches, $d_{i+1} \cup d_{i+2}$. After N-th interval of 10 successive mini-batches, the model was retrained over the whole training dataset (i.e. 21750 + 10N mini-batches) to avoid the loss of information corresponding to the past instances. Evaluation on future mini-batches in this way could help predict the model's practical performance in a disaster-prone situation. The model was evaluated using the metrics, Hamming Loss and AUC (AUC was calculated for every label). Hamming Loss is a widely used evaluation metric for multi-label classification, and is computed by,

$$\text{HammingLoss}(x_i, y_i) = \frac{1}{|D_t|} \sum_{i=1}^{|D_t|} \sum_{j=1}^{|L|} \frac{xor(x_{i,j}, y_{i,j})}{|L|}, \tag{2}$$

where $|D_t|$ is the number of samples in the test dataset, $|L|$ is the total number of labels, $x_{i,j}$ is the prediction (0 or 1) and $y_{i,j}$ is the ground truth (0 or 1) for the i^{th} data instance and the j^{th} label. It reflects the fraction of the wrong labels to the total number of labels.

Results and Analysis

The model is trained on a dataset of 27,150 unique instances. Results of 5-fold cross validation for the baseline model are shown in *Table 3*. We demonstarte the evaluation results with different combinations of linguistis features in *Table 4*. In *Table 5* we show the evaluation results in terms of F1-Score and AUC values for the best model (i.e.

[5]https://keras.io/
[6]http://scikit-learn.org/
[7]http://pandas.pydata.org/
[8]https://twython.readthedocs.io/
[9]http://www.nltk.org/
[10]https://docs.python.org/3/library/pickle.html

Category	F1-Score	AUC
Casualties and Public Impact	0.9221	0.811
Collateral Damages	0.958	0.776
General Awareness	0.978	0.787
Voluntary Services	0.934	0.746
Sympathy and Emotion	0.953	0.712
Crisis-specific Information	0.828	0.743
Non-informative	0.816	0.812

Table 3. Results of the baseline CNN in the offline setting on the dataset containing tweets related to multiple crises. AUC refers to Area Under Curve metric.

Set of Features	A	B	C	D	E	F	G
Hashtags	0.8201	0.7961	0.8034	0.7688	**0.7294**	**0.7604**	0.8341
User-mentions	0.817	0.7798	0.8058	0.7604	0.7197	0.7516	0.8311
URL Keywords	**0.8253**	0.7959	**0.808**	**0.774**	0.7273	0.7583	0.834
Hashtags + User-mentions	0.8111	0.7809	0.7996	0.7619	0.7273	0.7488	0.8317
Hashtags + URL Keywords	0.8223	**0.7985**	0.8082	0.7684	0.7278	0.7583	**0.8347**
User-mentions + URL Keywords	0.8156	0.7801	0.8008	0.7663	0.7175	0.7471	0.8316
Hashtags + User-mentions + URL Keywords	0.8127	0.783	0.7964	0.7611	0.7222	0.7482	0.8333

Table 4. Results (AUC values) of the proposed architecture with different combinations of twitter-centric textual features along with deep CNN. Labels A – G represent informative categories, as discussed in the Crisis Information Taxonomy Section, in the same order. Highlighted values represent models with highest AUC values for a given category.

Category	F1-Score	AUC
Casualties and Public Impact	0.9544	0.8253
Collateral Damages	0.9683	0.7985
General Awareness	0.9837	0.808
Voluntary Services	0.9427	0.774
Sympathy and Emotion	0.9717	0.7294
Crisis-specific Information	0.8516	0.7604
Non-informative	0.7502	0.8347

Table 5. Results of the proposed model in an offline setting on the dataset containing tweets related to multiple crises: Showing both AUC and F1-Score.

the model that produces the highest peformance) in each category. This model is thereafter used for the evaluation in an online setting. We report these results in Figure 5 and Figure 6.

A close scrutiny of the results as shown in Table 3 and 4 demonstrates that there is, indeed, a positive influence of twitter-centric features on the performance of the system. Even though all the three features contribute in improving the performance, the highest peak is seen with the 'Hashtags' and 'URL keywords' features. Such a behavior can be accounted for by the fact that all crises are events. In an environment like Twitter, hashtag is an indicative notion to the topic or a trending event. Prior research works in event detection rely on hashtags as an important feature. Moreover, due to the character limits imposed on tweets, users usually embed URLs in tweets pointing to the other web sources. In a crisis situation, such URLs can be considered as a rich source of information, especially in case of 'Casualties and Public Impact' and 'General Awareness' categories where government, humanitarian and media communities share information and awareness through their official websites. User-mentions are usually used for replying to specific users on Twitter. Thus, it is possible that the usage of user-mentions does not reveal much about the informativeness of a given message. This might be the reason behind the performance degradation when all three twitter-centric features are used altogether. F1-score is sensitive to the threshold at the output layer while AUC is not. In Table 5, we observe that F1 score for the non-informative category is lower with twitter centric features, but the AUC is still higher. Currently we round off values at the last layer to the nearest integer (ie. 0 or 1)

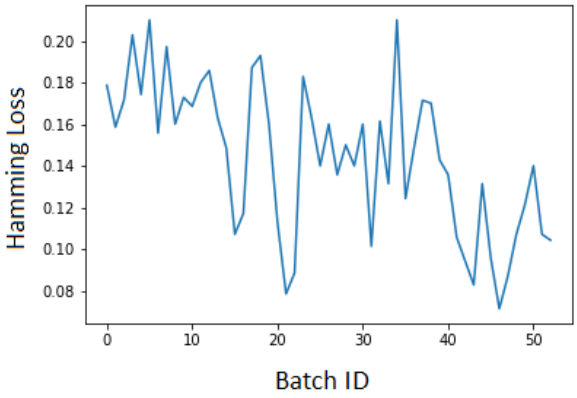

Figure 5. Hamming loss with respect to incoming batches of batch size 200 in online setting, as explained in Online Learning Evaluation

using 0.5 as threshold to obtain the label. The higher AUC shows that with different values of the threshold, it is possible to obtain a higher F1 score as well, and the overall performance of the classifier is still better with twitter centric features. Moreover, training and testing are done on a dataset containing tweets belonging to multiple crises. Thus, the good performance as exhibited by the architecture proves that the proposed model generalizes well to multiple crisis situations.

Results obtained in the online setting show a decrease in hamming loss with incoming batches (as shown in Figure 5). The noisy nature of the AUC curves could be due to the small number of tweets per label in some minibatches. Results show an overall increment in the AUC values for the majority of informative categories. These observations establish that the proposed architecture performs well in an online streaming scenario, making it a perfect fit for the practical purposes.

A quick stroll through the dataset also revealed that annotators were confused between non-informative personal tweets and the tweets belonging to 'Casualties and Public Impact' category. One possible reason for such a pattern is that while expressing suffering faced during the crisis, users tend to make it personal. For example, 'Lucky to be one among 25 people to be saved #hagupit' - This tweet is dominantly personal but it still gives minuscule information that 25 other people were also affected by the crisis. Thus, a tweet being informative and non-informative at the same time introduces ambiguity for annotation, and this affects the performance of the designed system. The unbalanced class distribution is yet another hurdle faced by the model. In our proposed model we use binary cross entropy as the loss function. Designing a category specific cost-sensitive loss function might improve the performance. Moreover, the proposed architecture uses twitter-centric textual features like hashtags, user-mentions and keywords extracted from embedded URLs. Exploring the effect of twitter-centric non-textual features like retweet count, presence of media files etc. can open tremendous opportunities for better feature engineering, and thereby improves the performance as well as the generalization capability of the model.

Comparison with existing models

Most of the prior works were mainly focused on binary and multi-class classification using classical supervised models. There have been a few attempts for multi-class classification using deep learning models. But, to the best of our knowledge none of these models dealt with a multi-label deep learning model. We introduce a model based on deep CNN architecture that is capable of multi-label classification. Moreover, we deal with a single dataset containing tweets associated with multiple crises, while majority of the existing systems tend to use data of a single crisis for both training and evaluation. The results obtained in the online setting by the CNN based binary classifier (informative vs. non-informative), as proposed in (Nguyen, S. R. Joty, et al., 2016), can be compared with that of our proposed model as both make use of the identical settings. Both the models were trained and tested on a dataset of multiple crises. Average AUC value of their model was around 0.74 – 0.75 while our proposed model attains an AUC value of 0.8347 (approx. 11.3% increase). This difference can be attributed to a variety of reasons. Our model is much more robust since it has an additional auto-encoder network which helps in dimensionality reduction and a faster learning process, along with twitter centric feature integration. Also, since they had modeled the problem as a single-label problem, the existence of multiple labels for the same tweet text could have confused the classifier. Imran, Elbassuoni, et al. (2013) mentioned about the development of a multi-label naive Bayes classifier, which was evaluated on the Joplin 2011 tornado dataset with a 4-class information taxonomy, namely 'Caution & Advice', 'Donation & Offers', 'Casualty' and 'Information Source'. However, we can not compare this model's performance

Figure 6. AUC values with respect to incoming batches of batch size 200 experimented with final architecture in online setting, as explained in Online Learning Evaluation

with the results obtained in our proposed model as the evaluations were carried out on two completely different experimental setups – we have used a dataset containing information from multiple disasters, and also a different taxonomy. Our proposed model achieves good performance on multiple crises (as shown in Table 4).

Experiments also show that in an online setting, our proposed architecture yields as output an evolving set of hashtags, user-mentions and relevant topics for each category. The resultant set obtained by taking the union of all such topics can be fed back into a tweet collection module that helps in better filtering of disaster-specific tweets from the public stream of messages.

CONCLUSION AND FUTURE WORK

In this paper, we have established the importance of viewing the classification of disaster-specific tweets as a multi-label problem, and have proposed a deep CNN-based architecture for this purpose. Twitter centric-features derived from the hashtags, user-mentions and keywords extracted from embedded URLs were also explored. Experimental results show that we can achieve significantly better performance with our proposed system compared to the existing state-of-the-art models. Results obtained from both the offline and online settings showcase the ability of our model to adapt and perform well in a practical scenario. The results show that our architecture is a step forward in solving the problem of harnessing the overwhelming flow of information through social media in a crisis situation.

Detailed performance analysis of the model has been performed, pointing at sites of future improvement which includes formulation of a category specific cost-sensitive error function and studying twitter-centric non-textual features which can be used to increase the classification efficiency. We hope to accomplish the above mentioned enhancements as part of our future work. Moreover, modeling information extraction corresponding to the categories to which a given tweet belongs to, is yet another research area that needs to be explored. In conclusion, we hope that our work would prove beneficial to the humanitarian community and foster further research in this field.

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Using Twitter Data to Determine Hurricane Category: An Experiment

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Abstract
Social media posts contain an abundant amount of information about public opinion on major events, especially natural disasters such as hurricanes. Posts related to an event, are usually published by the users who live near the place of the event at the time of the event. Special correlation between the social media data and the events can be obtained using data mining approaches. This paper presents research work to find the mappings between social media data and the severity level of a disaster. Specifically, we have investigated the Twitter data posted during hurricanes Harvey and Irma, and attempted to find the correlation between the Twitter data of a specific area and the hurricane level in that area. Our experimental results indicate a positive correlation between them. We also present a method to predict the hurricane category for a specific area using relevant Twitter data.

Key words
Social Media Data, Hurricane Category, Twitter, Prediction

INTRODUCTION

Nowadays, disaster control and analysis using social media data is gaining great popularity (Kireyev et al. 2009; Reuter & Kaufhold 2017). When a disaster happens, people who live nearby use social media to express their opinions, emotions, and feelings, or to ask for help. Special correlation between the data and the events can be implicit, but valuable for situations like emergency response, and can be found through applying data mining techniques. For example, researchers have used different techniques to determine the occurrence of some types of disasters, including their places and tracks (Musaev et al. 2015).

Hurricane Harvey and Irma have attracted a lot of attention due to the scale and damage they brought to the affected areas. Hurricane Harvey was an intensely devastating Atlantic Hurricane that affected southeast Texas, USA. Harvey formed on August 17 and dissipated on September 3, 2017 (Hurricane Harvey Recap from https://weather.com 2017). It was the first major Hurricane that affected south Texas after Celia in 1970. It strengthened into a hurricane on August 24, with first landfall on San Jose Island, followed by another landfall near Rockport and Fulton, Texas the next day. Another Hurricane named Irma, which followed Harvey, was the strongest Atlantic Hurricane in terms of maximal constant winds, and formed on August 30, 2017 and dissipated on September 16, 2017. Irma caused adverse damage starting from the Caribbean to the Southeast United States, especially Florida (Hurricane Irma Recap from https://weather.com 2017). On September 10, Irma moved over the Florida Keys as category 4 hurricane, making landfall with a wind speed of 130 mph at Cudjoe Key, Florida (Landsea & Mello 2017). Irma made another landfall close to Macro Island, Florida with wind speed of 115 mph.

During the period of these two hurricanes, thousands of tweets were posted all over the world. We are interested in evaluating a hypothesis that the scale of a hurricane in a location can be determined based on a given tweet or a set of tweets from that location. This can be generalized into finding the relationship between tweets and the level of the Hurricane and using the relationship to predict the actual hurricane level. Given the above research questions, we

have performed several experiments on a one-month (August 17, 2017 through September 16, 2017) geo-tagged Twitter data set, which contains 188,721 tweets, and every tweet has a hashtag "Harvey" or "Irma". After filtering out the irrelevant tweets, we build two data sets for Harvey and Irma. We annotate each of the tweets in both data sets with different categories depending on their location and the category of hurricane in that location. We then generate vectors for the data sets using Word2Vec (Mikolov et al. 2013) and Bag-of-Words (BOW) (Tsai 2012), after which, we apply different classification algorithms to evaluate the vectors.

The contributions of this paper are three-fold. First, by analyzing a current available Twitter data corpus, the hypothesis about a positive relationship between Twitter data and hurricane category is verified. Second, the methodology we use in this paper can be applied in future work and to different disaster type and an algorithm for predicting a specific area's hurricane category is presented. The third contribution is a release of a labeled data set of hurricane related tweets, which was generated over the course of the study.

RELATED WORK

Ashktorab et al. introduce a Twitter-mining tool that extracts actionable information for disaster relief workers (Ashktorab et al. 2014). Those workers need to glean actionable knowledge from a large volume of tweets and status updates; however, tweets and status updates can be very noisy. The goal of their tool is to extract information relevant for first responders in real time and enable analysis after the disaster has occurred. They use a combination of classification, clustering and extraction methods to extract actionable information. Similarly, Cornelia et al. present an approach based on convolutional neural networks to identifying informative messages in social media streams during disaster events and show significant improvement in performance over models that use the "bag of words" and n-grams as features on several datasets of messages from flooding events (Cornelia et al. 2016).

Sakaki et al. use Twitter to investigate the real-time interaction of events such as earthquakes and propose an algorithm to monitor tweets and to detect a target event (Sakaki et al. 2010). They produce a probabilistic spatiotemporal model for the target event that can find the center and the trajectory of the event location, and their application can deliver much faster than the announcements that are broadcast by Japan Meteorological Agency (JMA) with high probability (96%). Musaev et al. in their work of evaluating a landslide detection system, LITMUS, use Twitter as the main source of social media data to help detect landslides. Their integrated approach of using physical sensors and social media sensors (including Twitter) enables the LITMUS system to have a better precision and accuracy of landslide detection (Musaev et al. 2015).

Twitter data is also used to predict stock market movements (Pagolu et al. 2016). Their work is based on the fact that social media can represent the public sentiment and opinion about current events, and especially Twitter has attracted a lot of attention from researchers for studying the public sentiment. To observe how much the changes in stock prices of a company, the rises and falls, are correlated with the public opinions being expressed in tweets about that company, they applied two different textual representations, Word2Vec and N-grams.

Individual awareness of the severity of a disaster could be a key reason why we can use a collection of individual's social media posts to predict the severity of a disaster. A related work about individual awareness and disaster explores the possibility in the context of drought, examining what variables determine individual awareness of drought and further exploring how drought awareness influences risk perception and policy preferences (Switzer & Vedlitz 2017). They analyze related data and the results indicate that drought severity is the most significant factor for drought awareness, while ideological and demographic variables also play a role.

METHODOLOGY

In this section, we introduce the methodologies used in our research. The overall steps of our research are shown in Figure 1. We first briefly describe these steps and then, in the following subsections, we describe the setup of environmental issues and present more details for each step of Figure 1.

Geo-tagged Tweets Corpus: To achieve our research goal, the corpus of Twitter data needs to be extracted first. Geo-tagged tweets are the ones that have geo-coordinates or other type of location information in their meta-data. Using location information, we can identify the tweets published in any area of interest. In the subsection of "Twitter data corpus", we introduce the Twitter data set we use in this research.

Location Estimation for Hurricane Category: Referring to the information provided by wunderground (a commercial weather service) (https://wunderground.com Harvey/Irma 2017), we use the latitude and longitude information to record on the map with the locations' related hurricane information. In this step, we can find the related towns and cities for each hurricane category. For example, Rockport in Texas is of hurricane category 4.
Data Filtering: We search in the data corpus and find relevant tweets for each of the towns or cities identified for each hurricane category. The filters that we use include: location, hashtag, language, and country code. Then we label the tweets using their categories. For example, all tweets of Rockport area can be labeled with number of 4, which was the hurricane category of Rockport. In our research, we use labels "12" to annotate the tweets from hurricane category 1 and 2 areas, and use "34" to annotate the tweets from hurricane category 3 and 4 areas due to the limited amount of geo-tagged tweets for those relevant areas.
Generating Vector Model: We use Word2Vec and Bag-of-Words to generate vectors for the data set. Bag-of-Words represents a text as a bag (multiset) of its words considering multiplicity, whereas Word2Vec model represents words in a continuous vector space.
Classification and Comparison: In this step, we apply different classification algorithms to the training sets obtained from the last step and compare the F1 score (a measure of a test's accuracy) to find the best prediction approach. A 10-fold cross validation method is used to test the models in the training phase in order to give an insight on how the model will generalize to a new dataset.
Applying Prediction for a Location: We choose two new places, which are not included in the training data sets. We predict each of the tweets and label them as "12" (Hurricane Level 1 or 2) or "34" (Hurricane Level 3 or 4). If there are more tweets of "12" than "34", we identify the place as category "12". In this way, we can predict the hurricane category for a specific location.

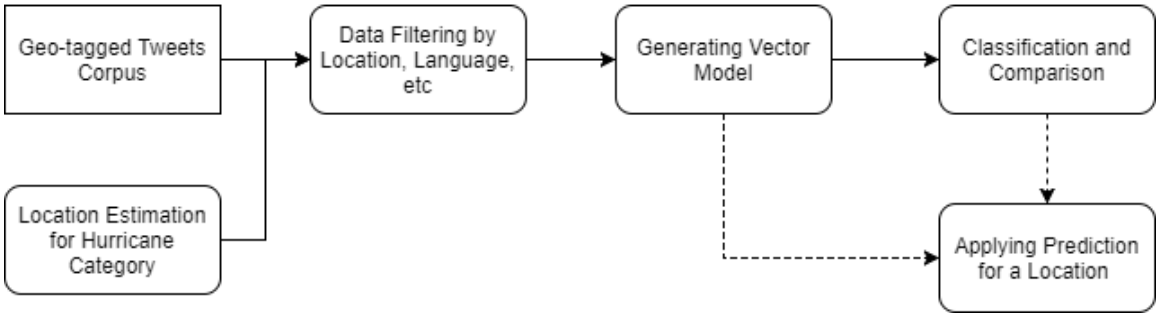

Figure 1. Overview of Our Working Processes

Environmental Issues Setup

Depending on the information given by the wunderground website, we can mark in the map using the latitude and longitude coordinates and the locations' related hurricane information. In this step, we can find the related towns and cities for each hurricane category. Figure 2 shows an example of a Twitter user post: "Rockport getting bad & it's just the start of the storm, don't underestimate #Harvey" at "8/25/2017 9:15:33 PM".

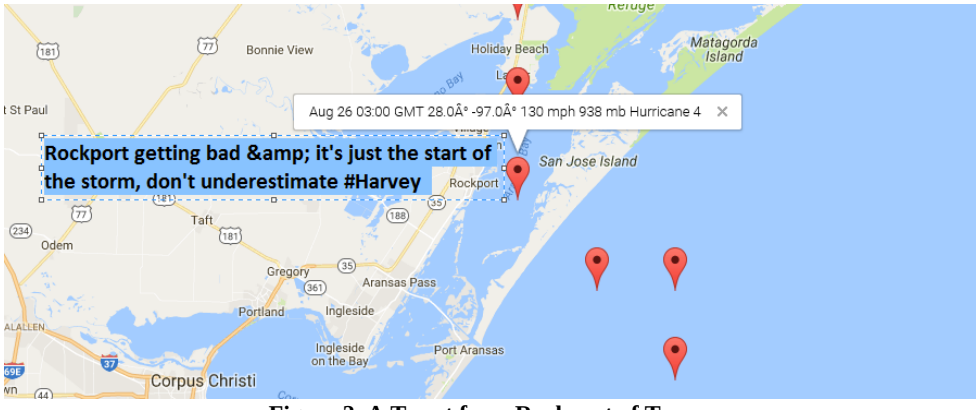

Figure 2. A Tweet from Rockport of Texas.

We first mark the places in the map with their category level and timing depending on the data from a trustworthy website (see Figure 3), and then identify the related places for a specific hurricane category. For example, for

hurricane level 4, we identified Aransas Pass, Corpus Christi, Fulton, Holiday Beach, Port Aransas and Rockport. For each of them, we can filter their related tweets using hashtag "Harvey".

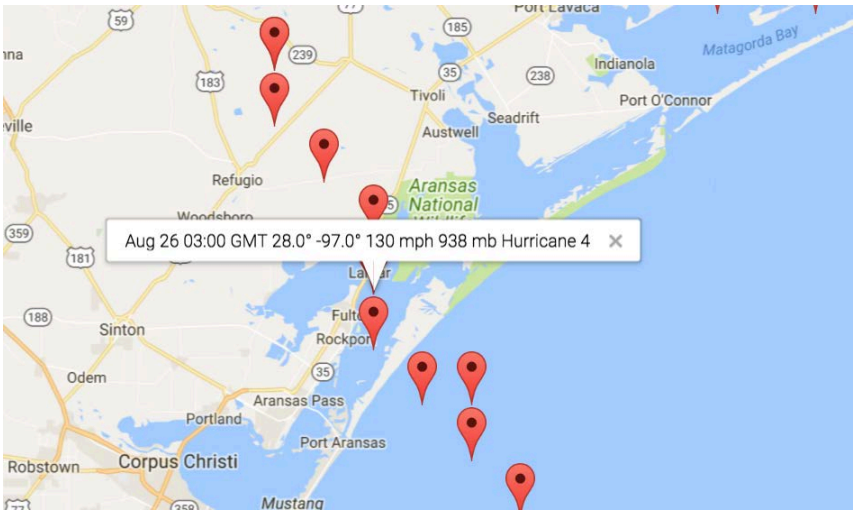

Figure 3. Google Map Marker for Harvey

Twitter Data Corpus

The Twitter data set we use is a one-month (from August 17 to September 16) tweets set of Hurricane Harvey, Irma and Maria, and has geo location information. The total number of the tweets is 188,721. From the data set, we can filter the tweets by location and hashtags. By using a text and Twitter analytics tool called DiscoverText, we can easily preprocess the tweets for experiments.

Data Filtering

In the Twitter data corpus, only a small part of the tweets has geo-coordinates, and all of them have location coordinates, which means we can search using location name – city name or town name. Although a lot of points are marked in the map, most of them are far from big cities, such as Houston or Miami, and highways. This leads to the conclusion that only hundreds of tweets are left for each category and its related locations. Table 1 shows an example of locations and number of tweets information for Harvey category 4 areas. In the future, if a new hurricane happens more data can be collected and combined with the historical data, but for this experiment, we only carry our experiment based on the available data sets.

Table 1. Example Locations and Number of Tweets for Harvey Category 4 Area

Places	Level	Number
Aransas Pass	4	5
Corpus Christi	4	416
Fulton	4	12
Holiday Beach	4	1
Port Aransas	4	13
Rockport	4	8

Because of the limited number of tweets, we put category 1 and 2 together to form a new label "12". Similarly, we put 3 and 4 together to have a new "34" label. In the labeling step, we label the tweets with "12" or "34". If we have more data in the future, we can split the categories into independent states for detailed analysis. For other filter methods, we use hurricane names like "Harvey" or "Irma". We only consider the tweets posted in English and inside the United States. The total numbers of tweets for each hurricane and category is shown in Table 2.

Table 2. Tweets after Filtering with Location Name, Hashtag, Language and Country

	Category 12	Category 34
Harvey	103	280
Irma	176	132

Classification and Validation

To prepare the data for classification, we annotate the tweets of categories 1 and 2 as "12" and label the tweets of categories 3 and 4 as "34". Using this labeling method, we generate two original ground truth data, one for Harvey and one for Irma. Then we apply two different base line methods to build vectors for each of the ground truth data sets: Word2Vec and Bag-of-Words (BOW). For the Word2Vector method, we use Google's pre-trained Word2Vec model, which includes vectors for a vocabulary of 3 million words and phrases trained on part of Google News dataset (about 100 billion words). For the BOW model, we use the most common type of characteristics, which is term frequency, the number of times a term appears in the text. The experiment is performed to primarily verify the hypothesis that there exists a relationship between the hurricane category of an area and the tweets for that area using the corpus of Twitter data. Additional types of characteristics will be applied in future work.

We apply a two-step experiment to verify our hypothesis. After generating the training sets, we apply cross validation to the two training sets and a combination using 5 different classification algorithms (Decision Tree, Naïve Bayes, Logistic Regression, Random Forest and Support Vector Machines). After evaluating the results, we find the best feature generation methods and algorithms, and then use them in the second step of predicting two small towns' hurricane category for further analysis.

EXPERIMENTAL RESULTS

Our two-step experimental results imply a positive relationship between the tweets posted in an area and the actual hurricane category in the area. We first use a 10-fold cross validation to validate each unique classifier model, and then apply a 10-fold cross validation to the combination of the two classifier models. Through analyzing the cross validation results we select the best feature generation baseline method and classification algorithm to predict two towns' hurricane categories.

Cross Validation

We perform 10-fold cross validation on Harvey's data, Irma's data and the combined data of Harvey and Irma using different classification algorithms, namely Decision Tree (J48), Naïve Bayes, Logistic Regression, Random Forest and Support Vector Machines (SVM). These algorithms represent different categories of classification algorithms. We apply the five algorithms to find the one with the best performance so that we can use it to make prediction for small towns in the next step.

The cross validation results are plotted as shown in figures 4 and 5. F1 score is a harmonic average of the precision and recall to measure a test's accuracy, and it is used as the measurement for demonstrating the results in our experiments. Figure 4 presents the cross validation F1 results using Word2Vec as the base line method. We can see that Random Forest has the best performance for cross validation on Harvey's data and the value is 0.775. For cross validation on Irma's data, SVM has the highest score, which is 0.649. For cross validation on the combination of Harvey and Irma's data, Random Forest has the highest score, which is 0.657. From the results we can find a moderate positive relationship between the tweets posted in an area or several areas and the hurricane categories in those areas.

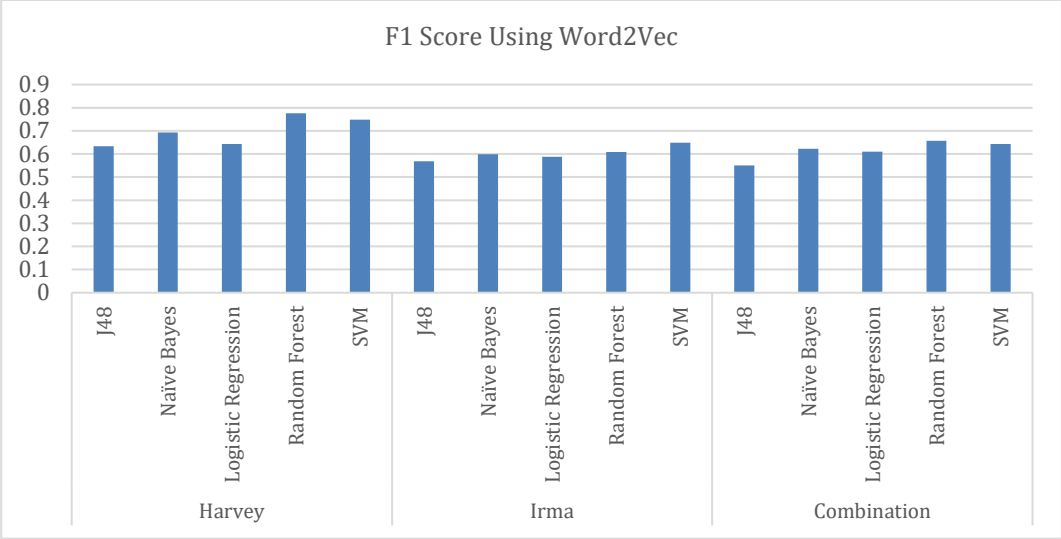

Figure 4. Cross Validation F1 Results Using Word2Vec

Figure 5 presents the cross validation F1 results using BOW as the base line method. We can see that Random Forest has the best performance for cross validation on Harvey's data and the F1 score is 0.796. For cross validation on Irma's data, Naïve Bayes has the highest score, which is 0.740. For cross validation on the combination of Harvey and Irma's data, Logistic Regression has the highest score, which is 0.829. Depending on the comparison of all the F1 scores presented in the two figures, we find Bag-Of-Words has an overall better performance

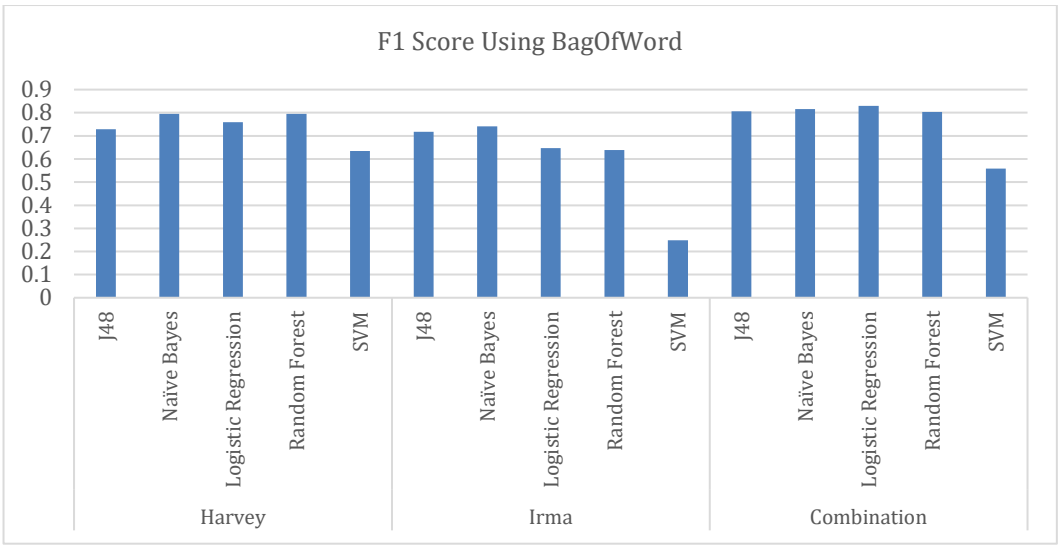

Figure 5. Cross Validation F1 Results Using Bag of Word

In the next step of experiment, we choose Random Forest algorithm to apply on Harvey training set, Naïve Bayes for Irma training set, Logistic Regression for a Combinational training set. Bag-of-Words will be used as the method for feature generation.

For Validation of a Selected Area

A positive relationship between Twitter data and hurricane category can be recognized through the result of the last step of the experiment. We use three different training sets to predict two small towns' hurricane category, namely, Plant City, Florida and Crystal River, Florida. Both towns were impacted by hurricane Irma. By classifying the tweets for the towns and applying a proposed predicting method, we have successfully predicted the categories for the two towns. Thus, the proof of our initial hypothesis is further enhanced.

For predicting Plant City, Florida, by using Irma training set and the Naïve Bayes algorithm, we can correctly predict 89.2% instances of tweets; by using Harvey training set and the Random Forest algorithm, we can correctly predict 2.7% instances; by using a combination training set and the Logistic Regression algorithm, we can correctly predict 86.5% instances. For predicting Crystal River, Florida, by using Irma training set and the Naïve Bayes algorithm, we can correctly predict 83.3% instances; by using Harvey training set and the Random Forest algorithm, we can correctly predict 0% instances; by using a combination training set and the Logistic Regression algorithm, we can correctly predict 58.3% instances. The results are shown in Figure 6.

Through the low prediction precision of using the Harvey training set and the Random Forest method to predict the two small towns' hurricane categories, we can see that it is not fit to use one hurricane's training set to predict a place in another hurricane's area. However, it is possible to use the combination of the training sets to do the prediction. The results imply that using related hurricane data to predict for related areas is the best approach. The reason may be that the posts in one hurricane's area consist of area-specific or hurricane-specific words. For example, tweets about Hurricane Harvey usually contain words like "Texas", "Houston" and "Harvey". If we filter out the area-specific words and special names, the results of using one hurricane's Twitter data to predict another might be improved.

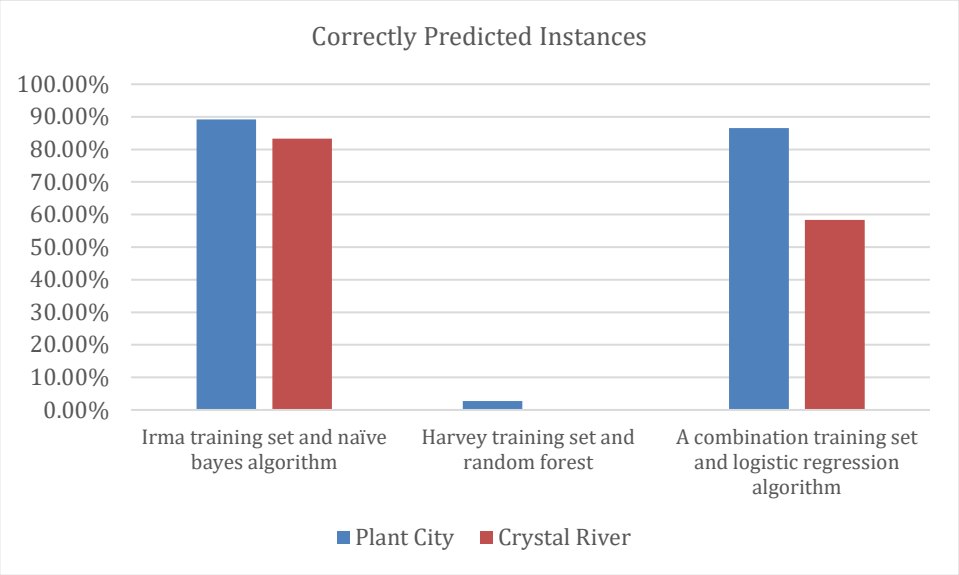

Figure 6. Correctly Predicted Instances Using Different Training Sets and Algorithms

To predict the hurricane level of a specific place, we propose an algorithm based on the observed results. The general steps are listed below. As described above, if we apply this algorithm, and use the Irma training set and the Naïve Bayes algorithm, or use a combination training set and the Logistic Regression algorithm, we can successfully predict the categories for the two places. The steps in the algorithm are:

1. Choose a proper training set and the most efficient classification algorithm.
2. Collect related tweets (set *s*) for a location.
3. Run classification algorithm to label each tweet in *s*.
4. Calculate the total number of tweets for each label, and find the majority label, which is of the final predicted category for that location.

Although our method of predicting hurricane categories performs well on the locations we chose, it can be not true for other locations. Different location can have different temporal, spatial or social features, which may affect the application of the method. It still needs more research based on more real world data to prove the efficiency of the method, as well as to improve the method.

DISCUSSION AND FUTURE WORK

To the best of our knowledge, this paper is the first attempt to use social media data to analyze and predict the category of a hurricane, or even the severity of a disaster. We can continuously collect the Twitter data for areas affected by hurricanes and verify the idea using the methods presented in this paper and a larger corpus of data. It is possible to analyze the relation between a disaster like hurricane and related social media data due to the wide area a hurricane can affect. However, during our experiment, we found several issues, other than the limit of data corpus, which necessitate further investigation as part of the future work.

Reasons about the Relation: It would be interesting to analyze the root cause of why there is a relationship between tweets and hurricane level. One possible approach could be using Bag-of-Words to find the most common words to make comparison.

Hurricane-specific Data: The precision is low if we use Harvey data to predict Irma data with respect to hurricane level. However, the precision is more significant if we use cross validation within Harvey data or Irma data. We found a lot of hurricane-specific words like "Florida", "Key West", "Texas", and "Rockport". For locations, they are unique to a specific area, making it hard to use one hurricane's data to predict another hurricane's severity unless we remove these words. This will be explored in our future work. If the hurricane-specific words or some irrelevant words are deleted from the text, the accuracy may be improved.

Temporal Factor: We are using one month of Twitter data. Another approach would be to use data in a specific period like the exact day the hurricane occurs. There would be less data if the period is short, however, since hurricanes usually happen in the same places (coastal areas), we can accumulate data of each hurricane to build a larger corpus as the ground truth. The tweets can be further categorized into three sets: before, during and after the hurricane. More complex relations can be used as a pattern to identify the category of the hurricane.

Number of Tweets: The tweets for each category we use in our experiment are not evenly distributed. Although the usage of vector generation methods can ease the effects of corpus size differences, the corpus size can impact the prediction results. In future experiments, we can take the number of tweets into consideration and examine what kind of impact it may bring to the experiment.

Threshold of Prediction: For predicting the category of a hurricane in a specific area, we can use a small set of tweets or a large set of tweets. The exact number depends on how many tweets can be obtained from the source data corpus. Future work needs to identify the exact threshold of the number of tweets, which can make the prediction most significant. The threshold may be determined by historic data or may also be determined by current hurricane related data.

Human Statistical Factor: This study did not consider the credibility of the authors of the tweets. This may be a limitation of our paper. The tweets can be posted by different groups: namely, individuals, newspapers, government departments, or advertising agents. Each group may have different demographic and ideological impacts on the experimental results.

The application of disaster prediction can help in real-time disaster response and decision making for governmental or civil agents. For a specific area experiencing a hurricane, we can predict the hurricane category using real-time Twitter data for that area by using historic data. It can be more meaningful if we apply our method to an area where it is hard to determine the severity of the damage, such as a valley area, high mountain areas, or near-coastal areas. Governmental or civil agents can use the evaluation results of social media data analysis as a reference. This paper explores hurricane categories, other disaster types might benefit from similar research methods.

CONCLUSION

In this paper, we introduced a study of finding correlation between Twitter data and hurricane category. Methods used and the preliminary results were presented. A moderate positive relationship was observed based on the experimental results. The contribution also includes a release of the data set, which was generated over the course of the study. We present an algorithm and implementation results of predicting an area's hurricane category. Depending on the experimental results, we can successfully predict the hurricane category for a given location.

However, intuitively, if we only have a small set of tweets for a small town, it is hard to predict the hurricane category. For future work, we can determine the proper magnitude of an area or the threshold number of tweets, related to the area for yielding better prediction results.

ACKNOWLEDGEMENTS

Thanks to Dr. Jacob Groshek, Boston College, for his grateful help with an introduction to Dr. Stuart Shulman. Dr. Shulman provides a tool called DiscoverText designed for big data processing and applying different learning techniques. Our research would not have been accomplished without their help in providing the related research data.

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Using Twitter Data to Determine Hurricane Category: An Experiment

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Abstract
Social media posts contain an abundant amount of information about public opinion on major events, especially natural disasters such as hurricanes. Posts related to an event, are usually published by the users who live near the place of the event at the time of the event. Special correlation between the social media data and the events can be obtained using data mining approaches. This paper presents research work to find the mappings between social media data and the severity level of a disaster. Specifically, we have investigated the Twitter data posted during hurricanes Harvey and Irma, and attempted to find the correlation between the Twitter data of a specific area and the hurricane level in that area. Our experimental results indicate a positive correlation between them. We also present a method to predict the hurricane category for a specific area using relevant Twitter data.

Key words
Social Media Data, Hurricane Category, Twitter, Prediction

INTRODUCTION

Nowadays, disaster control and analysis using social media data is gaining great popularity (Kireyev et al. 2009; Reuter & Kaufhold 2017). When a disaster happens, people who live nearby use social media to express their opinions, emotions, and feelings, or to ask for help. Special correlation between the data and the events can be implicit, but valuable for situations like emergency response, and can be found through applying data mining techniques. For example, researchers have used different techniques to determine the occurrence of some types of disasters, including their places and tracks (Musaev et al. 2015).

Hurricane Harvey and Irma have attracted a lot of attention due to the scale and damage they brought to the affected areas. Hurricane Harvey was an intensely devastating Atlantic Hurricane that affected southeast Texas, USA. Harvey formed on August 17 and dissipated on September 3, 2017 (Hurricane Harvey Recap from https://weather.com 2017). It was the first major Hurricane that affected south Texas after Celia in 1970. It strengthened into a hurricane on August 24, with first landfall on San Jose Island, followed by another landfall near Rockport and Fulton, Texas the next day. Another Hurricane named Irma, which followed Harvey, was the strongest Atlantic Hurricane in terms of maximal constant winds, and formed on August 30, 2017 and dissipated on September 16, 2017. Irma caused adverse damage starting from the Caribbean to the Southeast United States, especially Florida (Hurricane Irma Recap from https://weather.com 2017). On September 10, Irma moved over the Florida Keys as category 4 hurricane, making landfall with a wind speed of 130 mph at Cudjoe Key, Florida (Landsea & Mello 2017). Irma made another landfall close to Macro Island, Florida with wind speed of 115 mph.

During the period of these two hurricanes, thousands of tweets were posted all over the world. We are interested in evaluating a hypothesis that the scale of a hurricane in a location can be determined based on a given tweet or a set of tweets from that location. This can be generalized into finding the relationship between tweets and the level of the Hurricane and using the relationship to predict the actual hurricane level. Given the above research questions, we

have performed several experiments on a one-month (August 17, 2017 through September 16, 2017) geo-tagged Twitter data set, which contains 188,721 tweets, and every tweet has a hashtag "Harvey" or "Irma". After filtering out the irrelevant tweets, we build two data sets for Harvey and Irma. We annotate each of the tweets in both data sets with different categories depending on their location and the category of hurricane in that location. We then generate vectors for the data sets using Word2Vec (Mikolov et al. 2013) and Bag-of-Words (BOW) (Tsai 2012), after which, we apply different classification algorithms to evaluate the vectors.

The contributions of this paper are three-fold. First, by analyzing a current available Twitter data corpus, the hypothesis about a positive relationship between Twitter data and hurricane category is verified. Second, the methodology we use in this paper can be applied in future work and to different disaster type and an algorithm for predicting a specific area's hurricane category is presented. The third contribution is a release of a labeled data set of hurricane related tweets, which was generated over the course of the study.

RELATED WORK

Ashktorab et al. introduce a Twitter-mining tool that extracts actionable information for disaster relief workers (Ashktorab et al. 2014). Those workers need to glean actionable knowledge from a large volume of tweets and status updates; however, tweets and status updates can be very noisy. The goal of their tool is to extract information relevant for first responders in real time and enable analysis after the disaster has occurred. They use a combination of classification, clustering and extraction methods to extract actionable information. Similarly, Cornelia et al. present an approach based on convolutional neural networks to identifying informative messages in social media streams during disaster events and show significant improvement in performance over models that use the "bag of words" and n-grams as features on several datasets of messages from flooding events (Cornelia et al. 2016).

Sakaki et al. use Twitter to investigate the real-time interaction of events such as earthquakes and propose an algorithm to monitor tweets and to detect a target event (Sakaki et al. 2010). They produce a probabilistic spatiotemporal model for the target event that can find the center and the trajectory of the event location, and their application can deliver much faster than the announcements that are broadcast by Japan Meteorological Agency (JMA) with high probability (96%). Musaev et al. in their work of evaluating a landslide detection system, LITMUS, use Twitter as the main source of social media data to help detect landslides. Their integrated approach of using physical sensors and social media sensors (including Twitter) enables the LITMUS system to have a better precision and accuracy of landslide detection (Musaev et al. 2015).

Twitter data is also used to predict stock market movements (Pagolu et al. 2016). Their work is based on the fact that social media can represent the public sentiment and opinion about current events, and especially Twitter has attracted a lot of attention from researchers for studying the public sentiment. To observe how much the changes in stock prices of a company, the rises and falls, are correlated with the public opinions being expressed in tweets about that company, they applied two different textual representations, Word2Vec and N-grams.

Individual awareness of the severity of a disaster could be a key reason why we can use a collection of individual's social media posts to predict the severity of a disaster. A related work about individual awareness and disaster explores the possibility in the context of drought, examining what variables determine individual awareness of drought and further exploring how drought awareness influences risk perception and policy preferences (Switzer & Vedlitz 2017). They analyze related data and the results indicate that drought severity is the most significant factor for drought awareness, while ideological and demographic variables also play a role.

METHODOLOGY

In this section, we introduce the methodologies used in our research. The overall steps of our research are shown in Figure 1. We first briefly describe these steps and then, in the following subsections, we describe the setup of environmental issues and present more details for each step of Figure 1.

Geo-tagged Tweets Corpus: To achieve our research goal, the corpus of Twitter data needs to be extracted first. Geo-tagged tweets are the ones that have geo-coordinates or other type of location information in their meta-data. Using location information, we can identify the tweets published in any area of interest. In the subsection of "Twitter data corpus", we introduce the Twitter data set we use in this research.

Location Estimation for Hurricane Category: Referring to the information provided by wunderground (a commercial weather service) (https://wunderground.com Harvey/Irma 2017), we use the latitude and longitude information to record on the map with the locations' related hurricane information. In this step, we can find the related towns and cities for each hurricane category. For example, Rockport in Texas is of hurricane category 4.
Data Filtering: We search in the data corpus and find relevant tweets for each of the towns or cities identified for each hurricane category. The filters that we use include: location, hashtag, language, and country code. Then we label the tweets using their categories. For example, all tweets of Rockport area can be labeled with number of 4, which was the hurricane category of Rockport. In our research, we use labels "12" to annotate the tweets from hurricane category 1 and 2 areas, and use "34" to annotate the tweets from hurricane category 3 and 4 areas due to the limited amount of geo-tagged tweets for those relevant areas.
Generating Vector Model: We use Word2Vec and Bag-of-Words to generate vectors for the data set. Bag-of-Words represents a text as a bag (multiset) of its words considering multiplicity, whereas Word2Vec model represents words in a continuous vector space.
Classification and Comparison: In this step, we apply different classification algorithms to the training sets obtained from the last step and compare the F1 score (a measure of a test's accuracy) to find the best prediction approach. A 10-fold cross validation method is used to test the models in the training phase in order to give an insight on how the model will generalize to a new dataset.
Applying Prediction for a Location: We choose two new places, which are not included in the training data sets. We predict each of the tweets and label them as "12" (Hurricane Level 1 or 2) or "34" (Hurricane Level 3 or 4). If there are more tweets of "12" than "34", we identify the place as category "12". In this way, we can predict the hurricane category for a specific location.

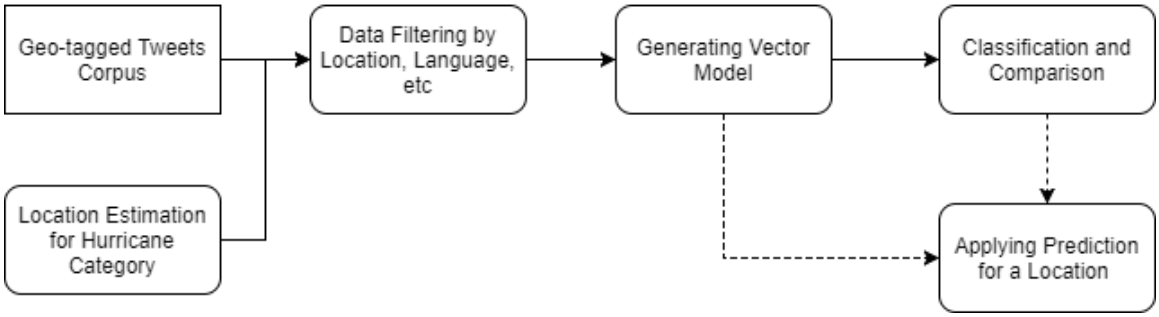


Figure 1. Overview of Our Working Processes

Environmental Issues Setup

Depending on the information given by the wunderground website, we can mark in the map using the latitude and longitude coordinates and the locations' related hurricane information. In this step, we can find the related towns and cities for each hurricane category. Figure 2 shows an example of a Twitter user post: "Rockport getting bad & it's just the start of the storm, don't underestimate #Harvey" at "8/25/2017 9:15:33 PM".

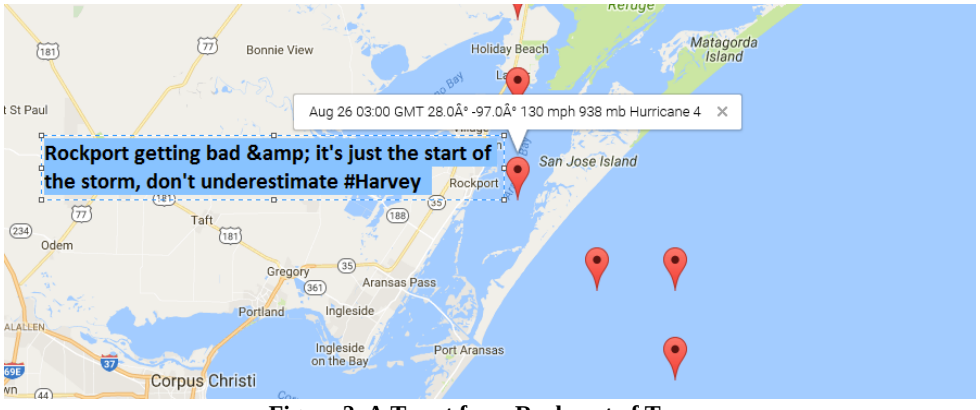
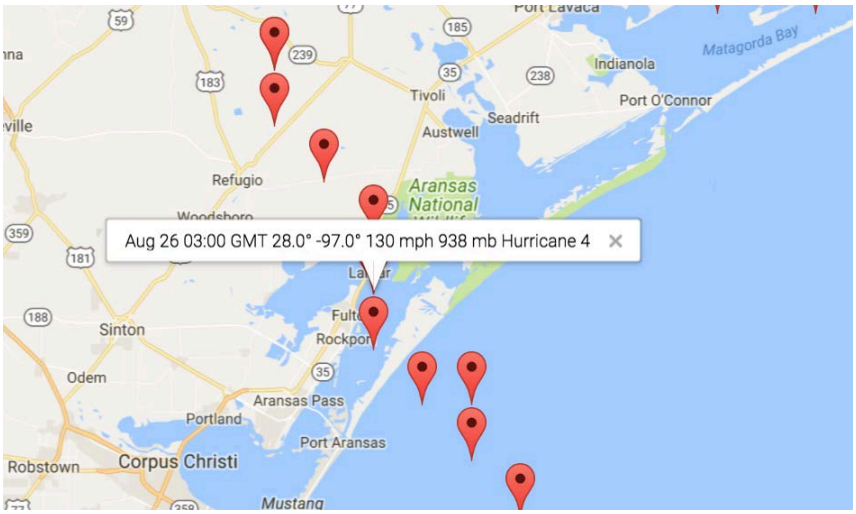


Figure 2. A Tweet from Rockport of Texas.

We first mark the places in the map with their category level and timing depending on the data from a trustworthy website (see Figure 3), and then identify the related places for a specific hurricane category. For example, for

hurricane level 4, we identified Aransas Pass, Corpus Christi, Fulton, Holiday Beach, Port Aransas and Rockport. For each of them, we can filter their related tweets using hashtag "Harvey".



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Cross Validation

We perform 10-fold cross validation on Harvey's data, Irma's data and the combined data of Harvey and Irma using different classification algorithms, namely Decision Tree (J48), Naïve Bayes, Logistic Regression, Random Forest and Support Vector Machines (SVM). These algorithms represent different categories of classification algorithms. We apply the five algorithms to find the one with the best performance so that we can use it to make prediction for small towns in the next step.

The cross validation results are plotted as shown in figures 4 and 5. F1 score is a harmonic average of the precision and recall to measure a test's accuracy, and it is used as the measurement for demonstrating the results in our experiments. Figure 4 presents the cross validation F1 results using Word2Vec as the base line method. We can see that Random Forest has the best performance for cross validation on Harvey's data and the value is 0.775. For cross validation on Irma's data, SVM has the highest score, which is 0.649. For cross validation on the combination of Harvey and Irma's data, Random Forest has the highest score, which is 0.657. From the results we can find a moderate positive relationship between the tweets posted in an area or several areas and the hurricane categories in those areas.

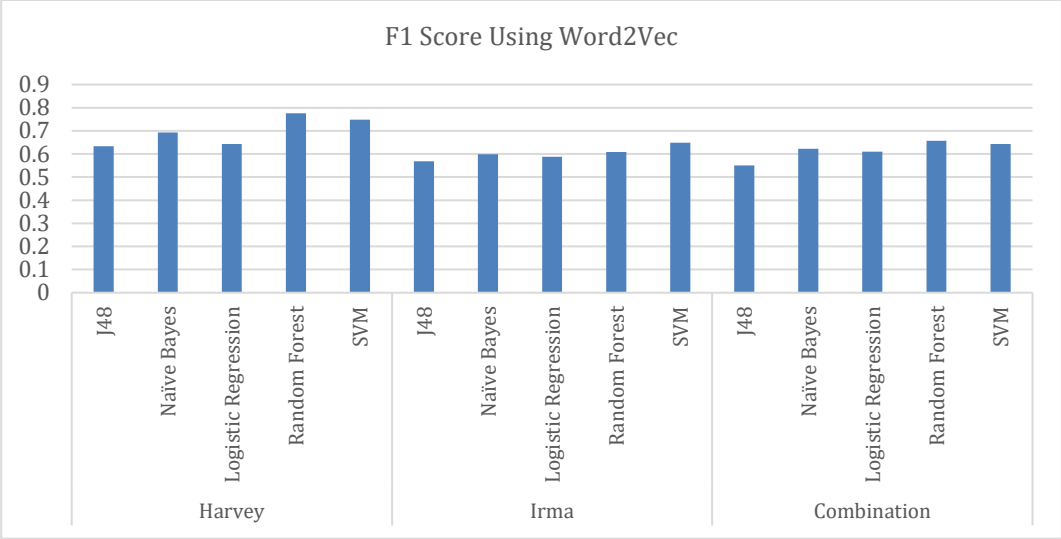

Figure 4. Cross Validation F1 Results Using Word2Vec

Figure 5 presents the cross validation F1 results using BOW as the base line method. We can see that Random Forest has the best performance for cross validation on Harvey's data and the F1 score is 0.796. For cross validation on Irma's data, Naïve Bayes has the highest score, which is 0.740. For cross validation on the combination of Harvey and Irma's data, Logistic Regression has the highest score, which is 0.829. Depending on the comparison of all the F1 scores presented in the two figures, we find Bag-Of-Words has an overall better performance

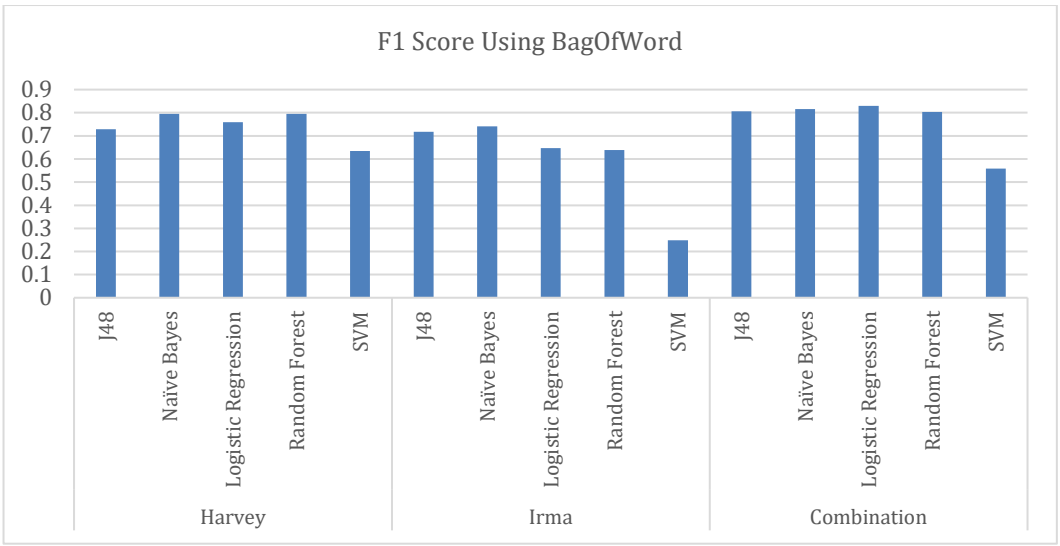

Figure 5. Cross Validation F1 Results Using Bag of Word

In the next step of experiment, we choose Random Forest algorithm to apply on Harvey training set, Naïve Bayes for Irma training set, Logistic Regression for a Combinational training set. Bag-of-Words will be used as the method for feature generation.

For Validation of a Selected Area

A positive relationship between Twitter data and hurricane category can be recognized through the result of the last step of the experiment. We use three different training sets to predict two small towns' hurricane category, namely, Plant City, Florida and Crystal River, Florida. Both towns were impacted by hurricane Irma. By classifying the tweets for the towns and applying a proposed predicting method, we have successfully predicted the categories for the two towns. Thus, the proof of our initial hypothesis is further enhanced.

For predicting Plant City, Florida, by using Irma training set and the Naïve Bayes algorithm, we can correctly predict 89.2% instances of tweets; by using Harvey training set and the Random Forest algorithm, we can correctly predict 2.7% instances; by using a combination training set and the Logistic Regression algorithm, we can correctly predict 86.5% instances. For predicting Crystal River, Florida, by using Irma training set and the Naïve Bayes algorithm, we can correctly predict 83.3% instances; by using Harvey training set and the Random Forest algorithm, we can correctly predict 0% instances; by using a combination training set and the Logistic Regression algorithm, we can correctly predict 58.3% instances. The results are shown in Figure 6.

Through the low prediction precision of using the Harvey training set and the Random Forest method to predict the two small towns' hurricane categories, we can see that it is not fit to use one hurricane's training set to predict a place in another hurricane's area. However, it is possible to use the combination of the training sets to do the prediction. The results imply that using related hurricane data to predict for related areas is the best approach. The reason may be that the posts in one hurricane's area consist of area-specific or hurricane-specific words. For example, tweets about Hurricane Harvey usually contain words like "Texas", "Houston" and "Harvey". If we filter out the area-specific words and special names, the results of using one hurricane's Twitter data to predict another might be improved.

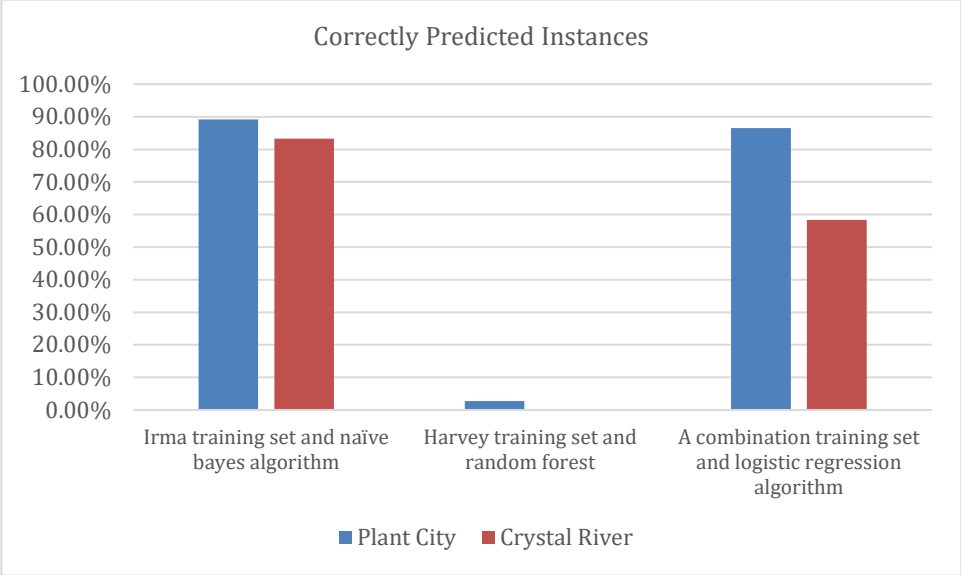

Figure 6. Correctly Predicted Instances Using Different Training Sets and Algorithms

To predict the hurricane level of a specific place, we propose an algorithm based on the observed results. The general steps are listed below. As described above, if we apply this algorithm, and use the Irma training set and the Naïve Bayes algorithm, or use a combination training set and the Logistic Regression algorithm, we can successfully predict the categories for the two places. The steps in the algorithm are:

1. Choose a proper training set and the most efficient classification algorithm.
2. Collect related tweets (set *s*) for a location.
3. Run classification algorithm to label each tweet in *s*.
4. Calculate the total number of tweets for each label, and find the majority label, which is of the final predicted category for that location.

Although our method of predicting hurricane categories performs well on the locations we chose, it can be not true for other locations. Different location can have different temporal, spatial or social features, which may affect the application of the method. It still needs more research based on more real world data to prove the efficiency of the method, as well as to improve the method.

DISCUSSION AND FUTURE WORK

To the best of our knowledge, this paper is the first attempt to use social media data to analyze and predict the category of a hurricane, or even the severity of a disaster. We can continuously collect the Twitter data for areas affected by hurricanes and verify the idea using the methods presented in this paper and a larger corpus of data. It is possible to analyze the relation between a disaster like hurricane and related social media data due to the wide area a hurricane can affect. However, during our experiment, we found several issues, other than the limit of data corpus, which necessitate further investigation as part of the future work.

Reasons about the Relation: It would be interesting to analyze the root cause of why there is a relationship between tweets and hurricane level. One possible approach could be using Bag-of-Words to find the most common words to make comparison.

Hurricane-specific Data: The precision is low if we use Harvey data to predict Irma data with respect to hurricane level. However, the precision is more significant if we use cross validation within Harvey data or Irma data. We found a lot of hurricane-specific words like "Florida", "Key West", "Texas", and "Rockport". For locations, they are unique to a specific area, making it hard to use one hurricane's data to predict another hurricane's severity unless we remove these words. This will be explored in our future work. If the hurricane-specific words or some irrelevant words are deleted from the text, the accuracy may be improved.

Temporal Factor: We are using one month of Twitter data. Another approach would be to use data in a specific period like the exact day the hurricane occurs. There would be less data if the period is short, however, since hurricanes usually happen in the same places (coastal areas), we can accumulate data of each hurricane to build a larger corpus as the ground truth. The tweets can be further categorized into three sets: before, during and after the hurricane. More complex relations can be used as a pattern to identify the category of the hurricane.

Number of Tweets: The tweets for each category we use in our experiment are not evenly distributed. Although the usage of vector generation methods can ease the effects of corpus size differences, the corpus size can impact the prediction results. In future experiments, we can take the number of tweets into consideration and examine what kind of impact it may bring to the experiment.

Threshold of Prediction: For predicting the category of a hurricane in a specific area, we can use a small set of tweets or a large set of tweets. The exact number depends on how many tweets can be obtained from the source data corpus. Future work needs to identify the exact threshold of the number of tweets, which can make the prediction most significant. The threshold may be determined by historic data or may also be determined by current hurricane related data.

Human Statistical Factor: This study did not consider the credibility of the authors of the tweets. This may be a limitation of our paper. The tweets can be posted by different groups: namely, individuals, newspapers, government departments, or advertising agents. Each group may have different demographic and ideological impacts on the experimental results.

The application of disaster prediction can help in real-time disaster response and decision making for governmental or civil agents. For a specific area experiencing a hurricane, we can predict the hurricane category using real-time Twitter data for that area by using historic data. It can be more meaningful if we apply our method to an area where it is hard to determine the severity of the damage, such as a valley area, high mountain areas, or near-coastal areas. Governmental or civil agents can use the evaluation results of social media data analysis as a reference. This paper explores hurricane categories, other disaster types might benefit from similar research methods.

CONCLUSION

In this paper, we introduced a study of finding correlation between Twitter data and hurricane category. Methods used and the preliminary results were presented. A moderate positive relationship was observed based on the experimental results. The contribution also includes a release of the data set, which was generated over the course of the study. We present an algorithm and implementation results of predicting an area's hurricane category. Depending on the experimental results, we can successfully predict the hurricane category for a given location.

However, intuitively, if we only have a small set of tweets for a small town, it is hard to predict the hurricane category. For future work, we can determine the proper magnitude of an area or the threshold number of tweets, related to the area for yielding better prediction results.

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Track 9

Universal Design of ICT in Emergency Management

Situation Detection based on Activity Recognition in Disaster Scenarios

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ABSTRACT

In disaster situations like earthquakes and hurricanes, people have difficulties accessing shelter and requesting help. Many smartphone applications provide behavioral advice or means to communicate during such situations. However, to what extent a person is affected by a disaster is often unclear, as these applications rely on the user's subjective assessment. Therefore, detecting a user's situation is key to provide more meaningful information in such applications and to allows first responders to better assess incoming messages.

We propose a predictive model that recognizes four normal and ten disaster-related activities achieving an average f1-score of up to 90.1%, solely based on sensor readings of the subject's mobile device. We conduct an extensive measurement-based evaluation to assess the impact of individual model parameters on the prediction accuracy. Our model is orientation-independent, position-independent, and subject-independent, making it an ideal foundation for future context-aware emergency applications.

Keywords

Disaster Relief, Activity Recognition, Prediction Model, Wearables

INTRODUCTION

Activity recognition based on smart devices has attracted remarkable attention from researchers in recent years (Attal et al. 2015), largely for monitoring fitness and health activities. Up until now such context-aware systems are used in several specific scenarios such as elder care (Alwan et al. 2006), health-care and health recovery (Guo et al. 2016; Garcia et al. 2013), stress detection (MacLean et al. 2013; Webb et al. 2013) and to enhance self reflection (Kefalidou et al. 2014). To the best of our knowledge, activity recognition systems were not specifically used before to detect disaster-related activities. In the following, we sketch a context-aware system with the main aim of helping people in disaster situations by recognizing their activity based on their physical movement.

Such a system can be divided into two main subsystems. The first subsystem is responsible for recognizing the current activity of a subject and decide whether it is related to a disaster or not. The second subsystem is responsible for using and integrating the information of a subject's activity in applications or communication systems for disaster relief. In this work, we address the first subsystem: detecting the situation of a subject based on activity recognition.

To recognize the activities of a subject, activity recognition systems depend on analyzing a series of observations that can be obtained from different sources. An example of such sources are wearable sensors that the subject wears in different positions of her/his body (Mantyjarvi et al. 2001; Gyorbiro et al. 2009).

Another source of observations are mobile devices like smartphones and smartwatches (Chetty et al. 2015; Otebolaku and Andrade 2016). In addition, several research works depend on smart environments for activity recognition (Cook 2010) where several sensors, for example motion, temperature, humidity, and power sensors, are integrated into the environment. Todays smartphones and smartwatches (Cecchinato et al. 2015) are equipped with a rich set of accurate sensors and come with sufficient battery capacity, storage and processing capabilities. In addition, they are widely deployed, making them an ideal source for observations in a disaster scenario.

The remainder of the paper is structured as follows: First, we present use-cases for the activity recognition in disaster scenarios. Afterwards, the approach for the activity prediction models, the resulting research objectives, and the necessary data collection process is described, followed by the development concept of the models. Then, we provide an in-depth description and performance evaluation of the developed impersonal and position-independent smartwatch and smartphone prediction models, as well as the combined smartphone-smartwatch prediction model. Finally, we discuss relevant related work and conclude the paper.

USECASES

Earthquakes, volcanic eruptions, and tsunamis are examples of spontaneous occurring natural disasters that cause huge destruction and jeopardize the life of many people. In such a case the affected population suffers from the difficulties of accessing safe places and contacting aid organizations to get help.

Knowing a person's current activity in exceptional situations is important for different use-cases. For emergency response and disaster relief there exist a variety of useful smartphone-based applications and communications services that help people to cope with the aftermath of a disaster (Lieser et al. 2017; Reuter et al. 2017; Hossmann et al. 2011). If the current activity of a user is known to the system (as additional meta-data), it could enable activity-aware support mechanisms. For example, if the activity *running downstairs* is detected, the user's interface (font and button size) of an emergency application could be enlarged to support the service's ease of use. Additionally, an emergency response center can use the user's activity information to filter incoming emergency messages according to their importance, to prioritize assistance efforts of those who seem to be injured or immobile.

Going one step further, an application can utilize information about the current activity of a person to proactively call for help or to provide situation relevant information such as evacuation maps or behavioral instructions. For example, badly wounded people need help immediately but are often not able to contact medical organizations or surrounding people by themselves. Automatically sending out SOS-messages containing the location of the user could save lives. Additionally, when people are hurrying to shelter places, protecting themselves from falling debris, or crawl, their hands are not free to operate a smartphone. By detecting this activity the respective application could switch to voice in- and output instead of requiring people to operate the phone with their hands.

The aforementioned use-cases are only a few examples of how activity recognition of a subject can be used to enhance and improve existing disaster related services.

PROPOSED APPROACH AND RESEARCH OBJECTIVES

In this work, we develop a system to recognize the physical activities of humans and decide whether this activity is related to the behavior typically performed in disaster situations. We build this system on top of sensor readings collected from the subject's smart devices. Table 2 shows the list of all the activities we consider in this work. These disaster related activities were specified after studying international guidelines for emergency preparedness from different governmental organisations[1,2], NGO's[3] and national disaster management authorities[4] and also during discussions with local fire departments and different emergency operation centers. We chose these specific activities since we consider them as the most relevant activities in disaster situations.

Some of the studied activities are normal activities that are daily performed by most of the people such as normal walking, sitting, going upstairs or going downstairs. The reason behind involving such general activities in our research work is to increase the capability of our model to distinguish between normal activities and the activities that are usually performed in disaster situations.

As will be clarified in the next section, we conduct our work by utilizing four smart devices, namely two smartphones and two smartwatches which have to be worn by the subjects. Our ultimate goal is to build a system which is position-independent, subject-independent, and orientation-independent. A position-independent model is characterized by being able to correctly recognize the activities regardless of the position in which a subject wears the smart device, for example the hand on which the subject wears her/his smartwatch. A model is said to be orientation-independent if it correctly predicts the target activity regardless of the orientation of the smart device. As the subject wears her/his smartwatch in only one specific orientation, a smartwatch-based model is implicitly orientation-independent. However, this is not the case for smartphone-based models. A model is said to be subject-independent if it is able to predict the activities of subjects for whom no data was available during the training phase.

We achieve the aforementioned goal by building a predictive model that can recognize subjects' activities solely based on the sensor readings collected from their smartwatches. By conducting a comprehensive evaluation study in which we utilize different combinations of our four smart devices as observation sources, we show that the smartwatch-based model can recognize all activities with very good predictive performance.

DATA COLLECTION PROCESS

In this work, we study a combination of activities that, to the best of our knowledge, has not been studied before. We collected our dataset using four smart devices, namely two Nexus 5X smartphones and two Samsung gear live S2 galaxy smartwatches. Another Nexus 5X smartphone is used as a master device to coordinate the data collection process conducted by the other four devices. Twenty-two contributors participated in the data collection process. Their characteristics are shown in Table 1. As stated before, we study fourteen different activities. Nine of the contributors performed all of the studied activities while the other contributors performed only subsets of those activities. Table 2 presents detailed information about each activity with regard to the number of contributors who performed it as well as the collection duration.

Table 1. Contributor characteristics

Age	18-60 years
Weight	70-110 kg
height	155-185 cm
Gender	20 males, 2 females

While performing the studied activities, each contributor wore a smartwatch on each of her/his hands and put a smartphone in each of her/his front trouser pockets. We call these four devices the slave devices and we use them to capture sensor readings. A third smartphone, namely the master device is used to control the collection process. To collect the data, we developed two Android applications, namely the

[1]www.ready.gov/
[2]www.fema.gov/
[3]www.redcross.org/
[4]www.ndma.gov.in/en/

Table 2. Activities List

Activities	Shortcut	Contributors	Duration (min)
Crawling backward	CB	12	11.6
Crawling like kids	CLK	12	18.3
Going upstairs	GU	12	16.3
Going upstairs fast	GUF	10	14.6
Going downstairs	GD	10	14.4
Going downstairs fast	GDF	9	12.7
Going downstairs with injured right leg	GDWIRL	10	21.2
Normal sitting	NS	4	35
Sitting with hands on head	SWHOH	19	40
Kneeling	K	16	23.6
Kneeling with hands on head	KWHOH	18	44
Normal walking	NW	18	38.7
Walking with injured right leg	WWIRL	12	20.4
Walking with injured left leg	WWILL	12	21.3

master application and the slave application. We chose Android as an operating system to build our applications on top of it as it provides several important features with regard to security, portability, and efficiency in networking, power, and memory management. In addition to that, Android is widely used by a wide spectrum of famous smartphone makers such as Samsung, Huawei, LG, and HTC which gives us the potential to run our application on top of several hardware platforms.

Through the master application, the user can start and stop the collection process. Moreover, she/he can log the user and activity names, specify the list of sensors to collect their readings, the collection frequency, and the collection duration. Each of the slave devices runs the slave application whose main role is to respond to the data collection commands sent from the master application over Bluetooth.

Table 3 shows the list of sensors we monitor during the data collection process. We did not use all of those sensors in our research work. Nevertheless, we captured their readings for future studies. We use a sampling frequency of 40 Hz.

Table 3. The sampled sensors

Smartphone sensors	Smartwatch sensors
Accelerometer	Accelerometer
Gyroscope	Gyroscope
Gravity	Gravity
Magnetometer	Magnetometer
Uncalibrated magnetometer	Uncalibrated magnetometer
Game rotation vector	Game rotation vector
Rotation vector	Rotation vector
Linear accelerometer	Linear accelerometer
Barometer	Barometer
Geomagnetic Rotation Vector	-

CONCEPT AND DEVELOPED MODELS

Based on the chosen combinations of smart devices, we develop three main types of predictive models, namely:

- The smartwatch model which is built based on the observations obtained from the left-hand smartwatch.
- The smartphone model which is built based on the observations obtained from the left-pocket smartphone.

- The hybrid smartphone-smartwatch model which is built based on the observations obtained from the left-hand smartwatch and right-pocket smartphone.

For each of the aforementioned models, we can distinguish between two different model types, namely personal and impersonal models. As its name implies, a personal model is designed to recognize the activities of a specific person. Therefore, a personal predictive model is trained and evaluated using the data of only one subject. In contrast to that, an impersonal model is supposed to recognize the activities of any subject even when no data belonging to this subject was a part of the training phase. Therefore, an impersonal model is trained using the data of a certain set of subjects and evaluated using the data of a different set for which no training phase has been conducted. In this work, we only focus on impersonal models as our goal is to build an activity recognition model which is able to generalize beyond its training data.

To extract the features required for building our predictive models from the raw sensor data, we split this data into time windows such that each window represents a training/testing instance for which we extract the designed set of features. We present the impact of window size on the selected set of features as well as on the performance of the predictive models by using four different window size values, namely 2, 4, 6, and 8 seconds. We also present the impact of the sensor sampling frequency on the performance of our models by considering four sampling frequencies, namely 1, 10, 20, and 40 Hz. As a classification technique, we use the algorithm of random forests (Breiman 2001) as it has proven to achieve very good results in building activity recognition models (Weiss et al. 2016)(Maurer et al. 2006).

IMPERSONAL SMARTWATCH MODEL

In this section, we introduce our impersonal smartwatch predictive model. We build this model based on the sensor readings obtained from the left-hand smartwatch. To create an impersonal smartwatch model, we apply the leave-one-out principle. As mentioned before, nine subjects performed all the studied activities while each of the other 13 subjects performed a certain subset of activities. As a first step, the data needs to be divided into training and testing sets. By following the leave-one-out principle, we select one of the nine subjects who performed all activities to be the testing set of our model. As a training set, we use that data of all other 21 subjects. This process is repeated for all the nine subjects so that we test our impersonal smart watch model on each one of them. As a result of this procedure, we obtain nine different impersonal smartwatch models based on the subject chosen for the testing set. The final predictive performance of our model is calculated by averaging the results obtained from all of these nine models.

We consider four different values for the window size, namely 2, 4, 6, and 8 seconds. As mentioned before, the used set of features depends on the selected window size. In the next sections, we introduce the steps we followed to build and evaluate the impersonal models corresponding to each of the window sizes.

Two-Second Impersonal Smartwatch Model

The first step in building a predictive model is to design a set of features that can efficiently discriminate the different classes from each other and thereby achieves a very good predictive performance. We choose summary statistics, namely minimum, mean, median, maximum, standard deviation (SD), quartile25 (Qu_1), quartile75 (Qu_3) to build our set of features. After dividing the raw sensor data into windows, we calculate these values during each window for the different axis combinations of the accelerometer sensor, linear accelerometer, gyroscope as well as the gravity sensor. Furthermore, we calculate the correlation between the time and the readings of the barometer sensor. In order to identify the important features out of the whole set of features, we utilize the varimp method provided by the R caret package (Kuhn 2016).

The third column in Table 4 shows the final set of features we got for the two-second impersonal smartwatch model after applying the algorithm of variable importance on the total set of features. As can be seen from the table, different sets of summary statistics have been identified as the most important for different axis combinations.

By applying the leave-one-out principle, we build and evaluate nine different models based on the subject chosen for the testing set. For the different models we use the average f1-score as performance indicator (Goutte and Gaussier 2005). The f1-score is the harmonic average of precision and recall. Precision denotes the proportion of predicted positive cases that are correctly real positives and recall is the

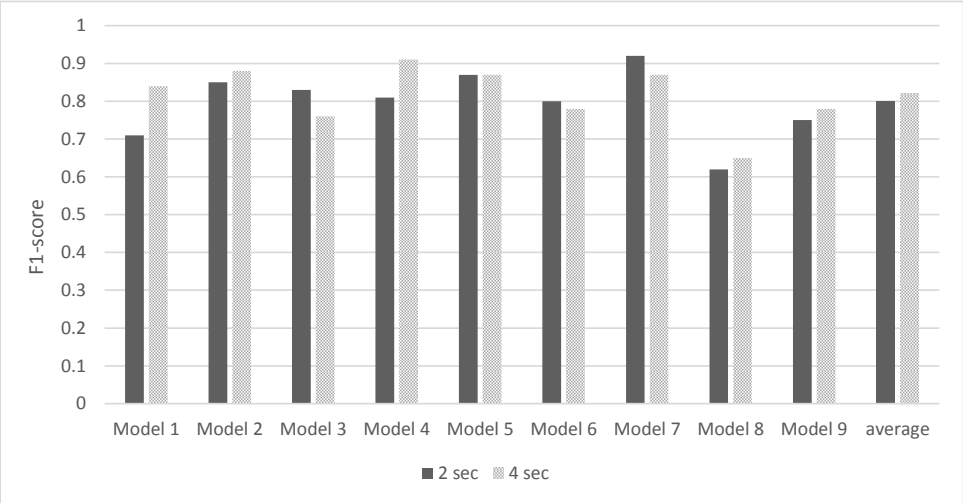

Figure 1. Performance evaluation of the two-second and four-second impersonal smartwatch model

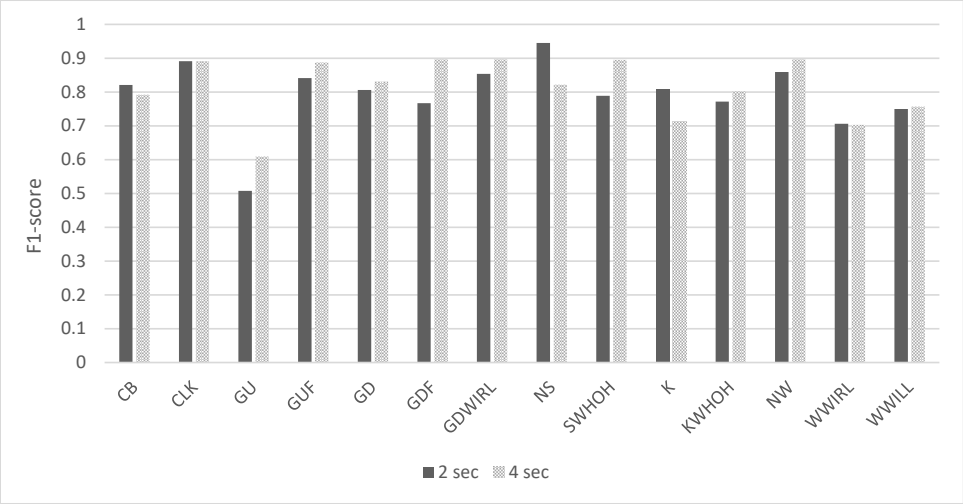

Figure 2. Performance evaluation of the two-second and four-second impersonal smartwatch model with regard to each of the studied activities

proportion of real positive cases that are correctly predicted positive. The f1-score reaches its best value at 1 when there is perfect precision and perfect recall.

The black bars in Figure 1 show the evaluation results for each of those models in terms of the average f1-score achieved in recognizing the designed set of activities. This figure shows that the two-second impersonal smartwatch model achieves an average f1-score value of 80% with regard to the nine testing subjects.

The black bars in Figure 2 show the achieved predictive performance with regard to each of the studied activities in terms of the average f1-score value that has been achieved by the nine models. We notice from this figure that the models achieve a low predictive performance with an average f1-score of 50.6% in recognizing the activity of going upstairs. In most cases, the models predict the examples belonging to this activity as normal walking or going downstairs. The reason behind that lies in the fact that the motion of the hands while performing those activities is almost the same which makes it difficult for a predictive model to separate them well.

Four-Second Impersonal Smartwatch Model

We build this model by following the same steps used in building the two-second model in the previous section. As a first step, we identify the set of important features we use to build this model. By applying the variable importance algorithm on the summary statistics, we get the set of features for the four-second model shown in fourth column of Table 4. Comparing with the features of the two-second model, we notice that some features are deleted and others are added. This can be explained by the fact that changing window size renders certain features more or less important.

By applying the leave-one-out principle on the data of the nine subjects, we build and evaluate nine different models as we did for the two-second model. The evaluation results corresponding to each of those models are shown by the gray bars in Figure 1. By comparing this model with the two-second model, we notice that the performance has slightly improved with an average f1-score value of 82%. The average performance of the nine models corresponding to each of the studied activities are represented by the gray bars shown in Figure 2. We notice a remarkable improvement over the two-second model regarding the activities of going upstairs, going downstairs fast, and sitting with hands on head with 10% to 14% increase in the average f1-score value. However, a remarkable decrease of 10% to 12% in the average f1-score can be noticed for the activities of normal sitting, and kneeling. Moreover, we still notice that the lowest predictive performance has been achieved in recognizing the activity of going upstairs.

Table 4. Two-second, four-second, six-second and eight-second impersonal smartwatch model: used set of features

Sensor	Axis/Axes-relation	Features			
		2 sec	**4 sec**	**6 sec**	**8 sec**
Accelerometer	Magnitude(x,y,z)	Mean, max, SD, Q_1, Q_3	Mean, SD, Q_1, Q_3	Mean, Q_1, Q_3	Mean, Q_1, Q_3
	x	-	Max, SD, Q_1	SD	-
	y	-	SD, Q_1	SD, Q_1	SD, Q_1
	z	-	SD, Q_1	SD	SD
	Magnitude(x,z)	SD	SD	-	-
	Magnitude(y,z)	Min, Q_1	Min, Q_1	Min, Q_1	Min
	Magnitude(x,y)	-	Mean, SD, Q_3	Q_3	Q_3
	x/z	Mean, max, Q_3	Mean, Q_3	Mean, Q_3	Mean, Q_3
	z/x	Mean, max, SD, Q_1	Mean, max, min, SD, median, Q_1	Mean, max, SD, Q_1	Mean, max, SD, Q_1
Linear Accelerometer	Magnitude(x,y,z)	Q_3	Q_1	Q_1	Q_1
	x	SD	Mean, SD, Q_3	Mean, SD, max, Q_3	Mean, SD, Q_3
	y	Mean, SD, Q_1	Mean	Mean	Mean
	z	SD	-	-	-
	Magnitude(x,y)	Median, Q_1	Q_1	Q_1	Q_1
	Magnitude(x,z)	-	SD	SD	SD
	z/y	Q_3	-	-	-
Gyroscope	x	-	-	Mean	Mean
	y	Mean, median	Mean, median	Mean, median	Median
	Magnitude(x,z)	-	Q_1	Q_1	-
	x/y	Median	Median, Q_3	Median, Q_3	Median
	y/x	Median	Median, Q_1	Median, Q_1	Median
Gravity	x	Mean, min, SD, median, Q_1	Mean, min, SD, median, Q_1, Q_3	Mean, min, SD, median, Q_1, Q_3	Mean, min, SD, median, Q_1
	y	-	SD	-	-
	z	Max, min	Max, min, Q_3	Max, min	Max
	Magnitude(x,z)	SD	-	-	-
	Magnitude(y,z)	-	SD	SD	-
	x/z	-	Max	Max	-
	z/x	-	Min	Min	-
Barometer	Readings, time	Correlation	Correlation	Correlation	Correlation

Six-Second Impersonal Smartwatch Model

Using the variable importance method, we identify the set of features used to build this model as shown in the fith column of Table 4. As we notice from this table, changing the window size to six seconds renders certain features as less or more important as it was the case for the four-second window.

Applying the method of variable importance on the six-second model generates a very important observation. With a six-second window size, the correlation between the time and barometer readings is identified as the most important feature for all nine models. This can be explained by the fact that a longer window size gives enough time for the barometer readings to have meaningful correlations with the different activities. Based on the accompanied changes in the sensed air pressure, we can categorize our set of activities into three categories, namely:

- Activities that lead to an increasing sensed air pressure such as going upstairs and going upstairs fast.
- Activities that lead to a decreasing sensed air pressure such as going downstairs, going downstairs fast, and going downstairs with injured leg.
- Activities that do not lead to a significant change in the sensed air pressure such as normal walking and normal sitting.

Figure 3 shows the time series representing the barometer readings corresponding to six different activities, namely going downstairs, going downstairs fast, going upstairs, going upstairs fast, normal walking, and normal sitting. Theses readings were captured for six seconds and with a 40 Hz sampling frequency. Under each sub-figure, we mention the respective activity along with the computed correlation between the time and its barometer readings. We observe from this figure that the correlation has a high positive value for the activities going downstairs and going downstairs fast. It has a high negative value in case of going upstairs and going upstairs fast. Therefore, using this correlation as a feature simplifies the process of distinguishing between going upstairs and downstairs. Regarding the activities of normal walking and normal sitting, the readings of barometer sensor do not remarkably increase or decrease along the time. Therefore, a very low correlation value can be noticed for those both activities.

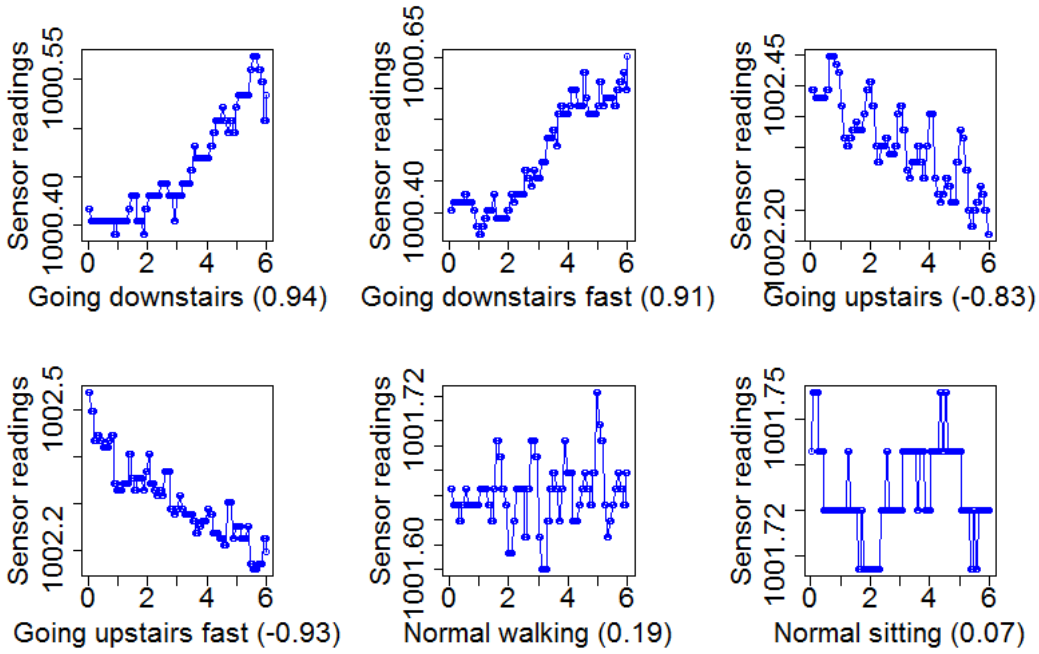

Figure 3. Correlation between the time and barometer readings

As a result, we conclude that increasing the window size improves the role of barometer sensor in recognizing the studied activities. To show its impact, we evaluate the performance of the six-second nine models with and without the barometer-time correlation as a feature. Figure 4 shows the predictive performance of the nine models in both cases. It is clear from this figure that the correlation feature positively affects the predictive performance of eight models. Moreover, we notice that the six-second model is more stable than the two-second and four-second models. Apart from the result corresponding to the eighth subject, all the f1-score values are above 80%. The stability in performance the model achieves when tested with data coming from different subjects proves that it generalizes well beyond the training data.

Figure 5 presents the predictive performance of the nine models for both cases with regard to each of the studied activities. This figure proves the importance of the correlation feature in improving the prediction results for most of the studied activities. We notice a significant increase in the average f1-score values achieved in recognizing the activity of going upstairs. As we have seen, all the previous models suffered from low f1-score values in recognizing this activity. Moreover, all of them confused between the activities

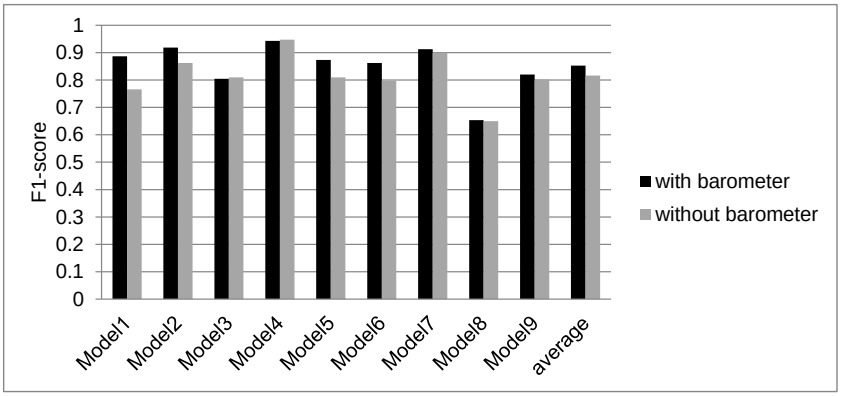

Figure 4. Performance evaluation of the six-second impersonal smartwatch model

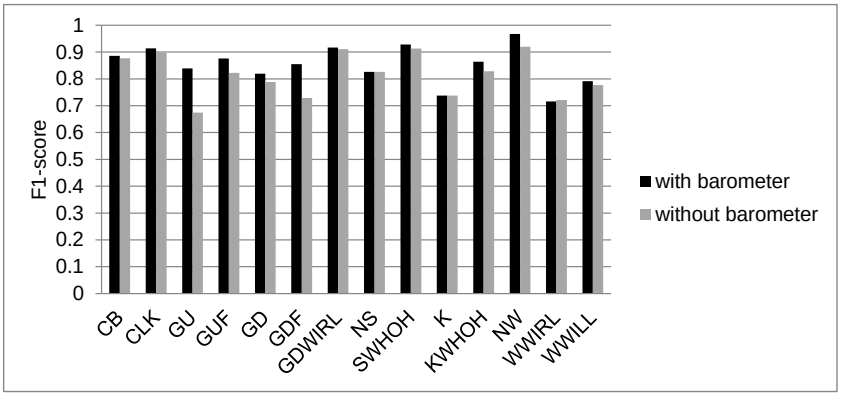

Figure 5. Performance evaluation of the six-second impersonal smartwatch model with regard to each of the studied activities

that are performed on stairs. We solved this problem so that no observable confusion between such activities can occur by utilizing the barometer-time correlation feature with the suitable window size.

Eight-Second Impersonal Smartwatch Model

To further inspect the effect of window size on the predictive performance of our impersonal smartwatch model, we increase it to 8 seconds and build the corresponding model. As done for all the previous models, we obtain the set of features shown in the last column of Table 4 and use it to build this model based on the method of variable importance. We build and evaluate nine different models by applying the leave-one-out principle. The black bars in Figure 6 show the evaluation results corresponding to each of those nine models. With an 82% average f1-score value, the eight-second impersonal smartwatch model achieves lower performance than the six-second model. Figure 7 shows the average performance of the nine models with regard to each of the studied activities. This figure clearly shows that the nine models are not able to achieve a good performance in recognizing the activity of going upstairs. With an average f1-score of 67.3%, the eight-second impersonal smartwatch model does not reach the performance achieved by the six-second model. As a result, we conclude that increasing the window size from 6 to 8 seconds has a negative impact on the performance of our impersonal smartwatch model.

Discussion and Comparison Between the Impersonal Smartwatch Models

The evaluation results of the impersonal smartwatch models with regard to the different window sizes clearly show that the six-second model outperforms all the other models. This can be seen in Figure 8 as it achieves the best f1-score value. By studying four window sizes, we have seen that the features corresponding to each window size should be independently extracted as the features have different importance levels based on the used window size. To prove that, we use the features of the two-second model to build a model with a window size of 6 seconds. This model achieves an average f1-score value of

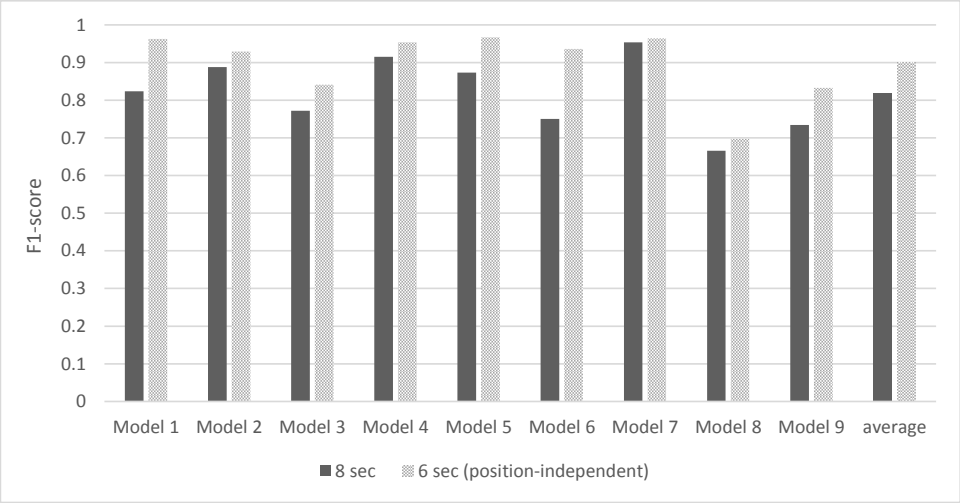

Figure 6. Performance evaluation of the eight-second impersonal smartwatch model and the position independent six-second impersonal smartwatch model

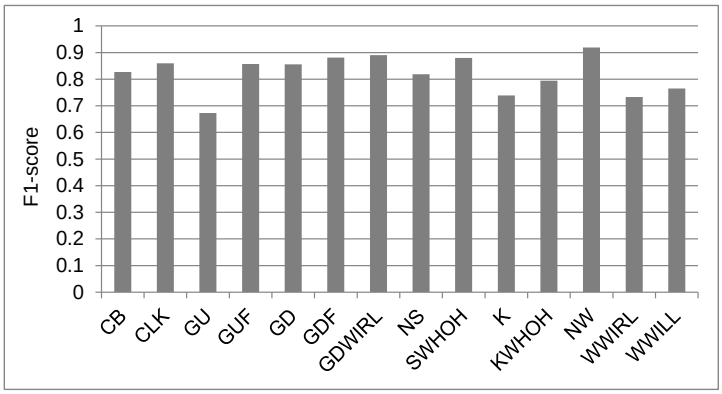

Figure 7. Performance evaluation of the eight-second impersonal smartwatch model with regard to each of the studied activities

83.9%. By comparing this value to the 85.2% f1-score achieved by our six-second impersonal smartwatch model, we notice that identifying a new set of features enhances the predictive performance.

As mentioned before, we used a sampling frequency of 40 Hz to capture the sensor readings. Using such a high frequency consumes the battery of the smart device and requires high processing capabilities. To check whether it is possible to reduce this frequency and get the same level of performance, we used four different sampling frequencies, namely 1, 10, 20, and 40 Hz. Figure 9 shows the results achieved by using those different frequencies with the six-second impersonal smartwatch model. The model gives its best predictive performance with a frequency of 40 Hz. This performance decreases to reach an f1-score value of 52% using a frequency of 1 Hz. By using a sampling frequency of 10 Hz, the model achieves an f1-score value of 84.6% which is 0.6% less than the value achieved with a sampling frequency of 40 Hz. These results indicate that a sampling frequency of 10 Hz can be used to reduce the required power and processing capabilities while keeping the predictive performance almost at the same level.

Position-independent Impersonal Smartwatch Model

Based on the previous evaluation results, the six-second impersonal smartwatch model proved to achieve the best predictive performance with an average f1-score of 85.2%. This model is orientation-independent as it only uses the smartwatch as an observation source. Moreover, it is subject-independent as it achieved a stable performance for eight testing subjects. Our goal in this section is to make this model position-independent. We achieve this goal by training it using the sensor readings of both left-hand and right-hand smartwatches. We use the same set of features listed in the fifth column of Table 4. Before building this model, we need to perform the following steps:

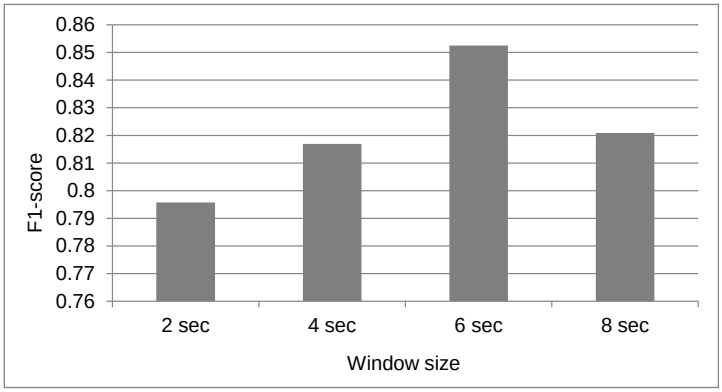

Figure 8. Evaluation summery of the impersonal smartwatch models

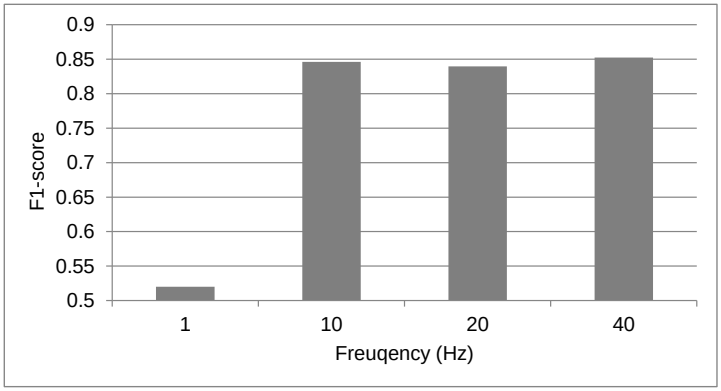

Figure 9. Performance evaluation of the six-second impersonal smartwatch model with different sampling frequencies

- We delete the activity of going downstairs with injured right leg from the dataset as it has been only performed where the handrails are on the left side of the stairs.
- We combine the activities of walking with injured right leg and walking with injured left leg into one activity with the name walking with injured leg (WWIL).
- We combine the activities of kneeling with hands on head and sitting with hands on head into one activity with the name hands on head (HOH).
- We combine the activities of kneeling and normal sitting into one activity with the name sitting (S).

By following the same previous leave-one-out principle, we evaluate the predictive performance of this model using the same previous nine subjects as testing sets. For evaluation purposes, we only use the sensor readings obtained from the left-hand smartwatch as we assume the subject to be wearing only one smartwatch in real-world applications. The gray bars in Figure 6 illustrate the average f1-score achieved for each of the nine subjects as well as their average. As we notice from this figure, this model outperforms all the previous models with an average f1-score of 90.1%. Figure 10 shows the average f1-score values achieved by this model with regard to each of the studied activities.

IMPERSONAL SMARTPHONE MODEL

To build our impersonal smartphone model, we use the sensor readings obtained from the left-pocket smartphone. We consider four different window size values, namely 2, 4, 6, and 8 seconds. Based on the method of variable importance, we identify the set of important features for each window size. We build and evaluate the models by following the same previous leave-one-out principle. Table 6 shows the evaluation results corresponding to each window size. We notice from this table that the six-second impersonal smartphone model outperforms all other models. Table 5 shows the set of features used in building this model. This table shows that we only use orientation independent features. With regard to

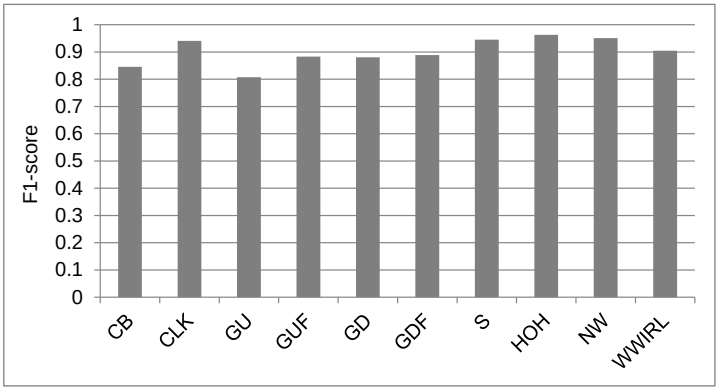

Figure 10. Performance evaluation of the position-independent six-second impersonal smartwatch model with regard to each of the studied activities

x- and y-axes, we only use the magnitude over both of them as it is orientation-independent. All the readings captured over the z-axis are implicitly orientation-independent.

Table 5. Six-second impersonal smartphone model: used set of features

Sensor	**Axis/Axes relation**	**Features (6 sec)**
Accelerometer	Magnitude(x,y,z)	Mean, max, SD, Q_1
	Magnitude(x,y)	Max, Q_3
	z/Magnitude(x,y)	SD, median, Q_1
	z	SD, median
Linear Accelerometer	Magnitude(x,y,z)	Median, Q_1, SD
	Magnitude(x,y)	SD, median, Q_1, Q_3,
Gyroscope	Magnitude(x,y,z)	Mean, Q_1, median, Q_3
	Magnitude(x,y)	Mean, median, Q_1, Q_3
Gravity	Magnitude(x,y)	SD
	Magnitude(x,y)/z	Median, SD, Q_1
	z/Magnitude(x,y)	SD, median, Q_3
	z	SD, Q_3
Barometer	Readings, time	Correlation

Table 6. Performance evaluation of the impersonal smartphone model with different window size values

Window size (Min)	2	4	6	8
F1-score (%)	59.6	61.7	64	63.7

As shown by the black bars in Figure 11, the average f1-score value corresponding to the nine models is 64%. It represents a low value in comparison to the performance of the six-second impersonal smartwatch model. The f1-score values corresponding to each of the studied activities are represented by the black bars in Figure 12. This figure illustrates the reason behind such a low predictive performance. The f1-score values corresponding to the activities of kneeling, normal sitting, sitting with hands on head, and kneeling with hands on head are between 27.9% and 43.8%. The position of smartphone in the trouser pocket results in similar sensor readings corresponding to these activities. This is because the subject's legs while performing those activities are still and have the same direction. Although the other activities are considered as hand- and leg-based activities, the impersonal smartphone model does not achieve a good predictive performance in recognizing them. The reason behind that lies in using only orientation-independent features to make the system applicable in real-world scenarios and comparable to the impersonal smartwatch model.

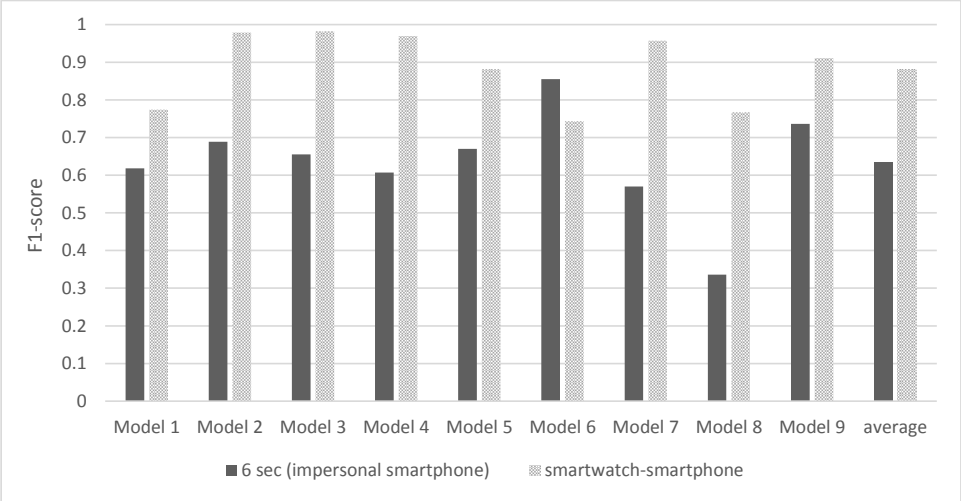

Figure 11. Performance evaluation of the six-second impersonal smartphone model and the smartwatch-smartphone model

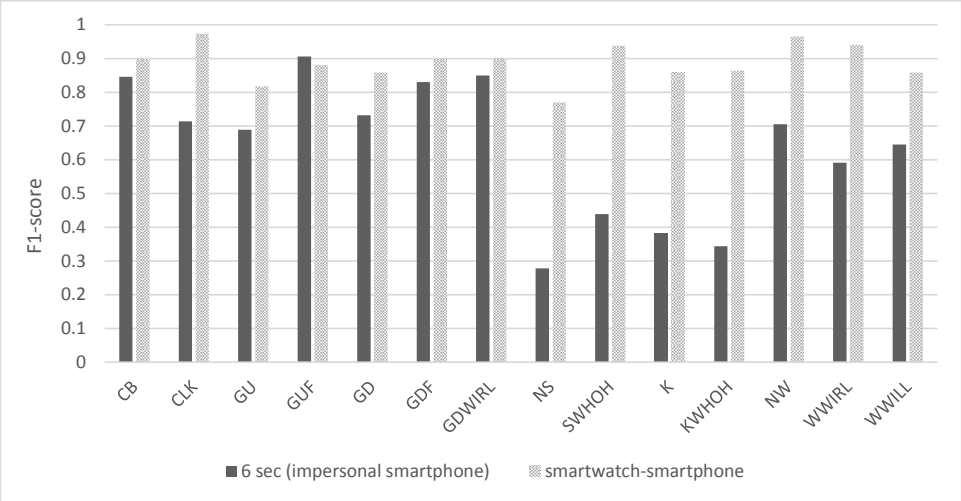

Figure 12. Performance evaluation of the six-second impersonal smartphone model and the smartwatch-smartphone model with regard to each of the studied activities

HYBRID SMARTPHONE-SMARTWATCH MODEL

In this section, we discuss the effect of combining two smart devices, namely a smartphone and a smartwatch on the predictive performance of our activity recognition model. In this setting, we assume the subject to wear a smartwatch on her/his left hand while carrying a smartphone in her/his right pocket. The goal of building such a model is to show the impact of capturing sensor readings from different positions of subject's body on the predictive performance of activity recognition models. Several of our activities are hand-based, namely normal sitting, sitting with hands on head, kneeling, and kneeling with hands on head. All smartphone models achieved low predictive performance in recognizing those activities. The remaining set activities is considered as hand- and leg-based activities.

By capturing the readings of sensors that are positioned on the hand and leg of a subject, the model should be able to achieve a better predictive performance in recognizing our set of activities. To build this model, we use a six-second window size with a 40 Hz sampling frequency. As an evaluation methodology, we utilize the previous leave-one-out principle with a feature set which combines the features listed in the fifth column in Table 4 and in Table 5.

The gray bars in Figure 11 show the predictive performance achieved for each of the nine subjects in terms of f1-score values. The average f1-score values with regard to the single activities are represented by the gray bars in Figure 12. These results show that using a combination of smart devices leads to an enhancement in the predictive performance of activity recognition models. Such results prove that capturing the motions of subject's hand and leg simplifies the process of body-based activity recognition. However, smartwatch-based models are more applicable in real-world scenarios as it is more realistic in disaster situations to assume the subject to be wearing a smartwatch than to be carrying a smartphone while being affected by the disaster.

RELATED WORK

Several research projects have been presented in the domain of activity recognition using smart devices. In this section, we introduce a group of these projects with the main focus of identifying the factors that affect the predictive performance of activity recognition models using smart devices. Examples of such factors are window size, model type i.e. personal or impersonal, and sensor placement. Kwapisz et al. (Kwapisz et al. 2011) studied the effect of window size on the performance of their activity recognition model. They came out with the result that a 10-second window size leads to a better predictive performance when compared to a 20-second window. However, they did not provide a detailed discussion regarding the reasons behind such a result.

Shoaib et al. (Shoaib et al. 2013) showed that the performance of activity recognition models is highly affected by the position and type of used sensors. They studied the effect of using accelerometer and gyroscope sensors together and individually where they found out that using both sensors leads to an improvement in the performance of their final model. Moreover, they studied the effect of incorporating the magnetometer sensor data into the feature space. Based on their evaluation study, they found out that the magnetometer, when used individually or in combination with the accelerometer and gyroscope sensors, does not provide any remarkable improvement in recognizing their set of activities. Rasekh et al. (Rasekh et al. 2014) studied the effect of high dimensionality on the performance of their activity recognition models. They showed that reducing the dimensionality of the feature set improves the predictive performance of their models.

Lockhart et al. (Lockhart and Weiss 2014) studied the impact of model type on the performance of activity recognition models. In their work, they compared between personal, hybrid, and impersonal models. Their evaluation results showed that personal models achieve the best predictive performance. Moreover, they found out that hybrid models tend to outperform the impersonal models. Weiss et al. (Weiss et al. 2016) compared the performance of smartwatch- and smartphone-based models in recognizing hand-based activities. Their results showed that a remarkable improvement in recognizing hand-based activities such as eating and drinking can be achieved by utilizing smartwatches as observation sources.

CONCLUSION, DISCUSSION & FUTURE WORK

In this paper, we presented our system for detecting people in disaster related situations by recognizing their physical activities. We built this system using two smartwatches and three smartphones. We designed a set of activities that are typically performed by people in disaster scenarios. We created a

dataset containing 22 contributors performing the disaster activity set as well as everyday activities. Based on this dataset we conducted a comprehensive evaluation study to achieve our goal of building an orientation-independent, position-independent, and subject-independent model which is applicable in real-world scenarios. We built and evaluated a diverse set of models based on different combinations of smart devices. Our optimal model achieves a high average f1-score value of 90.1% in recognizing ten different activities related to disaster scenarios solely based on one smartwatch as an observation source. This model is characterized by being orientation-independent, position-independent, and subject-independent.

This work discussed the factors affecting the predictive performance of activity recognition models. We studied the impact of window size on designing the optimal set of features used to build the classification models. Moreover, we proved that the predictive performance is highly dependent on the chosen window size and sampling frequency. Our work shows the possibility of achieving a trade-off between an accurate recognition model and a moderate sampling frequency which preserves the resources of smart devices.

Since the created dataset contains only activities which mainly involve persons younger than 40 years old, the question arises how well the created models can reliably detect activities of persons of other age groups. In future work, we want to focus especially on the elderly who are often limited in their mobility and often need special help in the event of a disaster. A further uncertainty of the data set lies in the realistic execution of disaster activities. After best efforts, during the data collection, we tried to ensure that the volunteers carry out the activities as realistically as possible. However, it is assumed that the real catastrophic situation, including various stress factors, can lead to different movement patterns during the execution of the activities. To minimize this potential source of error, we want to include more contributors of different age groups and health conditions. Utilizing our data recording procedure in planned emergency drills, for example earthquake and tsunami drills (Johnson et al. 2014), more situation aware and more realistic data could be recorded and used for the training. Even though we proposed a pre-learned subject-independent prediction model, each model could also be improved by an individual learning phase performed by the smartphone/smartwatch owner. An interesting research question arises, if the mentioned individual learning phase, containing only everyday activities, could lead to higher prediction accuracy of the disaster activity set. This way the additional training could be executed during the day without any disturbance of the user.

ACKNOWLEDGMENT

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[5]Networked Infrastructureless Cooperation for Emergency Response
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The sensor to decision chain in crisis management

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ABSTRACT

In every disaster and crisis, incident time is the enemy, and getting accurate information about the scope, extent, and impact of the disaster is critical to creating and orchestrating an effective disaster response and recovery effort. Decision Support Systems (DSSs) for disaster and crisis situations need to solve the problem of facilitating the broad variety of sensors available today. This includes the research domain of the Internet of Things (IoT) and data coming from social media. All this data needs to be aggregated and fused, the semantics of the data needs to be understood and the results must be presented to the decision makers in an accessible way. Furthermore, the interaction and integration with existing risk and crisis management systems are necessary for a better analysis of the situation and faster reaction times. This paper provides an insight into the sensor to decision chain and proposes solutions and technologies for each step.

Keywords

Sensors, Internet of Things, Ontology, Knowledge Base, Ontology Visualization, Decision Support, Early Warning

INTRODUCTION

Recent research from the World Meteorological Organisation showed that the global temperature increase caused by climate change could reach 3°C by the end of the century (World Meteorological Organisation, 2017). As a consequence, the probability for the occurrence of natural catastrophes like heat waves, floods and forest fires is rising. The United Nations have long been calling for the intensified worldwide development of early warning systems (UNISDR, 2005). In the 2015 resolution "The Sendai Framework for Disaster Risk Re-

duction 2015-2030" this requirement was extended to include the consideration of chained disasters (UNISDR, 2015). Thus, the authorities of potentially affected regions need to prepare themselves. Early warning, risk and crisis management systems can provide these authorities with the necessary methods for decision support.

In this context, we developed and are presenting in this paper a general method to facilitate decision support by data integration via sensors and semantic data analysis, which can form the basis and integration framework of such systems: the sensor to decision chain in crisis management. The goal of the chain is to provide decision support functionality for responsible decision makers using a DSS.

The following sections of this paper will explain the sensor to decision chain. Since not all aspects can be covered in this paper, the focus lies on the harmonized sensor data collection, the semantic modelling of the multiple domains (climate change, crisis management, data analysis) and the decision support. In the rest of the paper, section "Related Work" discusses existing decision support workflows. The next section introduces "beAWARE", the project in which the decision chain is developed and tested with three large scale use case studies. Section "Sensor Data and Access to Sensor Data" explains the Open Geospatial Consortium (OGC) SensorThings API[1] and gives examples how it is integrated in the beAWARE demonstrator. Section "Semantics" explains methods for storing and accessing the data in the Knowledge Base (KB) and provides examples based on the beAWARE ontology. Section "Data Analysis and Decision support" explains ideas for the fusion of the data and how the information from the data is derived, and, finally, section "Conclusions and Future Work" recapitulates our findings and discusses directions for future developments.

RELATED WORK

Sprague defined DSSs through a group of properties, where one of the key characteristics is the support of decision makers in specific questions (Sprague, 1980). The goal of our sensor to decision chain lies exactly in providing this support.

In the meantime, DSSs did undergo a big development. Newman et al. describe in their current survey of "decision support systems for natural hazard risk reduction" (NHRR-DSS) the status and future research directions (Newman et al., 2017). They introduce a classification system for NHRR-DSS and found that most of the relevant systems considered single hazard situations. This shortcoming is addressed by the sensor and semantic components in our proposed solution, which enable the system to integrate multiple data sources.

A good overview over current architectural design and technologies of early warning systems is provided by Moßgraber (Moßgraber, 2017). These systems are supposed to deliver information about an emerging threat in order to allow persons and organizations to react accordingly. However, the design of an early warning system presents complex challenges to the system architects. In order to propose a solution to alleviate this problem, the presented work provides a framework for the architecture of next generation early warning systems. Particular attention is paid to solve various architectural problems by means of semantic technologies and the automation of workflows.

Another DSS combining current technical possibilities is introduced by Fang et al. in "An Integrated System for Regional Environmental Monitoring and Management Based on the Internet of Things" (Fang et al., 2014). The system combines IoT, Cloud computing and GIS technologies into an information system for environmental monitoring. Fang points out that research for data acquisition and fusion is important. Thus, as in the sensor to decision chain, Fang's proposed system architecture reflects the integration of sensors in the Perception layer, foresees services in the Middleware layer, and introduces decision support in the Application layer, but semantic integration is not considered.

Semantic integration is discussed in other recent works. Ontologies (Fensel, 2001) have been used for several purposes in DSSs. Wanner et al. present an "ontology-structured knowledge base from which then information relevant to the specific user is deduced and communicated in the language of their preference" (Wanner et al, 2014), while Moßgraber et al. use the ontology for improving the understanding of the use case domain, for visualizing the relations between the stakeholders and for structuring the information of the current situation (Moßgraber et al, 2015).

Decision Support for crisis management is discussed by di Pietro et al. (di Pietro et al., 2017). The introduced DSS manages critical infrastructures vulnerable in case of natural disasters. They structure the DSS architecture along the main functional blocks "Monitoring of functional phenomena", "Prediction of Natural Events", "Prediction of Damage Scenarios", "Prediction of Impact and Consequences" and "Support of efficient Strategies".

[1] https://github.com/opengeospatial/sensorthings

As in the work by Fang et al., semantic integration is not considered to improve the cross-domain integration of multiple data sources and risk domains.

THE BEAWARE PROJECT

The main goal of beAWARE[2] (Enhancing decision support and management services in extreme weather climate events) is to provide support in all the phases of an emergency incident. More specifically, it proposes an integrated solution to support forecasting, early warnings, transmission and routing of the emergency data, aggregated analysis of multimodal data and management of the coordination between the first responders and the authorities. It relies on platforms, theories, and methodologies that are already used for disaster forecasting and management and adds the elements that are necessary to make them work efficiently under the same objective.

The overall context for beAWARE lies in the domain of situational awareness and command and control. The first phase concerns the forecast of the extreme condition and the relevant preparations. Once a disaster occurs, an initial assessment needs to be conducted as soon as possible to determine the scope, geographical distribution, and scale of the incident. Situational awareness refers to being able to accurately determine what has happened, what is happening now, and what will come next, all in order to plan and coordinate the most effective response possible with the resources available. This observation phase will lead to an orientation phase suggesting both an individual as well as collective "cognition" orientation to data that is sensed and communicated. Once orientation to the data (or the lack of it) occurs, then a decision is made, ultimately resulting in the final step, which is "act". The crisis management center is always struggling to acquire a complete overview of the situation and to make the "best possible" decisions given the severe circumstances.

The proposed sensor to decision chain for crisis management is applied as the backbone of the architecture of a cross-domain crisis management system. Therefore, the key challenge of the project is to collect heterogeneous data from several resources, such as environmental, social media, input from first responders and/or people in danger, and to semantically integrate them in order to provide decision support services to the crisis management center.

Pilot Use Cases and Sensor Data

The beAWARE pilots cover different types of extreme weather events and, thus, employ different types of sensors, representing the *Sensor* part of our sensor to decision chain.

Flood Pilot

The most relevant sensors for the flood pilot are the water-level sensors in the different rivers in the pilot area, and the weather stations recording precipitation, since they reflect the current situation. The Finnish Meteorological Institute (FMI) makes forecasts of the weather, and the Italian Alto Adriatico Water Authority (AWAA) makes forecasts of the water-levels in the different rivers in the pilot area. The models used to create these forecasts can be seen as virtual sensors. Furthermore, first responders and the general public can send messages (including images and video) to the beAWARE system. However, the system cannot directly use this data once it arrives, as it has to be analyzed first by the respective analysis components.

Fire Pilot

An important indicator for fire-risk is the current and predicted weather. Important sensor data for this pilot are therefore data from weather stations and the weather forecast. High temperature, combined with low humidity and little precipitation increases the risk of fire. Regarding the detection of fires actually taking place, the most efficient way is by using static cameras that constantly record the area of interest and analyze the data from those cameras (near real-time) using video analysis software. Finally, the messages, images and videos sent by first responders and the general public are handled the same way as in the Flood Pilot.

Heatwave Pilot

Also for the Heatwave Pilot, the weather situation and the weather forecast are important sensor inputs, the same as for the other two pilots. Whereas for the Fire Pilot a low humidity increases the risk of fire, for the heatwave pilot a high humidity increases the severity of a heatwave. The messages, images and videos sent by first re-

[2] http://beaware-project.eu/

sponders and the general public are also handled the same way as in the previous two pilots. Finally, another relevant type of information is the location of shelters and how much space is still available in a specific shelter.

THE SENSOR TO DECISION CHAIN

As already motivated above, an integrated DSS needs to solve the problem of facilitating the broad variety of sensors available today. They can be accessed via Internet of Things (IoT) or Machine-2-Machine (M2M) standards. Furthermore, data coming from social media (human sensors) needs to be collected and analyzed, for example to get a better understanding of a crisis situation and to find people in need of rescue.

In this context, the key contribution of the paper is a proposed general method for facilitating decision support by data integration via sensors and semantic data analysis, which can constitute the foundation for crisis management DSSs. We call the chain of steps from retrieving sensor readings to reaching decision support as "the sensor to decision chain" in crisis management (see Figure 1).

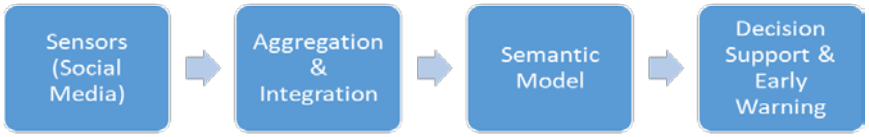

Figure 1: The sensor to decision chain

For integrating and harmonizing the data and for creating a common basis for further analysis, the Open Geospatial Consortium (OGC) developed a data model and API called the SensorThings API (Liang et al., 2016), which is further described in the following subsection.

All this data needs to be aggregated and fused, the semantics of the data needs to be understood and the results must be presented to the decision makers. To create a knowledge base (KB) that will assist in the decision support process, first an ontology needs to be created which semantically integrates the different pertinent domains like the sensor metadata, climate change, crisis management, etc. Once the KB schema is established, analysis services provided by the various components of the system can populate the KB with the respective analyses results. For example, a video analysis algorithm may detect that a street is flooded with several drowning cars. An instance of a corresponding incident is created in the KB, which is linked to vulnerable objects, in that case the cars. Based on that, the system can now generate automated suggestions to the decision maker; e.g. in the specific example, to check for people who might get trapped in a car. More information on these aspects is given later in the paper.

Stakeholder Access to Sensor to Decision Chain

In each pilot different types of stakeholder needs to access the Sensor to Decision Chain. Stakeholders providing data like FMI or AWAA will use the means of the Sensor Things API. People in danger or First Responders are also data sources for the DSS. They may access the chain directly via a mobile app, which will support means for the integration of their information into the Semantic Model. Additionally data provided through common Social Media (e.g. Twitter) will be crawled and included into the chain. The results of the Sensor to Decision Chain will be presented for two types of Stakeholder groups: firstly decision makers, which will get access via a desktop application and secondly the general public via a mobile app.

OGC SENSORTHINGS API

The OGC SensorThings API (Liang, 2016) is a REST interface and a data model for exchanging sensor data and metadata. The data model (see Figure 2) is based on the OGC/ISO Observations and Measurements model (OGC, 2011), but simplified to make it more suitable for use in the Internet of Things domain. It describes the eight entity types that can be accessed through the REST interface, and the relations between those entity types. The REST interface is based on the OASIS OData standard and allows Create, Read, Update and Delete actions on all entities (OASIS, 2014). It also offers powerful search capabilities, including geospatial and temporal filtering. Besides the REST interface, the OGC SensorThings API offers a Message Queue Telemetry Transport (MQTT) extension that allows for push notifications when entities change.

The data model of the OGC SensorThings API consists of the following eight entities:

- Thing: A virtual or physical object. Depending on the use case this can be the object being observed, such as a river or river section, or the sensor platform, such as a weather station.

- Location: The locations of Things. These can be geographic locations, encoded as points or areas, or symbolic locations, like “Crossing of road X and street Y”.
- HistoricalLocation: the link between a Thing and a Location, with the time indicating when the Thing was in a certain Location.
- Sensor: The metadata of the sensor that generates data. This could be a real sensor, or mathematical model generating a prediction.
- ObservedProperty: A property of the feature of interest that is being observed by a sensor. For instance, the water level in a river.
- Datastream: a collection of Observations of one ObservedProperty, made by one Sensor, and linked to one Thing.
- Observation: a measurement made by a Sensor.
- FeatureOfInterest: The geographic area or location for which an Observation was made. This can be the same as the Location of the Thing, which is often the case for in-situ sensing. In the case of remote sensing, the feature of interest can be different from the location of the Thing, depending on what is chosen as the Thing. The feature is a geographical point or a polygon encompassing an area or volume, usually encoded in GeoJSON.

Figure 2: The OGC SensorThings API data model

The relations between these entities are also defined by the data model and most of them are one-to-many.

The relations of Location are a bit more involved: A thing can have zero or more Locations, but these Locations must all be different representations of the same physical location. For instance, one geospatial location represented by GPS coordinates, and one symbolic location. A Location can have zero or more Things.

Each time a Thing is linked to a new Location (or set of Locations) a new HistoricalLocation is generated that tracks the time when the Thing was at this Location. A HistoricalLocation also has the restriction that if it has more than one Location, these Locations have to be different representations of the same real-world location.

An important feature of the OGC SensorThings API is that it is possible to request data from related entities in a single query. For example, one can, in a single request, fetch a set of Things, with the Datastreams belonging to those Things, and for those Datastreams the ObservedProperty, and the last Observation. This makes it very easy to write data visualisation tools, since it is possible to fetch all relevant data in one request, instead of having to make many separate, asynchronous requests.

One of the first implementations of the OGC SensorThings API is made by Fraunhofer IOSB (van der Schaaf, 2016). This implementation is open-source, using the LGPL license. The current version offers a complete im-

plementation of the standard, and all extensions, except for the batch-processing extension. It is written as a Java web-application and uses the PostgreSQL database system for data storage. This implementation has been used to include the meteorological data like temperature und rainfall and the water level data into the demonstrators of the pilots. It represents the second process step, the *Integration*, of the sensor to decision chain.

SEMANTICS

This section represents the *Semantic Model* step of our sensor to decision chain. The aim of the beAWARE ontology is twofold: (a) to represent natural disasters, along with the associated conditions and climate parameters characterizing them, and, (b) to represent the analysis results of input items (image, video, text) fed from sensors to the various beAWARE analysis components. Part of the ontology's design is inspired by existing models for representing similar notions:

- *MOAC* (*Management of a Crisis*) (Ortmann et al., 2011) constituted the basis of our representation for disaster impacts;
- The ontologies from the *SoKNOS* project (*Service-Oriented Architectures Supporting Networks of Public Security*) (Babitski et al., 2011) assisted us in the categorization of damages and resources;
- The scheme for representing environmental and meteorological conditions is based to some extent on the *PESCaDO* ontologies (Rospocher & Serafini, 2012).

Representing Natural Disasters

Figure 3 illustrates how the beAWARE ontology covers point (a) above, namely, representing natural disasters. Class "*Natural Disaster Type*" represents the various types of disasters, like e.g. floods, forest fires, storms or earthquakes etc. Disasters may lead to other disasters (via property "*leads to*"); for instance, a heat wave may lead to fires, or storms may lead to floods. Each type of disaster is characterized by certain climate parameters, represented via class "*Parameter*"; for example, solar radiation and temperature are two parameters that characterize a heat wave.

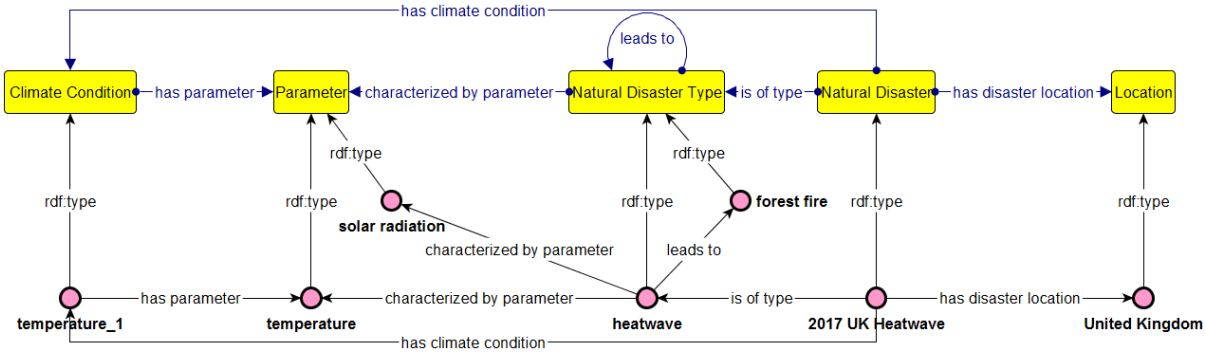

Figure 3: Representing natural disasters in the beAWARE ontology.

As seen in the figure, the actual manifestation of a natural disaster is represented via class "*Natural Disaster*", an instance of which (e.g. a heat wave in the city of Thessaloniki during the summer of 2015) has specific climate conditions with specific values.

Representing Analyzed Data

The array of beAWARE sensors submit the input data to the beAWARE analysis components, the analysis results of which are then fed to the ontology and are represented as displayed in Figure 4. These constructs facilitate representing the notions from point (b) above.

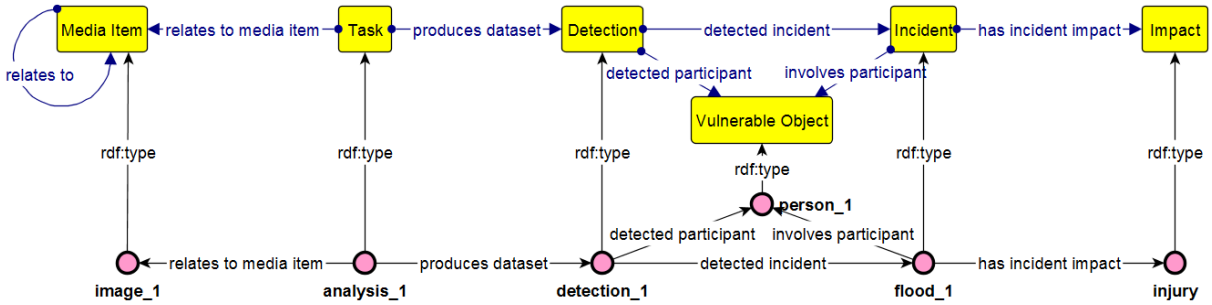

Figure 4: Representing analyzed data in the beAWARE ontology.

Class "*Media Item*" represents an item of analyzed data, which is related to some analysis task (via class "*Task*"). The analysis (text analysis, image analysis or video analysis) produces a "*Detection*" dataset containing all relevant information (e.g. an object detection task may produce a dataset of detected incidents, objects, and confidence scores). For reasons of brevity, we have not included in the figure the complete typology (i.e. hierarchy) of vulnerable objects (e.g. assets, persons, infrastructure, buildings etc.), impacts and incidents. For the same reasons, we are not displaying various data type properties, like e.g. severity levels, confidence scores, detection timestamps etc.). Moreover, the figure also demonstrates an example of a video analysis instance, where a potentially injured person is detected in the flood.

ONTOLOGY VISUALIZATION

Visualizations of the ontology play an important role in helping an end user to understand the model's inherent structure, so that he can efficiently work with the ontology. Thus we integrated means for visualizing the above described ontology into the DSS to facilitate the access to the semantic model for decision making stakeholders. When a user is viewing a specific instance or concept, he has to be given an overview of the relations to other instances and concepts that this instance or concept has. Furthermore, which relations to display can differ from case to case, and often it is not sufficient to simply show all primary relations of the instance or concept. Often it can be very helpful to display the instance or concept in a specific, larger cluster, or to show several images, with different sets of relations of the instance or concept.

The best graphs are those that are composed by hand, but drawing images in an external tool, and uploading them to the DSS is time consuming, especially when the ontology is subject to change. Therefore, a tool was integrated into the DSS that allows users to easily compose images of concepts and instances by hand. The tool allows a user to create images for any concept or individual. When a new image is created, the concept or individual it is created for is automatically added. By right-clicking on an item in the image, the user can add any related concept or individual to the image as well. The relations between the concepts and individuals are automatically drawn by arrows.

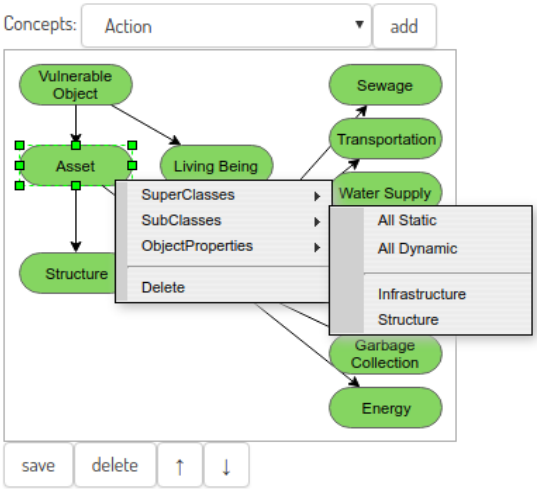

Figure 5: Adding relations to a concept

Every time the image is shown, the entities and relations in the image are checked, and if they do no longer exist, they are also removed from the image. New relations between entities in the image are automatically added to the image. When adding all relations of a certain type, for instance all subclasses of a class, it is possible to

set this action to "dynamic" (see Figure 5). When relations are added in dynamic mode, when, at a later date, the ontology is extended and new relations of this type are created in the ontology, they are also added to the diagram. This way the diagrams are always up-to-date, even if the layout might need to be corrected a bit manually.

DATA ANALYSIS AND DECISION SUPPORT

As already described previously, the main operation of the beAWARE ontology is to semantically fuse information from different sources (i.e. analysis results from the various analysis components of the framework) and to subsequently provide a contextualized overview of the crisis situation. The key aim is to support end users with combined information, which will form the basis of and assist them in decision making for crisis response. This represents the *Decision Support* step of our sensor to decision chain.

A dedicated software component called *KB Service* (*KBS*), serving as the interface with the knowledge base/ontology, is also responsible for the semantic fusion of the incoming analysis results. Each analysis component provides its results in JSON format, and KBS's role is to parse these results, and to generate and add respective instances to the ontology. Independently from their source, all results will lead to creating instances of media items, tasks, datasets, incidents and vulnerable objects (see subsection "Representing Analyzed Data").

A set of *SPARQL*[3] rules (W3C, 2012) running "on top" of the ontology are responsible for performing further inferences. Representative examples include the following:

- Grouping incidents taking place in neighboring locations together under a common "umbrella" incident;
- Calculating incident priority levels, e.g. an incident where people are in danger has higher priority than an incident where traffic is reported;
- Calculating incident certainty, severity and potential impact.

For example, a sample query that retrieves all the incidents classified as "highly likely" (i.e. have a confidence score of at least 75%) is illustrated in Figure 6.

```
SELECT DISTINCT ?incident
WHERE {
    ?incident rdf:type :Incident .
    ?detection rdf:type :Detection .
    ?detection :detectedIncident ?incident .
    ?detection :hasConfidenceScore ?score .
    FILTER(?score >= 0.75)
}
```

Figure 6: SPARQL query that retrieves all highly likely incidents.

The results of the above inferences are appended to the ontology. With the initially asserted and the subsequently appended inferred knowledge, the ontology may enter the decision support mode, during which it is able to respond to a wide variety of queries; in knowledge engineering, these are typically referred to as *Competency Questions* (*CQs*). The list of CQs was jointly created by the knowledge engineers of beAWARE and end-users and includes queries such as:

- Which location is the one with the most/least incidents?
- Which and how many vulnerable objects (e.g. persons, buildings, and assets) are at risk at a specific location?
- Are people at (or approaching) a location at risk? (e.g. a flooded location)
- Which location is the one with the most people (or buildings, or any other specific type of asset) at risk?

Each CQ is again formulated as a SPARQL query; CQs may either be submitted to the ontology at periodic intervals (e.g. every 1 minute), or, alternatively, the end-user may explicitly request that the CQs be submitted at a specific point in time. Depending on the result set, the user interface has to be updated accordingly (e.g. a change in the colors of pins on the map, or alerts displayed to the operators in case people are in danger). Such a sample query that retrieves the location with the most incidents is displayed in Figure 7.

[3] SPARQL is a set of specifications for querying and manipulating ontology models.

```
SELECT ?location (COUNT(?incident) AS ?countOfIncidents)
WHERE {
    ?incident rdf:type :Incident .
    ?location rdf:type :Location .
    ?incident :hasIncidentLocation ?location .
}
GROUP BY ?location
ORDER BY DESC(?countOfIncidents)
LIMIT 1
```

Figure 7: SPARQL query that retrieves the location with the most incidents.

Nevertheless, this is an ongoing work with still a few notions left that should be added to the ontology, in order to better facilitate the whole decision support process. The key notions that are currently missing and are planned to be integrated in the next revision of the ontology are the responder units and assigned actions, as well as a variety of stakeholders and their respective roles.

CONCLUSIONS AND FUTURE WORK

This paper presented the sensor to decision chain, which gets currently applied to three large scale use-case tests. The goal was to use and test existing standards and tools like the Sensor Things API and combine it into a methodology which can be applied to DSSs. The applied SensorThings API proved to be very helpful to solve the problem of harmonizing heterogeneous data and making it easily accessible from different processing services. Additionally, the developed beAWARE ontology had to integrate the knowledge of multiple domains and therefore, required the interaction of multiple domain experts. Using an online tool which supports a graphical visualization speeds up the process. The ontology can be used as a basis for many more research projects which will tackle the problems of climate change and involve a set of heterogeneous sensors and processing algorithms.

Regarding future work, besides the various additions to the ontology model discussed above, further research will focus on the reasoning techniques which will be applied to the semantic data. One example for that is generating automated warnings (including reports) based on the current situation and respective context stored in the knowledge base. Another imminent step is to have end-users evaluate the ontology-based decision support and the recommendations provided by it. This assessment will take place in a few months' time, when the first pilot deployments will be evaluated in the field, and our findings will then be publicly released.

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Information gain in sociotechnical systems

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ABSTRACT

Communication issues persist in sociotechnical systems with functioning communication equipment, prompting researchers and practitioners alike to bemoan the absence of information sharing. Computer scientists envision a broadly accessible virtual display, but lack the principles for selecting, formatting and organizing content to make it useful. We argue that what is needed is information rather than data, and that situating data in context is key to the provision of information. Documentation of information exchange issues in real crisis management is quite superficial, generally pointing to conclusions without any supporting data. Using documentation of the Deepwater Horizon Accident in 2010, we suggest three requirements for the design of computationally supported information exchange: 1) computational support to distribute distilled information, not low-level data, 2) a computationally accessible, current plan to provide context to guide the routing of information to interested parties and 3) a means to detect and elevate newly relevant, but formerly suppressed detail.

Keywords

Communication, information sharing, virtual information display.

INTRODUCTION

Communication is an important factor in socio-technical systems, particularly during emergencies related to natural disasters, terrorist attacks, or combat. Recognizing this, the crisis management literature focuses on improving the integrity of communication equipment, vulnerable for example to the loss of electricity or communication satellites. Though the integrity of communication equipment is surely necessary, this is but one factor in effective communication. Communication issues arise even in the presence of functioning communication equipment, generally attributed to the absence of information sharing. Quarantelli (1986) is a prominent voice in this realization, pointing to the need for rapid and accurate communications in crisis management. Lagadec (2007), Dautun (2007), Karsenty (2015) and Weick (1995) enrich our understanding, pointing out problems specific to crisis management such as the unexpected nature of events with extensive consequence and the need for a several teams of response experts representing many different but interacting domains with their own concerns, organizations and cultures (e.g., health and utilities). The complaints regarding communication challenges are numerous, but the theory of effective communication is thin and vague, lacking in constructs to guide analysis and remedy. For example, Lee & Seppelt (2012) consider the interaction with

automation as a communication problem, but still rely on constructs founded on the properties of an individual, human information processing architecture. More recently, Projet GénéPi (Granularité des Niveaux de Pilotage en Gestion de Crise, 2015) identifies the importance of context in the interpretation of crisis data; data do not have persisting relevance, affected by the passage of time and human intervention. For example, a road may not stay flooded indefinitely, and debris eventually gets removed. Context is not an issue that emerges from a human information processing perspective; this is an issue that emerges from domain analysis including the influence of, and interaction between, multiple agents with different responsibilities. Our goal here is to reveal exactly what "context" means, to assure that context is preserved in any attempts to remediate communication issues with computational tools.

While the literature is full of conclusions, the actual data regarding information distribution issues during a crisis is quite sparse and therefore lacking in implementation implications. This paper provides specific examples to illustrate general claims regarding the nature of context. Our examples are drawn from the explosion that occurred on the Deepwater Horizon oil rig on April 20, 2010, in the Gulf of Mexico, well documented in widely available US government reports. Our concern here, however, is not the resulting crisis, however tragic. Rather, as a result of the crisis, extensive documentation of the preceding events provides an unusually detailed, publically accessible account of the communication work practice in complex distributed socio-technical systems. Daily work practice on Deepwater Horizon has most of the critical properties of crisis management noted above, including unexpected events, extensive consequence, the involvement of numerous disciplines with diverse responsibilities, and a key role for context in the interpretation of data.

Although we note limited scholarly analysis regarding either computational capability or human behavior in the available documentation of Deepwater Horizon, we do not attempt to re-assess responsibility nor take a position on sensitive policy matters. We do however take issue with the superficial claim that "*there is no apparent reason why more sophisticated, automated alarms and algorithms cannot be built into the display system to alert [...] anomalies."* Figure 1 betrays a profound mis-appreciation for the human role in such complex socio-technical systems and the challenge of data interpretation in a noisy, stochastic and generally successful work practice in which the base rate of nominal conditions vastly outnumbers the base rate of consequential, off-nominal conditions (see Moray, 2003 regarding the cost-effective human response to automation). Revealing the true human role in the interpretation of data and the exchange of information, particularly concerning context sensitivity, provides a proper foundation for computational tools for information exchange.

> "In the future, the instrumentation and displays used for well monitoring must be improved. There is no apparent reason why more sophisticated, automated alarms and algorithms cannot be built into the display system to alert the driller and mudloggers when anomalies arise. These individuals sit for 12 hours at a time in front of these displays. In light of the potential consequences, it is no longer acceptable to rely on a system that requires the right person to be looking at the right data at the right time, and then to understand its significance in spite of simultaneous activities and other monitoring responsibilities."

Figure 1. Commission impression of human fallibility in sociotechnical systems (National Commission, 2011a, p.121).

Consistent with Hong & Page (2008), we claim that a primary responsibility of humans is to *interpret* data with knowledge, and distribute these interpretations to other participants whose subsequent or simultaneous activities depend on these interpretations. Humans do not function like sensors (Sheth & Thirunarayan, 2012; Hampton & Shalin, 2017) but rather use knowledge and experience to place their observations in the context of work goals and responsibilities. Participants in a complex domain differ not only in work goals and responsibilities, but also knowledge and experience, and are therefore differentially sensitive to particular features of the world. Observers share information (rather than data) and so must our communication tools. However, in distributed and/or mediated work, participants do not share responsibilities, access to the same data or knowledge to interpret the data. As a result, we claim that shared information is tailored in detail (Wilson & Sperber, 2004) according to the anticipated needs of a trusting recipient. This paper aims to illustrate the process of transforming data into information by situating them in context, resulting in the suppression of reasoning details in the transmission of conclusions; the necessarily evolving work plan provides a key component of context; and previously suppressed domain-specific details take on importance in the interpretation of new data. We employ data from the President's commission, a separate report of recommendations, and C-Span video testimony to provide a qualitative analysis. In so doing, we expose the key challenge in the development of computational support for the distribution of information: to maintain and complement the fundamentally context-sensitive features of communication.

THE DEEPWATER HORIZON ACCIDENT

On April 20, 2010, the Deepwater Horizon (a mobile drilling platform such as show in Figure 2) dug the deepest well ever offshore in the Gulf of Mexico. A resulting explosion caused a fire that killed 11 and injured 17. The event was subject to extensive investigation, including an independent U.S. White House commission of inquiry and the U.S. House Energy and Commerce Committee. Investigation identified some clear areas of concern regarding risk management and construction oversights. We employ the report from the President's commission (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011a)[1], informed by National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011b) and the Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future (2012)[2], and C-Span video testimony[3] as indicated below.

Figure 2. Mobile oil drilling rig positioned on a drilling site.

According to the National Commission Report (2011a, p.76) British Petroleum (BP) contracted with Transocean for the services of the Deepwater Horizon mobile offshore drilling rig to conduct drilling operations at the Macondo well site in the Gulf of Mexico, off the Louisiana US coastline. BP contracted separate services for cementing from Halliburton, well data logging from Sperry Sun, well and cement logging services from Schlumberger and services from several other companies of tangential interest to this paper.

While problem solving often proceeds by decomposing potentially separable elements into sub-problems, the approach is merely heuristic (Simon, 1962). Complex systems are only "nearly" decomposable, and potential dependencies eventually require evaluation. Snook & Connor (2005, p.196), notes NASA's failure to recognize the cross-disciplinary foam strike problem that doomed STS-107. *"Whatever you divide, you have to put back together again."* (Snook & Connor, p.199). In particular, we are concerned with the distribution of responsibilities across multiple contractors with different organizational cultures. This is characteristic of sociotechnical systems, including crisis management. We will see below that re-assembly depends on the communication of information between tasks rather than data.

Our analysis of communication problems in socio-technical systems (Linot, Dinet, Charoy & Shalin, 2018) takes inspiration from several sources. Pickering & Garrod's (2004) model of verbal exchange between two participants emphasizes a generic goal of communication, to establish aligned situation models. However, Pickering and Garrod omit several constructs that we believe are important in a model that serves the development of information technology. First, and emphasized here, we add a distinction between observable features in the world (data) and the resulting information. Information results from interpretive, knowledge based processes. Drawing from Mayer et al (1995), we consider propensity to trust, risk perception and evaluation, which we believe influences interpretive processes and information exchange. The recipients of information may lack the knowledge required for interpretation. Because detail is intentionally omitted in this exchange, trust is fundamental to the process. Recipients must trust in the source to provide comprehensible, relevant content, enhancing what Endsley (1995) calls *"situation awareness"*. Complimenting Pickering & Garrod, we include a role for communication tools, which must preserve communication goals for alignment founded on trust.

IMPLICATIONS OF DEEPWATER HORIZON FOR THE DESIGN OF COMPUTATIONAL SUPPORT FOR COMMUNICATION

Recipients in the exchange of information trust their sources to tell them everything they need to know, and nothing more (Grice, 1967; Wilson & Sperber, 2004). Below we sample the Deepwater Horizon data to make three related points to guide an implementation of tools that respect this over-arching property of information exchange. First, information is contextualized data. We require computational support to distribute distilled information, not low-level data. An interpretive process necessarily suppresses otherwise overwhelming detail

[1] Hereafter referred to as the National Commission (2011a) report.

[2] Hereafter referred to as the Committee on the Analysis of causes report.

hidden within the responsibilities of separable disciplines. Second, a key part of context is the work plan, which almost certainly changes in response to emergent circumstances. We require a computationally accessible, current plan to provide context to guide the routing of information to interested parties. Finally, suppressed detail can become newly important with respect to an evolving plan. We require a means to detect and elevate newly relevant, but formerly suppressed detail in the design of computational support for communication.

To select the examples we report here, we reviewed the cited investigation reports, and viewed the publicly available testimony. Our method does not follow anthropologically rigorous grounded theory, in the sense of elevating subtle issues that emerge from systematic analysis of an extensive corpus. Instead, our examples and analysis specifically respond to the quote in Figure 1, to challenge a misguided "alarm" model of information exchange in socio-technical systems. Our sampling method does not establish the base rate for the phenomena we identify in the domain we are studying or for domains in general. We assert, but cannot demonstrate, that the phenomena we note are representative of nominal operations. Skeptics should consider the coding exercise that a compelling quantitative demonstration entails, and its dependence on the scope and detail of the source account outside our control. However, more consistent with the anthropologist's challenge, we frame our interpretation of specific events with a potentially generalizable account to infer their implications for the design of computational support for communication.

Information is contextualized data

A key point of our analysis is that exchanged information, whether during a crisis or nominal operations, is not data, but an interpretation of the data that turns it into information. Figure 3 presents an excerpt from the testimony of Andrea Fleytas, a 23-year-old female responsible for navigating the mobile drilling rig. She was stationed on the vessel bridge, remote from drilling operations. Ms. Fleytas was responsible for monitoring and acknowledging alarms for the engines, ballast control and combustible fire, and was to inform senior officers of any issues.

E: […] their only words to you were **"we are in a well control event"**
W: Yes, they said **"we have a well control situation"** and they hung up.
E: And shortly thereafter you had a call from the engine control room asking you what was going on?
W: That's right. I responded **"we have a well control situation"**
[…].
W: before the phone call I got a, **we were getting the combustible gas alarms**.
[…].
W: **There were so many alarms, there were hundreds of them on that page.**

Figure 3. Andrea Fleytas Testimony (22:24) US Coast Guard & Bureau of Ocean Energy Management. October 5, 2010.

Figure 3 illustrates the distinction between data and information. In this case, the data are the combustible gas alarms. But the information is what this means, that is "*a well control situation".* While Ms. Fleytas received the data from her control panel on the bridge, the information came from elsewhere. When she received a subsequent inquiry from the engine control room what she reported was not the data, but the information she had received, "*we are in a well control situation*". Unfortunately, a key piece of context was not exchanged – the location of the alarms, potentially due to alarm cacophony.

Although Ms. Fleytas recounts an exchange during the unfolding crisis, we propose that turning data into information is characteristic of all exchange. This is particularly challenging when artifacts are the source of data. Figure 4 illustrates this interpretive problem, for the ordinarily routine problem of determining well-flow. Figure 4 indicates some of the logic required to turn flow data into information: the assumptions, the dependence upon the specific well, and a preference for a particular data source.

W: The flow out meter that Sperry Sun has, I believe it is an acoustic meter. **The flow out meter that Transocean has is a paddle.** They are both relative readings that are calibrated by, you know, seeing how much pump and how much goes into the pit. **It has to be calibrated.** The top line number on there, your flow in, is a calculated number. It is not measured. **It is calculated** from pump strokes **assuming a pump stroke efficiency**.
[…]
W: In Deepwater wells **the main thing you look for is flow back signature. It's called fingerprinting.** So, you see, when you make a connection, since you are using compressible fluid, you see how long it takes the flow to dissipate and does it flow down and level off. And then you time this. And **depending upon the well you are on** you know it could be 2 ½ minutes, it could be ten minutes. Every trip I went out there, and there were many, and I was talking to any of the folks on the rig, **they were always watching the Transocean flow out meter.**
[…]
E: You think even calibrated that the system that Sperry Sun was not as good as the system that Transocean had?
W: That was the feedback I got from the guys on the rig.

Figure 4. John Guide Testimony (1:01:42) US Coast Guard & Bureau of Ocean Energy Management, October 7, 2010.

Figure 5 shows that different cultures may disagree on the merits of different data sources. This extended testimony further illustrates the complex logic of sensor interpretation, in particular, the purpose of the sensor. In addition to confirming the calibration issue raised in Figure 4, Figure 5 raises additional concern for the role of context in sensor interpretation. Calibration is an activity specific to all sensors; recipients of sensor data could reasonably be expected to ask about the recency of calibration. The concern here is that numerous external, common sense events can affect sensor readouts, including crane operations and fluid movements between pits. Operators are responsible for manually logging common sense context, such as which pit is active. Without this information, sensor data are just that, and not information. Figure 5 also disposes of the idea that more alarms will solve the situation awareness problem; they merely add noise because their interpretation is context sensitive.

Although adjudicating between the Sperry/Transocean preferences may be relevant to the accident investigation, it is not relevant here. Different organizations may have different experiences and ownership in different, legitimate data sources. This is one basis of cultural differences between organizations. Most obviously, the observer must understand how the sensor works. Confidence in the resulting interpreted information comes from knowing how it was determined. Second, sensor values reflect a closed world assumption independent of other mitigating factors. However, sensors function in an open world, under the influence of many other factors that affect interpretation. Crucially, the world is not necessarily instrumented to take all of these influences into account in the automated processing of such data. Human observers are aware of these however, and adjust the sensor processing and interpretation accordingly. Therein lies the critical challenge of computationally supported information distribution. Trust is a function of the data source and the logic used to interpret it, but at least some interested parties likely lack the knowledge to conduct interpretation themselves. Moreover, recording the context such as pit activity in machine readable fashion is burdensome.

W: Uh, the flow out sensor that Sperry used was as I mentioned was the sonic sensor. It determines fluid levels, fluid height, the flow return line. […] I don't know the sonic, sorry, I don't know the Transocean model name that they used for their flow out sensor. I just know that it's type was of a paddle.
E: And of the two, which one would you think is the most accurate method or sensor?
W: **I would say the sonic or radar sensor that detects the fluid levels has a greater ability for detecting minute flows**, small flows whereas the paddle does not. Sperry moved to the sonic sensor, they used to employ the paddle sensor, some years ago.
E: […] Mr. Guide he indicated that […] he felt that the **crew relied more on the Transocean paddle type sensor.**
W:[…] **It was their sensor. I expect they would trust their sensor.**
[…]
W: **But the flow out was never intended to be an actual measure of volume. If you want to see the volume, the actual amount of a gain or loss, you would always use the pit volumes. You would never use the flow out over a given time.**
[…] If you have a good calibration then you can expect over a period of time for it to be relatively accurate. But that calibration is in need of constant tweaking. **That's because the flow-out sensor is influenced by so many activities.** Just rig movement will affect your flow out reading, whether it is rig movement due to crane operations or ballasting, or sea movement. […] they **would calibrate them according to whatever rig activities were going on at the time. So, if they were drilling say during crane operations and the crane operations were throwing their flow out sensor off, they might try to recalibrate then.**
E: […] Earlier when I asked you about flow in and flow out you said you would actually have to look at the pit volumes. **How do you do that when you simultaneously have multiple activities going on in the rig? When you are moving fluid from multiple pits to another pit?**
W: **It's difficult.** Um if they are transferring fluid to what is determined to be the active pits at the time, or removing fluid from the active pits, then **it becomes difficult to determine what influences on that active pit are due to that fluid transfer and what influences are due to drilling conditions.** So, if you are say transferring fluid to the active system and you are at the same time taking a gain from the well, it's difficult to determine that gain because you don't know the exact rate of the transfer. The pump system that moves fluid from one pit to another is not monitored for flow. […] **And it is up to the mudloggers to designate in the system which pits are active at the time. For the majority of time pits 9 and 10 were deemed active. But if the rig were to switch to say pit 6 then the mudloggers would go into his system and say 9 and 10 are no longer the active and go into the auxiliary book and designate pit 6 as the active.** And that would be reflected in the actual pit volume change.
[…]
E: And are there alarms on each one of those sensors in case there is a noticeable difference in volumes between the two?
Well, the Sperry system has the capability of setting up an alarm for any data that is stored in its database. So, the mudloggers will typically set up an alarm for what is deemed to be critical information, to see if it would cross certain thresholds or to see if they are not receiving data within a certain time period. So, for instance, gas. If gas were to exceed a certain threshold, the computer would give a visual and an audio alarm. So, the mudloggers, if he hears this, say he is examining a sample, he hears an alarm go off, he can look at his computer and see what crossed what threshold. Typically, there is not an alarm on the flow in or the flow out, **because they vary so often and they stop and start so often. You would have alarms going off every five minutes, every hour.**

Figure 5. John Gisclair Testimony (5:08) US Coast Guard & Bureau of Ocean Energy Management, October 7, 2010.

An (evolving) plan provides essential context

We have already made the claim that information is data placed in context. Here we make the point that the plan—the purpose of the coordinated work along with how it will be achieved, provides this context. Figure 6 presents the plan as represented and distributed in text.

> At 10:43 a.m., **Morel e-mail an "Ops Note" to the rest of the Macondo team listing the temporary abandonment procedures for the well. It was the first time the BP Well Site Leaders on the rig had seen the procedures they would use that day.** BP first shared the procedures with the rig crew at the 11 a.m. pre-tour meeting that morning. The basic sequence was as follows: 1. Perform a positive-pressure test to test the integrity of the production casing; 2. Run the drill pipe into the well to 8,367 feet (3,300 feet below the mud line); 3. Displace 3,300 feet of mud in the well with seawater, lifting the mud above the BOP and into the riser; 4. Perform a negative-pressure test to assess the integrity of the well and bottom-hole cement job to ensure outside fluids (such as hydrocarbons) are not leaking into the well; 5. Displace the mud in the riser with seawater; 6. Set the surface cement plug at 8,367 feet; and 7. Set the lock down sleeve.

Figure 6. The final plan for temporary well abandonment. Step four was not properly conducted (National Commission, 2011a, p. 104).

First, we note that plan steps provide the language of communication. Figure 7 summarizes the exchanges surrounding step 1, the positive pressure test for casing integrity.

> Once the pumps were off, a BP representative and Vincent Tabler of Halliburton performed a check to see whether the float valves were closed and holding. They opened a valve at the cementing unit to see whether any fluid flowed from the well. If more fluid came back than expected, that would indicate that cement was migrating back up into the casing and pushing the fluids above it out of the top of the well. Models had predicted 5 barrels of flow back. According to Brian Morel, the two men observed 5.5 barrels of flow, tapering off to a "fingertip trickle." According to Morel, 5.5 barrels of flow-back volume was within the acceptable margin for error. Tabler testified that they watched flow "until it was probably what we call a pencil stream," which stopped, started up again, and then stopped altogether. While it is not clear how long the two men actually watched for potential flow, they eventually concluded the float valves were holding. With no lost returns, BP and Halliburton **declared the job a success.** Nathaniel Chaisson, one of Halliburton's crew on the rig, sent an e-mail to Jesse Gagliano at 5:45 a.m. saying, **"We have completed the job and it went well." He attached a detailed report stating that the job had been "pumped as planned" and that he had seen full returns throughout the process. And just before leaving the rig, Morel e-mailed the rest of the BP team to say "the Halliburton cement team . . . did a great job."**

Figure 7. Information exchange reflects the steps of the plan (National Commission, 2011a, p. 90).

The information to be exchanged is not decontextualized flow-back volume and its change over time, but the status of completing a procedural step, and its implications for the success of the prior cement job. We see the same type of high-level language in communication regarding the success of step 4, in figure 8.

> At 8:02 p.m., the crew opened the annular preventer and began displacing mud and spacer from the riser. Halliburton cementer Chris Haire went to the drill shack to check on the status of the upcoming surface cement plug job. Revette and Anderson told him the **negative-pressure test had been successful and that Haire should prepare to set the surface cement plug,** (p. 109).
> Senior Toolpusher Randy Ezell left the evening meeting with BP feeling pleased at their praise "on how good a job we had done…How proud they were of the rig. "He stopped in at the galley to get a beverage before continuing to his office. At 9:20, he called Anderson up on the rig floor and asked", "**How did your negative test go?"65 Anderson: "it went good".** We bled it off. We watched it for 30 minutes and we had no flow." Ezell: "**What about your displacement**? How's it going?" Anderson: "It's going fine […] It won't be much longer and we ought to have our spacer back." [...], (p. 7).

Figure 8. Two accounts of the status of negative pressure test (step 4) in preparation for surface plug setting (step 6). As described later in the report a spacer is a liquid that separates drilling mud used during the drilling operations from the seawater that is pumped in to displace the mud once drilling is complete, that is a reference to step 5 (National Commission, 2011a).

We suggest that these are nominal exchanges between professionals with different specialties. Some detail behind the conclusion might be articulated, but certainly not all. *In the nominal case*, the abbreviated account is a necessity in distributed work, without which participants would be mired in endless speculation. The recipient needs to know whether the prerequisite step has been completed, and that is the focus of communication. Consistent with Gricean communication principles (1967) and Cooke et. al (2009) who show that more information is not necessarily better, participants trust other participants to provide important information. If observers omit detail, recipients are justified in assuming that the omitted detail is not relevant; the absence of report implies the absence of import.

A further challenge lies in plan changes (see Figures 9, 10 and 11).

> While initial well design decisions undergo a serious peer review process and changes to well design are subsequently subject to a management of change (MOC) process, **changes to drilling procedures in the weeks and days before** implementation are typically not subject to any such peer-review or MOC process. At Macondo, such decisions appear to have been made by the BP Macondo team in ad hoc fashion without any formal risk analysis or internal expert review. This appears to have been a key causal factor of the blowout. A few obvious examples, such as the last-minute confusion regarding whether to run six or 21 centralizers, have already been highlighted.

Figure 9. Documentation of frequent changes in the plan (National Commission, 2011a, p. 122).

While accident analysis focuses on the absence of change management protocols, our point is that the plan always changes in response to prevailing circumstances. Because the plan provides important context for the interpretation of information, communicating plan changes becomes relevant, as does re-situating data previously conceptualized in terms of a now stale plan.

> The evidence to date does not unequivocally establish whether **the failure to use 15 additional centralizers** was a direct cause of the blowout. But the process by which BP arrived at the decision to use only six centralizers at Macondo illuminates the flaws in BP's management and design procedures, as well as poor communication between BP and Halliburton. For example, it does not appear that BP's team tried to determine before April 15 whether additional centralizers would be needed. Had BP examined the issue earlier, it might have been able to secure additional centralizers of the design it favored. Nor does it appear that BP based its decision on a full examination of all potential risks involved. Instead, the decision appears to have been driven by an aversion to one particular risk: that slip-on centralizers would hang up on other equipment. **BP did not inform Halliburton of the number of centralizers it eventually used**, let alone request new modeling to predict the impact of using only six centralizers.
> **Halliburton happened to find out that BP had run only six centralizers** when one of its cement engineers overheard a discussion on the rig.

Figure 10. Plan changes associated with the number of centralizers (National Commission, 2011a, p. 115-116).

> Another clear example is provided by the temporary abandonment procedure used at Macondo. As discussed earlier, **that procedure changed dramatically and repeatedly during the week leading up to the blowout**. As of April 12, the plan was to set the cement plug in seawater less than 1,000 feet below the mud line after setting the lockdown sleeve. Two days later, Morel sent an e-mail in which the procedure was to set the cement plug in mud before displacing the riser with seawater.
> By April 20, the plan had morphed into the one set forth in the Ops Note": the crew would remove 3,300 feet of mud from below the mud line and set the cement plug after the riser had been displaced.

Figure 11. Additional plan changes in temporary abandonment procedure (National Commission, 2011a, p. 123).

The integrity of the cement job is crucial, indicated in Figure 12, and echoed in the report "Given the risk factors surrounding the primary cement job" (p. 119), including a change in cement materials (National Commission, 2011a).

> BP's overall approach to the centralizer decision is perhaps best summed up in an e-mail from BP engineer Brett Cocales sent to Brian Morel on April 16. Cocales expressed disagreement with Morel's opinion that more centralizers were unnecessary because the hole was straight, but then concluded the e-mail by saying. **But, who cares, it's done, end of story, [we] will probably be fine and we'll get a good cement job.** I would rather have to squeeze [remediate the cement job] than get stuck above the WH [wellhead]. So Guide is right on the risk/reward equation.

Figure 12. Additional plan changes to cement job (National Commission, 2011a, p. 116).

Suppressed Details can Matter

The fatal error concerns the determination of a successful negative-pressure test, resulting from two different types of problems: 1) proximal errors concerning the logic surrounding the declaration and 2) distal errors concerning the absence of relevant context to guide the interpretation of negative test data.

Logic surrounding the negative pressure test

Figure 13 explains the general idea behind the test.

> Instead of pumping pressure into the wellbore to see if fluids leak out, the crew removes pressure from inside the well to see if fluids, such as hydrocarbons, leak in, past or through the bottom hole cement job. In so doing, the crew simulates the effect of removing the mud in the wellbore and the riser (and the pressure exerted by that mud) during temporary abandonment. If the casing and primary cement have been designed and installed properly, they will prevent hydrocarbons from intruding even when that "overbalancing" pressure is removed. First, the crew sets up the well to simulate the expected hydrostatic pressure exerted by the column of fluids on the bottom of the well in its abandoned state. Second, the crew bleeds off any pent-up pressure that remains in the well, taking it down to 0 psi. Third, the crew and Well Site Leaders watch to make sure that nothing flows up from and out of the well and that no pressure builds back up inside of the well. If there is no flow or pressure buildup, that means that the casing and primary cement have sealed the well off from external fluid pressure and flow. A negative-pressure test is successful if there is no flow out of the well for a sustained period and if there is no pressure build-up inside the well when it is closed at the surface.

Figure 13. Logic of the negative pressure test (National Commission, 2011a, p. 105).

Figure 14 describes what actually happened. We see here what is by now the crucial communication feature. The information is in terms of the plan for abandonment, a successful negative pressure test. Spectacularly problematic logical details are suppressed. The above documentation in Figure 8 reveals that the conclusion and not the details get distributed through the work system.

According to outcome, the crew was clearly wrong in their conclusion. Additional documentation (see Figure 15) distributes the flawed proximal reasoning across both BP and Transocean personnel, (National Commission 2011b, p. 240). Figure 16 further documents a failure to seek additional input from on-site expertise.

The crew opened the drill pipe at the rig to bleed off any pressure that had built up in the well during the mud-displacement process. The crew tried to bleed the pressure down to zero, but could not get it below 266 psi. **When the drill pipe was closed, the pressure jumped back up to 1,262 psi.**
[…]
BP Well Site Leader Vidrine then insisted on running a second negative-pressure test, this time monitoring pressure and flow on the kill line rather than the drill pipe. (The kill line is one of three pipes, each approximately 3 inches in diameter, that run from the rig to the BOP to allow the crew to circulate fluids into and out of the well at the sea floor.) The pressure on the kill line during the negative pressure test should have been identical to the pressure on the drill pipe, as both flow paths went to the same place (and both should have been filled with seawater). Vidrine apparently insisted the negative test be repeated on the kill line because BP had specified that the test would be performed on the kill line in a permit application it submitted earlier to MMS. For the second test, the crew opened the kill line and bled the pressure down to 0 psi. A small amount of fluid flowed, and then stopped. Rig personnel left the kill line open for 30 minutes but did not observe any flow from it. **The test on the kill line thus satisfied the criteria for a successful negative pressure test—no flow or pressure buildup for a sustained period of time.** But the pressure on the drill pipe remained at 1,400 psi throughout. The Well Site Leaders and crew **never appear to have reconciled the two different pressure readings.**
[A] "bladder effect" may have been proposed as an explanation for the anomaly—but based on available information, the 1,400-psi reading on the drill pipe could [..] only have been caused by a leak into the well. Nevertheless, at 8 p.m., BP Well Site Leaders, in consultation with the crew, made a key error and mistakenly concluded the second negative test procedure had confirmed the well's integrity. **They declared the test a success** and moved on to the next step in temporary abandonment.

Figure 14. The negative pressure test was declared successful for the kill line instead of the drill line, (National Commission 2011a, p. 107/108).

BP and Transocean have sparred since the blowout regarding the relative competence of Transocean rig workers [I.E., Anderson] to interpret negative pressure test data. [...] BP personnel **certainly believed that Transocean personnel were not only competent to interpret those test results, but experienced and worthy of consultation**. [...] BP's well site leaders appear to have accepted a facially implausible explanation of the negative pressure test results from Transocean personnel. [...] Transocean **personnel were experienced and the BP well site leaders thus believed they could rely on Transocean personnel**. [BP personnel] Kaluza and Vidrine both appear to have **deferred to Transocean tool pusher Jason Anderson' s experience**. And Guide told the Chief Counsel's team emphatically that the **Transocean personnel were in fact capable and competent** to recognize the problems with the well during the negative pressure test. [...] Transocean agrees that its crew is expert in monitoring for and identifying kicks, even in underbalanced situations. Hence the rig crew did not call the BP well site leaders for advice when they noticed anomalous pressure readings during the displacement of the riser but instead relied on their own expertise to determine whether there was a kick.

Figure 15. Distributed responsibility for flawed reasoning proximal to event (National Commission, 2011b, p. 240).

Trust in personnel judgment is key to the proliferation of a flawed conclusion. A final concern is the availability of information to raise suspicion regarding the anomaly.

Information about drilling at Macondo was compartmentalized both within and between companies. It does not appear that the well site leaders ever contacted BP onshore personnel to discuss their inability to bleed off drill pipe pressure during the negative pressure test. They did not seek a second opinion from Sims or O'Bryan, both of whom are engineers and were on the rig during the negative pressure test as part of the VIP visit. Instead, according to their own accounts, the well site leaders accepted an explanation from a Transocean tool pusher who had no more training on test procedures than they had (p. 228).

Figure 16. Additional experts were not consulted (National commission 2011b).

The pressure data were not ambiguous. Rather, they showed repeatedly that formation fluids, in this case hydrocarbons, were flowing into the well. **The failure to properly conduct and interpret the negative-pressure test was a major contributing factor to the blowout.** Given the risk factors surrounding the primary cement job and other prior unusual events (such as difficulty converting the float valves), the BP Well Site Leaders and, to the extent they were aware of the issues, the **Transocean crew should have been particularly sensitive to anomalous pressure readings and ready to accept that the primary cement job could have failed.** It appears instead they started from the assumption that the well could not be flowing, and kept running tests and coming up with various explanations until they had convinced themselves their assumption was correct. Finally, due to poor communication, **it does not appear that the men performing and interpreting the test had a full appreciation of the context in which they were performing it. Such an appreciation might have increased their willingness to believe the well was flowing** (p. 119).

Information appears to have been excessively compartmentalized at Macondo as a result of poor communication. BP did not share **important** information with its contractors, or sometimes internally even with members of its own team. Contractors did not share **important information** with BP or each other. As a result, individuals often found themselves making critical decisions without a full appreciation for the context in which they were being made (or even without recognition that the decisions were critical). For example, many BP and Halliburton employees were aware of the difficulty of the primary cement job. But those issues were for the most part *not* **communicated to the rig crew** that conducted the negative-pressure test and monitored the well. It appears that BP did not even communicate many of those issues to its own personnel on the rig—in particular to Bob Kaluza, who was on his first hitch as a Well Site Leader on the Deepwater Horizon (p. 123).

Figure 17. Distal contributions to the accident (National Commission 2011a).

Absence of Contextual Information

We have already argued about the challenge of interpreting anomaly, for example in well flow rates due to the role of context. This is why alarms do not solve the information distribution problem. Figure 17 summarizes the distal context that should have influenced the interpretation of the anomalous negative pressure test data.

In this case, trust in the system to distribute relevant contextual information was badly misplaced, a likely reflection of organizational cultures at BP, and contributing to misalignment between subcontractors. Several procedural changes, many of which were either unknown or not salient, and some of which occurred well prior to drilling activity, constituted context that should have raised suspicion regarding the results of the negative flow test. These include: changes in the well equipment, reducing the number of centralizers employed (National Commission, 2011a, p. 116), changes in the composition of well cement (National Commission, 2011a, p. 117), the absence of a final cement test (National Commission, 2011a, p. 117), changes to the cements procedure (National Commission, 2011a, p. 120; National Commission, 2011b, p. 233), ambiguity regarding the adequacy of the float valves (National Commission, 2011a, p. 98) and changes to the procedure for conducting the negative flow test (National Commission, 2011a, p. 108).

CONCLUSION

The outcome of Deepwater Horizon is too easily dismissed by blaming less than admirable profit motives. Moreover, such a conclusion has little bearing on crisis response. While "poor communication" accurately labels the phenomena contributing to the Deepwater Horizon accident, the label does little to reveal the general principles one might employ to design computational tools that effectively support communication.

To this end we have made three related points in this paper: Data become information by situating them in context resulting in the suppression of reasoning details in the transmission of conclusions; the necessarily evolving work plan provides a key component of context; and previously suppressed domain-specific details take on importance in the interpretation of new data. Organizational culture likely influences both the interpretation processes and the scope of information detail to be exchanged between organizations. Any tool purported to support communication must consider these points as requirements in selecting formatting and organizing information. This is the focus of our future work (Linot, Charoy, Dinet & Shalin, in review).

The solution is surely not simply to provide more information (Cooke et al, 2009). Misses occur in noisy, complex sociotechnical systems that although stochastic, rarely fail. Misses occur in the presence of potentially millions of

mundane, correct decisions and responses. Changing decision criteria for the communication of information for possible future relevance must consider the resulting information overload in a system largely composed of correct behavior. Information overload is particularly critical when resources, especially response time, are limited. This is as relevant to crisis management as Deepwater Horizon, perhaps moreso.

Building shared awareness across the participants in distributed work, founded on information rather than data appears key. Lack of awareness concerning task dependencies and differences in organizational culture surely contribute to inconsistency in information sharing. However, in this case, pressure on subcontractor performance hardly encouraged the cross-sharing of doubt regarding the satisfactory completion of responsibilities. We can hope this property of Deepwater is not characteristic of crisis response.

The Deepwater data and our analysis are far from ideal in at least three respects. First, although they result from a real incident, they are post hoc accounts. Except for written records such as e-mail we cannot be certain that the language of recollection is the language actually used. Moreover, they result from investigative inquiry and though generally under oath, the data are not spontaneous. Finally, Deepwater is just a placeholder for a true crisis management event. The problem is not the absence of procedure and method in crisis response (FEMA, 2009). The problem is that the purpose of the system is different, to save lives and provide assistance to those in need. We cannot be sure that this context does not influence the nature of exchange, for example, by creating increased urgency by assembling teams even less familiar with each other than the teams in Deepwater or by magnifying the need for distributing an ever-evolving plan. The spatial modeling and reasoning in crisis management is more complex, as both the event and response likely involve the displacement of goods and services. Pre-existing instrumentation (fixed sensors) are less likely, as crisis generally occurs in unexpected, otherwise ordinary environments. In this view, relative to the complexity, diversity and necessarily ad-hoc response to crisis management, the communication lesson of Deepwater and the implications for the design of computational support is likely a best-case scenario.

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Towards an Interoperable Operational Emergency Response System for Large-Scale Situations: POLARISC

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ABSTRACT

After a lot of recent natural and human-made disasters all over the world, the large-scale emergency response process is becoming very critical and challenging. Lives can be lost and property can be harmed. To respond to these major threats, an effective operational emergency response system needs to address the necessity of data sharing, information exchange and coordination between the different involved Emergency Responders (ERs) including firefighters, police, healthcare services, army, municipality and so on to successfully respond to large-scale disasters. Therefore, the goal of this paper is to introduce POLARISC, an interoperable software solution based on a common modular ontology shared by all the ERs. Its main objective is to solve the problem of heterogeneity of data, to guarantee a common understanding among the various ERs, and to enable interoperability among them in order to coordinate their interventions and to obtain a real-time operational picture of the situation.

Keywords

Emergency response, Emergency Response System, Semantic interoperability, Ontology.

INTRODUCTION

Today, people are threatened by disaster situations, whether they are natural or human-made, disasters have been happening all around the world, every day and every single hour. Disasters can be defined as a sudden, accidental event of great magnitude that may cause deaths, severe injuries and property damage if not handled properly. For a safer future and to reduce disaster impacts, a large network of heterogeneous services of Emergency Responders (ERs) from various Emergency Response Organizations (EROs) including firefighters, police, healthcare services, army, municipality and so on are working hard to manage the large-scale disasters. The need to face these threats make the emergency response process very critical and challenging. Emergency response can be divided into three phases: (1) pre-crisis is about prevention and preparation, (2) crisis response is when management must actually respond to a crisis, and (3) post-crisis phase looks for better ways to prepare for the next crisis (Coombs, 2007). In this context, we will focus on the crisis response phase. In fact, in crisis response, ERs necessitate an ample need of timely information sharing and data exchange to obtain a real-time operational picture of the situation. But, each ERs has deployed its own information system. As a direct result of this situation, the main ambiguity that shows up is that information is heterogeneous; they are stored in different data sources, with different semantics and in different formats. Moreover, the major drawback is the deficiency of interoperability between the different information systems of the ERs. These issues lead to the misunderstanding and lack of coordination and data sharing among the ERs. Accordingly, almost without exception, reports and reflections after disasters express concerns over the EROs' abilities to collaborate. A

recent example of this can be found in the concluding report on the terror attack in Norway on June 22, 2011, stating that the various EROs (firefighters, police, healthcare services, etc.) were unable to effectively communicate and coordinate their effort (Eide et al., 2012). Thus, an effective operational emergency response system needs to address two key challenges; First, information interoperability is primordial among the different stakeholders during a crisis. Second, information should be semantically understandable by all the ERs since each stakeholder requests information in their own vocabulary, data representation and graphical charter (various color codes, different graphical symbols).

To address these challenges, in this paper, we introduce a novel solution POLARISC («*Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile*»), an ontology-based operational emergency response system. It is a new French project which started in 2017. It is an interoperable inter-services software solution for reliable and timely information sharing for the operational management of large-scale crisis situations. The focus is about offering to all ERs a real-time operation picture of the situation in order to enable multi-stakeholders and multi-level coordination within the EROs including firefighters, police, healthcare services, army and other government services. The rest of this paper is organized as follows. First, we describe the French structure of civil protection and emergency response. Later, a literature review on recent works and projects on emergency response is presented. Then, section 4 goes into the details of the proposed solution and the system architecture. At last, the conclusion and the future work are presented.

FRENCH STRUCTURE AND LEVELS OF EMERGENCY RESPONSE

Each country has its own culture and structure of Emergency Response Organizations in emergency situations. As regards the French Republic, it is a unitary state that includes four levels as shown in Figure 1. At the national level, the prime minister of France is responsible for the civil protection in the whole country. He takes control of the COGIC («*Centre Opérationnel de Gestion Interministérielle de Crise*», inter-ministerial operational crisis management center). It ensures round-the-clock monitoring of large-scale rescue operations and coordinates the use of resources in the event of a major incident. Afterward, at the zone level, the zone prefects are in charge of the COZ («*Centre Opérationnel de Zone*», Zonal Operations Centre) that ensures the coordination of the aid and rescue operations. Next, local branches of central ministries are directly controlled by prefects. Then, at department level, the prefect governs the COD («*Centre Opérationnel Départemental*», Departmental Operations Centre), he counts on the PCO («*Poste de Commandement Opérationnel*», Operations Command Post), which is located in a safe place near the crisis area and in charge of coordinating the various actors in the field. Finally, at the communal level, each commune has its own mayor, responsible for everyday public safety and security on the territory of the municipality. In case of disaster, the mayor is the first to step in. As the "emergency operations director" during crises, he manages resources and coordinates communication between firefighters' brigade, police, healthcare services and all actors who may be implicated in a crisis (Coste et al., 2013).

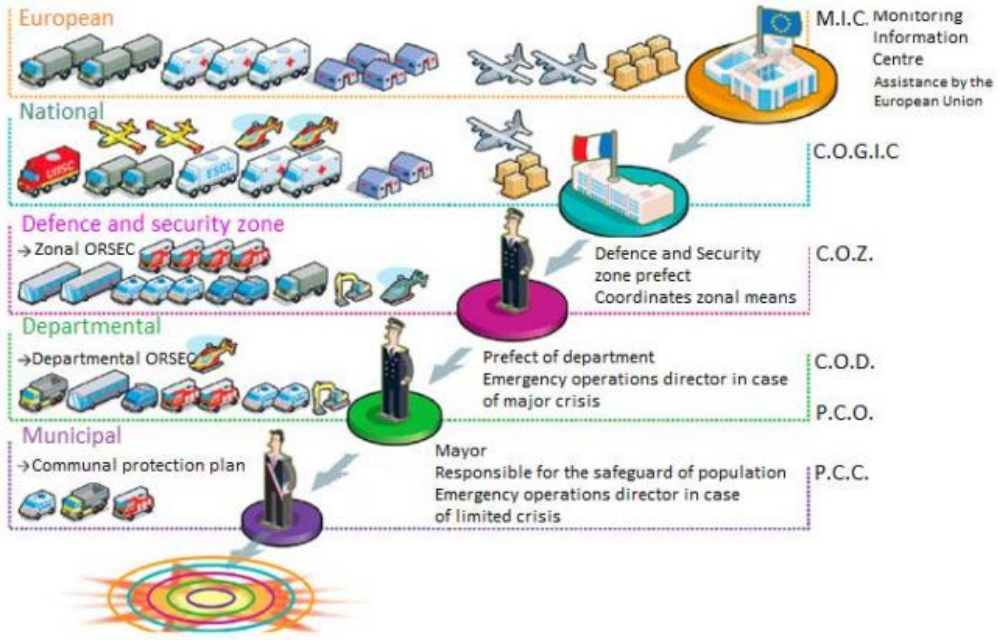

Figure 1. French Structure of Emergency Response (Source: Ministry of the Interior, 2009)

The ORSEC («*Organisation de la Réponse de SEcurité Civile*», Organization of the civil security response) plan provides the general framework for the civil security response. It is the basis of inter-services operational management regardless the origin of the major event affecting the population (natural or human-made disasters). Since 1999, major events have occurred in France, such as the 1999 storm of the century, the 2001 explosion at the AZF factory (Toulouse), the 2003 heat wave and the Xynthia storm (2010), specifically contributed to raising awareness, highlighting the complexity of the civil security organization (Coste et al., 2013). The feedback from the Xynthia storm, which caused at least 53 of persons killed and about 1.2 billion Euros of damage (Le Parisien, 2010), elaborated by the SDIS («*Services départementaux d'incendie et de secours*», Departmental fire and emergency services) of "Charente Maritime" highlights that information remains the essential element in crisis response. It should be treated in terms of content and flow. Indeed, this feedback brought to light a number of weaknesses that should be improved including:

- The necessity of the development of a common semantic terminology between the SDIS and the COD.
- The need of a common visualization tool of the tactical situation (SITAC) among COD, SDIS and PCO to obtain a real-time operational picture of the situation.
- A better coordination and cooperation between stakeholders.
- An essential improvement in terms of data sharing and information among stakeholders.

To conclude, the French structure of emergency response is characterized by the multiplicity of the involved actors and their cultures. To deal with this diversity, an efficient coordination is a primordial requirement. Therefore, the need for an interoperable multi-level and multi-stakeholders' operational emergency response system based on a common understanding of the meaning of terminologies for the operational management of large-scale disasters has been recognized.

STATE OF THE ART

For many years, there have been considerable efforts and growing interest to propose improvements in the emergency response field. Many solutions have been developed trying to solve real issues that cause slower and inefficient decision making in responding to emergency situations such as semantic heterogeneity of data, deficiency of interoperability in emergency management systems, misunderstanding and the lack of coordination and data sharing between all stakeholders.

At a national level, the project POLARIS is an essential component of the rescue operations developed by the society EXYZT (Σ: the set of, X, Y, Z: spatial landmark (3D), T: temporal dimension) in 2011. More specifically, it is an operational emergency response system used by the firefighters' tactical chain of command. This software allows the SDIS to coordinate all their interventions according to the topology of the field, the weather, the direction and strength of the wind, the available means, etc. It is built based on the national graphical charter GOC («*Gestion Opérationnelle de Commandement*», Operational Management of Commandment) (Figure 2). It allows each level of the firefighters' chain of command to have a real-time operational picture of the situation and also to add new tactical information. It has been able to manage important intervention such as the European exercise RICHTER-2012.

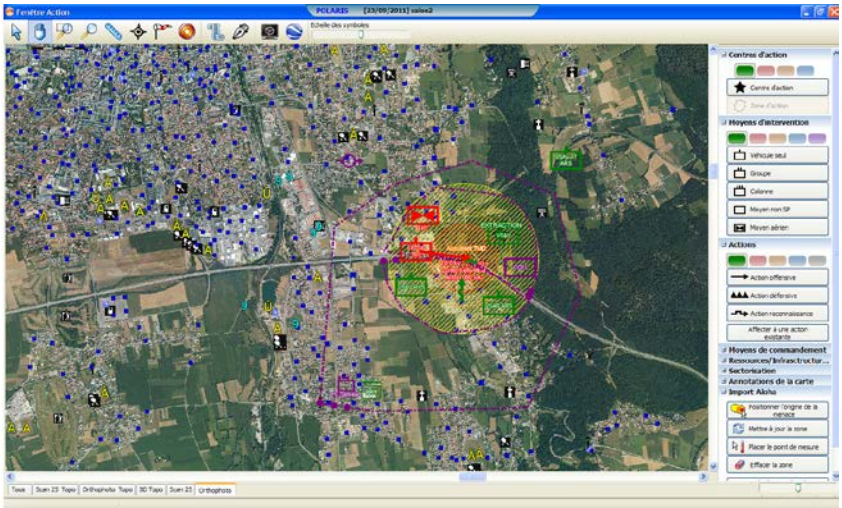

Figure 2. Example of an intervention managed by POLARIS

This software is used nowadays by the French firefighters. But, its major drawback is the fact of not enabling communication and information sharing among stakeholders. Disappointingly, operational ERs still communicate and coordinate through the prefect by means of telephones rather than information systems. If this kind of operational software, POLARIS, oversteps firefighters to include the different stakeholders, the result will be so advantageous to the emergency response field.

At the European level, there are a few research projects that have been working on the field of cross-border collaboration in emergency response such as DISASTER (Data Interoperability Solution At Stakeholders Emergencies Reaction) (Casado, et al., 2014). It tries to solve linguistic, semantic and cultural difference between countries by proposing a methodical basis for connecting and translating emergency management systems. It transforms the needed resources to the appropriate language, vocabularies, formats and protocols. In the same context, another project named INCA (A Decision Support Framework for Improving Cross-border Area Resilience to Disasters) focusses on the resilience of medical dependent citizens and the management of volunteers in a cross-border area (Lotter et al., 2017). They develop a resilience framework that helps decision-makers before and during cross-border incidents specifically on the French and on the German side. They propose a set of scenarios and guidelines to figure out the most appropriate measures.
Furthermore, DRIVER (Driving Innovation in Crisis Management for European Resilience) (van der Ven and Stolk, 2015) proposes a distributed Pan-European test-bed to provide guidelines on how to perform experiments as well as a framework to evaluate results. It is about three major thematic: First, Civil Society Resilience focus on citizens and civil society actors that are not professionally trained in crisis management, then, Strengthened Responders shows the benefits of innovative solutions to professional stakeholders. Finally, Evolved Learning aims to enhance the capabilities of professionals by performing a series of training modules to all the actors from first responders to the highest level of decision makers. In fact, the test-bed implies on a portfolio of Crisis Management tools where researchers, citizens and stakeholders can progress on new solutions. In the same context, Driver has some related ongoing project such as DARWIN2. It aims to provide emergency responders guidelines so as to facilitate crisis response. However, in these works, authors don't propose an end-user emergency response system.
Another European project named SecInCoRe (Secure Dynamic Cloud for Information, Communication and Resource Interoperability based on Pan-European Disaster Inventory) (Petersen and Büscher, 2017), looks for improving interoperability and data sharing among stakeholders by means of the development of a common information space based on information systems employed in past disaster events by first responders and police authorities by providing cloud-based semantic services. To do this, authors did a Pan-European inventory of disasters and their consequences and then elaborated a dynamic cloud-based communication system concept basing on a formulated knowledge base. In fact, it is a common information space concept documentation rather than an operational emergency response system.
Indeed, most of the proposed emergency response systems in literature lack a proper support to semantic interoperability. The interoperability among the various ERs requires a common ontology to overcome semantic heterogeneity. To do so and to guarantee a consistent shared understanding of the meaning of information, the use of ontologies is crucial (Antunes et al., 2013). Ontologies are expressed in a logic-based language, so that accurate, consistent, and meaningful distinctions can be made among the classes, instances, properties, attributes, and relations to reveal the implicit and hidden knowledge in order to understand the meaning of the data. Thus, they offer the richest representations of machine-interpretable semantics for systems and databases (Obrst, 2013). They serve as both knowledge representation and as mediation to enable heterogeneous systems interoperability (Song et al., 2013).
In (Fan and Zlatanova, 2011), authors looked for solving the problem of spatial data heterogeneity in emergency situations and their transmission to stakeholders. For this purpose, they proposed an ontology model that focuses on two types of data static data (topographic data such as TOP10) and dynamic data (data gathered after a disaster; damaged building, damaged car). Unfortunately, the work proposed is still at a very early stage and no ontology exist that can be used in emergency response.

In fact, in crisis response, there are two levels of intervention in the conduct of a crisis, namely, the crisis management level that includes political, strategic and tactical stages and the operational management level. As regards the French Republic, in case of a large scale situation, the president of the Republic and the prime minister take charge of political and strategic actions. The Ministry of Interior is responsible for activating, if required, the inter-ministerial crisis committee (CIC). Then, the CIC is in charge of the transmission of decisions from the political level to the operational centers respectively within the national firefighters, gendarmerie, police and civil security services.

To conclude, few systems are presented to enhance the field of large-scale emergency response. These systems are typically specific to certain aspects of emergency response, but unable to cover all of them. In addition, they are concerned about crisis management at a higher level (strategic level) but there is no system that focusses on

the inter-services operational level, unlike POLARISC that includes all actors involved in operational emergency response level (Figure 3) such as healthcare services, firefighters, police department, etc. At last, in the literature, there is a lack of a common terminology or standard. Therefore, our solution aims to overcome these limits by proposing an inter-services operational emergency response system for large-scale situations basing on a common modular ontology that covers all the stakeholders' knowledge.

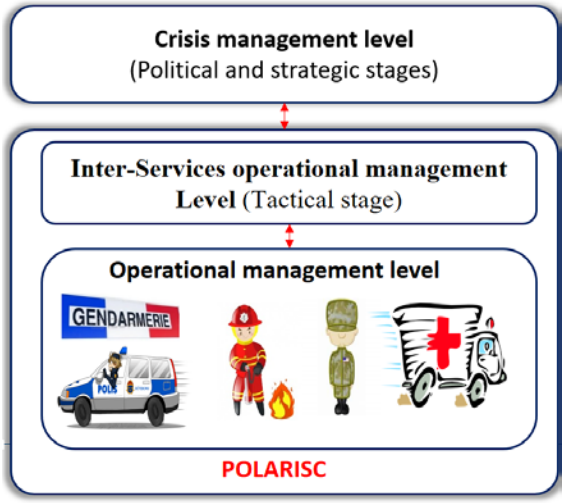

Figure 3. POLARISC positioning compared to other systems

THE PROPOSED SOLUTION

Information accessibility and availability is vital during a large-scale emergency response. For this purpose, POLARISC aims to offer a common operational picture, timely access to the needed information, data sharing and coordination among stakeholders. Figure 4 illustrates the architecture of POLARISC as a whole system and also shows the proposed modular ontology for semantic interoperability between stakeholders. POLARISC is mainly a software solution that plays the role of mediation between ERs that require coordination and cooperation for large-scale operations. It is composed of three layers; First, the users' layer is composed of the different stakeholders that will use the system (firefighters, police, healthcare services, etc.).

Second, the integrated services layer is about suggesting a set of services designed to support the ERs in emergency response. Among these services, Evacuation of victims' service allows finding as quickly as possible the appropriate health care institutions and reserves it according to the patient state (Mhadhbi et al., 2015). Messaging service will ensure a semantically adaptive information exchange between the different stakeholders in order to consolidate information and also to send the appropriate information to the appropriate actor by taking into account the hierarchical levels of commandment. Geospatial service provides to stakeholders a smart cartography to have a real time operational picture of what happen on the field and also to add on the map the different interventions (the involved means, stakeholders, etc.). Operational service is about means management on the field. The tactical service proposes a decision support tool for prevision and simulation of emergency response. Then, mediators layer is responsible of transforming the data according to the appropriate vocabulary and graphical charter (color codes and graphical symbols) of the stakeholder. It is a gateway between end-user systems, the services layer and the data layer. As a result, each stakeholder receives information and uses the proposed services in accordance with his vocabulary and checks the operational picture of what is happening exactly in the field according to his graphical charter.

At last, the data layer is the core of the proposed system. To overcome semantic heterogeneity among stakeholders, the definition of a common terminology is essential. Thus, we resort to ontology to reveal the ERs' complex knowledge in order to understand the meaning of the data and transmit it to the correct ERs. The ontology encompasses ERs vocabulary to contain also the different process, workflows and rules.

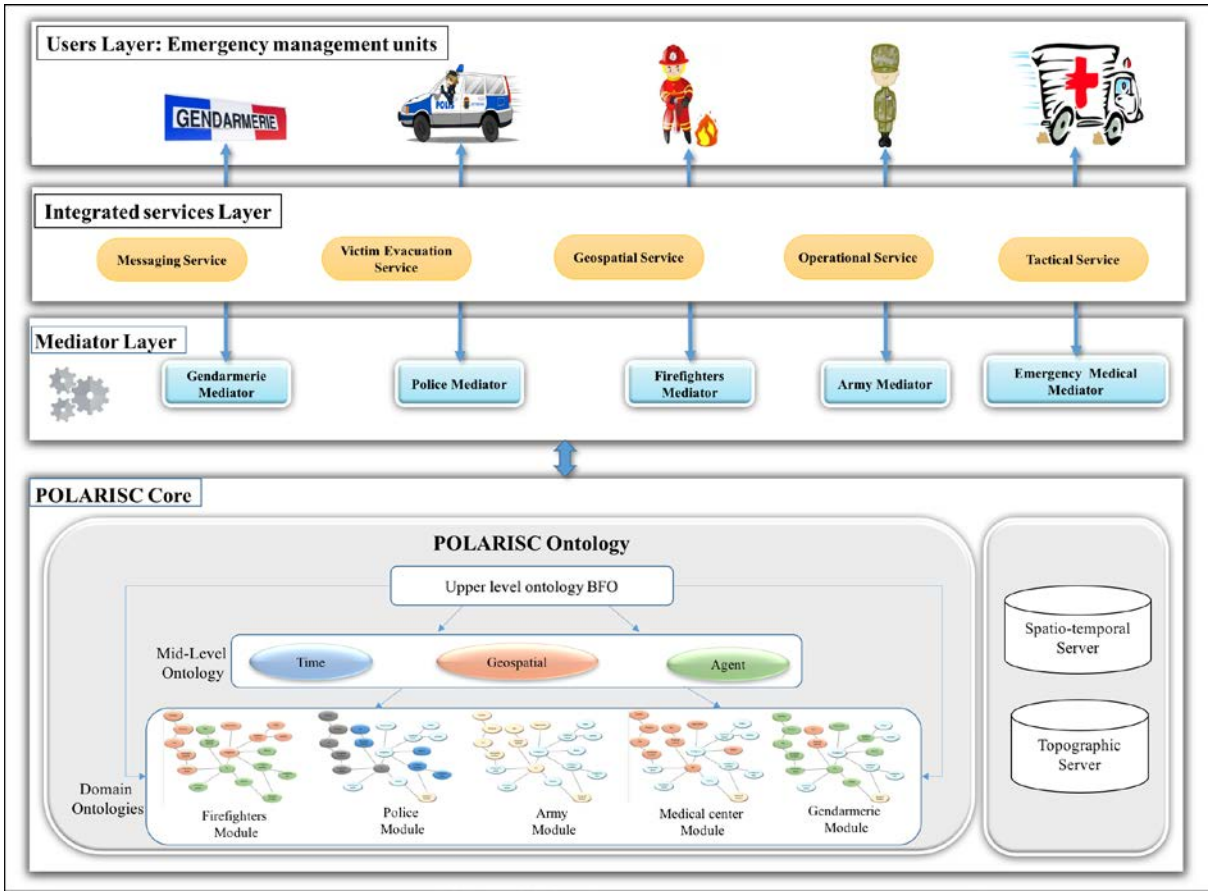

Figure 4. POLARISC architecture

To develop our proposed modular ontology (a module for each stakeholder), first, we reused an upper-level ontology. Indeed, the use of upper-level ontologies facilitates the alignment between several domain ontologies and enable interoperability between them. In other words, if the ontologies to be mapped are driven from a stander upper-level ontology, this will make the mapping task very easy. In addition, upper-level ontologies play the same role as libraries in software programming tasks. Once they are used, one could reuse the defined concepts and relationships and so as to inherit the inferencing capabilities furnished by them. In this way, developing a domain ontology is an easier task that requires less time than usual. Moreover, the aim is to avoid having several incompatible domain ontologies. The usage of upper-level ontologies for integrating information and sharing knowledge among heterogeneous sources has been motivated in various related works (Baumgartner and Retschitzegger, 2006).

To select the appropriate upper-level ontology, we first looked for a realist upper ontology that represents the world as is and not underlying natural language and human common-sense. Then, to ensure that the upper-level ontology can be extended to an emergency management ontology, it should be universal. Universal classes are often characterized as natural classes that abstract or generalize over similar particular things. Person, Location, Process, etc., are examples of universals (Semy etal., 2004). Accordingly, in this work, we employed Basic Formal Ontology (BFO) as an upper-level ontology (Smith and Ceusters, 2010) (Seppälä etl., 2014). — We might say that the ontology encapsulates the knowledge of the world that is associated with the general terms used by scientists in the corresponding domain (Arp et al., 2015). As a starting point, BFO uses the term «*entity*» as a common representation of anything that exists in the world from the point of view whether of philosophers or scientific researchers. Then, it incorporates two categories of entity «*Continuants*» and «*Occurrents*» in a single framework as a top-level distinction between entities. Continuants are entities that persist through time including three axes; objects (Material entity) or and spatial regions (Immaterial entities) as Independent continuant, functions and qualities as Specifically independent continuant and finally, Generically dependent continuant. Occurrents are entities that happen or develop over time such as process.

As a mid-level ontology, we decide that Common Core Ontology (CCO) meets most our requirements since it inherits from BFO as an upper-level ontology and defines a modular set of extensible classes and relations that can be connected to our domain ontology. The ten mid-level ontologies that compose the common core ontology are: The Information Entity Ontology, the Agent Ontology, the Quality Ontology, the Event Ontology, the Artifact Ontology, the Time Ontology, the Geospatial Ontology, the Units of Measure Ontology, the Currency

Unit Ontology, and the Extended Relation Ontology (Ron, 2016). In our work, we reused only three modules that will be extended according to the domain level needs which are Agent Ontology, Time Ontology and Geospatial Ontology.
Concerning the domain ontologies and to develop the different modules, interviews were conducted with stakeholders so as to capture their needs and to identify their technical vocabulary (Commandment hierarchy, means, types of intervention, roles, etc.).
We started first by firefighters' module. At the end of this stage, the firefighters' ontology had around 429 classes and 246 relations. The classes are labeled in English and in French. The final step consists on the evaluation of the proposed ontology by domain experts in term of inconsistency, incompleteness and redundancy. To summarize, the ontology we created, once it is complete and all the emergency management actors' modules are integrated, it will be instantiated to test it by means of a concrete use case and it will be used in an Emergency Management System as a common shared vocabulary. Domain expert and users should then evaluate and validate the obtained results.

CONCLUSION AND FUTURE WORK

In large-scale disasters, coordination of emergency responders is challenging due to the heterogeneity of systems in use. In this paper, we have introduced POLARISC, an inter-services operational emergency response system for data sharing among heterogeneous ERO in large-scale situations. It offers a real-time operation picture of the situation. In addition, we have highlighted the use of POLARISC Ontology, a common modular ontology, that ensures semantic interoperability in emergency response and guarantees a common understanding between stakeholders. For all we know, the modular ontology proposed in this paper is the first ontology based on BFO and CCO that aims to define the emergency responders' knowledge. As a future work, we will develop the rest of the stakeholders' modules and then integrate them in a global ontology that will be validated by domain experts. As future directions, the project can be extended to take into account more actors such as volunteers and people with disabilities or limited language skills.

ACKNOWLEDGMENTS

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A Volunteer Coordination System Approach for Crisis Committees

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ABSTRACT

In disaster situations security authorities and organizations have the responsibility and duty to manage the disaster response. These organizations work in elaborated command and control structures with well-trained employees. But in recent events, supported by new technologies like social media and mobile devices, spontaneous volunteers from the local population gained new importance as helpful force in disaster response. The high amount of volunteers bears high potentials to improve the efficiency of several activities through pure manpower. However, these people are not integrated in existing structures and lack a proper qualification. The proper coordination of spontaneous volunteers poses new challenges for disaster authorities. In this paper we introduce the prototype of a novel information system enabling crisis committees to coordinate spontaneous volunteers by semi-automated purposive communication and allocation. The results of first staff exercises are discussed to emphasize potential benefits and open challenges.

Keywords

spontaneous volunteers, coordination system, prototype demonstration

INTRODUCTION

In case of a disaster incident volunteer helpers from the local community have always made their contribution in disaster response by supporting officially responsible security authorities and organizations (SAOs). But currently the way people provide their help is changing in different ways. SAOs in many countries recognize a decreasing willingness of citizens to volunteer in the context of an honorary appointment where they are bound to an established organization (e.g. McLennan et al. 2016, Angermann & Sittermann 2010). On the other hand dissemination of new technologies like social media and mobile devices massively influences the involvement of volunteers. Incidents like the flood catastrophe in middle Europe in 2013 and the hurricane Katrina showed how unaffiliated volunteers using these technologies made important contributions in disaster response. These changes force established SAOs to rethink current methods to activate and integrate unaffiliated volunteers. The novel possibilities for interaction and collaboration open new opportunities to utilize potentials of the civil society and coordinate unaffiliated volunteers to support the goals of responsible SAOs for a more efficient and effective disaster response (Sauer et al. 2014).

In the literature, unaffiliated volunteers, people who are neither through work or honorary appointment bound by a SAO, are separated in two types: digital volunteers and physical volunteers (Whittacker et al., 2015). Former are using information systems directly to gather and distribute information about the current disaster event to support SAOs or share them with the community. A well-known example is the earthquake in Haiti in 2010 where digital volunteers used the crowdsourcing geo-platform Ushahidi to visualize and aggregate the information about the incident they collected and analysed from social media and other communication channels (Morrow et al., 2011).

In contrast to that, physical volunteers offer their workforce and support at the disaster response sides within their range. They use information systems primarily to coordinate their response activities and to get information about help requests and possible response locations where they spontaneously decide to offer their help. In this paper these kind of physical volunteer is called spontaneous unaffiliated on-site volunteer (SUV). In

the middle European flood catastrophe of 2013 thousands of SUVs supported official helpers in their work. They communicated and organized their spontaneous activities via social media like Twitter or Facebook without consulting responsible crisis managers. Reports showed the enormous support capacities which could be activated but also revealed that some disaster response sites were nearly overrun by SUVs whereas other sites were in urgent need for additional manpower. SAOs were often overwhelmed by spontaneous converging volunteers and were not able to coordinate the large amount of people especially in critical situations. The self-organization of SUVs is not integrated in established command and control structures of existing SAOs so that the potentials are not directly accessible for crisis managers. Deficits in the volunteer coordination can lead to waste of workforce, decreasing motivation to offer help or even improper and counterproductive actions, necessitating further response efforts or even cause new damages (Barsky et al. 2007).

In this paper we address the problem of coordination of spontaneous unaffiliated on-site volunteers through disaster managers in established security authorities and organizations and especially crisis committees. We focus on the design of a volunteer coordination system (VCS) using modern information technology for a demand-oriented assignment of SUVs to adequate response sites with help of semi-automated communication processes. Thereby we emphasize the applicability of the system for as many people as possible to exploit the highest potential of volunteer workforce. This paper is part of a bigger research project for the development and evaluation of a holistic system taking the needs of different actors into account and aiming at a largely automation of volunteer coordination to allow an effective and efficient employment of SUVs. The research in this project follows the design science research process of Peffers et al. (Peffers et al., 2006). While the problem identification (phase 1) and objectives of a solution (phase 2) (Betke et al., 2017) have already been addressed in former publications, as well as different aspects of the artefact design and development (phase 3) (Lindner et al., 2017; Lindner et al. 2018; Rauchecker & Schryen, 2018) the paper at hand mainly addresses the demonstration (phase 4). The special focus of this paper is the presentation and discussion of a first prototype system. The results of a live test by crisis staff members in a standard training situation give evidence of the possible benefits of the system and describe open challenges. The paper is structured as following: in the next section we will introduce the functional system requirements derived from interviews and literature analysis. Build on that a first simple system prototype consisting of three mayor components is presented. Furthermore we will describe the testing of the prototype and discuss the insights. The paper closes with a summary of the results and a critical outlook in the conclusion.

CHALLLENGES OF VOLUNTEER COORDINATION

The coordination of unaffiliated volunteers is not a new challenge and different aspects of this topic have already been subject of research in recent and current projects like KOKOS or EMERGENT. For a comprehensive overview of respective projects see e.g. Zettl et al. 2017. The research presented in this paper is part of the *KUBAS* project. As mentioned before the project aims at the development of a volunteer coordination system for to improve the employment and management of spontaneous unaffiliated volunteers by official crisis committees. Thereby the project focuses on some special concepts which are researched and developed in own subproject. These concepts are: (1) building of a workflow-based system structure to allow automated, individual communication processes for each volunteer, (2) optimization of matching between volunteer offers and help requests by sophisticated algorithms to allow optimal utilization of volunteer potentials and (3) simulation of SUV behaviour for staff education and system evaluation. The project also pursues additional targets like diversification of communication channels for spontaneous volunteers and open interfaces for integration in existing operational command systems. However, these concepts and aspects are discussed in own papers or part of a system design paper.

In this paper we want to emphasize the requirements directly from the two user groups. Therefore we conducted guided interviews with participants of each user group: 9 members of disaster response authorities with different roles in crisis committees and 19 spontaneous volunteers with experience gained in former disasters. The guided interviews comprised questions about their previous experiences as or with spontaneous volunteers in regard to conducted work, positive experiences and potentials, negative experiences and concerns, integration in command and control chains, communication behaviour as well as individual requirements on a volunteer coordination system from their respective point of view. We used the interview results in combination with existing literature about computer supported cooperated work esp. in disasters (e.g. Ludwig et al. 2017, Meissen et al. 2017, Weigand et al. 2003) and volunteer coordination (e.g. Fernandez et al. 2006, Johansson 2013, Lorenz et al. 2017, Rogstadius et al. 2010, Whittaker et al. 2015) to derive a set of functional requirements in the form of user stories for each user group. Table 1 comprises an overview of the resulting user stories. Whereas the original set of user stories has a 3-level hierarchical structure we decided to just present the second level of requirements for place and clarity reasons. We also cut out user stories addressing the matching algorithm since this discussion is detailed part of other papers. The whole set of user stories was taken as target specification for

the development of a new VCS. However, we do not regard these user stories as the final system requirements but just a starting point. They will be enhanced and refined based on an iterative development process considering user feedback and further research efforts.

Table 1. User Stories for a Volunteer Coordination System

Nr	User Story
RV1	As a volunteer I want to be informed about relevant help requests so that I do not have to search for them.
RV2	As a volunteer I want to get detailed information about help request so that I can make a decision to help.
RV3	As a volunteer I want to see my volunteer mission details at any time so that I do not lose any information.
RV4	As a volunteer I want to provide sufficient information about my volunteering offer so that I can get the best help requests.
RV5	As a volunteer I want to group with my friends so that we can work at the same sites.
RV6	As a volunteer I want to change my volunteer offers so that it matches my current circumstances.
RV7	As a volunteer I want to get information if my volunteering offer was recognized to be sure it will be taken into account.
RV8	As a volunteer I want to be able to get offers from more than one request so that I can help at different sites.
RV9	As a volunteer I want to use mobile devices so that I am not bound to a single location.
RV10	As a volunteer I want to use different devices so that I can be sure that I get help request information.
RV11	As a volunteer I want to get information about disaster incidents in my home area so that I can prepare myself.
RV12	As a volunteer I want to share on-site information with disaster authorities so that I can report potentially dangerous incidents.
RV13	As a volunteer I want to get information about the traveling options so that I arrive on site as fast as possible.
RS1	As staff member I want to create and communicate help requests with sufficient information so that I get suitable volunteers.
RS2	As staff member I want to get Information about the status of assigned volunteers so that I can react to capacity problems.
RS3	As staff member I want to have an event history so that I can reproduce every action in the aftermath of the disaster.
RS4	As staff member I want to have detailed information about all running help requests, so that I can overview the situation.
RS5	As staff member I want to use a situation map with volunteer related information so that I always have an overview about the entire situation.
RS6	As staff member I want to register volunteers arriving on site so that I have a better overview of the capacity situation on that site.
RS7	As staff member I want to change the information in help requests so that I can react on a changing situation.
RS8	As staff member I want to to send custom information to individual volunteers or groups so that I can warn them in critical situations.
RS9	As staff member I want to get address information about volunteers so that I can associate compensation claims in the aftermath.

VOLUNTEER COORDINATION SYSTEM PROTOTYPE

The following chapter is part of the demonstration phase (phase 4) in the design science process of the research project (Peffers et al., 2006). It will give an insight into an early prototype system and show which feature meets the user stories. Although until now not all user stories and requirements could be addressed, the first iterations of the design and development process succeeded in a functional prototype system consisting of three major components: the Task Manager as interface for crisis committee members, the Volunteer App as interface for SUVs and the VCS server.

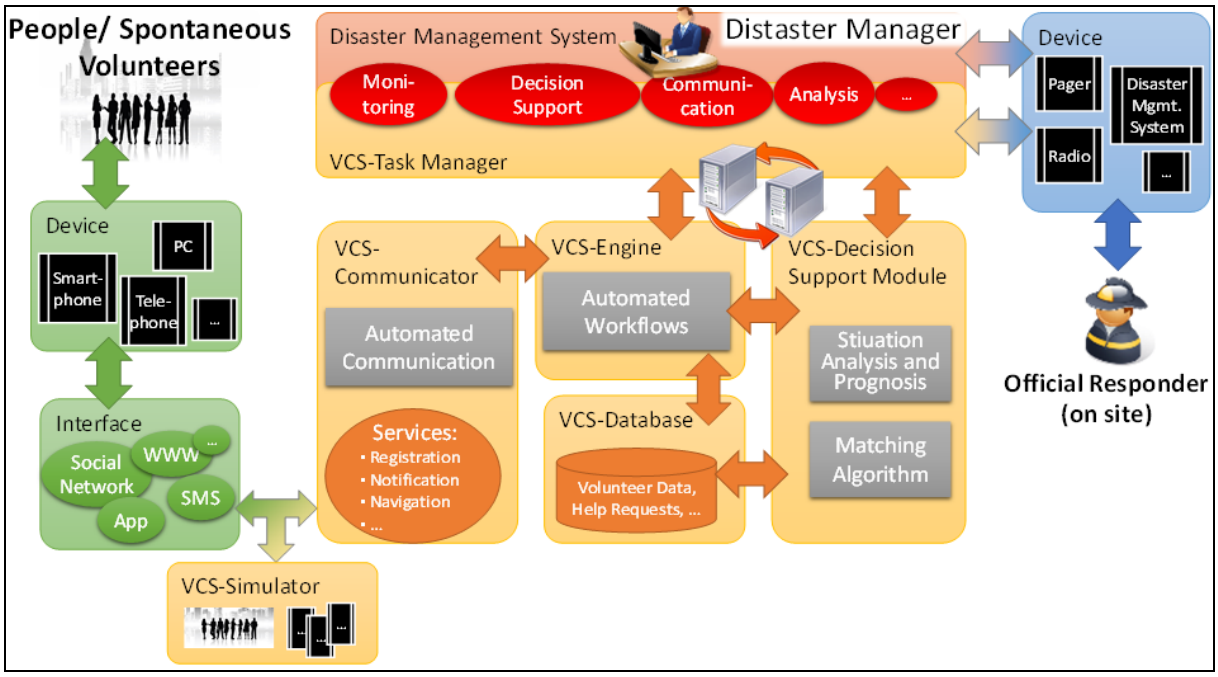

Figure 1. VCS General Architecture

The VCS server comprises five modules which interact with each other for a purposive processing of the information from Task Manager and Volunteer app (see figure 1). The main engine of the VCS is a workflow management system whereby we more precisely decided to use the Camunda BPM Workflow Engine due to its high flexibility and open architecture (for a comparison of current open source workflow engines see Bischoff & van Dinther 2016). The workflow engine is the main hub for all in- and outgoing information and manages the interaction of all further system components. The engine also controls the individual communication workflows for each volunteer. The second basic module is the Database where all information about volunteer offers, help requests and volunteer user data is stored. We decided to use PostgreSQL as it offers all necessary functionality and is often discussed as the best open source database system. Another key server component is the decision support module whose task is to constantly analyse the situation on volunteer offers and help requests to determine matches and provide information about which SUV should be alarmed for open help requests. For a detailed discussion of this module and presentation of the underlying algorithms see Rauchecker & Schryen, 2018. The fourth server module is the Communication Manager, which can be seen as a wrapper that converts the in- and outputs from and to the volunteers regarding on their preferred communication device. It is currently very simple since there is no other Interface than to the Volunteer App, whereby an integration of SMS, speech dialog systems and social media using an intelligent, purposeful chat bot and further communication interfaces is currently in development. Also part of the current research project but not a server component is the VCS-Simulator. It uses a multi agent approach to simulate the behaviour of an adjustable amount of SUVs who interact with the VCS in the same way and via the same interfaces as a human SUV would. The simulator is used for evaluation purposes as well as to support staff education and exercises providing a large number of SUVs. For more information about the simulation see Lindner et al., 2017 and Lindner et al., 2018. The last server module to be mentioned is the Web Server running the Task Manager which is currently an Apache HTTP Server. Alternatively the VCS server also provides an interface for existing disaster management systems. Using this interface, it is possible to integrate the VCS functionality in a familiar system for easier use and advantages like a shared event diary. The server features are crucial to address almost every user story but especially the basic requirements like **RV1**, **RV8**, **RV10**, **RS2**, **RS3.**

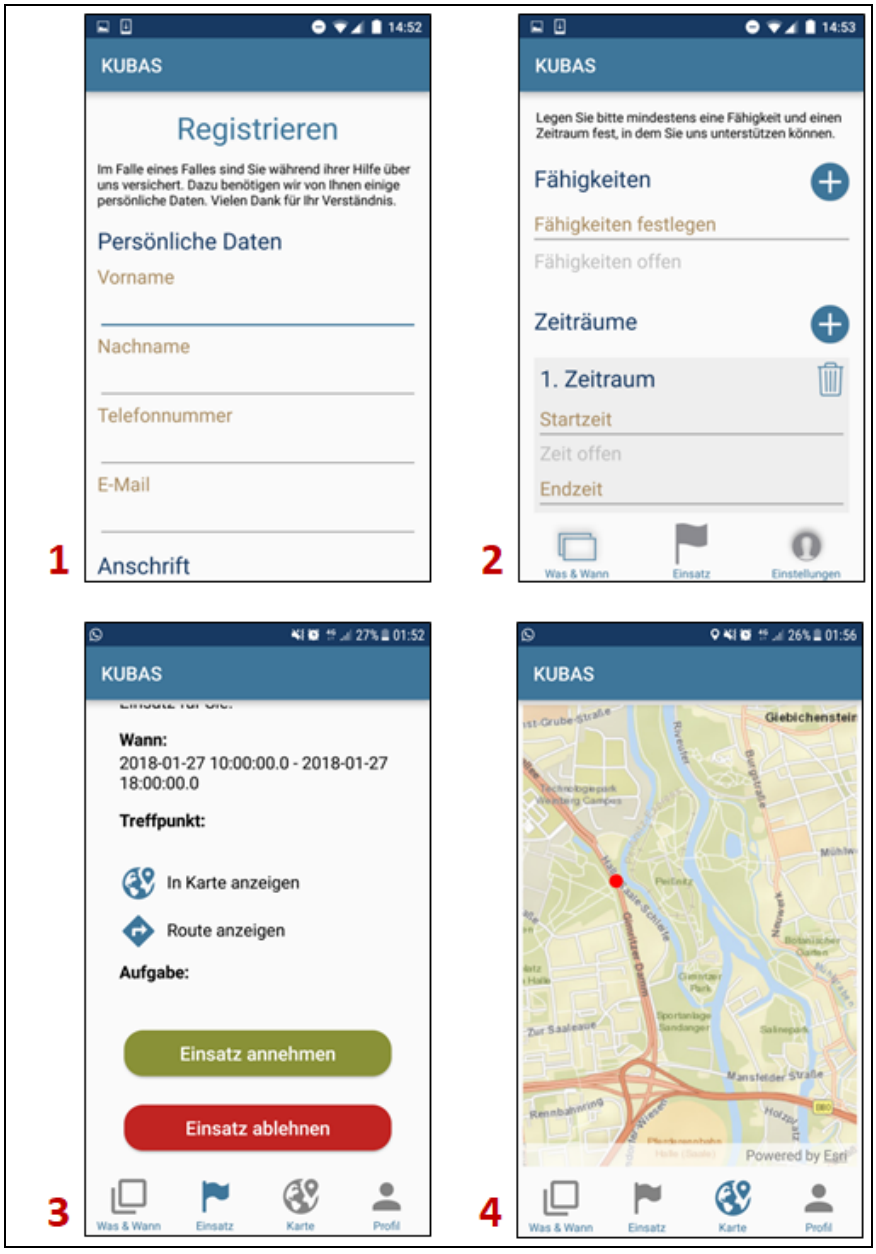

Figure 2. Volunteer App - Different Screenshots

The Volunteer App shown in figure 2 is the first implemented communication channel and was chosen because it allows the most comprehensive interaction with the VCS in the simplest way and provides the best flexibility for users (**RV9**). In the current version volunteers can already use all core features of the system. They can register (figure 2 – Screenshot 1) with the system by just setting a nickname and password or additional submission of some personal data for an easier processing of possible insurance cases (**RS9**). When logged in, the user has the possibility to offer their volunteer work (**RV4**, figure2 – Screenshot 2) by specification of capabilities (hard work, medium work, light work, information delivery, transport, care), available working time and current location, whereas the letter can be automatically stated via GPS tracking or otherwise is set to the home address of the user. The existing offer of a user is overwritten when he resubmits new information (**RV5**). Users get a short acknowledgement if the offer was successfully received (**RV7**). The app also provides an automatic alarm, to inform the user about an incoming mission request. This request can be accepted or rejected after notification of the general mission information (**RV1**, **RV2**, figure 2 – Screenshot 3). If the mission is accepted, the user is routed to the mission meeting point (**RV13**) and, with help of geo-fencing, automatically registered as on-site if he allows GPS tracking (**RS6**, figure 2 – Screenshot 4). The user can always change to a detail view of his accepted missions (**RV3**).

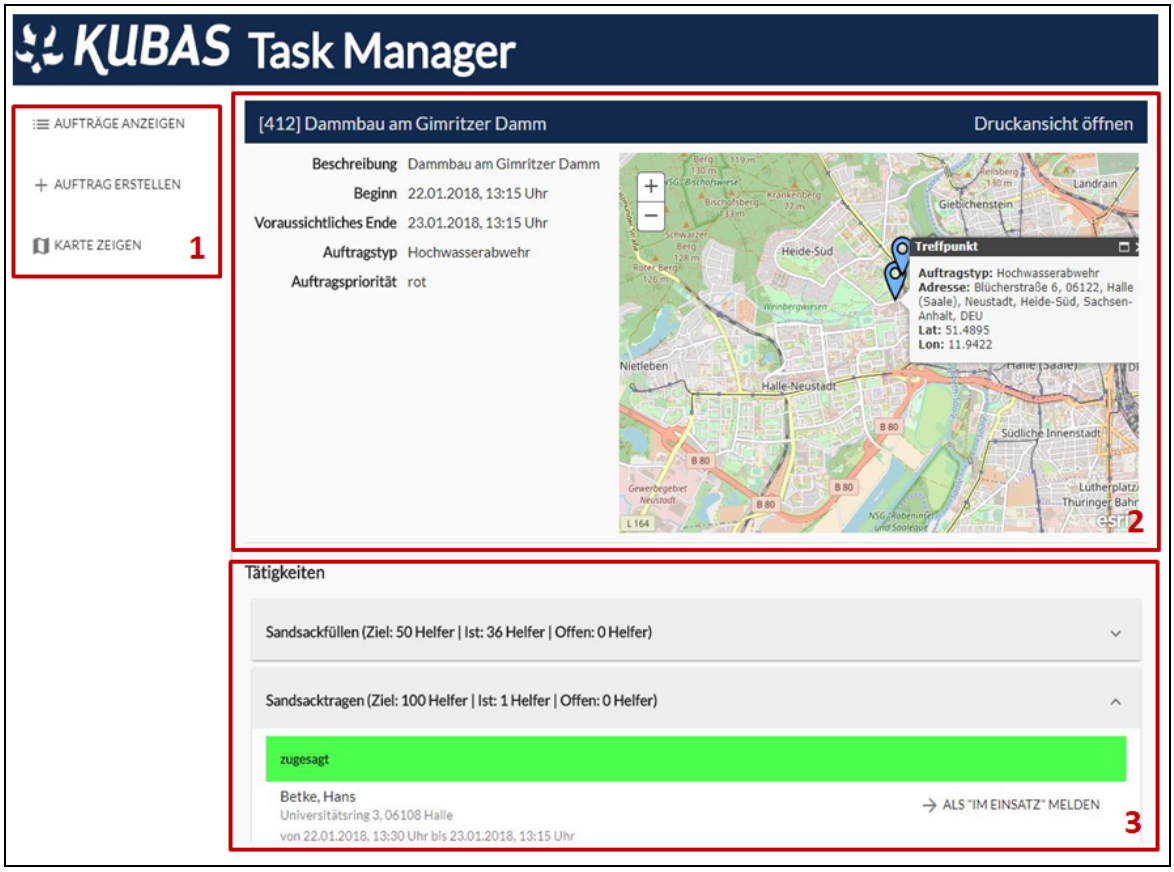

Figure 3. Task Manager Detail View – Screenshot

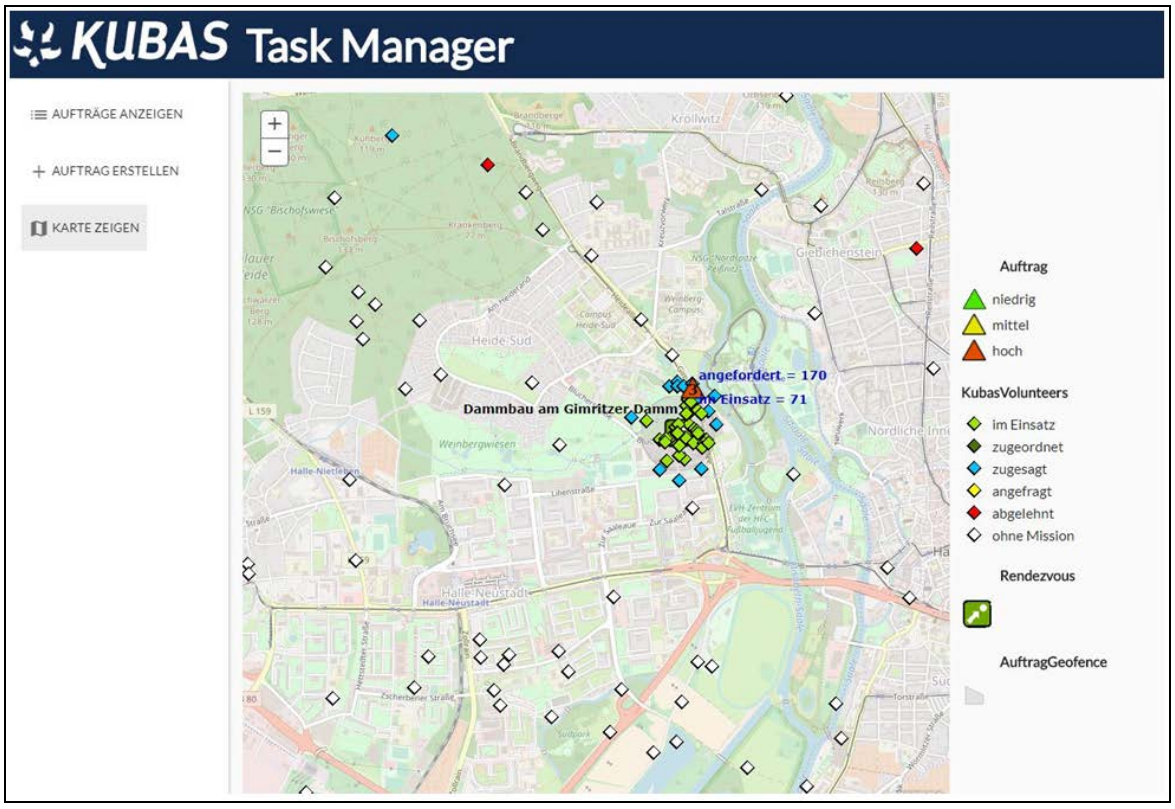

Figure 4. Task Manager Map View - Screenshot

The Task Manger is the dedicated, browser-based user interface for crisis committee members or disaster managers which can be used if there are no existing operational command systems with integration of the VCS.

Similar to the app, the Task Manager is not complete but already supports the basic features to allow a volunteer coordination through creation and monitoring of tasks as well as a map overview (figure 3 – box 1). To create a volunteer task, users must set start and end time, priority, description, the activities to be executed, demand of volunteers for each activity, the task location and an optional meeting point (**RS1**). The Task Manager also provides a detail view for every created task (**RS4**, figure 3 – box 2) and information about the status of all assigned volunteers (**RS2**, figure 3 – box 3). A feature for the on-site commander in chief is the possibility to mark volunteers as "present" in the system, generate attendance lists or add on-site volunteers which have not yet been registered in the system (**RS6**). The last big feature is the map view where all tasks and optionally also all volunteers are displayed with their respective status and some basic information (**RS5**, figure 4).

The VCS prototype currently focuses on providing the basic functionality of the system which could be achieved with the presented version. Although a huge amount of user stories is already considered, especially those about custom information exchange (**RV11**, **RV12**, **RS 8**) or with sophisticated detail challenges (**RV5**) demanding further specification could not yet be implemented. However, the prototype demonstrates that the development of a VCS as demanded by the user stories is technically possible.

ACCESSIBILITY OF THE VCS

The VCS and its components are designed to incorporate a large number of volunteers with different abilities, skills and motivations. In order to achieve that, simplicity and variety were important requirements for the system development. However, main goal of the system is the coordination of spontaneous volunteers to support on-site response. While every volunteer offer is always welcome this purpose nevertheless restricts the targeted user group on volunteer side to people being able to provide this kind of support. The following discussion describes the most important key features of the system addressing the universal design principles as stated in Story, 1998.

The system supports a variety of different communication channels like smartphone app, telephone, SMS and some social networks. While this variety should also provide a fall-back mode, if the internet is not available it is first of an offer to all volunteers to use their preferred or maybe only usable communication device. In this way we can involve volunteers with different abilities like illiterates, who can use the telephone or mute people, who can use one of the text-based communication channels. Furthermore, the final system provides open-source interfaces for each of the supported communication channels, allowing users to develop own solutions for user interaction. If e.g. the standard smartphone app may not provide a sufficient usability for some kind of disabilities it is possible to write an own app using the features of the system.

Another point is the minimalized and simplified user interaction. In the simplest case, telephone-based registration, the user has to enter just 4 information (refusal of personal data survey, preferred volunteer time, capabilities and location) to submit the volunteer offer followed by telephone call with a yes/no question when he/she was assigned to a mission. The system also tries to automatically find necessary information in the registration process, so that the user do not has to think about it. For example the location can be automatically submitted from the GPS feature of a smartphone, if this device is used. Another example is the unique identifier of each volunteer, which is automatically either his telephone number or social media account nickname. The system also has a high tolerance to incorrect entries while entering location or residence since every entry is automatically checked against a post office database of all existing addresses so that it can be corrected before saving or demand a second entry. Information regarding volunteer time and capabilities will be surveyed via multiple choice queries to prevent misunderstandings.

The volunteer capabilities are kept very simple to exclude as few people as possible. Every volunteer can chose at least one up to all of the following capabilities: hard physical work, medium physical work, easy physical work, paper work, care, information retrieval. These capabilities were defined in multiple workshops with disaster managers trying break down all imaginable volunteer tasks to a simple set of required competences. In the system database each of the capabilities is bound to a predefined but extendable set of different volunteer tasks for different situations. When creating a volunteer mission the disaster managers choose one or more of these tasks and can add further mission details. The volunteers matched by the decision support module will get this information and still can decide if they are able to do this work or decline the mission. This processing allows an easy registration of the volunteer offer without forcing the volunteers to think about dozens of possible tasks whereby they still can decide if they are suitable for the specific mission.

STAFF EXERCISES

In this state of development, the system is far from being complete but already suitable to test the main concepts of the projects and collect feedback for further iterations of the development process. Hence, up to now, the

system has already been tested at one large and three small staff exercises of the crisis committee of a large city (population > 200.000) in Germany. The designated users (n=3) were experienced staff members with responsibilities in different subject areas (supply and logistics, communication and public relations, chief of staff). Users on volunteer side were mostly simulated by a multi agent simulation developed in the project to imitate the behaviour of SUVs in large-scale disasters for exercise and evaluation purposes (Lindner et al., 2017, Lindner et al., 2018). A small amount of volunteer users was played by project members and members of the local fire department by using the Volunteer App.

Hereinafter we give a short summary of the feedback without mentioning every detail statement and feature suggestion of the participants. A substantial evaluation of the mature system based on field exercises with real volunteers and a novel coordination-performance measurement method will be subject of a following completed research paper. The overall feedback in all previous exercises was positive whereby staff users emphasized different aspects depending on their professional background. The supply and logistics expert was especially pleased to know the number of volunteers at each task site as it would facilitate the planning of necessary supplies and concrete information about present volunteers will save a lot of work in the processing of possible insurance and compensation claims. The communication expert positively mentioned the direct and short communication channel to volunteers as well as the automatically selection and limitation of the target audience in contrast to the usually used mass media. He also stated, that the acceptance of the system by volunteers must be analysed. The chief of staff highlighted an improved situation overview due to the task and volunteer map and the detailed information on occupancy rates of each task. The creation and communication of precise tasks would allow him to make better use of the volunteer potentials as he can employ them sophisticated and more goal oriented. He also mentioned the importance to evaluate the reliability of the system information. All participants positively mentioned the ease of use of the Task Manager as well as the Volunteer App and stated this as a critical requirement for the application of the system. However, no consistent position could be derived regarding the information that should be communicated using the app. While some people wanted the app to share more information on the disaster and their respective task with the volunteers others did not share this opinion because more information could bring volunteers to draw the wrong conclusions and behave undesirable e.g. by independent actions which could harm themselves. This issue was recognized and will be analysed in further research. In summary, first feedback underlined the assumption, that the system can improve coordination of SUVs by crisis committees whereby some research still has to be done.

CONCLUSION

Inquiries of disaster events of the recent past led to the presumption that the potentials of SUVs could be better utilized by responsible crisis committees if modern information technology and respective methods are applied. In this paper we derived requirements for a volunteer coordination system by analysing the literature and interviewing staff members as well as former spontaneous volunteers. In consideration of the resulting user stories we developed and presented the first prototype of a volunteer coordination system aiming for bringing volunteer offers and official help requests together. Although not all requirements were taken into account in this early version the general concepts of the VCS could be brought to a practical application. First user feedback from staff exercises was overall positive giving first indication for the usefulness of the approach. The development of a more comprehensive and mature system seems possible and desirable by potential users.

However, the research in the project and the development of the VCS is not completed and many open challenges persist. An important concept of the project is the diversification of communication channels, but up to now just the smartphone app could be implemented. Further communication channels like SMS, speech dialog system and social media apps need to be integrated to reach a wider range of spontaneous volunteers and improve resilience by using different communication infrastructure. Also the communication workflow is currently concentrated on the essentials with just four general functions (registration, offer creation, mission request, mission tracking) although further features like grouping or carpooling are desired by volunteers. Other crucial system components like the optimizer for allocation of volunteers and the multi agent are also constantly enhanced and refined. The results of the respective research efforts can be found in other papers (Rauchecker & Schryen, 2018, Lindner et al., 2018). The last substantial prototype enhancement worth mentioning is the integration of the system into existing operational command systems to create a consistent user interface and a better integration of volunteers into existing command and control structures. To reach this, the project team is currently enhancing the standardized, disaster specific XML-interface “XKatastrophenhilfe” to allow the easy exchange of information for coordinating spontaneous volunteers. The operational command system DISMA, whose usage is obligatory by disaster response agencies in different German federal states, will be the first system to use the VCS functionalities, providing a prototype in February 2018. The final step prior to a comprehensive evaluation is the development of a measurement method for the coordination performance. Performance indicators need to be defined to make a comparison between situations with and without usage of

the VCS. The last phase of the project and the design science process is the evaluation which will be conducted in three large scale exercises with a huge number of volunteers and further small staff exercises.

We do not assume the VCS to completely replace current coordination practices or render the engagement of crisis committees in social networks and mass media redundant in order to coordinate spontaneous volunteers. Although the system can provide considerable benefits and is easy to use, some people will prefer to use their familiar communication and information platforms which in turn have features that are out of scope of the VCS. However, the approach has the potential to make a notable contribution in improving the efficiency and effectiveness of coordinating SUVs. If the evaluation proves this thesis it would be interesting to analyse the potentials of the system in other parts of the worlds with different conditions in infrastructure or disaster challenges. A current idea is to make use of the system in third world countries like Ethiopia, where SMS is an important communication channel. For example in a drought catastrophe the roles in the system could be changed so that crisis committees of NGOs and government state their support offerings whereas citizens communicate their support requests and the system informs about the nearest supply stations. The approach may be part of a solution for different disaster specific problems and previous achievements encourage further research efforts in this area.

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Track 10

Case studies and reflections from practice

Hurricanes Send Signals for the Future of Emergency Preparedness

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ABSTRACT

Trends over the past decades, when coupled with recent disaster events, call into serious question whether our typical reactions to natural disasters will be sufficient for what we can expect in the future. This paper summarizes current events and scientific understanding of our planet to provide insights of the authors into what should be the basis for future policies and plans.

Keywords

Hurricane, Puerto Rico, Climate Change, Disaster Preparedness, Disaster Recovery

INTRODUCTION: CLIMATE CHANGE AND NATURAL DISASTERS

In the 2017 hurricane season, there were five hurricanes in the Atlantic by the end of September that reached scales of levels 4 and 5. For the one that hit Houston, the U.S. president referred to it as a 1 in every 500 years natural disaster event. Since we have been recording Atlantic hurricanes, there has not been this many level 4 and 5 hurricanes in one season (Astor, 2017). The 2017 season seemed unique and occurred a year after a fairly mild hurricane season in 2016.

With tropical storm Ophelia's transition to hurricane Ophelia in October 2017 (Astor, October 12, 2017) this became the first year in more than a century—and only the fourth on record—in which 10 Atlantic storms in a row reached hurricane strength. The last time for 10 storms reaching hurricane strength was in 1893. There were also 10 hurricanes in 1878 and 1886. However, there is not good data for how strong these prior 10 storm seasons were. In 2017, two storms reached level 5 and two reached level 4. The number of named storms of 10 hurricanes and 5 tropical storms has made the 2017 Atlantic hurricane season one of the busiest on record.

We have good models for where a hurricane will go once we detect its birth and measure its properties and those of the surrounding ocean. However, we have no model of the Atlantic Ocean that predicts the birth of a hurricane. We also have evidence that there are some interactions between the various oceans that can influence disasters. A recent study shows that differences in water temperature between the Pacific and the Atlantic oceans together with global warming impact the risk of drought and wildfire in southwestern North America (Chikamoto et al, 2017). However, we have no models that measure the interactions between the oceans and the creation of hurricanes, let alone the properties of some of the strong currents that intersect the various paths of hurricanes. Our climate and its interactions with all the properties of the earth involves a great many complex variables:

- Carbon Dioxide content of the atmosphere
- Ocean water temperatures, salt content, currents, interactions with fresh water bodies
- Ocean currents and special areas (e.g. El Niño, the Caribbean, Artic, Antarctica, glaciers,
- Rainfall, air currents, air temperatures, storms, tornados, cyclones, hurricanes, humidity
- Volcanos, earthquakes, relative position of the moon and other planets,

The earth is a very complex system. To be able to predict the future of the earth in terms of all the above variables and really predict changes and resulting disasters we would have to have a model that integrated all the above factors and understood how they affected one another to be able to predict things like the occurrence of hurricanes and their strength.

The 2014 launch of the Orbiting Carbon Observatory-2 Satellite started monitoring of the comings and goings of CO2 from the atmosphere. Scientists knew that El Niño was a factor that caused more CO2 to build up in the Earth's atmosphere. El Niño is the appearance of unusually warm water in the Pacific Ocean off the coast of South America, recognized by local fisherman as early as the 17th century. El Niño tends to lead to drying in parts of the tropics, resulting in less photosynthesis and less uptake of carbon dioxide (Thompson, 2017). The new satellite detected a large 2015-2016 El Niño which helped to cause the biggest year-over-year jump in global CO2 concentrations on record. The new satellite detector also allows the observation of higher CO2 levels over urban areas verses rural areas. The satellite also picks up the decline in the difference during the summer due to plant growth.

The calibration of a sensor in the first of several satellites launched to measure the height of the sea surface using radar had a problem that seemed to show that the rate of sea-level rise was holding steady or even declining (Tollefson, 2017). After the error was discovered the review of the past data and related adjustments of the data suggests that sea levels are indeed rising at faster rates each year. This current analysis was presented this year and indicates the sea level increase in 1993 was 1.8 millimeters per year and increased to 3.9 millimeters in 2016 (2017 Steven Nerem, in press). If the sea level rise continues to accelerate at the current rate, Nerem predicts a rise of 75 centimeters (2.5 feet) over the next century. However, this ignores any unusual variation in land ice melt, volcanic activities, and earthquake activity.

If the Earth's warming continues beyond 2 degrees Celsius, sea levels will rise faster than any time throughout human history (Waldman, 2016). The Atlantic coast of North America will be the worst-hit area. New York and other cities could see seas rise by more than three feet by the end of century. If warming exceeds 2 degrees by 2100, as some climate scientist worry it might, about 80 percent of the global coastline will experience a rise in sea levels of six feet. While researchers typically focus on the loss of glaciers in Antarctica and Greenland, the loss of land ice in other spots across the globe is now contributing to sea-level rise at almost the same rate as the Arctic's melting ice.

There are five different forms of flooding that can occur as a result of hurricanes. Part of the problem is that 93% of the extra heat being trapped in the atmosphere by increased greenhouse gases is being stored in the ocean. Higher heat levels can even alter ocean currents like the Gulf Stream and atmospheric currents like the Jet Stream (Englander, October 11, 2017). These are:

- Rainfall: More water evaporates due to warmer oceans, increasing precipitation.
- Runoff: Extreme rainfall can trigger the problem of runoff.
- Storm surge: The cyclone force of a hurricane "sucks" a huge amount of water with its low pressure and pushes a giant wall of water as it moves.
- Sea Level: The primary driver is ice melt on land (i.e., glaciers). It is rising slowly and steadely due to climate warming.
- "King Tides:" The pull of the moon and other planets, the oceans change height on a regular tidal cycle. The extreme high tides are called "King Tides" and when they occur together with a storm surge, there are massive flooding effects.

Preparing for Future Disasters

The lessons of the recent set of hurricanes are that major changes are needed in Puerto Rico, Houston, in much of Florida and other low-lying coastal areas. The physical changes needed in the areas involved are in zoning, building codes, improved water management, and more survivable electric networks. For example: large tracts of land cannot be paved over with waterproof toppings to prevent the absorption of water; and forests cannot be removed from areas where excess water can produce major mud slides.

It is clear the heat wave in mid-California in 2017 is another result of climate change. There have been historical droughts in that area in the past but not some of the temperatures that have occurred recently. This year there was a temperature of 106F degrees in San Francisco and 109F in the Santa Rosa area. These are temperatures that are a real record in recorded history for those areas. Moreover, the south of California has expanding desert areas. In addition, in the U. S., the water systems are the oldest of all the infrastructures and will be a growing major problem in the near future (Turoff, 2015). They have passed an average age of 100 years and are getting older at about ½ a year per year. All the major infrastructures suffer from a lack of raising local, state, or federal tax funding that has all the major infrastructures aging and increasing vulnerabilities

(Turoff 2015, Turoff et al 2016, Turoff et al 213, Turner 1976).

Given our demonstrated vulnerabilities, is the Hurricane season for the year 2018 going to be like the year 2016 or 2017? As yet, we cannot answer this. The Atlantic Ocean is a "very big complex system" and there are some general principles about complex systems that have been observed in some natural systems such as biological systems over long periods of time, involving weather changes as well as the included living things. A complex system (Complex System, Wikipedia) over time undergoes a repeatable cycle, on say a yearly time period, and usually exhibits a series of stable conditions with smooth transitions between the outputs of the system which tend to be repeatable over time. These outputs are based upon inputs which may vary but be repeatable over time as well. When the input or control variables begin to change their expected input to the system, the stability of the system starts to disappear and extreme changes begin to occur outside the stability region of the output as the system seems to seek a new stability condition. As the input changes continue to exceed prior ranges, at some point the system may find a new area of stability and the output will find a new stability as well. It has been widely reported, recently, that the cost of natural disasters in the U.S. for the year 2017 is the largest ever recorded and largely due to the conditions generated by climate change. Given our lack of true preparedness, we can expect as well higher costs in the future.

We have to ask, dose the hurricane season for 2017 in the Atlantic Ocean represent a new stability for the occurrence of hurricanes? We cannot tell yet, for instance, if it will repeat in 2018 or if it is a two year cycle (or longer because of factors like El Niño) where 2018 will be like 2016 (mild) and the large hurricanes in series will repeat in 2019. Given the very clear occurrence of climate change and the warming of the oceans as well as the reduction of salt density taking place, we should believe a very significant change is taking place. Besides the record heat and many more severe wildfires as a result in the Western U.S., we have water shortages developing as well. In Oklahoma, a history of injecting waste water into the ground as well as considerable fracking for oil has now generated frequent earthquakes in a state that did not have more than one or two a year previously.

Given that it is possible that we are facing a future increase in the magnitude of natural disasters, is it correct to just try and replace what was destroyed with the same facilities that existed before? Or do we need to make major investments in a new preparedness level that will be able to cope with what we faced in 2017? A recent article that appeared online in Scientific American pointed out how Florida, using its current growth practices over the past decade, actually set the stage for a much larger case of destruction by the hurricane that struck Florida (Sneed, 2017). The article pointed out that in the last decade the amount of cement and asphalt not allowing water to seep into the ground was more than doubled. Pavements that allowed water to pass through were more expensive and not used even though advice was given to use that. This was one of many items reviewed. A similar spread of concrete and asphalt occurred in Houston before its devastating hurricane-related flooding.

Even if this sequence of large scale hurricanes does not reoccur for the next few years it is clear that within the next decade the warming of the planet and the increase in the sea level and temperature of ocean areas are going to produce quite a few level 4 and 5 hurricanes. If the professionals in Emergency Management are going to be effective in the future, they are going to have to convince the leadership in local areas to be prepared to deal with this new future. Even more importantly, the professionals and the leadership have to convince the public of why they should support this new emphasis and how the total community can become a critical part of preparedness for future disasters. The public can become the most critical part of the preparedness process for dealing with future disasters (Turoff, 2015). In some countries emergency plans for natural disasters are open to the citizens in a given location. This has to be a new approach in the U.S. and elsewhere (Canos et al, 2013).

In a classic paper by Turner (1976) it was pointed out that the lack of public understanding of how to prepare for future disasters increases with the length of the period since an occurrence of a similar disaster, and thus the next occurrence was often worse than the prior one. The best way we can undertake to prevent this is the development of a total community information system which integrates all the necessary infrastructures (Turoff, 2016) and the public into a community based geographical information system. Social media systems will not have what is needed to build an integrated community system to develop the plans and preparedness for a major disaster that is likely to occur at some point in the future. This information system should have the following characteristics.

1. Every citizen member of the community has their own identity on the system.
2. Every organization that a citizen has any need for at any time to contact is represented. This includes all the utilities, all government services, all government groups, all community organizations, all medical facilities, and community organizations, as well as commercial organizations.
3. Natural disaster plans will be open to the public and organizations so they can be reviewed and the involvement of organizations and individuals as well as resources will be clear to all.

If a citizen has any problem he or she can choose, the appropriate party or organization and fill out a form indicating the problem and/or need. If necessary the user can request a human interaction if the standard form for that organization does not cover it. If a party has resources or talents that might be useful in an emergency or disaster, those items may be added to his or her record for future use. All verbal reports going into the system, including telephone calls, will be translated automatically to text so the computer can monitor and use any useful information that is reported. This system will, of course, be the system that is used to respond to any emergency or disaster that occurs. For example, citizens who have bulldozers, boats, or any other useful items should always update a change of location of those items. Any citizen can put in a record of their necessary medications and any other information that might be relevant in a specific emergency. In an emergency, a person could enter any problems they are having or are observing.

The system could also be tied into sensors like ones that would indicate water levels at places in roads that are likely to flood. Clearly if, for example, there was a small earthquake, reports of natural gas problems by citizens might well cluster in an area and be an immediate indicator of what could be a dangerous gas leak. It would be possible to place any sensors into the system that might be of significant use in any major emergency or natural disaster. Citizens in given areas would have contacts with sick or disabled individuals that would need to be checked for their condition. The detection of road blockages from any cause would be straightforward. The community information system becomes the emergency response system when it needs to serve that function.

Electrical Systems and the Puerto Rico Example

The explosion of a hydrogen bomb over the Pacific or the U.S. mainland could have considerable negative consequences. The March 1954 Castle Bravo H-bomb test has been studied extensively over the past six decades (Greenemeir, 2017). The Castle Bravo bomb—code-named "Shrimp"—remains the most powerful nuclear weapon ever tested in the atmosphere by the U.S., about 1,000 times stronger than the atomic bombs dropped on Hiroshima and Nagasaki during World War II. Shrimp's detonation unleashed a 15-megaton blast that was two-and-a-half times greater than expected. (A megaton has the explosive force of one million tons of TNT.) It also resulted in the largest nuclear contamination accident in U.S. history, as shifting winds carried radioactive fallout across the inhabited atolls of Rongelap, Ailinginae and Utirik as well as Rongerik—where U.S. servicemen were stationed—in the central Pacific's Marshall Islands.

The Economist (2017), pointed out that a surge of energy on March 13th 1989 due to coronal mass ejection from the sun took down Quebec's electrical grid for nine hours. A transformer-wrecking pulse (EMP) is produced by a nuclear bomb, if donated high up, like 40 miles. A midrange missile tested by North Korea on April 29th 2017 exploded 44 miles up. A nuclear blast, say occurring above eastern Nebraska, would radiate out EMP over most of the continental United States. It could permanently damage the grid's multimillion-dollar high-voltage transformers. Many are old (their average age is about 40). Some would burst into flames. There has been some thought that some of the California fire starts were due to exploding transformers. America runs on roughly 2,500 large transformers, most with unique designs. Only about 500 of them can be built in the U.S. per year. The U.S. federal government has suggested specific improvements to correct this very vulnerable situation; however, due to prior congressional action it has no jurisdiction to enforce new standards for the electrical network. The problem can also occur from a solar storm headed in the right direction. NERC (the North American Electric Reliability Consortium) has repeatedly and successfully lobbied the US Congress to prevent legislation that would require EMP-proofing. This is something that could one day be seriously regretted.

Hurricane IRMA skirted the north side of Puerto Rico beginning on September 7, 2017 at 11:00PM and when it cleared the island, it left around one million people without electricity. Hurricane Maria hit the south east corner of the island on September 20, 2017 at 6:15AM and continued to travel most of the length of the island, leaving from the north east corner of the island. The electrical system was almost complete destroyed. While the Jones Act was lifted in Texas and Florida almost immediately after they were hit, it was not until September 28th that the Jones Act was lifted for Puerto Rico (Vicens, Sep. 27, 2017). The Jones Act, which requires that all things delivered by a ship from a U.S. destination to a U.S. destination must use U.S. crews, was not immediately removed after two hurricanes that hit Puerto Rico. Apparently, the department of Homeland Security was not "formally" aware of the complete lack of electricity and phone capability to most settlements outside of San Juan and in many parts of San Juan. Those FEMA personnel first brought to the island seemed to be completely unaware of the lack of electricity, communications, and roads, were telling **all citizens** to sign in online to fill out forms to get things and to come into the city of San Juan to pick up things.

The widespread lack of electricity had already occurred right after the first hurricane hit Puerto Rico and after the second hurricane hit the whole network was almost totally destroyed so that 95 percent of the territory was without power (Vincens, Sep. 30, 2017). In addition, most of the communication and electrical poles were destroyed. The concentration of the Homeland Security personnel in one "air conditioned" building in San Juan

did not seem to be aware of this situation for some time. Also, no FEMA personnel showed up in any of the remote areas until after a big boost in military personal and helicopters were finally brought to the island after the president's first visit. The FEMA personnel began to focus on the **local mayors** and were telling them to gather the requirements and bring those to them. They also said the mayors should arrange to have the needed supplies picked up. The mayors still had no communications, electricity, or clear roads for vehicles.

The only area outside of San Juan that the President visited on his second trip was an upscale area where most of the single family housing was made from cement, which was able to survive much better than the typical construction on the island. Given the possibility that the future will have much more frequent hurricanes at the 4 and 5 level, for these islands to survive with housing intact, the rebuilt houses and other buildings have to use cement for all housing. But even those cement houses in that one small area lost their electricity after the second hurricane.

On October 9, 2017, reporters from MSNBC visited a town in Puerto Rico that had not yet had any delivery of food, water, or medical services. It had one received visit from FEMA people but only to get the needs of the town to be written down by the mayor. Their claim was still that they do not deliver food, water, or medicines. They will gather what is needed but the Mayor had to arrange for the material to be picked up. The mayor had to get on the web to find out when the materials were ready for pick up. Without any electricity, phone service, or roads, this approach by FEMA was completely unworkable. In some cases, locals hiked out and in to bring in food but often locals had to rely on uncertain local water sources.

The lack of electricity situation has caused many deaths and continued generating increases in medical problems. Three weeks after the second hurricane the lack of medical facilities and care resulted in more deaths. One person who needed added Oxygen died at age 58 after a week without added oxygen; another died from a reduction in his allocated time on a dialysis machine due to a lack of fuel for the generator. The lack of electricity for most of the island is a clear cause of generating added deaths due to existing medical problems. People who became ill found it difficult to get to available facilities and Puerto Rico did not have any added capacity to treat the size of the population with medical problems (Robles, October, 10, 2017). A number of people got sick from contaminated floodwaters. Less than half of Puerto Rico's medical employees had reported to work in the weeks after the storm. It was still impossible in October for the local government to track the employees that had left the island for the mainland or were stuck in cut off areas of the island.

As of October 10, the number of deaths due to the disaster had risen to 43. There was a growing supply of facilities like the Navy medical ship but the key problems for those scattered throughout the island was the lack of electricity, the lack of any phone or online communications, and roads that were still impassible for vehicles. It is suspected that a number of people had died from leptospirosis, a bacterial disease likely in some of the floodwaters people had to walk through and increasingly in the only water access in the cutoff isolated areas. There were not adequate facilities to evaluate this. People were being warned to drink only bottled water and to wear protective shoes near bodies of water that can be contaminated with animal urine. These are not items that were in the usual preparation instructions from less strong storms and there was no ability to convey information of this sort to many localities on the island. Clearly water purifiers, solar radios, and water boots, are not typical items conveyed by local governments to the public for emergency preparation. Confirming the infection for leptospirosis is currently taking about a week. Usually Puerto Rico sees a few dozen cases a year and perhaps one death.

On the 26th of October over MSNBC, it was announced that FEMA had a specific plan for handling a major storm attack on Puerto Rico. It was also announced that FEMA would not make that plan public or available to the government of Puerto Rico.

As of the middle of October, forty percent of the island still lacked running water because of the lack of electricity which affected still 85 percent of the island (Acosta, 2017). As a result, many people were bathing in streams and non-potable water from huge tanks. One likely victim cut his hand a few days before the storm and it had not completely healed. A few days later he had pain in his feet and knees and his temperature went to 106 degrees. He was taken to the hospital more than a dozen times. Many of the medical facilities on the island were short of necessary supplies. Oxygen was another item in short supply. Infected insect bites were a common cause of swollen limbs. Puerto Rico had over 6,000 dialysis patients which clearly forced reduced time on such equipment and difficulties reaching the equipment. Dialysis treatment of 12 hours a week had been reduced to only 9 hours as the power emergency persisted. There was a local group arranging the ability of some dialysis patients to get a trip and location on the mainland where they can get better dialysis treatment.

Before these hurricane events, Puerto Rico was a supplier of water to other islands and had a number of factories producing bottled water for export. With the lack of an island wide electricity system, those facilities have not gone back into operation. The lack of electricity also created a demand for generators of any possible size available. It got so bad in some settled areas that there were now complaints of noise in many housing

areas (Fausset et al, Oct 7, 2017). Generators vary in size from lawn mower size to a moving truck size. With a 45% poverty rate, it is only half the population that can afford those machines and the cost of fuel. Currently, near the end of October, 85% of the island was still without island wide electrical power and it may be many months before a new island wide system is in place. At the end of October, there are still many localities where the military had to fly in food and water and there is no real data on the actual count of causalities in some areas. With respect to generators, the sales rate has been 250-300 units a day and they have used up U.S. sources recently and were now (i.e. November) importing them from Canada. Without a real island wide electrical system, it is doubtful that the water bottle industry or a number of factories for specialized medical items will reopen anytime soon.

Given the likelihood of future major hurricanes, the new electrical system has to be much more survivable than the prior one and needs, as well, to make major use of solar, and wind sources as well as significant battery backup for homes. The Governor of Puerto Rico estimated on Oct. 17th that it would be December before they would have a new electrical system (Fausset, 2017). Also, thousands have fled Puerto Rico, without knowing if they will ever return. Puerto Rico should go to buried water-proof electric cables everywhere and very sturdy metal supports buried in concrete for above ground use such as Wi-Fi/cellphone systems. They also should install an island wide broadcast Wi-Fi system not dependent upon cables.

The initial objective was to restore energy to one hospital in each region of the island. There are at least two regions where the electrical network was completely destroyed. Some patients were being encouraged to travel to the mainland to get the medical service they needed. A lot of the facilities were supported by generators running on diesel fuel and not a working electrical network. As of October 25th , a 300 million dollar contract for restoring the original network was given to a company in Montana with two initial employees and one of the owners was related to the head of the U.S. Interior department. This was done by the present company owning the network which was in bankruptcy. This has caused some concerns and by various parties even though the governor of Puerto Rico agreed with this action. As now planned, it is unlikely to be an improved system that might resist future hurricanes of similar size. As of January 12th 2018 in THE WEEK (page 14) included is a summary of news items appearing in many papers that only 50% of the power system in Puerto Rico was working and it would be May sometime before the total system will be restored. Deaths resulting from the disaster are expected to be more than 1000 persons which makes the results more like Katrina. There is no indication in local news that road repair equipment is in place. The funds made available by FEMA for bringing in crews and equipment from other state utilities were much less than that for Houston or Florida even though Puerto Rico had far more damage.

The 28,000 acre forest (El Yunque National Forest) in the South-Eastern part of the main Puerto Rican Island was largely destroyed. It was the only tropical rain forest in the United States and was a significant tourist destination. The billions of gallons of water that rain every year on the eight rivers that originate at this site supply 20 percent of the drinkable water in Puerto Rico (Ferre-Sadurni, October 12, 2017). The foliage and moss that made this a capture area for rain are now totally defoliated and this means this major source of drinking water may no longer be available for a very long time. The resulting climate will be dry and hot. There is also a likely loss of a unique breed of parrot that lived in this area and it could take a century for this forest to rejuvenate.

Some areas had not had power for 45 days due to the earlier hurricane Irma (Acosta, Oct 20, 2017). In Texas and Florida, thousands of professionals in the electrical network area were brought in almost immediately to repair a much smaller outage of the local electrical networks. In Puerto Rico there were only around 500 brought in to handle a much greater sized outage of the electrical network. The power loss in Texas was only about 10% the size of the Puerto Rico outage. The Puerto Rico situation was further complicated by possibly around 1000 mudslides blocking roads in the settled hilly areas. Getting to those areas required hiking and in some cases only motorcycles, rather than cars or trucks, could get by. The lack of any air conditioning and the lack of light at night made life in a very hot climate quite difficult. None of the bridges that were destroyed were being rebuilt by November. Shortly after President Trump's visit, a mudslide hit the neighborhood that Trump visited and destroyed a local bridge in Guaynabo, stranding families who then had to hike through mountainous, overgrown terrain to get food and water (Weir, B. and R. Clark, CNN, 20/16/2017).

The death rate has been increasing and on Oct 21, 2017 there was a outage reducing electrical power from 20% to around 10%. They had initially had 230 brigades (electrical repair teams) and as of Oct seventh they were beginning to bring many hundreds more. Associated problems include bringing in enough replacement equipment (e.g. poles, transformers, generators, etc.) and many of the plants date back to the 1950's. At least three repaired grids have subsequently collapsed. There was not yet any mention of attempting to build an electrical system that will survive future hurricanes of similar strength to the two that destroyed the original system.

In Puerto Rico, we seem to have developed an "after the disaster evacuation." All the available flights and boats that can carry passengers were packed every day in October. Those with relatives and friends already in states like Florida and New York were receiving large numbers of fleeing Puerto Rican residents. This is something that should have been part of the plans for islands subject to strong hurricane attacks. In fact, we do not do a good job of planning evacuations in urban areas because all the public and organizations in the area need to be involved by knowing the plans and agreeing to participate in the process. Many urban plans do not have agreements and participation by local private organizations and business as well as community organizations. There is also no prior involvements of the citizens and the community groups to hash out many details. Examples are the lack of services like stopping for gas and eating during the evacuation as well as assurance that those without cars can also evacuate. For example, in Katrina, the plan called for the bus drivers of the city's buses to not bring their families and the participants not to bring their pets. As a result, many bus drivers chose to drive their own cars and families out rather than report for driving the city buses. While the federal government normally supplies aid to move people out of danger areas, it does not include evacuating those they rescue farther than a temporary shelter area. This is a limitation that should be eliminated.

Summary and Conclusions

We need to start assuming that a new level 5 hurricane, or a set of them, can occur every year and hit any Caribbean island or any major urban area on or off the Gulf or Atlantic coast of eastern Mexico or North America. We need to evolve a set of national standards in the U.S. for our electrical system and connections of neighboring systems as well as with Canada and Mexico. In addition, we have to design the electrical nets to handle better destructive EMP forces from the future use of nuclear weapons. The earth could have a solar storm that would also create EMP interference and destruction of our current electrical network as it is currently designed. Strongly encouraging local solar and wind generation of electricity is also very desirable. In 2017, the costs of solar production of electricity have fallen to be less than a kilowatt hour more than the use of the typical utility networks. As we have discovered from the Puerto Rico network failure, the production network of transformers is not sufficient for the replacement of the Puerto Rican system, let alone a major U.S. continental failure. According to various news items and photos, Puerto Rico is replacing the system as it was instead of deciding to bury local cables and greatly reinforce the long distance line supports and, perhaps, better protect transformers with concrete structures. This applies to all of the U.S. as well as Puerto Rico. In the recent fires in California, it is believed some were started by transformers creating fires remote from the main blaze. However, in January 2018, the federal government has put a tariff on importing solar electrical generation panels.

We need to allow the maximum ability of pavement and road areas to pass water into the earth. This was also a significant problem in both Florida and Houston. For urban and rural areas, we should move to wide scale Wi-Fi networks for local communications. This would allow distributing sensors on a large scale and being able to determine the conditions of roads, water ways, traffic, buildings, fires, etc. We need to construct all types of buildings, including homes, based upon cement. All windows should have metal shutters that can be closed and help to prevent pressures on roofs and doors. At the very least, this should be required for whatever distance hurricane water surges augmented with king tides can reach.

A recent irony for those in Texas and Florida is that five weeks later a great many people had not yet been assigned home inspectors (Fermandez et.el, October 23, 2017). Homeowners must have this inspection before they can receive money to repair their home. To reach FEMA by phone, waits of 3-5 hours holding the phone were typical. FEMA was seeking additional contractors rather than authorizing local building inspectors to take up the slack based upon a simple payment scale, with the cooperation of local governments seeking additional help. The U.S. policies on insurance for water damage need great improvement not likely to occur. The original intent for that U.S. program was to encourage people to take the funds they received and move to an area not likely to flood in the future. Instead, the lack of proper zoning approaches has caused people to rebuild many times and spend government funds many times the value of the house over an extended period with reoccurrence of many natural disasters.

In looking at infrastructures it has been shown that without drinkable water all the other attempts to restore a disaster situation to normal will fail (Turoff et al, 2016). Clearly, by November 10, 2017, this was not yet solved for Puerto Rico and had led to bacterial infections that can be fatal if not treated. A recent satellite photograph shows what looks like around 500 dirt slides around the island but the photo is such that it does not show slides for all the possible areas and the actual number could well be over 1000 (Bessetter-Kirton et al, October 25, 2017). As of November 2017, there did not seem to be the manpower and heavy equipment to do major repairs of roads. Many remote areas had to be hiked into or at best allowed motorcycles in. There were also cases of destroyed bridges to be repaired. It is going to take a few years, at the least, to repair Puerto Rico, or longer if we have more severe hurricanes in the next few years. We would hope at some point there is more realization of what is needed for the probable future we all face with respect to natural disasters.

In local areas, we need the complete involvement of the population in understanding and evaluating our efforts and plans for handling any likely natural disasters. One suspects that the people of Puerto Rico are ready to realize future natural disasters are something they have to decide to prepare for with the total commitment of the population to secure their future. They have not received from the government the aid and financial assistance that a U.S. state would have received and there needs to be the corrections to allow that population of U.S. citizens to prepare for a decent future.

A recent article expresses very well the situation in Puerto Rico long after the storms:

"It is not just water and electricity that are in scarce supply, Cellphone service ranges from spotty to nonexistent. Cars are damaged and roads blocked. For many, work and school still have not resumed, so they wander the streets, play board games and sit around telling stories by candlelight." (Dickerson and Ferre Sadurni, October 25, 2017)

Perhaps, the most important message the Puerto Rico situation can stimulate is that we have to go back to a time when we had an office of Emergency Preparedness that could impose requirements on local situations that strongly influence the ability of local areas to invest in preparing for likely disasters and reducing the likely negative consequences. For just one example of many, insurance money for flooding should go to having people move to safer areas and the locations turned to other functions useful to the community (Turoff, et al, 2004). We have to have a federal level body that will establish national guidelines and standards to reduce the negative impacts of likely disasters and insure a reasonable level of preparedness. We need national safety standards for all our infrastructures and especially for electrical systems, communication systems, and water purification.

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Immersion and Presence in Virtual Reality Training for Mass Casualty Incidents

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ABSTRACT

Preparation for mass casualty incidents (MCIs) is highly important but difficult to accomplish. Incidents are rare, often complex, and training is costly. However, with the development of consumer grade virtual reality (VR) hardware, immersive training simulations have become affordable for competency training. To make simulations effective, users have to be immersed and feel present in the simulation. We have developed a VR training system for MCIs in a user centered design process with emergency personnel and further improved the system to increase immersion and presence. In an evaluation with eighteen paramedic trainees, we compare six hypothesized design improvements between the two simulations, such as using a menu or a simulated emergency bag for interaction. Results indicate clear user preferences of interaction styles related to immersion and presence in MCI VR simulations.

Keywords

User-Centered Design, Virtual Reality Training Simulations, Mass Casualty Incidents, Immersion, Presence

INTRODUCTION

A mass casualty incident (MCI) is defined as an "event which generates more patients at one time than locally available resources can manage using routine procedures" (World Health Organization, 2007, p. 9). MCIs can include anything from area-wide natural disasters (e.g., earthquakes, hurricanes), large scale accidents (e.g., massive car crashes, industrial fires) or terrorist attacks, to smaller incidents (e.g., a car crash) when the number of injured persons overwhelms the available resources. Thus, an essential task for first responders in MCIs is to perform an initial quick examination of the casualties in order to prioritize treatment. This process, commonly named "triage", is often defined in form of algorithms (e.g. START, e.g. Kahn et al., 2009). It aims to provide the basis to make optimal use of these limited resources.

In addition to overwhelming the available resources, MCIs are also exceptional cases in emergency care (Mentler & Herczeg, 2013). They are infrequent, vary widely (e.g., natural disasters, car crashes, train derailments, terrorist attacks) and the nature of the incident is often unpredictable. The paramedics who are the first responders also have a high responsibility. The triage process is "perhaps the most important point in mass casualty management" (Frykberg, 2005) and literally decides about life and death. In addition to the huge responsibility, treatment approaches are fundamentally different to daily routine of emergency personnel. Adding the time pressure, MCIs can lead to extreme stress (Zinke et al., 2010). As the classic studies by Berkun et al. (1962) have shown, stress and urgency generated by an emergency can severely impair performance. Intensive training is an important way to prepare paramedics for these challenges.

However, despite the necessity to face MCIs with calm, deliberate action grounded in sound training, MCI trainings are insufficiently done. The scope of such trainings places huge demands on time, effort and costs (Hsu et al., 2013) as MCIs involve multiple casualties that have to be simulated by lay actors in order to create an as realistic situation as possible for the paramedics. Additionally, the desired locations for training (e.g., locations with a high risk for MCIs like harbors and major motorways) cannot be closed for training purposes in many cases. Thus, trainings cannot be conducted as frequently and as realistically as needed, even though being important for readiness of the paramedics, including the self-perceived readiness (Hsu et al., 2013).

Given the need and the difficulties of training in real physical settings (number of actors needed, impossibility of closing down likely areas), computer simulations seem to be an obvious choice for MCI training. However, simulations come with the risk of trainees not taking the simulated situation seriously and treating it too much like a game (Heldal & Wijkmark, 2017). To take the simulated incident seriously, it is crucial for trainees to become immersed in the simulation and feel present in the simulated MCI.

The degree of immersion partly depends on the technology used. Virtual reality technology can encompass anything "from simple environments presented on a desktop computer to fully immersive multisensory environments experienced through complex headgear and bodysuits" (Ausburn & Ausburn, 2004). Immersion differs depending on the technology used – with limited immersion on desktop computers with mouse and keyboard controls to higher immersion with CAVEs (cubic rooms with image projection on each wall; Wilkerson et al., 2008) or head-mounted displays (HMDs, Gutiérrez et al., 2007). HMDs seem to be very promising – providing not only sensory input that completely replaces the real world, but also allowing for more direct behavioral feedback. Several studies show the advantage of HMDs to non-immersive computer screen setups for training in emergency care and MCIs (e.g. Vincent et al., 2008; Gutiérrez et al., 2007).

While originally expensive and requiring a huge technical overhead, the recent mass production of consumer grade VR HMDs (e.g., Oculus Rift, HTC Vive) promises to make these immersive simulations available for a wider audience. VR is no longer limited to large training schools or stations. However, it remains unclear which factors and design elements increase immersion and presence in MCI VR simulations using consumer-grade HMDs.

In this paper, we use recent developments in consumer grade VR technology and compare two traditional methods of MCI training for paramedics (large-scale exercises and paper-based simulations) with the characteristics of VR simulations. While the precise representation of behavior for the treatment of causalities is an important and a long-term goal, we first focus on immersion regarding different forms of user interactions and the sequence of triage behaviors (see description of the Systems A and B below). For evaluation, we conduct an experimental comparison of two MCI training simulations using consumer VR technology (Oculus Rift) and look specifically on the impact of different design aspects on paramedics' immersion and perception of presence. The participants in the study came from the main target group of paramedic trainees, who are currently trained with the aforementioned traditional approaches. Other areas of application are formal trainings of experienced paramedics (to refresh existing skills), or self-directed learning of individual paramedics. The results of this experiment with paramedic trainees are discussed regarding the suitability of consumer technology-based VR simulations for MCI training. We also discuss possible future developments to increase immersion and presence and provide conclusions on the suitability of VR MCI trainings.

BACKGROUND AND RELATED WORK

In this section, we describe immersion and presence and look at trainings for MCIs before we focus on MCI VR simulations and recent technological developments.

Immersion and Presence

As mentioned in the introduction, trainees must be immersed and feel present in a simulation to accept it. However, the term "immersion" is not clearly defined. According to Witmer and Singer (1998) involvement and

immersion of the user are necessary for achieving presence. Sherman and Craig (2003) differentiate between "mental immersion" (meaning "a state of being deeply engaged" or involvement) and "physical immersion" (meaning the "stimulation of the body senses") as two aspects of immersion. Especially when it comes to replacing the sensory input from the real world by simulated input and reacting to the user's actions in real time, the right technology and a robust technical implementation are important.

"Presence" describes the subjective perception of being in the simulated environment, of "being there" (Minsky, 1980). It can be distinguished in physical ("the sense of being there") vs. social presence ("the sense of being together with another"; Biocca et al., 2001; Schwab & Lange, 2016). Given the importance of the simulated environment (incl. its hazards) and the importance of the people involved in the incident, both physical and social presence are important for simulated MCIs.

Current Trainings for Mass Casualty Incidents

Asking domain experts of MCIs in Germany, two non-digital approaches for MCI training are frequently used: large-scale exercises and paper-based simulations. Other training approaches are less common, e.g. simulation games using physical or digital landscape models.

Large-scale exercises are conducted with lay actors and props (e.g., wrecked vehicles), if possible at locations with a high potential risk for MCIs. They allow many emergency personnel to train at once. However, they are costly and have a huge organizational overhead. Individual training for paramedics is limited, as many paramedics usually participate in these exercises and a paramedic can often do only a few tasks during the whole exercise. According to a study with more than 1500 German participants with a qualification similar to a paramedic, only 69% participated in an exercise that contained a triage process in their working careers (Ellebrecht, 2013). The actual triage process was likely done by even fewer participants. Given the high number of participants and the limited number of observers, individual feedback is often limited as well (Sautter et al., 2016). Also, despite actually "being there", immersion and presence should not be taken for granted, as constraints of the exercise (e.g., no actual fire or hazardous materials) as well as the use of lay actors can break the illusion. Some medical symptoms cannot be simulated in a realistic way (e.g., respiratory failure or cardiac arrest) and lay actors might not always present the injuries convincingly during the exercise.

Paper-based simulations are used in training courses to simulate MCIs. They make use of paper cards as a substitute for lay actors. Emergency personnel can check symptoms and simulate treatment by applying adhesive stickers to the cards. These trainings are cheap to conduct and require little effort. They are also easier to supervise and to replicate. Unlike large-scale exercises, in paper-based simulations time is monitored with stopwatches, and treatment times as well as changes of the situation can be simulated. Thus, they are often referred to as "dynamical" simulations (BBK, 2012). However, they are much less realistic than large-scale exercises, and both immersion and presence are poor.

Virtual Reality Simulations as Trainings for MCIs

Virtual Reality training applications have been used in various domains, including emergency contexts. For example, Farra et al. (2013) looked at virtual reality simulations in disaster training, Wilkerson et al. (2008) and Vincent et al. (2008) highlighted the potential of VR for first responder training. Thus, such simulations seem to be an appropriate choice for MCI trainings, especially considering the benefits:

- **Sinking Costs due to Consumer-grade Technology:** As mentioned, consumer-grade plug-and-play VR technology has become available, especially in the gaming sector with VR systems being introduced for specific consoles (e.g. PlayStation VR) or for personal computers in general (e.g., Oculus Rift). These recent advances in consumer-grade VR technology provide an opportunity to make virtual reality simulations affordable and scalable. Regarding the hardware, the system comes out of the box and the costs are manageable. Promising possible future developments might include omnidirectional treadmills (e.g., Cakmak & Hager, 2014) which might be market-ready soon. Additionally, environments suitable for 3D development are available (e.g., Unity).
- **Efficiency and Ease of Use, especially for Individuals:** One of the main advantages of simulations is their cost-effectiveness. Simulations can allow single paramedics to train for MCIs under realistic circumstances, without the costly need for additional human actors or organizational overhead. Thus, they allow for an increase in the number of trainings. Moreover, paramedics could focus on scenarios or aspects of MCIs they personally find difficult or for which training needs have been identified before. By selecting predetermined scenarios that require minimal oversight by instructors, instructor effects could be eliminated (instructor's engagement/involvement influencing learning, see Heldal &

Wijkmark, 2017). As all inputs and actions are computer-mediated, detailed recordings of all events in the MCI simulation are possible. This data can provide the basis for automatic, objective and reliable feedback and performance measures, or used as data-basis for face-to-face debriefings (cf. Heldal & Wijkmark, 2017).

- **Plasticity:** Simulations can cover the wide heterogeneity of situations in which crises and disasters can occur (cf. Mentler, 2017). Variables like extraordinary operational conditions (e.g., heavy rain, snow, time pressure), dynamic changes (e.g., number of casualties, area), or perceptual, cognitive and physical workload (e.g., difficulty to reach an area with inherent dangers) can be simulated. Simulations can also be adapted to include new scenarios, like new technological developments or hazards.
- **Realistic Timing and Display of Consequences:** Akin to paper-based simulations, time for the treatment can be enforced in the MCI VR simulation. Moreover, results of treatment or missing measures can be simulated (e.g., blue lips for shortness of breath). Physics engines can show the physical consequences of actions or developments, including safety hazards.
- **Safety and possibility for making mistakes):** In contrast with exercises on site, there is little if any danger to the paramedics in a VR simulation. Mistakes can be made without adverse consequences (Mantovani & Castelnuovo, 2003), allowing for experimentation and learning by experience. Because of safety requirements on site, some risks can be presented in an even more realistic way in VR simulations (e.g., fire, explosions, toxic gas).
- **Replicability:** Simulations can be exactly replicated, allowing not only individual paramedics to repeat trainings, but also allowing for empirical comparisons of conflicting best practice approaches.
- **Scalability and Adaptability:** The same simulations can be distributed to many people and locations and may also be adapted to the specific hazards the paramedics are likely to face in their environment, as well as the resources they will likely have available (Hsu et al., 2013).
- **Motivational aspects**: When combined with features from serious games, simulations can be highly motivating (see Heldal & Wijkmark, 2017). However, participants must be prevented from "gaming the game" (Werbach & Hunter, 2012) in order to "win" in the simulation – on cost of correct procedures or other learning goals.
- **Adaptive difficulty and use of stressors:** By determining prior experience, accessing user data, or monitoring performance/physiological data, simulated MCIs can be adapted to the skill and stress level of the user. For example, it is possible to increase stress via a lack of time, to increase perceptual and cognitive load via environmental conditions and hazards, or to use emotional stressors like the category of casualties (e.g., children) or the type of injuries (e.g., result of violence, burn victims). Looking at news reports (e.g., Bucktin, 2016), even subtle stimuli like the repeated ringing of a cellphone of a deceased victim could have strong emotional effects.
- **Group Use and Distributed Trainings:** While often seen as isolated experience, VR can be used for group trainings, even when the participants are not at the same location (akin to multiplayer games, cf. Heldal & Wijkmark, 2017). This advantage is extremely important in sparsely populated areas.
- **Testing, Accident Analysis and Prevention**: Simulations can also be used for testing, e.g. of emergency response plans to identify gaps and areas of improvement (Hsu et al., 2013) and for recreation of real-world MCIs for accident analysis and learning purposes. Accident documentation can be used as suggested by Heldal and Wijkmark (2017). Using actual incidents could also increase the authenticity of the MCI, compared with fictional MCIs.
- **Testing of New Technologies:** New technology can be simulated and examined in exactly the same triage situation, e.g. different interfaces of a simulated device. Testing can also include the effects of failing technology on the paramedics, for example due to harsh environment.

In conclusion, VR simulations can combine the realism of large-scale exercises with the economy of paper-based simulations. However, VR training simulations are also seen critically. While arguing for the advantages of simulations and serious games, Heldal and Wijkmark (2017) warn about the potential problems in implementing successful VR trainings. Crucial differences are the lack of the same physiological stimulation, the longstanding problem of possible simulator sickness (Kolasinski, 1995), and the lack of tactile feedback and "hands-on" experience of real-life exercises (Hsu et al., 2013). Tactile feedback is usually limited to vibrating controllers, thus providing only a very limited range of stimuli. Until augmented reality can be used to monitor the physical environment and match actual physical props (e.g., position of actual car wrecks, CPR-puppets), or

VR gloves are introduced that provide situation-dependent resistance, tactile feedback is unlikely to be achieved. However, while perfect correlations with the behavior in the real-world are unlikely to be achieved in simulations, behavior only has to be similar enough to be useful (cf. Reimer et al., 2006, regarding driving simulators and real-world driving).

Thus, we agree with Heldal and Wijkmark (2017) and see simulations as a complementary training method instead of a replacement for other training types. Furthermore, the development of immersive MCI simulations is not trivial and should be well-considered. Thus, the question remains how immersion and presence can be achieved with out-of-the-box consumer technology.

TWO ITERATIONS OF MCI VR SIMULATIONS

The need for MCI training and the developments in consumer VR technology have raised interest in the development of MCI VR simulations at our institute. Two training simulations (here referred to as System A and System B) have been developed using a user-centered design process (for more details about UCD in MCI, see Mentler, 2017). Both simulations were developed for the Oculus Rift, with System B being a redesign of System A – enhanced with features designed to enhance immersion and presence (see Figure 1). Both simulations enable the user to select treatment options needed in triage (e.g., checking breathing, placing casualty in recovery position) as well as some distractors, like treatment options only suitable for individual care. In particular, the user must prioritize casualties using triage cards. The focus is on the procedure (e.g., sequence of treatment and chosen options) and not on the specific step-by-step implementation of the measures themselves.

System A (2016)

System A was developed iteratively via a user-centered design process to understand the triage context and determine the necessary functionality. The first iteration used mock-ups, the second one an actual implementation. As MCI scenario, a large-scale traffic accident was chosen, containing damaged vehicles as well as casualties with different injuries. To ensure adaptability, the number of casualties and the weather can be configured by the instructor. The system was formatively evaluated with three domain experts. For development, the Development Kit 2 of Oculus Rift was used; however, we ensured compatibility with the newer Consumer Version 1 of the Oculus Rift device.

System B (2017)

System B was developed using the Oculus Rift Consumer Version 1. This version allows for spatial tracking and can be used with specialized VR controllers (compared to the previously needed standard console controller). More importantly, several design aspects of System A were identified as detrimental to immersion and presence. A formative evaluation with three instructors from a school for emergency personnel was conducted to ensure consistency with the triage process. To add realism, videos from large scale exercises were examined to determine behavior of casualties. These aspects were redesigned to create an improved and consistent MCI VR simulation.

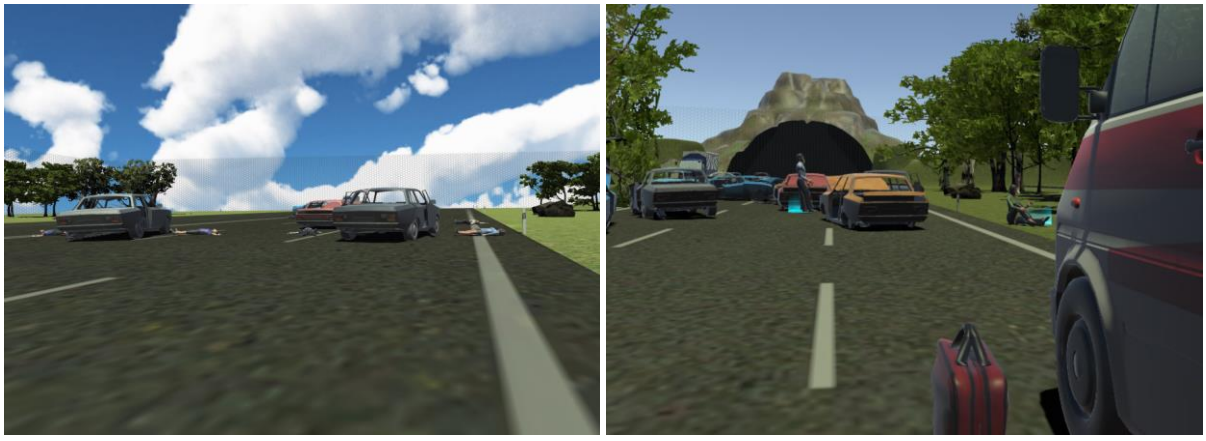
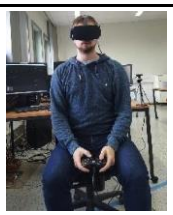
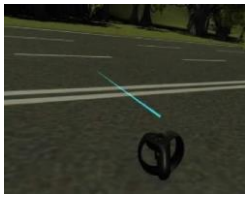
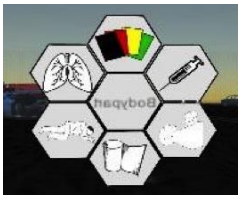


Figure 1. Screenshots of System A (on the left) and System B (on the right)

Differences between System A and System B

While both simulations run on the same system (Oculus Rift Consumer Version 1), the changes between the systems allow for a comparison of the design elements in their effect on immersion and presence. Key differences between the two systems are actual user movement, simulated movement, the used controller, the interface for the treatment of casualties, movement of casualties, and sounds. Table 1 illustrates the key differences between System A and System B.

Table 1. Differences between System A and System B

	System A	System B
Actual User Movement	 The user sits on a chair during movement and treatment.	The user has limited movement in the room (2x2m) and can kneel near a casualty for treatment.
Simulated Movement	The user moves forward, backward or sideward by pressing the left stick of the controller. He or she can turn left and right in a limited way by gaze control or turn completely using the right controller stick.	 The user teleports by indicating the target with a simulated light beam. Starting the beam and teleporting is done via a controller button. Treatment positions are highlighted near casualties. Teleportation was implemented to avoid simulator sickness and to allow for user movement within a limited physical space (see above).
Controllers	A standard Xbox game controller is used. Typically, the user holds the controller with both hands.	Oculus Touch Controllers are used. Interaction is done by both hands separately for some treatment options, e.g., turning the casualty in a recovery position.
Treatment of Casualties	 Treatment is done by opening a circle menu with a controller button. The items are selected via gaze control and confirmed by pressing a button.	Instruments and tools are in a simulated emergency bag. The bag opens when kneeling near a casualty. The user must grab instruments and hold them onto the

	System A	System B
		correct body part of the casualty for treatment. To place people in the recovery position, the shoulder and the leg must be grabbed. Pulse can be checked by touching the wrist.
Movement of Casualties	All casualties lie on the ground and do not move until treatment.	Casualties can be unconscious but also can have injury-dependent motion. They also look at the user to get attention when he or she is approaching.
Sounds	Basic sounds are used, like footsteps of the user, breathing sounds when the user has chosen to check the breathing of a casualty, and simple answers of the casualties when being asked to stand up.	Casualties cry out to get the users attention. They are also able to express pain, in general as well as related to their injuries. Behavior was modelled after participants in MCI trainings (using video recordings) and by asking volunteers to act as if they had been injured. Additional ambient sounds are simulated (e.g., car engines, wind).

Essentially, the user in System A sits on a chair uses the control stick of the controller to move in the simulation and selects treatment options from a menu to select on casualties. The casualties show little movement and only give a few verbal reactions to treatment. In System B, the user actually moves, can kneel next to the casualties, can teleport in the simulated world, and treats casualties by selecting the instruments or tools and holding them to the correct body parts. The casualties scream or shout and move or contort realistically depending on their injuries. The realization of the key differences for System B was much more time-consuming than in System A since the model is much richer and tracking of user movement (see "actual user movement" in Table 1) had to be implemented.

SUMMATIVE EVALUATION OF KEY DIFFERENCES REGARDING IMMERSION AND PRESENCE

The evaluation has two goals: First, to determine the degree of immersion and presence of each system, and second, to directly compare the design differences between the two systems regarding immersion and presence.

Method

Design: A within-subjects design was used to allow for direct comparisons between the two systems. To avoid sequence effects, the order of the systems was changed after each participant (e.g., A-B, B-A, A-B, B-A, …) to avoid training effects due to increased familiarity with VR environments over the course of the study. As the number of participants was unknown beforehand, this approach ensures an equal distribution of the two possible sequences.

Sample: Participants were 18 paramedic trainees (“Notfallsanitäter” in Germany) in their second year of training as trainees are the main target group for the system. Age varied between 19 and 38 years with a mean of

23.1 years (SD = 5.26, n = 17, one missing value). The participants had comparable knowledge and experience, and already knew the procedures for MCIs. Eight participants had prior experience in emergency medical service, one of them for more than two years. As for MCIs, all but one stated to have at least some knowledge about it due to their training.

Setting and Simulations: The evaluation was conducted in a classroom of a paramedic school (see Figure 2). The setting was chosen because it is the place in which these VR trainings would be conducted if the technology gets adopted. In both simulations, six casualties of a large car crash were simulated. The location of casualties stayed the same to keep the simulated physical distances equal; however, the injuries were swapped to avoid learning effects by knowing the specific injury beforehand.

Measures: In addition to socio-demographic information and prior experience (medical emergencies, MCIs, gaming, VR), a translated and modified version of the "Presence Questionnaire" was used (Witmer et al., 2005, values from 1 "not at all" to 7 "completely" and middle value 4 "somewhat"). This questionnaire measures presence and includes 10 items measuring "immersion". For forced choice between the design features, a differential scale with ten steps was used. The images of the respective design features of System A and B (see Table 1) were used as endpoints, and users were asked to indicate which implementation they experienced as more immersive. Users were also interviewed regarding the different simulations and observed while solving the task. We also asked for prior experience in emergency medical service (e.g., prior qualifications or volunteering) and whether they already had experiences with MCIs (see sample).

Procedure: Participants were briefed and asked to fill in the socio-demographic/experience questionnaire. They then saw a short introductory video of the first simulation and were tasked with treating the six casualties. Once finished, they were asked to fill in the presence questionnaire for that simulation. Afterwards the same procedure was repeated for the second simulation. After both simulations had been evaluated, participants filled in the forced-choice questionnaire, were interviewed, and thanked for their participation.

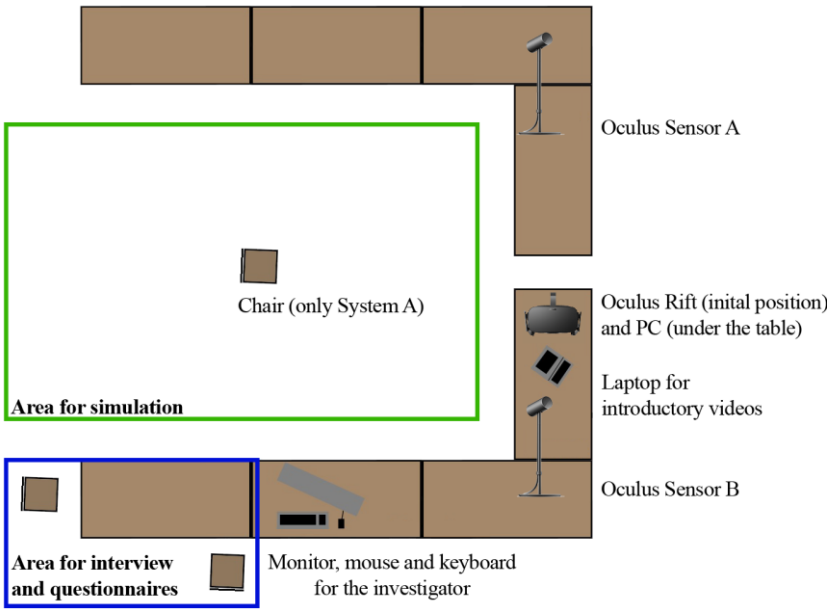


Figure 2. Experimental setup for the evaluation in a classroom of a paramedic school

Results

For the results, we first describe the results of the statistical analysis of comparisons in presence and immersion, followed by observation and interview results.

Presence (separately): The average value for the presence questionnaire was computed for each participant and system (Cronbach's alpha for System A = .80, and for System B = .79). One-sample t-tests were used separately for both systems to determine whether the values were statistically significantly different from the middle value of the scale (4, "somewhat"). Average values for System A (M = 4.85, SD = 0.52; $t(17) = 6.90$, $p < .001$) and B (M = 4.82, SD = 0.49; $t(17) = 7.17$, $p < .001$) were statistically significant above the middle value of the scale.

Prior Knowledge and Presence: No statistically significant influence of prior experience in gaming or experience as paramedic could be found. However, participants with VR experience did show higher presence in System B.

Immersion (separately): Regarding the immersion items, a subset of the presence scale, the 10 items could be combined as well (Cronbach's alpha for System A = .82, for System B = .71). As with the overall presence questionnaire, the values in System A (M = 5.25, SD = 0.91, $t(17)$ = 5.83, $p < 0.001$) and B (M = 5.57, SD = 0.64, $t(17)$= 10.43, $p < 0.001$) differed statistically significant from the middle value of the scale ("somewhat").

Comparison of Presence and Immersion between System A and B: Comparing the values of the presence questionnaire between System A (M = 4.85, SD = 0.52) and B (M = 4.82, SD = 0.49), a paired-samples t-test did not show statistically significant differences ($t(17)$ = 0.167, p = .869). Likewise, the mean of the 10 immersion items did not differ statistically significantly either between systems (M_A = 5.25, SD_A = 0.91; M_B = 5.57, SD_B = 0.64; $t(17)$ = -1.35, p = 0.19).

Direct Comparison of the Effect of the Design Differences on Immersion and Presence: Table 2 shows the results of one-sample t-tests against the neutral middle of the forced-choice scale (values ranged from 1-10, thus 5.5) for each design difference. Figure 3 shows the distribution of answers as box plots. Four out of six design differences were in favor of System B – treatment of casualties, movement of casualties, sounds, and actual user movement. For simulated movement, simulated walking (A) was preferred to teleportation (B). The kind of controller used was not significant.

Table 2. Results for the evaluation of the key design differences. Differences of System A and B (see Table 1) as endpoints. 1 = System A absolutely preferred, 10 = System B absolutely preferred

Design feature	*M*	*SD*	*t*	*P*
Actual User Movement (A: sitting, B: room-tracking)	8.28	2.72	4.34	< .001
Simulated movement (A: controller, B: teleportation)	3.28	2.56	-3.68	.002
Controllers (A: Xbox game controller, B: Oculus Touch)	7.06	3.78	1.75	.099
Treatment of casualties (A: menu, B: medical bag)	8.33	2.03	5.92	< .001
Movement of casualties (A: little, B: injury-dependent)	9.50	0.71	24.00	< .001
Sounds (A: only basic, b: casualties cry out)	9.22	1.17	13.54	< .001

Direct Comparison of System A vs System B: Asked whether participants were more present in the situation in System A or System B, 15 out of 18 decided for System B. Participants emphasized the interaction style (treatment of casualties), movement of casualties, and sounds. However, teleportation was seen as both complicated and too fast – especially given the role of time, incl. movement time, during MCIs.

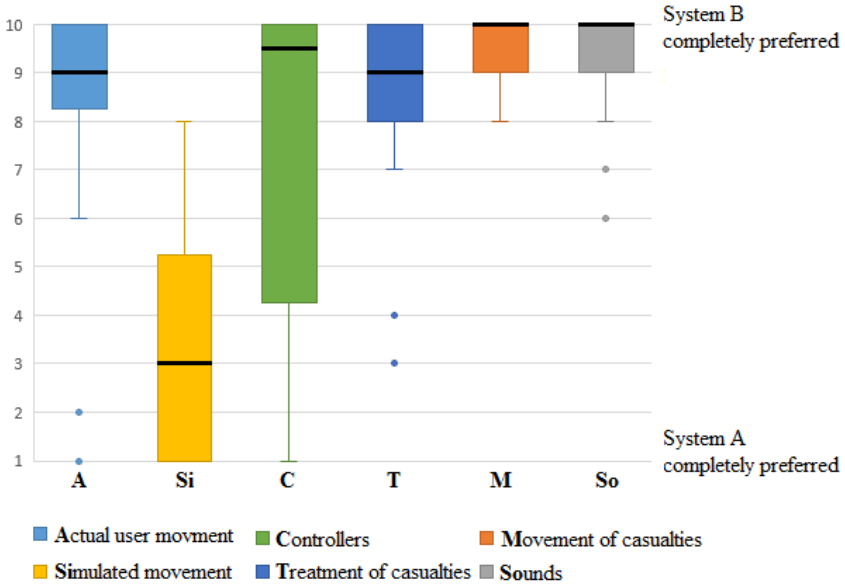


Figure 3. Box plots for the evaluation of the key design differences

Interviews and Observations: Some participants complained of simulator sickness while using System A. They moved more slowly and stopped more frequently. While using System B, participants turned away from the sensors, resulting in a loss of tracking. Despite using teleportation in the simulated world, participants also tried to move out of the tracking area of the device. When a participant came nearer to the borders of the simulation, a blue rectangle showing the borders became visible on the ground. In some cases, attempts to walk out of the area led to participants bumping into the surrounding tables. In severe cases, they tugged at the cables, resulting in a temporary signal loss (black screen).

Discussion

The focus in this evaluation was on immersion and presence as necessary conditions for learning and to ensure that participants take the simulation seriously. Both examined simulations use consumer grade VR hardware and both lead to moderate presence and immersion. Thus, both can be seen as promising. This supports the assumption derived from literature research (e.g., Gutiérrez et al., 2007) that VR technology facilitates immersion. While System B is richer and should be more immersive than System A, the values for presence and immersion were similar. However, loss of tracking and the temporary black screen might have temporarily broken immersion and presence in System B, thus attenuating the overall impression of immersion and presence. An additional sensor would likely prevent the loss of tracking, while wireless transmission would likely avoid the signal loss. System A did not have this problem, as the participants were sitting the whole time. These results suggest that improvements in the technical stability of the simulation are crucial. Currently, the results cannot show that the richness of the simulation is positively correlated with immersion.

However, regarding the design differences, clear preferences became visible. Users strongly preferred using an emergency bag to treat casualties, moving casualties, sounds (incl. shouts and screams), and to move physically, including kneeling by the casualties. They preferred walking in the simulation to teleportation, despite some participants suffering from simulator sickness. While teleportation reduced the simulator sickness problem as expected (see Table 1), it was seen as too complicated and unrealistic, thus likely impeding immersion. Hence, both movement options have specific problems, likely explaining the lack of significant differences between the two systems. Giving the problems with this alternative form of movement, other options should be explored. In a recent study comparing a gamepad, a hand interface, and a walk-in-place approach, Lee and others (2017) conclude that users must actually move their legs in order to facilitate immersion and to avoid VR sickness. Thus, walk-in-place should be considered in further studies. Moreover, once they are ready for market, omnidirectional treadmills might be a worthwhile investment. The reason for the non-significant preference in controller use might be prior experience with gaming controllers. The Oculus Rift controllers are new and might have been unfamiliar to the participants. It is possible that higher familiarity with gaming controllers influenced the results. On the other hand, prior general gaming experience did not influence presence. While VR experience did have a positive effect in System B, all participants were quickly able to interact with both systems.

Compared to traditional methods of training (paper-based simulations and large-scale exercises), MCI VR environments can be seen as a worthwhile addition. While they require more effort and investments than paper-based simulations, which likely continue to have their use to train processes, communication and organization in MCIs, they require much less effort and investments than large-scale exercises. Once developed, they are easily scalable and can be implemented even for individual, self-directed learning (in addition to the other potential benefits of VR simulations mentioned before). However, large-scale exercises have their use, as VR training environments are unlikely to accurately replicate the situation in all aspects (not only in sensory experiences like smell, but also in the required physical actions and stressors). Thus we see MCI VR trainings as occupying an important and needed place between paper-based simulations and large-scale exercises.

However, the benefits of VR are not guaranteed and VR training simulations must be developed with care. Developing richer VR experiences to improve immersion can result in higher development costs as well as potential technical issues that can prevent the users from being immersed in the simulation. At the same time, cost-effectiveness and organizational effort in operation should be considered. In our study, the richer System B not only required more development effort than System A, but also a free space (2x2m + safety distance per user) and a more complex setup for the sensors. The proposed use of omnidirectional treadmills could solve the simulator sickness problem, but adds additional costs to the simulation (see section "Virtual Reality Simulations as Trainings for MCIs"). The right scope has to be defined carefully.

Comparing the design aspects directly with forced choice has its limitations. It is not possible to determine the influence each variation had on overall immersion and presence in the simulation. Doing so would require testing all variations independently, resulting in 64 comparisons. This design would require a prohibitive high number of participants or repetitions. However, to determine which design aspects were seen as more beneficial

to presence, the used within-design worked well. We did not assess the number of errors as the focus was on immersion and presence. However, if the performance is recorded (e.g., screen capture or log files), detailed analysis can be performed.

CONCLUSION

In this paper, we examined the two traditional methods of MCI training for paramedics and compared them to virtual reality simulations. Given the resurgence of VR and the availability of consumer grade (and thus affordable) VR hardware, we identified the potential for immersive VR training simulations. The preliminary work highlighted the potential of VR technology to facilitate immersion. To research the effect of design options on immersion, we developed two MCI VR simulations for consumer hardware. The simulations varied in key aspects related to immersion, with richer features implemented in System B. Both systems were evaluated with the main target group of MCI VR simulations: trainees from a paramedic school. Both simulations were sufficiently immersive and led to presence. However, presence can likely be increased by using an emergency bag with direct control approach, movement of casualties, sounds (screams/shouts), and allowing for actual user movement. Movement in the simulation itself is still a crucial open question, with game controllers directed movement leading to simulator sickness and teleportation seen as unrealistic. A walk-in-place approach or omnidirectional treadmills might be possible ways to solve this dilemma.

Our study did show that immersive MCI trainings with consumer grade technologies are possible. They can also occupy an important place between paper-based simulations and large-scale exercises. If developed further and made available in paramedic schools and rescue stations, paramedics can train for MCIs in order to allow them to face these situations with increased confidence and perform the right actions, even if MCIs – thankfully – happen rarely and infrequently.

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Practical Insights into the Design of Future Disaster Response Training Simulations

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ABSTRACT

A primary component of disaster response is training. These educational exercises provide responders with the knowledge and skills needed to be prepared when disasters happen. However, traditional training methods, such as high-fidelity simulations (e.g., real-life drills) and classroom courses, may fall short of providing effective and cost-efficient training that is needed for today's challenges. Advances in technology open a wide range of opportunities for training using computer-mediated simulations and exercises. These exercises include the use of mixed reality games and wearable computers. Existing studies report on the usefulness of these technologies for training purposes. This review paper synthesizes prior research and development of disaster response simulations and identifies challenges, opportunities, and lessons learned. Through this review, we provide researchers and designers with an overview of current practices in designing training simulations and contribute practical insights into the design of future disaster response training.

Keywords

Training, Simulation, Disaster Response, Mixed Reality, Coordination, Planning, Zero-fidelity.

INTRODUCTION AND BACKGROUND

Disaster response is a complex set of activities to mitigate the effect of an incident (U.S. Department of Homeland Security 2008). Responders are typically professionally trained, licensed practitioners who contain the impact of disasters while trying to prevent further loss of life and property (Bigley and Roberts 2001). Such response is crucial because disasters cannot be prevented entirely, but their impact can be contained and reduced. Disaster response training is essential for active responders to retain and enhance their knowledge, competence, and skill, particularly

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as new equipment and technology is adopted by different disaster management agencies (Bigley and Roberts 2001; Toups and Kerne 2007). However, traditional training methods, such as real-life simulated drills, classroom courses, online courses, and computer-mediated simulations present challenges in advancing disaster mitigation. Training in classroom settings lack realism, while real-life drills may be unavailable, costly, risky, and inconsistent. Computer-mediated simulations have often been pointed to as a means through which to provide cost-effective, high fidelity training, but the results of such training are often insignificant (Hsu et al. 2013). Advances in technology open a range of opportunities for training, including computer-based training simulations, mixed reality, virtual reality, and wearable computers.

Within computer-mediated simulations, there are many different stakeholders all interested in the success of such products. Significant resources have been invested in developing near-perfect representations of all types of training exercises. One set of stakeholders are the developers of simulations, who focus on the fidelity of such products as a means to report their effectiveness (Lif et al. 2011; Salas et al. 1998). These types of simulations operate under the assumption that the higher the fidelity of the operating environment, the more likely that users will learn (Hays and Singer 1989).

Within each of these simulators, the traditional method of examining the effectiveness of such training is to ask trainees how they felt about the simulator. What is often missing are the skills those being trained should acquire that are based on practitioner knowledge from outside those developing the simulation. For example, some simulations represent near-perfect simulations for flying fighter jets. Each of these simulations are rated highly by users and instructors; however, when users moved to actual aircraft, the knowledge these users brought with them was not significant when compared to lower fidelity exercises (Taylor et al. 1993). Other high-fidelity simulations have been created to aid train surgeons of many different kinds (e.g. (Sutherland et al. 2006)). No matter the type of surgery being simulated, the benefit of the high-fidelity digital simulation was moderate at best (Zendejas et al. 2013). Interestingly, more and more types of surgery simulation research are calling out these pieces of research saying that, like the above examples of fighter-jet training, the way evaluations are conducted are suspect (Kirkman et al. 2014).

The purpose of this paper is to provide practical insights into the design and development of disaster response simulations. This review will largely draw upon our prior work that spans over 10 years of research and development in the domain of disaster response training (Toups and Kerne 2007; Toups, Kerne, Hamilton, and Blevins 2009; Toups, Kerne, and Hamilton 2011; Toups, Hamilton, Keyes-Garcia, et al. 2015; Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017; Alharthi, Sharma, et al. 2018; Alharthi, Torres, Khalaf, Toups, et al. 2018). We contribute a set of challenges, opportunities, and lessons learned from prior research in this domain, developing insights for researchers, designers, and training organizations on the design of disaster response training simulations.

Mixed Reality, Virtual Reality, and Wearable Computers

Mixed reality and virtual reality provide a new dimension for developing efficient training simulations and games (Fischer, Jiang, et al. 2014). *Mixed realities* (MR) are systems that connect virtual and physical reality in some meaningful way through the use of networks, sensors, and databases (Benford and Giannachi 2011). These range from augmented reality, in which conformal 3D imagery is integrated with a perspective on the physical world, as with most aircraft head-up displays, to augmented virtuality, in which physical-world artifacts and spaces are integrated into a virtual world (Milgram and Kishino 1994). Mixed reality provide users with a sense of immersion and engagement with their surroundings through interacting *physically* with tangible objects in the physical reality, *mentally* with the virtual elements of the simulation, and *socially* with other users or players in both the physical and virtual environment (Hinske et al. 2007; Sharma et al. 2017).

Virtual reality (VR) is defined as "a real or simulated environment in which the perceiver experiences telepresence" (Steuer 1992). VR allow users to interact with and navigate through a computer generated three-dimensional environment, which offers highly immersive experience. These systems can simulate animations in real-time so that the user is immersed in and can control and move in the simulated virtual environment through different body and position trackers, and the use of a wearable head-mounted display for visual output (Steuer 1992).

Wearable computers are computing devices that can be worn on various locations on a person's body (Mann 1997). These devices establish constant interaction between the environment and the user and often form their own network of intercommunicating effectors and sensors. Wearable augmented reality, using wearable computers help wearers to view visual information that is overlaid onto reality (Starner et al. 1997). When input is needed, input wearable devices vary widely and can include mini-QWERTY keyboards or virtual keyboards; however, these types of explicit input modalities require visual attention, impacting mobility. Also, when output is needed, a number of interfaces exist, from full color high-resolution, or monochrome low-resolution head-mounted displays (HMDs), to

wrist-worn displays (Mann 1997). All of these emerging technologies together offer opportunities for designing training simulations and games that are immersive, consistent, and effective.

Game-based Learning and Game Design

Simulations and games have been shown to be an effective tool for learning and training (Kiili 2005). Digital game-based learning provides a fun and convenient way to experiment and interact with virtual and realistic environments without real-world consequences. These type of games have been successfully used for developing different skills, such as teamwork (Alsaedi et al. 2016) and perceptual and motor skills (Green and Bavelier 2003; Tabor et al. 2017).

An important aspect of designing effective game-based learning and training simulations is to have a deep understanding of key elements of game design concepts and terminology. Salen and Zimmerman (2004) characterize games as interconnected systems of *rules* and *play*. *Rules* are the boundaries that constrain player action, the logical and mathematical structures of the game. *Play* is the freedom to make decisions within the rules. *Game mechanics* are the choices, constructed by the game designer, that a player makes, resulting in an observable outcome (Salen and Zimmerman 2004; Adams and Dormans 2012). Mechanics that are repeatedly invoked, and that affect the underlying subsystems of the game in important ways, are the *core mechanics*.

Prior Research and Development of Training Simulations

Prior disaster response training simulations address a wide range of skills including team coordination, decision making, planning, and sensemaking (Williams-Bell et al. 2015). Designers of these simulations and games need to take into consideration the challenges, opportunities, and insights from prior work. These lessons can be applied to future designs of training simulations. We provide an overview of current practices in designing training simulation.

Computer-mediated simulations using a desktop or personal computer provide training opportunities for emergency responders on different skills. The *Distributed Dynamic Decisionmaking* simulation (Silva et al. 2012) is an open-source command-and-control training simulation where participants solve problems in ambiguous situations by collaboratively managing resources. This simulation helps responders build decision-making and collaboration skills. Other computer simulations focus on developing sensemaking skills, such as the *Levee Patroller* (Harteveld et al. 2010), a single-player training game in which a player must find levee failures in a region and report them in a timely manner. It was designed to target the Dutch water authorities to help trainees make sense of risks and develop decision-making skills. While these simulations provide training opportunities, the results of such training are often insignificant, and their benefits can be limited due to their classroom settings.

With advances in technology, new opportunities for training have emerged. VR has been increasingly used in the design of training simulations. Hsu et al. (2013) provide an overview of how VR has been used for disaster preparedness training by governmental agencies and their benefits and potential drawback. In healthcare, Mantovani et al. (2003) explore the benefits of VR for surgical skills acquisition and patient care. The study suggests that these types of training can be beneficial, but should be considered only as a supplement or preoperative training. Smith and Ericson (2009) developed a VR training simulation to teach fire-safety skills to children. The result of the study shows that these types of simulations can enhance the enthusiasm of children to learn even when topics are tedious. VR can provide immersive experiences and alternative method to disaster response training, in which training is placed in a fully virtual environment. However, the immersive nature of VR can introduce different challenges when designing hands-on and face-to-face experiences (Hsu et al. 2013).

An alternative way to balance between immersion and reality in training is the use of mixed reality simulations. While the adoption of such designs in different training domains are increasing, it remains limited in disaster response training. Studies on using mixed reality games provide insights into the benefits of this approach in disaster response training. Supporting team coordination and decision-making training through the use of a scenario-based mixed reality simulation has been used, allowing responders to coordinate with each other in real-time, face-to-face and remotely, to mitigate a simulated disaster (Fischer, Jiang, et al. 2014). These types of live mixed reality simulations also provide training opportunities for human-agent coordination and collaboration (Ramchurn et al. 2016; Fischer, Greenhalgh, et al. 2017), helping responders to build advance coordination skills. Advances in personal computers and wearable technologies have the potential to enhance the design of mixed reality experiences and training (Feese et al. 2013). All of these prior studies provide innovative approaches to the design of disaster response simulations, pushing toward the adoption of advanced technologies and moving away from conventional methods of training.

Design Principle	Description
mix communication modalities	Teams should work in situations in which members spend some periods collocated and others remote, which enforces the need for learning and practicing implicit coordination and overhearing.
distribute information with uncertainty	Different members of the team should have different pieces of information, requiring team members to share and integrate information and enabling the formation of team cognition constructs.
enhance situation awareness	Audible clues should supply information about the local situation and made available to other team members through a shared audio system, engaging team members in processes of developing situation awareness.
engage developing intelligence	Team members should make informed decisions about how to collect information and need to make judgments of its authenticity and value to identify essential elements of information.
create emergent objectives	Emergent objectives may be discovered and lost as a scenario of a disaster plays out, team members may identify new objectives through gathering information.
support collaborative planning	Team members need to consider converging and diverging lines of activity that happen in the field, in which they should learn how to collaboratively plan for contingencies when activities enter exceptional states.

Table 1. A summary of the design implications and game design patterns resulted from our prior qualitative studies (Toups and Kerne 2007; Toups, Hamilton, and Alharthi 2016)

QUALITATIVE STUDIES & GAME DESIGNS

Prior research has used qualitative methods to deeply understand the nature of disaster response and look for ways to improve training and operation through system design (e.g., (Toups and Kerne 2007; Denef et al. 2008; Fischer, Reeves, et al. 2015)). One approach used in many of these studies is ethnography, in which an ethnographer is immersed in the life of people they study to uncover their practices and facilitate a deeper understanding of the complexity of the work settings (Agar 1997). For example, observations of humanitarian assistance in emergencies (Muhren and Van de Walle 2009), situational uncertainty of disaster response (Fischer, Reeves, et al. 2015), and on-line social convergence in disaster (Hughes et al. 2008), reveal how ethnographic research is useful to explore the ways people work and inform the design of systems.

Through years of qualitative observations, Toups et al. developed a deep understanding of the reality of disaster response work, which informed the design of training simulations (Toups and Kerne 2007; Toups, Kerne, and Hamilton 2011; Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017). The research team conducted a number of different observations of disaster response practices: interviews with professional emergency responders and observations of students performing burn training exercises, urban search and rescue full-scale exercises, and incident command simulations. Through these field observations, the team developed an understanding of the information-centric components of response. One of the main contributions of the prior ethnographic observations was a set of design principles in the form of implications for system design and game design patterns[1] that enable designers to develop games and simulations that engage players in disaster response style communication, coordination, planning, and sensemaking activities (Table 1). In the following, an overview of the designed games and wearable interfaces are presented as case studies of how future games can be informed by observations of disaster response practice.

The *Team Coordination Game*

The *Team Coordination Game* (*TeC*) focuses on teaching team coordination skills to student fire emergency responders. Following a *zero-fidelity* design approach (Toups, Kerne, and Hamilton 2011), characteristics of the real world are not captured in the game, focusing learning on team skills. *Zero-fidelity simulations* develop and invoke the principle of abstraction, addressing not the concrete environment, but, instead, focusing on human-information and human-human transfers of meaning, to derive design from work practice. These type of simulations shift the focus of education and reduce the costs in resources and safety.

[1] *Game design patterns* are repeatable design solutions to support the creation of games (Björk et al. 2003).

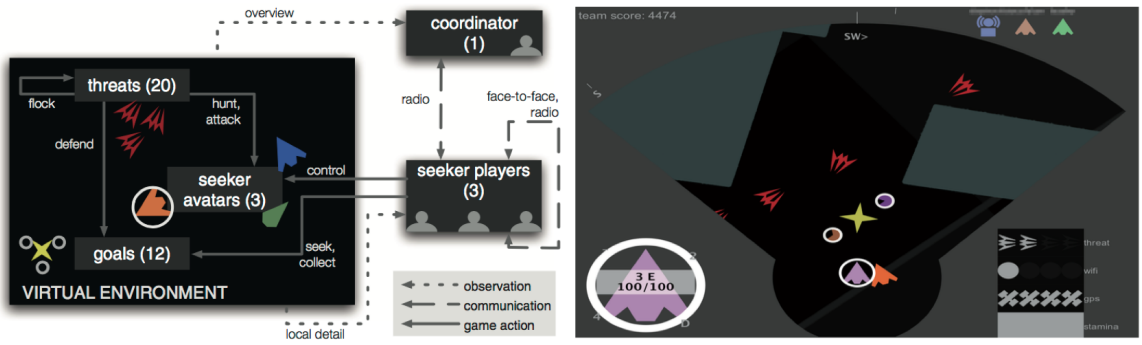

Figure 1. The *Team Coordination Game (TeC)*. Left: Game mechanics of *TeC*. Human players are to the right, communicating with one another; game entity interactions take place on the left side of the diagram, in the virtual environment. Right: screenshot of seeker view, the purple player navigate the environment searching and collecting goals and avoiding nearby threats. The visualization in the lower left shows where the avatar is located and health.

Design

In the game, players are motivated by rules that create real-time stress and information distribution, requiring a cooperative response. Participants' perspectives on the same information differ so they are reliant on one another. One of the core mechanics of *TeC* is information sharing and communication tasks. Players take on roles similar to those of fire emergency responders. The media of communication: radio and face-to-face communication, are unchanged from the source distributed cognition environment (Figure 1). Dividing information along participant roles reflects fire emergency responder work practice. Real-time stress ensures that participants must make quick decisions about what information to share, and how to share it. In this way, the play of *TeC* focuses on the human-centered aspects of team coordination.

Players take on alternative roles with different capabilities and information access. Four players make up a team: three seekers and one coordinator. Seeker players move an avatar in the virtual environment terrain, searching for goals while avoiding threats (Figure 1). A coordinator observes the virtual world with limited detail. S/he communicates with the seekers to direct them. The game environment includes threats, goals, and score to provoke a sense of crisis through game play and afford coordinated response. Because game time is limited, the team members are pushed to mutually communicate, sharing information in order to work together effectively.

Evaluation

The *TeC* game was evaluated through two user studies with both non fire emergency responders and with fire emergency responders (Toups, Kerne, and Hamilton 2011). The results of these studies show improvement in cooperative task completion, improving communication efficiency by shifting to implicit coordination. In the study, participants collected and used information from the game and from one another, reflecting fire emergency responders practice.

Designs that are based on work practice, similar to the *TeC* game, show the potential benefits of conducting field studies to gain a deep understanding of the reality of the practice. The zero-fidelity approach to the design of training simulations can lead to the design of efficacious team coordination education for crisis responders, and can open up new opportunities for training responders on other skills. This approach shows that sophisticated and glitzy high-fidelity simulations are not needed, instead, simple design and a focus on skill learning is effective.

The *Icehouse* Wearable Augmented Reality Interface

The *Icehouse* game, developed by MIT's Lincoln Lab, offers a simulation game environment in which a team of disaster responders use wearable computers and interfaces designed specifically for this game to test the usefulness of wearable interfaces in the context of disaster response (Alharthi, Sharma, et al. 2018). In this live action role playing game, players move through a physical simulated disaster space that requires team coordination and physical exertion to mitigate virtual hazards and stabilize virtual victims. The researchers developed wearable computer interfaces that integrate physiological and virtual environmental sensor data and display actionable information through an HMD (Figure 2), enabling team coordination and situation awareness. The design provides insights into the design of wearable interfaces that can be used for mixed reality training simulations.

Figure 2. The designed wearable interfaces for the disaster response mixed reality live action role playing game (*Icehouse*). 1. The team status view with player information. 2. The decision support view shows the optimal order of activities to clear a room, as well as which player should do what. 3. The interface is displayed on top of the transparent lens of the smart glasses. 4. The Sony SmartEyeglass used in the game. 5. Photos of the live mixed reality game.

Design

The design approach of these wearable interfaces was focused on enhancing situation awareness and team coordination. The designed wearable interface making use of peripheral attention and avoid displaying any information to the central of the HMD (Figure 2.3). User inputs are minimal to free hands, and only required for either switching between the information views or to account for state changes that the system cannot detect automatically. Components of the HMD include a peripheral display of the health status of teammates and activity status. This enables players to attend to the information when they need it, yet enables attention to the physical environment.

The primary value of the design came from the four information views that is provided through the smart glasses, facilitating play and communication. Using the swipe bar on the smart glasses (Figure 2.4), players could cycle through the four views to the one that was most useful to them at the time. For the smart glasses, no further interaction was required. In the following, a description of the four information views:

- *Team Status View*: this view provides situation awareness, showing the state of each team member in a compact representation at the bottom of the screen, where it minimally interferes with awareness of the nearby environment (Figure 2.3). For each player, the interface displays the player's identifier, specialty icon, exposure, room identifier, and activity status (Figure 2.1).
- *Decision Support View*: the decision support system provides players with recommendations on optimal task ordering, given data about the state of the room and using the activity priority system (Figure 2.2).
- *Map View*: this view gives a player the digitized version of the paper map provided to the players at the start of the game. In this view, the system displays a monochrome map of the game world.
- *Blank View*: the HMD did not provide a feature to turn off the display in case the user wanted to focus entirely on the environment. Thus, the designed view allow for an unobstructed view of the the physical world.

Evaluation

Members of the U.S. Coast Guard played *Icehouse* to test the performance of the wearable interface designs during a major international conference. The designed wearable interfaces were judged based on the performance of the disaster responders, including: number of victims stabilized, level of exposure, number of mitigated hazards, and feedback from the players. The results of the playtest show that using the wearable interfaces support team coordination and situation awareness. The designed interfaces provided responders with specific information about what is happening around them, allowing responders to focus on the surrounding physical environment when necessary, reducing hindrance.

The design of such wearable interfaces can provide an effective way to engage responders in training that incorporates physical aspects of disasters. These type of simulations also can be beneficial to test future disaster response wearable

Figure 3. The *Team Coordination and Planning Game (TeCP)* interface. A. The top-down map allows players to see part of the play space to develop strategies and plans. B. Players use the mouse to draw on the map to establish plans. Drawings are colored differently to be easy to identify and follow. C. The drawing is made visible directly on the gameworld, enabling its use during action gameplay, allowing players to follow their plan in real time.

technologies. The *Icehouse* wearable interface provides players with a high level of awareness of their remote teammates and their own status through awareness cues provided by each interface (Wuertz et al. 2018; Gutwin and Greenberg 2004). These wearable interfaces can be easily modified for the real world to show responders' air pack pressure, heart rate, approximate distance, and distance from a leader, making these wearable interfaces practical. Further development of wearable interfaces for disaster response practice and training is needed.

The *Team Coordination and Planning Game*

The *Team Coordination and Planning Game* (*TeCP*), focuses on engaging players in collaborative planning activities, which are a central aspect of disaster response (Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017; Alharthi, Torres, Khalaf, Toups, et al. 2018). It is a two-player cooperative game in which players are physically separated and need to communicate and plan through the game and work together to complete objectives. A map of the gameworld provides a top-down view of the game space, allowing players to see part of the play space to develop strategies and plan. Players can also move through and manipulate objects in the gameworld to escape a maze (Figure 3). The design of this game provides insights into how future disaster simulations games can be designed. The main purpose of the design of this game is to test the benefits of different interfaces and mechanics that can then be used in the design of disaster response training simulations.

Design

The design of the game was informed by our prior research (Toups, Hamilton, and Alharthi 2016), in which the we developed game design patterns to engage players in disaster-response-style planning activities. The *TeCP* game make use of the following patterns: *collaborative planning*, *emergent objectives*, and *developing intelligence* (Table 1).

At the beginning of the game, players have a set of objectives that need to be completed. Players start by collaboratively establishing a plan using the top-down view of the gameworld, which details some of the objects in the game. Play in *TeCP* involves planning strategies to complete puzzles that require efficient collaboration. Using the annotation interfaces provided by the game, players may collaboratively draw on the map to mark locations, draw pathways, and divide tasks to complete objectives and escape the maze. Dependencies in the game force players to collaborate, creating information distribution. Specific objects in the game are assigned to one of the players; to manipulate these game objects, players need to coordinate activities and divide tasks as required.

Evaluation

The *TeCP* game was evaluated in a formal experiment with non-disaster response teams to test the impact of the different annotation interfaces on game performance and collaborative planning behavior (Alharthi, Torres, Khalaf, Toups, et al. 2018). The results of the study showed a significant improvement in performance when annotations on the map were available. The use of these interfaces helped engage teams in collaborative planning activities, which resulted in better communication and planning between players. These results suggest that using such interfaces can be helpful in engaging players in collaborative planning activities, allowing them to interact with space through a map, which can enhance spatial skills.

CHALLENGES, OPPORTUNITIES, AND LESSONS LEARNED

Designers and developers of disaster response training simulations face a number of challenges. These include conducting field studies, determining fidelity level, designing immersive experiences, ensuring usability and replayability, and evaluating training effectiveness. The following section highlights the challenges designers face, discusses opportunities to overcome them, and identifies lessons learned from prior research and development of disaster response training simulations.

Qualitative and Field Studies

Qualitative and field study research is increasingly being conducted, resulting in rich and informative studies of different cultures and practices, which help inform the design of different technologies and training solutions. These types of studies has proven to help inform the design of disaster response training simulations that are effective (Toups, Kerne, and Hamilton 2011; Fischer, Reeves, et al. 2015). However, since researchers conducting these studies are usually working with a particular community, observations can only represent a small aspect of a community's practices, thus making it difficult to generalize from the results (Pink and Morgan 2013). These limitations of field studies are also caused by live training being not always available to designers and researchers and, in most cases, dangerous and expensive[2]. To overcome some of these challenges, different approaches to conducting qualitative studies can be used, such as rapid ethnography (Millen 2000), short-term ethnography (Pink and Morgan 2013), and participatory design (Muller and Kuhn 1993). Observations using these approaches are usually undertaken in a shorter time frame, in which one or more researchers immerse themselves at the center of the action while the participants are engaged in the studied practice.

Observations over a limited time, however, may not yield sufficient insights into the everyday practice and experience of disaster response training and needs. Thus, to overcome this limitation, after conducting short-term observations, designers can engage responders in the design process through a participatory design approach (Muller and Kuhn 1993). This approach has been successfully employed in designing training simulations (e.g., Toups, Kerne, and Hamilton 2011; Fischer, Reeves, et al. 2015), which resulted in a deep understanding of disaster response practice and the design of effective training simulation. Also, live training can be inconsistent across training agencies, which limits the use of virtual training developed within a particular context. This limitation can be profound, especially when designers focus on developing high fidelity and realistic virtual simulations, which is not always necessary or more effective (G. Norman et al. 2012).

Toward Low-Fidelity Simulations

One of the main challenges in designing simulations for training is how they can be designed in such a way that they are relevant to actual practice (e.g., firefighting, search and rescue). Current games and simulations for disaster response training might not capture the actual training experience including its physical, cognitive, and social complexity (Williams-Bell et al. 2015). Prior simulations usually aspire to high-fidelity, capturing as much of the actual practice and environment as possible, in an attempt to improve practicality and effectiveness. However, including all the practice aspects into a simulation might not be always possible or even needed (Jensenab et al. 2013).This imposes challenges for designers to balance between capturing the actual experience and making the training practical, but at the same time, effective.

One way to overcome these challenges is reducing the fidelity of the developed simulation, focusing only on conceptual learning. For example, *TeC* developed a zero-fidelity simulation design approach to overcome these challenges (Toups, Kerne, and Hamilton 2011). Zero-fidelity simulations addresses not the concrete environment, but, instead, distributed cognition characteristics, abstracting alternative means by which participants can learn to perform tasks. These games help teach different skills while entertaining, so that players are encouraged to learn, providing intrinsic motivation. Zero-fidelity simulations have two main advantages over high-fidelity simulations: they are economical in that they are simpler to produce by abstracting out details that would be expensive to replicate, and those simulations usually focus on one aspect of the practice such as coordination or planning, making it possible to evaluate (Toups, Kerne, and Hamilton 2011).

[2]An example list of training courses and their costs at: https://teex.org/Pages/Course-Catalog.aspx

Toward Mixed Reality Training

While designing high-fidelity simulations are not necessary for effective training (Hays and Singer 1989), mixed reality can offer unique opportunities for designing training simulations that capture the different aspects of disaster response practice. Mixed reality games have received increasing attention across multiple disciplines (Pan et al. 2006), however, the adoption of such designs in disaster response simulations remains limited (Champney et al. 2016). One of the main contributions to the benefits of mixed reality is its ability to present a contextual experience that use the real physical world as a stand for the game world (Benford and Giannachi 2011). Unlike the complete artificial world of VR, mixed reality combines virtual information with a physical reality experience that takes place in physical environments. Designers do not need to simulate the environment, they simply use an existing one, such as an open field, an abandoned construction, or even an existing training ground (e.g., TEEX Disaster City[3]). The physical environment affords and constrains actions in the game through a combination of layout, size, climate, history, purpose, and/or social contracts (Sharma et al. 2017).

Using context-sensitive devices in mixed reality reduces the need for direct interaction, allowing trainees to interact naturally in the environment around them, without burdening them with complex interfaces (Mann 1997). One of the main advantages of mixed reality simulations is a strong support for both seamless and seamful interaction between the trainees and the environment (Bell 2003). Interaction in mixed reality games can be explicit (e.g., clicking a button) or implicit (e.g., passively moving) (Schmidt 2000). These interactions can be performed through different modalities, including speech, air-based gestures, vital signs, or interacting with the real world through physically moving in the environment. This enables training to move beyond the classroom, placing it in the natural context of the practice.

In disasters, responders face highly cognitive intense work and physical exertion, which are not incorporated into most virtual training simulations. In mixed reality simulations, the use of biometric and environmental sensors, location tracking, and HMDs, help to incorporate some of these aspects of disaster response into training simulations. This opens up new and innovative ways to train responders on different cognitive skills such as visual-spatial skills, navigating in a disaster scene using maps or GPS, and decision making in extreme situations. In disasters, data might be generated automatically through sensors, such as biometric sensors that can be used to determine physiological and environmental information. Designers can take advantage of these existing technologies used in disaster response and incorporate them into their designed simulation. Balancing between the use of sensors and wearable computers in mixed reality training simulation and how they can be connected to the real practice is important.

While mixed reality can help overcome many challenges and open up new ways to design training simulations, it introduces its own unique challenges. In the *Icehouse* game, the designed wearable interface relied on both data entered manually by the players and sensors from the environment, which is not always ideal. In disasters, manually entering data about the situation might hinder the responder or even reduce situation awareness of the surrounding environment, which is life-threatening. Balancing between the use of sensor data and interaction modalities in the simulation and how they can be relevant to the practice of disaster response is important. Wearable interfaces for training simulations can be designed to provide situation awareness to players. When designing wearable interfaces for mixed reality simulations, designers need to provide the right amount of information about the team and game status with minimal interferes with awareness of the nearby environment.

Despite some of the challenges with moving toward mixed reality training, new technologies and wearables are powerful and can deliver mixed reality experiences via wearable interfaces, body sensors, and mobile devices that combine the real world with sophisticated augmented information and seamless interaction. Combining these new technologies and training approaches with existing methods have the potential to improve the efficiency and effectiveness of disaster response training.

Routine Use of Training Simulations

A further issue revolves around the routine use of simulation games. Disaster response training is performed constantly over time, demanding the simulation game to be replayable. To overcome this challenge, considerations needs to be given to how the game can sustain repeated playthroughs. Gameplay in these simulations can depend on the skill of the player to an extent, which can be developed through repeated playthroughs. The evolution of players' skills needs to be tracked and presented to the player. The player can get such feedback by progressing further in the game or observing an increase in score, which can be used as an assessment metric for performance. However, this requires a game to have enough depth and scope that it requires a significant amount of time from the player

[3] https://teex.org/Pages/about-us/disaster-city.aspx

to master all the game aspects. Alternate outcomes, multiple paths to victory, achievements, increasing difficulty levels, and direct consequences for the decisions a player make within a game can make repeated playthroughs valuable (Adams and Dormans 2012).

Effective use of procedural generation content also can make simulations more replayable (Togelius et al. 2011). Creating infinite content such as emergent objectives, in which the game could gather information about the game status to trigger new objectives or quests for players can provide an extended experience (Toups, Hamilton, and Alharthi 2016).

In mixed reality simulations, however, ensuring a replayable experience can mean extensive use of technologies such as environmental sensors, body sensors, and wearable devices. These technologies need to be selected carefully, ensuring durability and ease-of-use for routine training. Designing ubiquitous mixed reality games allows players to experience mixed reality continuously in all directions in the physical environment (Sharma et al. 2017). In these types of simulations, the player can move freely to explore the environment, which can provide a highly replayable experience. Designers need to explore new and innovative ways to increase the replayability of training simulations.

Evaluation Approach

Evaluating designed training simulations poses different challenges to designers. Conducting studies with disaster responders is not always possible and in most cases difficult to arrange. Designers need to make sure that when testing the training simulation with disaster responders, the design is in a state that can benefit from the disaster responders feedback and further development. To evaluate the design, using an iterative, human-centered evaluation approach can help in assessing the effectiveness of the designs throughout the design cycle (D. Norman 2013). This involves testing the simulation with non-disaster response users first to assess the effectiveness and outcomes of the training. Focusing early in the design process of conducting multiple user studies that test different aspects of the training simulation such as the user interface, gameplay mechanics, and usability is crucial.

Evaluating the effectiveness of the training itself and the responders performance, however, remain challenging. A common approach is the use of pre- and post-training assessments and the use of different statistical measures (Farra et al. 2016). One advantage of mixed reality and the use of wearable sensors over conventional training methods is the ability to track and record the physiological data of the trainees and game statistics. These data can be then saved and/or streamed back to a central training facility, allowing for real-time evaluation of individual and group performance and assessment of the overall training effectiveness. These type of physiological and performance data can enhance the reliability and validity of the assessments and opens the door to a much wider range of training measurement instruments (Dolgov et al. 2017).

CONCLUSIONS

This review paper synthesizes prior research and development of disaster response simulations and contribute an overview of current practices in designing training simulations. Through challenges, opportunities, and lessons learned from prior development of training simulations, we provide designers with practical insights into the design of future training simulations. We believe that progress in designing disaster response simulations is needed and the use of advance technologies has a lot to offer. The potential gains from moving towards low-fidelity and mixed reality simulations can be significant: the invention of new methods of combining wearable computers with mixed reality gameplay, ensuring replayable and long-term experiences, and advance training measurement instruments are all possible.

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Risk Analysis and Management of IT Systems: Practice and Challenges

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ABSTRACT

Risk analysis is important for safety-critical IT systems and services, both in public and private organizations. However, the actual practices and the challenges of risk analysis in these contexts have not been fully explored. This paper investigates the current practices of risk analysis by an interview-based investigation. This study investigates several factors of the risk analysis process, e.g., its importance, identification of critical resources, definitions of roles, involvement of different stakeholders, used methods, and follow-up analysis. Furthermore, this study also investigates existing challenges in the current practices of risk analysis. A number of challenges are identified, e.g., that risk analysis requires competence both about the risk analysis procedures and the analyzed system, which is challenging to identify, and that it is challenging to follow-up and repeat a risk-analysis that is conducted. The identified challenges can be useful when new risk analysis methods are defined.

Keywords

risk analysis, current practice, challenges

INTRODUCTION

Safety-critical systems are managed by both public and private organizations. Failures in these systems can have catastrophic consequences in society. These systems are typically subject to risk analysis in order to prevent that they unduly harm people, property, or the environment.

Today, both public and private organizations are facing different types of risks, e.g., policy, operational, project, financial, technological, health, safety, and human resources (Berg 2010). Risk analysis and management are often conducted in the organizations that are responsible for these safety-critical systems and provide critical services to society, which means that risk analysis is carried out by several different organizations when circumstances are changed. Therefore, clearly described methods and guidelines for conducting these analyses are needed. That is, an effective risk management approach is needed that requires a continuous assessment of potential risks in an organization at relevant lower levels and then it aggregates analysis results at the higher level to improve decision making.

Today, almost every organization has procedures and rules regarding risk analysis and management and knows how one should carry out risk analysis and management, based on available methods, frameworks and guidance documents. That is, organizations often have formal processes defined for how risk analysis should be conducted. Furthermore, there exist a large number of reported normative research studies that investigate how risk analysis and management can be carried out (Sulaman, Weyns, et al. 2013). However, there are only few studies available that investigate how risk analysis and management are actually carried out in practice. This study is carried out to investigate and understand the current state of the practices of risk analysis and management in large-scale organizations for their IT systems. It is intended to provide insights into how practitioners deal with risk analysis and management in different large-scale organizations and to understand what they see as the main challenges.

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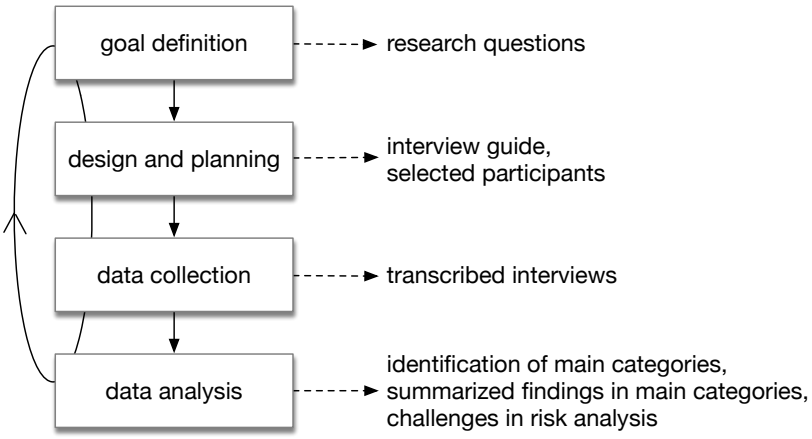

Figure 1. Methodology

BACKGROUND AND RELATED WORK

There are several frameworks developed by different national and international organizations, e.g., the ISO 31000 standard (International Organization for Standardization 2009) for risk management, the ISO/IEC 27005 for Information security risk management, CRAMM by the British Central Communication and Telecommunication Agency (CCTA) (Central Computer and Telecommunications Agency 1993), OCTAVE by the SEI Software Engineering Institute (Alberts and Dorofee 2003), and the Risk Management guide for information technology systems by the National Institute of Standards and Technology (NIST) (Stoneburner et al. 2002). A detailed comparison of some of these frameworks is presented by the European Union Agency for Network and Information Security (ENISA) working group on risk assessment and risk management (ENISA 2006). Furthermore, for a more detailed risk analyses of technical systems, there also exist a number of risk analysis methods. Some of the most well-known methods of this type are Fault Tree Analysis (FTA) (Ericson 1999), Failure Mode and Effect Analysis (FMEA) (McDermott et al. 1996), and Hazard and operability study (HAZOP) (Redmill et al. 1999). Some of the more high-level frameworks described above specifically recommend one or more of these risk analysis methods.

There are a number of studies that discuss and present the current practices of risk analysis and management in different domains (Meyer and Solomon 1984; Murdock et al. 2011; Henschel 2010) but not for IT systems. For example, Murdock et al. 2011 present lessons learned and best practices for risk management for developing an enterprise-wide risk management framework are identified from 14 case studies. Henschel 2010 describes the current state of risk management practices in German small and medium size enterprises (SME) in a study based on questionnaires and interviews. The research on current practices in risk analysis in IT systems is by no means complete, and more knowledge would be needed. Most of the presented research on available methods and frameworks for risk analysis and management is of normative nature that guide how one should carry out risk analysis and management. It is not sufficiently investigated how different organizations are actually carrying out risk analysis and management.

RESEARCH METHODOLOGY

The main objective of this study is to investigate the current practices of risk analysis and management for IT systems in the large-scale organizations. Moreover, this study also investigates the existing challenges in the current practices of risk analysis. The research method used for this study is a qualitative interview research method (Brinkmann and Kvale 2014) in the form of a qualitative survey, based on the discussions by Jansen 2010. According to Jansen 2010 the qualitative survey analyses the diversity of member characteristics within a population as opposed to the statistical survey, which analyses frequencies in member characteristics in a population. The research process in this study includes goal definition, design and planning, data collection, data analysis, and reporting, as described by Brinkmann and Kvale 2014. The first author of this study was responsible for the thematizing, design and planning, collection of data through interviews, transcription, and analysis of the collected data. However, there is one interview that was carried out and transcribed by the second author because it was carried out in Swedish. The methodology is illustrated in figure 1. The circular arrow indicates the iterations that took place in the research. The steps were not carried out in strict order without going back. Instead there were several iterations where new findings affected the detailed goals and the interview questions.

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Table 1. Overview of interviewees' roles and their organizations

Org.	Type of org.	Role of interviewee	# empl.
A	Education	Chief security officer	7-8 k
B	Municipality	Coordinator of info. security	21-23 k
C	Health care	Head of IT security	32-34 k
D	Municipality	Responsible of info. security	9-10 k
E	Municipality	Security and safety officer	9-10 k

Goal definition

A set of goals and research questions were defined based on the experience, knowledge of the authors, and literature reviews of the area. The main research questions of the presented research are

- RQ1: What are the main current practices of risk analysis and management for IT systems in the studied governmental organizations?
- RQ2: What are the main challenges in the current practices of risk analysis and management for IT systems in the studied governmental organizations?

RQ1 is answered by interviewing people responsible for risk analysis and management in large-scale organizations about the current practices of IT systems risk analysis. The interviewees were asked how they carry out risk analysis and then the collected qualitative data was analyzed and the results were presented. RQ2 is answered by asking interviewees about the challenges and problems that they face while carrying out risk analysis in their organizations.

Design and planning

This section presents the research procedures carried out in designing the study and the preparations made for the data collection. This include designing the interview guide with interview questions, and the selection of interviewees. The general design of the study is qualitative. That is, the analysis is based on understanding of the data, and not quantitative findings based on statistical significance, see e.g. Weiss 1994.

The interview guide for the semi-structured interviews was designed based on the research objective and questions of the study. The interview guide was updated several times, e.g., after review by the second author and after carrying out the first interview. In the last update of the interview guide (after the first interview) the general content of the guide remained the same, however the structure and order of the interview questions were modified and improved.

The interview guide was designed in three themes with questions about current practices of risk analysis, existing challenges in carrying out risk analysis and questions about improving current practices of risk analysis. Before these three main themes there were a number of introductory questions about the interviewees' roles in organizations and their experience with risk analysis, etc. The questions of theme one, current practices of risk analysis, were divided into three groups (general questions about the risk analysis process, questions about carrying out risk analysis and after this questions about risk management). After this in theme two, challenges in current practices, the questions were mainly about identifying the existing challenges in carrying out risk analysis. Finally, in theme three, improvements for current practices of risk analysis, the questions were mainly intended to get suggestions for improvement. However, theme three is not included in this study.

The selection of participants was carried out with the objective to represent the relevant range of viewpoints from security, safety, risk analysis and management domains for IT systems. The following selection criteria were used to select the participants for this study. Participant should be involved with risk analysis and management of IT systems, and must be working or having experience from working in a large-scale organization. Participants should also be located in southern Sweden for ease of accessibility. Initially, 32 persons from 30 different Swedish municipalities, and 3 persons from the regional health care, were contacted through emails. After this, very few responses were received and then all persons who did not reply were contacted again through email after 3 weeks. In total 5 persons responded that they were willing to participate in the study and they all fulfilled the selection criteria, see Table 1.

The interviewees are all responsible for the risk analysis in central units of their organizations. The central unit, which is responsible for the whole organization manages all sub-departments and sub-organizations regarding risk analysis and management e.g., hospitals, schools, emergency services, etc. Furthermore, the persons responsible for risk analysis in the sub-departments and sub-organizations working under a municipality get support from the central risk unit for risk analysis and then after analysis they report analysis results back to the central risk unit for aggregation. This way it can be said that a person responsible for the central risk unit has knowledge about how others are carrying out risk analysis and managing their risks.

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Data collection and analysis

A semi-structured interview strategy (Robson 2002) was, as described above, used for the interviews. The interviews were conducted over a period of about four months. After having consent by the interviewee to record the interview, audio recordings were made of each interview. On average an interview lasted for about 50 minutes. The interviews were transcribed and the transcripts were validated through member checking by sending them to the interviewees for review. After this, the transcripts were divided into chunks of text consisting of a couple of sentences each to map with the themes or categories of the interview questionnaire. Three main themes or categories we defined: current practices, exiting challenges, and suggestions for improvements were defined in the interview guide.

A set of codes, i.e. keywords, based on the research and interview questions was first produced and then iteratively updated during the analysis. The final set of codes consists of 16 codes related to current practices, and 8 codes related to existing challenges. Then, the text relevant to each category was analyzed to find the diversity between the experiences of the interviewees about the risk analysis practices.

Validity evaluation

According to Brinkmann and Kvale 2014, the overall validity of an interview-based research study is described by the research reliability, research validity, and the possibility to generalize the research results. The reliability refers to the consistency and trustworthiness of research findings (Brinkmann and Kvale 2014). Here, consistency and trustworthiness denote to what extent a finding is reproducible at other times and by other researchers. This can be interpreted as if another researcher subsequently conducts the same study, the results should be the same. In this study, the interview guide was designed and developed, which helped to carry out interviews in a consistent way. Moreover, all findings were also reviewed by the second author, which means that this threat has been addressed at least to some extent.

The research validity determines if a statement is true, correct, and strong. It helps to solve the issue of whether a method investigates what it claimed to investigate (Brinkmann and Kvale 2014). In this study, it can be assumed that the topic being analyzed (risk analysis and management in large-scale organizations for IT systems) was well known by the all interviewees. Moreover, during the interviews, care was taken not to ask questions with over-complicated terms in order to make sure there was good understanding by the both interviewees and interviewer.

The generalizability is concerned with generalization of results from the chosen population and topics that have been investigated. The main threat to the generalizability of this study has probably to do with the sampling of interviewed subjects. The interviewed subjects can be seen as a representation of risk professionals, not the least since they are collaborating and supporting many risk professionals in their work in the same organizations. The findings are more in the form of understandings than in the form of distributions, which means that the findings are not that difficult to transfer to other situations when the context can be seen as similar. However, the analysis is based on a rather small number of interviews, which needs to be taken into account when conclusions are drawn.

ANALYSIS AND RESULTS

Current practices of risk analysis

This section presents the analysis and results of the main categories, that is, the current practices of risk analysis, and the existing challenges that were defined in the interview guide of this study.

Importance of risk analysis

During the interviews, it was investigated to what extent risk analysis is seen as important for the interviewees in their work-related activities. According to the majority of the interviewees, it is crucial to carry out risk analysis because most of their security and safety countermeasures and mitigations in different sub-departments and projects are based on it. So, if one finds a severe risk then there is a need to take counter-measures to mitigate the possibility for someone to exploit or miss-use of the system. Furthermore, the interviewees (organizations B and E) mentioned that, in most situations, IT systems that are maintaining other services are not of primary concern in risk analysis. Instead, the services themselves are more critical. For example, if a service is to provide health care, then one needs a system, which consists of staff with expertise, infrastructure, medical facilities etc. However, an important part that is needed is an IT system for the management of different tasks and patient information, which means that these IT systems are more critical because of their importance. Here, the question arises how it is possible to know about the importance and dependency of these services and the answer to this is by carrying out risk analysis. Finally, one of the interviewees (organization D) mentioned that the public organizations are funded by the tax, and therefore

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need to be really effective. For this effectiveness they should be able to see what parts or services are important. That is, risk analysis is important for the organizations to carry out their tasks and risk analysis helps them manage their critical systems and services.

Identifying critical assets and services

Identification of critical assets and services and their prioritization are important activities in the risk analysis process. Most of the interviewed organizations are aware of this vital activity and in their first step of risk analyses they determine which services are important for society. For example, for delivery of these services one needs several elements, e.g., software, hardware, and staff with knowledge. Therefore, one has to know how important the services are, as they are setting the requirements to the system. For example, organization B has many services that it is providing to the society and for these services they have performed a prioritization for the both normal operations and crisis situations. The IT department at Organization B knows which services are most important for the functioning of the municipality and its inhabitants. If something goes wrong in the infrastructure, then the IT department has a prioritized list of services.

> "The IT department knows which services are most important to serve the municipalities and inhabitants. If something goes wrong in the infrastructure then IT department prioritizes what is more important. Then, they know we have to prioritize for example health care system instead of library service work." (Organization B)

Another interviewee mentioned that:

> "From an IT perspective there is a 'crisis list' that shows what IT systems are important and they are prioritized in a certain order. Moreover, we have developed a critical assets list based on many risk and crisis analyses conducted with in different departments." (Organization C)

However, there are a few organizations (A, D and E) that are aware of this fact but they are trying to improve the overall risk analysis process, including the identification of critical assets. Few organizations are very systematic in doing risk analysis of their IT systems and critical services although they are improving this particular activity and in general the whole risk analysis process.

That is, identification of critical assets is seen as important, but some organizations are still working on defining complete records of important assets.

Defining roles and responsibilities

Definition of roles and responsibilities for normal and crisis situations is important. If there is a critical system then it is important to have an owner of it from the risk analysis and management perspectives. Regarding this the interviewed organizations, municipalities and health services providers are at least following a systematic approach and they use some models. For example, one organization B is using a model named PM3[1] for definition of roles and responsibilities. The model demands that all assets need to have an owner or someone responsible.Then, there is an independent audit unit for these organizations. It serves as a bridge between these public organizations and the government to monitor and regulate different activities.

Carrying out risk analysis

Regarding the responsibility of risk analysis it was noticed that mostly head of department, project manager or anyone who is responsible for an organization or sub area is responsible for carrying out risk analysis. In the public sector there are normally a few persons responsible for risk analysis and management who carry out risk analysis for central systems. Moreover, they also support other employees, i.e., persons responsible for risk analysis in different sub-departments or organizations, to carry out their risk analysis. The central responsible person or unit for risk analysis requires risk information from all sub-departments or sub-organizations to aggregate risk information to take countermeasures from the central point.

Regarding how these organizations carry out risk analysis, it can be explained in an abstract level because it is not exactly the same in all organizations. The following example presents analysis of acquiring a new information system for health record system. In step 1, they analyze what kind of information is important and what are the potential risks to this information along with legal restrictions, e.g., the personal information act. Based on this they

[1] http://pm3.se/en/

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have requirements of the system in hand. This step does not involve technical details at this stage of analysis. In step 2, they have requirements in hand with a list of identified potential risks. In this step they involve technical parts and identify more potential risks by analyzing the requirements to secure the information. Then, they consider potential identified risks with their likelihood and consequences. In carrying out both steps they follow the ISO 27000 standard. In the final step most, but not all, of the investigated organizations re-analyze the acquired system for potential risks after a fixed time interval.

Almost all interviewees carry out risk analysis in their organizations by themselves internally. However, one interviewee mentioned that sometimes they hire a third party to carry out their risk analysis.

Involving people with different knowledge

Almost all the investigated organizations involve more than one person in order to get people with different knowledge in the risk analysis process. It is important from the completeness perspective of the risk analysis process i.e., yielding complete risk analysis results. Generally, all the interviewed organizations involve 5 to 7 people in risk analysis consisting of IT function, law function, end-user, system developer representative and one person from higher level management working with the strategies and policies. Here, the IT function means IT security specialist along with system administrator, system architect and system owner. In some cases all representatives from an IT function take part in risk analysis. Then, the law function represents legal team who checks that all legislation is being followed in the risk analysis process. However, there exist some challenges that are presented elsewhere in this paper. For example, one of the interviewees (Organization E) mentioned a risk analysis case where they tried to include people with different knowledge and they ended up with 30 people, which posed several problems in risk analysis.

Used methods for risk analysis

The majority of the interviewees mentioned that generally their main focus is to have a simple method or technique to work with for risk analysis. Almost all of the organizations are using qualitative risk analysis methods with qualitative descriptive values to anticipate probabilities and consequences of unwanted events. They are not using quantitative methods and estimates because they do not want to make the risk analysis process more complicated and difficult.

Almost all organizations are following international standards but they have adapted these standards and methods to their needs. Organization A is using their own risk analysis method that is based on international standards and methods. Organization B is also using their own risk analysis method based on ISO 27000 and ISO 31000, and Organization C is using a risk analysis method that is based on ISO 31000. The risk analysis method used by Organization D and E is based on ISO 27000, adapted by a national organization[2].

Follow-up analysis

Follow-up risk analysis means that if a critical risk is found and is being treated then it requires to carry out risk analysis again for whole system or a specific part of system depending on the treatment of found risk. Most of the investigated organizations carry out follow-up risk analysis. For example, Organization B carries out follow-up after every two years and Organization C and Organization D carry it out every time after introducing significant changes in the system. However, Organization C is dealing with more safety critical systems as it is providing health services to a large number of inhabitants. Moreover, because of its severity it does not have any defined time period for follow-up analysis instead it has instructions that follow-up analysis should be carried out after every major change.

Education and training about the risk analysis process

Not very many concrete activities regarding education and training about risk analysis in the investigated organizations were described. It was found that these organizations are not investing enough to educate and train their employees to carry out or participate in the risk analysis process. For example, persons responsible for risk analysis in these organizations has duty to educate his/her sub-departments or organizations to carry out risk analysis by their own. The majority of the interviewees (organizations A, B and E) mentioned that they educate others about the risk analysis methods and models. However, except this education there is no other courses or trainings for risk analysis in these organizations. Only one interviewee (Organization C) mentioned that they have both internal and external training courses about risk analysis.

[2]Swedish Association of Local Authorities and Regions, https://www.skl.se

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Existing challenges in carrying out risk analysis

This section presents the identified challenges, which are encountered by interviewees while carrying out risk analysis of their IT systems.

Required competence and skills

The required competence and skills are considered to be significant to carry out risk analysis. In general, all of the interviewees mentioned that the required competence and skills are important to carry out risk analysis. The required competence and skills are not the same in all sub-departments or organizations. For example, one of the interviewees mentioned that:

> "The competence and skills change dramatically between different sub-departments and sub-organizations. This variation in competence and skills of different sub-departments makes the risk analysis process more difficult and complex." (Organization B)

The important challenge is knowledge of doing risk analysis because most of the times there is a need of someone who leads the risk analysis process with the understanding of what should be covered in the risk analysis process. Therefore, lack of people with required competences and skills could be a risk in itself for risk analysis because it can yield incomplete analysis results.

Different opinions about risks and the risk analysis process

The next unfolded challenge by this study is that people involved in risk analysis have different opinions about risks and the risk analysis process itself. Here, the difference in opinions regarding risks and the risk analysis process exist because of how people perceive and trust them. Trust in the risk analysis and management process is very crucial and helps in yielding better results, which consequently improves critical societal services. The view of distrust comes from considering something not important. Slovic 1993 argues that this distrust among people is not because of ignorance. On the other hand, after these many years, today we can notice that it is somehow because of public ignorance. Therefore, there exist challenges that risk practitioners are facing because people think differently and sometimes do not have enough information. All the interviewees mentioned that more or less they encounter this challenge, e.g.,

> "Mostly people involved with risk analysis are divided into three categories i.e. people who say 'yes', people who say 'why?', and people who say nothing about carrying out risk analysis." (Organization A)

People who say 'yes' represents the group that knows the importance of risk analysis and this group trusts in it. People who say 'why?' represent the group that knows the importance of risk analysis but only partially. Therefore, after carrying out risk analysis once they are reluctant to carry out a follow-up analysis. Then, the third group who says nothing seems ignorant and this group does not believe and trust in the risk analysis and management process. Usually the third group tries to move to next step without carrying out risk analysis. One of the interviewees mentioned that it is really important to communicate that risk analysis is an important activity for a project or mission and it can not be skipped at any cost.

After this, comes the issue of different priorities in a department, which is also relevant to the different thinking about the risk analysis process. For example, one of the interviewees mentioned that everything has a priority and it might be that carrying out risk analysis for critical IT systems and services in a particular department is not given the highest priority. Sometimes, when the central risk unit question about it then the department's risk people answer yes we know that risk analysis is important but we do not have time to carry out. Here, it seems like these kinds of problems are more exposed to the large-scale organizations however it is interesting to investigate this in small-scale organizations as well.

Pre-understanding of the risk analysis process and its context

To carry out an effective and complete risk analysis, people involved in it should have good pre-understanding of the potential risks, the risk analysis process, and the system being analyzed within its context. Almost all of the interviewees mentioned that having a clear pre-understanding about these elements is very important, although they do not always see this in their practices. One of the interviewees mentioned that if an analysis unit does not have this pre-understanding then there are chances that they will also identify some risks that are ongoing or already been eliminated.

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Subjectivity in risk analysis

There is a discussion going on whether risk analysis is subjective, objective or some combination of both, e.g. (Campbell 2006; Hurst 1998). Since the risk analysis process involves subjective judgments or estimates in its all activities, it does not produce exact estimates that means one cannot call it a complete objective process. Here, it worth to mention that the estimates for potential risks made by either experts or a normal user of an analyzed system can not eliminate involved subjectivity in the risk analysis process (Redmill 2002).

In this study, all the interviewees mentioned issues related to subjectivity in the risk analysis process. Some of the interviewees mentioned that this subjectivity is a severe challenge that makes risk analysis more complex and difficult to carry out. People think differently and have different opinions about things similarly this goes for potential risks and the risk analysis process as well. Interestingly, one of the interviewees mentioned that this subjectivity, of course, brings some challenges, but it is also a significant strength of the risk analysis process. All the interviewees also mentioned that because of subjectivity they carry out risk analysis in groups and try to reach consensus regarding risks and their values. Furthermore, they mentioned by involving different kinds of roles in risk analysis could eliminate this challenge at some extent.

Follow-up risk analysis

All investigated organizations have well defined and designed normative documents saying that they should carry out follow-up analysis after some specified time interval. However, because of priorities in the organizations, they are not always following these instructions strictly. One of the interviewees mentioned that:

> "We are reworking with the instructions for follow-up analysis that it should be carried out more on the regular basis. We have work in progress there to improve this area." (Organization C)

Interestingly, Organization D has this follow-up analysis as a major activity in their risk analysis and management process, and it has also defined the person responsible for it. However, here the challenge is if one has performed risk analysis a year or more ago then he/she question why this should be done again.

Moreover, the interviewee from Organization A, mentioned that he carried out more than 20 risk analyses of different departments. He tried to educate all employees about risk analysis and also motivated them to carry out risk analysis on regular basis to improve decision-making. He offered to all departments of the organization that whenever they need help or suggestions to eliminate risks or regarding anything for risk analysis and follow-up they can contact him. After this, no one contacted him regarding anything just because they think risk analysis is over and now they can do other things by saying that we are done with risk analysis.

DISCUSSIONS

Several factors were investigated regarding the current practices and existing challenges of risk analysis as presented in detail in the results section. For example, regarding the importance of risk analysis in large-scale organizations the findings show that it is an important activity for organizations that are dealing with safety-critical systems and services corroborating the findings of (Murdock et al. 2011). It is an important activity because most of an organization's security and safety countermeasures or mitigations in different sub-departments and projects are based on risk analysis and assessment. However, the associated challenge with risk analysis is that different employees have different opinions about risks and the risk analysis process. This difference in opinions is probably because of different level of perception, trust, and priorities about the risk analysis process. Therefore, this difference in opinions about importance of risk analysis makes difficult to carry out risk analysis.

Then, regarding carrying out risk analysis practices (RQ1) more or less all investigated organizations are analyzing their critical systems or services in the same way, at least on an abstract level. The reason for this could be that all organizations are of the same nature, i.e., governmental organizations dealing with critical services to society. It was found that these organizations mainly focus on the information or services in risk analysis instead on an IT system. Here, it can be said that they are using the system level analysis method (Motta et al. 2010). The associated challenges with carrying out risk analysis practice are the following. Firstly, the required competences and skills are a great challenge in carrying out risk analysis in these critical organizations. The findings of this study suggest that lack of knowledge and expertise about doing risk analysis is itself a risk. Moreover, the knowledge about the system context that is being analyzed and its boundary definitions are very crucial as discussed in (Lindholm et al. 2014). Secondly, pre-understanding of the risk analysis process is also a challenge while performing risk analysis of safety-critical services. This challenge is very similar to the required skills and competences challenge. However, it is about having good pre-understanding of potential risks, the risk analysis process, and the system being analyzed

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with its context. On the other hand, required skills and expertise deal with the knowledge of different risk analysis methods or tools and then the knowledge used for defining the system boundaries. The best practices of risk analysis and management identified in study (Murdock et al. 2011) also suggest that the risk management process should start with context establishment that includes organizational objectives, stakeholders, constraints, risk criteria, and other factors.

Next, involvement of different people (RQ1) in risk analysis is investigated and it is found that these organizations involve more than one person with different knowledge in the risk analysis process. Several authors, e.g., Leveson 2012, Ierace 2010, and Sulaman, Wnuk, et al. 2014 advocate to involve various roles or perspectives in risk analysis. Regarding involvement of different people in risk analysis the investigated organizations are seem to be mature. The associated challenge (RQ2) with this practice is subjectivity involved in risk analysis.

Furthermore, the analysis of this study reveals that the simpler methods, models and tools for risk analysis are better and being used in the investigated organizations as this corroborates with the findings of the study (Murdock et al. 2011).

There is, of course, an evolution of risk analysis methods for IT systems. There are methods available today, and there will be new methods developed. Based on this study it is possible to point at some of the challenges which could be possible to take into account in the development of new methods. Especially the fact that risk analysis on the one hand requires involvement of many experts in the organization but on the other hand that it is challenge to overcome the need for training about risk analysis and that it is not always given the highest priority in all parts of the organization as described above. This means that risk analysis approaches must overcome these challenges.

CONCLUSIONS

This study investigates and presents the current practices (RQ1) and existing challenges (RQ2) of the risk analysis and management process for IT systems in different large-scale organizations. Based on the results of this study regarding RQ1, it can be concluded that risk analysis is an important activity in large-scale organizations because most of their security and safety countermeasures are dependent on it. Furthermore, based on the findings of this study it can be concluded that the investigated organizations are not sophisticated regarding the identification of critical assets and services and its documentation, which is an important activity for risk analysis. Regarding methods for risk analysis it can be concluded that the simpler methods, and models for risk analysis are better than the complex ones because they are being used in the investigated organizations.

Based on the results of this study, regarding RQ2, it can be concluded that the required competences and skills are a great challenge in carrying out risk analysis in large-scale critical organizations. Another identified challenge is lack of knowledge and expertise about doing risk analysis, which is itself a risk. Next, the pre-understanding of potential risks, domain, and the risk analysis process is also a challenge while performing risk analysis of safety critical services. The findings of this study also found that involvement of different roles in the risk analysis process eliminates at least the negative effects of subjectivity in risk analysis. After this, the next challenge identified is relevant to follow-up analysis that is how people perceive risk analysis and its priority among other things, which is different in different organizations and their sub-departments. There is a need for further research in order to provide general suggestions to improve the risk analysis process in large-scale organizations dealing with safety-critical IT systems and services. New risk analysis methods that are defined should meet the identified challenges.

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Information Systems for Disaster Management Training: Investigating User Needs with a Design Science Research Approach

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ABSTRACT

Societal threats such as global warming and terror attacks make crisis preparedness and crisis training a major priority in governments worldwide. Unfortunately, training is limited, partly due to complex and resource-demanding planning of traditional exercises. Several crisis training software have been developed as a complement. However, reports in research on their usage are rare, which indicates that the diffusion is limited. A potential explanation is that the systems fail to meet important needs in the organizations and/or sound information systems (IS) design principles. This paper describes the first phase of a design science research (DSR) project aiming at developing information systems for disaster management (ISDM) training, and accompanying training methods in local and regional governments. The purpose of this paper is to investigate perceived problems in current crisis training and identify opportunities for ISDM training in the application domain. Another purpose is to outline expected artifacts in the project.

Keywords

Crisis management training, information systems for disaster management, user need analysis, design science research.

INTRODUCTION

Natural disasters such as floods and storms are causing loss of human lives and severe damages worldwide. Only in 2016 approximately 8 250 persons were killed in natural disasters and the global economic losses were estimated at 210 billion USD, stemming from 315 separate events (Aon Benfield, 2017). Due to global warming, there is a risk that natural disasters will become even more frequent in the future. In addition, man-made crises such as terrorism and riots are threating our society. A vital part of a sound preparedness for crises and disasters is crisis training. Steinberger (2016:70), for example, argues: ”Training provides skills, informs those involved about every actor’s roles and responsibilities, builds informal networks and serves as a stress test for disaster response plans”. In this paper crisis *training* is used an “umbrella concept” that includes everything from individuals’ training for their role in a crisis to cross-functional and multi-agency exercises. Furthermore, while the concepts emergency, crisis and disaster represent a sliding scale of increased severity (Boin & McConell, 2007) we will use the concept *crisis* training to cover training for all of these, starting from Steinberger’s (2016:61, sic) defining of disasters as “unplanned natural or man-made events with a sudden and severe negative impact on human live, the functioning of society and/or the physical environment”.

Traditional crisis exercises require the trainees to meet at a fixed time for table top discussions, crisis simulation with counter-acting or live field exercises. Planning and coordinating these events are complex and resource-demanding which result in a long planning time (e.g. Field et al. 2012). A crisis scenario needs to be developed, different organizations/roles coordinated, a suitable date for the exercise set, resources made available, etc. With a long planning time there will also be a long time between exercises in many organizations. In recent years, several computer-based training applications have been developed to complement traditional training methods, potentially enabling resource-efficient, flexible and frequent training (c.f. Lukosch et al., 2012). However, although numerous applications exist and have been tested in crises training (e.g. Ahmad et al. 2012; Cesta, 2014; Lukosch et al. 2012), their diffusion seems to be limited as reports in research on ongoing usage are rare (Magnusson & Öberg, 2015). This is puzzling considering the fast digitalization and the importance of crisis preparedness in all of society. Furthermore, Cesta et al. (2014) claim that most of the state-of-the-art training support systems are aimed at the operational or tactic level. This is unfortunate as the strategic level in particular needs more training opportunities. As crises are rare, strategic level actors seldom get to practice crisis handling in their daily operations and building up their skills is thus difficult (Sniezek et al., 2002).

Several theories have been applied in the IS research field to explain the up-take or adoption of different innovations. In the technology acceptance model (TAM), for example, perceived usefulness and perceived ease-of-use of an IT system have been found to have a direct positive effect on the intentions to use information technology (IT) (Venkatesh & Davis, 2000). For new IT products to be adopted and used the developers thus need to have a well-grounded understanding of the features that are useful for the target groups. This is in line with design science research methodology (DSRM) where identification of problems and opportunities in the user context is a recommended early activity of the development process (e.g. Drechsler & Hevner, 2016; Peffers et al. 2007). So far, there are a few examples of studies using a DSR approach in the development of ISDM training software.

We have only identified a few earlier studies of what Drechsler & Hevner (2016) call the external and internal environment of crisis management training. This comprises the people or target audience for ISDM training, the societal and organizational systems involved, the technical systems in use today, and last but not least, the problems encountered in current crisis training and the opportunities perceived with ISDM training (Drechsler & Hevner, 2016). The study of problems and opportunities in its organizational context as a separate step beforehand, or as a first step in systems development, is sometimes called need analysis, need elicitation, or change analysis. We have found few such studies in the area of crisis management training. It is important to increase knowledge about user needs for ISDM based training in government agencies in order to facilitate adoption and design software that creates value. The purpose of this study is therefore *to investigate perceived problems in current crisis training and identify opportunities for ISDM training in local and regional government agencies.*

This will be done by gathering empirical data from a Swedish-Norwegian R&D project outlined later in this paper. The project strives to follow a DSRM approach. A second purpose of this research-in-progress paper is thus to outline expected design artifacts and suggest research fields for their scientific grounding.

LITERATURE REVIEW

CRISIS MANAGEMENT TRAINING

Emergency preparedness is defined by Perry and Lindell (2003, p. 338) as "the readiness of a political jurisdiction to react constructively to threats from the environment in a way that minimizes the negative consequences of impact for the health and safety of individuals and the integrity and functioning of physical structures and systems." Local authorities in Norway are obliged to regularly make a risk and vulnerability analysis and to have an emergency plan (Meum & Munkvold, 2013). Also, disaster exercises are mandated in regulation in most industrialized countries (Perry 2004 referring to Selvarajah, 1993[1]). Exercises serve several functions, one of which is to test the plan (Perry, 2004). Frequent and efficient training is often regarded as crucial for organizations to be prepared for crises. McConnell and Drennan (2006, p. 67), for example, argue that "the usefulness of simulated and full-scale exercises is almost universally lauded". However, they continue by stating that it is impossible to for every organization to exercise every possible scenario. Although it may be impossible to know or cover the exact training needs, Sniezek et al. (2002, p. 150) claim that "it is likely that domain knowledge and procedural knowledge as well as general problem solving strategies are crucial to crisis management". Sniezek et al. (2002, p. 153) also list a number of problems with crisis management training.

[1] Selvarajah, C.T. (1993) Training System Effectiveness in Australia, *Human Systems Management*, 13, 3, 295–302.

Among these are the time required for training, its costs and assessing the effectiveness of training, in addition to the problem of finding and recruiting experts, defining a training content and performing team training. Other problems are connected to the interaction with the trainer, giving feedback to trainees, the realism in training, and the transfer of training/ learning to future crisis (Sniezek et al., 2002).

Many of the problems mentioned in Sniezek et al. (2002) can be referred to the role of the planner/trainer. While the political leadership technically has the responsibility for safety and security in a municipality, the coordination of local work is delegated to emergency coordinators (Meum & Munkvold, 2013). In smaller municipalities a sole employee may have to cover the tasks, sometimes in a part-time position, having many assignments besides crisis training (e.g. Meum & Munkvold, 2013).

Traditional exercise methods mean that a number of actors are gathered simultaneously, with complex planning as a result. The need to involve different organizations is however vital, as Bharosa et al. (2010:50) point out: "The need for coordination in disaster management is undisputed, with lack of coordination leading to a number of possible failures, for instance inappropriate allocations of first responder resources, counter-productive ordering of sequential relief processes, and delayed evacuations, which often result in crisis escalation and even higher numbers of causalities."

Preparing not only the operative and tactic levels but also the strategic level of government agencies is crucial. During stressful conditions the strategic managers are expected to identify key issues and prioritize required actions, i.e. decide the strategy for resolving a crisis and communicate it to lower levels (Cesta et al. 2014). Decision-making at this level is mainly unstructured due to the nature of the problems and the creativity that is necessary to identify and construct courses of action in response. Cesta et al. (2014) claim that training play a fundamental role for training decision-makers to focus on the potential consequences of their actions and the need to work in collaboration with other organizations.

INFORMATION SYSTEMS FOR DISASTER MANAGEMENT TRAINING

Computer-based training may be divided into individual or collaborative training (e.g. Arafa et al. 2011). The latter is often referred to as exercise. Furthermore, the training setting can be distributed or co-located (e.g. McKinnon & Bacon, 2012). A review of research concerning information systems to support crisis training or response reveals that a number of terms are used such as *disaster management information systems* (Lee et al. 2011), *emergency response systems* (Turoff et al. 2004), *exercise support systems* (Pottebaum et al. 2014), *simulation training game* (Lukosch et al. 2012) and *training systems* (Rankin et al. 2011). Some systems support both the training and actual response. Two such systems are the national systems WIS, offered by the Swedish Civil Contingencies Agency MSB, and its equivalent CIM in Norway.

We have not been able to find any studies of how common ISDM training systems are in practice. Meum and Munkvold (2013) mention that approximately 40 % of the Norwegian municipalities had adopted CIM and a fact sheet from 2013 claims that more than 80 % of the Swedish municipalities and all county administrative boards and county councils had adopted WIS.[2] It is not clear from these sources if the adoption includes the exercise/training module of the systems and if so, to what extent it is used. Meum and Munkvold (2013:86) claim that the uptake of CIM has been slow so far and their informants "point to the challenge of getting the intended users engaged in a new system that is not in daily use". Overall, there are few studies of ongoing usage of ISDM for crisis training (Magnusson & Öberg, 2015). In the wake of the ongoing digitalization of society, it is reasonable to assume that IT will have a more prominent role in crisis training in the future. McKinnon and Bacon (2012) predict that virtual technologies for training will have greater acceptance as the 'digital native' move into senior positions. This remains to be seen as Aedo et al.'s (2010) study, although based on a small empirical material, suggests that it is not necessarily technology resistance as such that is hindering the adoption of new IT applications.

Bharosa et al. (2009, pp. 1) claim that "In order to design successful information systems for disaster management, a context related understanding of the organizational and technical measures for achieving these requirements is necessary". Thus, without a detailed understanding of the needs and prerequisites in government agencies, ICT applications may not offer enough advantages to seem worth the cost and effort to adopt them. While there are some examples of participatory approaches in ISDM development (e.g. Lukosch et al. 2012) reports of systematic user need analysis are rare in earlier research. Ahmad et al. (2012, p. 3), for example, argue that it is painfully clear that software engineers do not communicate with crisis scholars which "leads to IT

[2] https://www.msb.se/Upload/Produkter_tjanster/wis/Faktablad_wis.pdf

products that crisis managers do not need".

RESEARCH METHOD

This study presents the first step of a design science research (DSR) project. Next, DSR is introduced followed by a presentation of the studied project. Also the collection and analysis of empirical data are discussed.

Design science research (DSR)

Design Science Research (DSR) has become a growing part of IS research since the 1990s (Peffers et al. 2007). However, in the ISDM field DSR seems still to be in its infancy. The search string TITLE-ABS-KEY (*"design science"* AND *"crisis management"* OR *"disaster management"* OR *"emergency management"* AND *"information system*"* OR *"information technology"* OR *software*) resulted in fewer than twenty papers in Scopus (January 2018). Equivalent searches in Google Scholar and Web of Science support the impression that design science research is still not particularly common in the field.

> *The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts.*
>
> Hevner et al. (2004, p. 75)

Hevner et al. (2004) proposed a framework and guiding principles for design science in information systems research. Later Hevner (2007) extended the framework with three inherent research cycles. The cycles stress the need of iterative interaction between designing, building and evaluating artifacts, and establishing relevance for the user context/environment while also ensuring rigor by theoretical grounding in existing knowledge. To this a fourth, change and impact, cycle was added in Drechsler and Hevner (2016), see Figure 1, including both the external and the internal environment. The idea of considering not only the immediate application domain but also the external context to better understand the needs, opportunities and limitations for new IS as well as their wider impact is in line with earlier research on IS development and implementation (c.f. Alter, 2006).

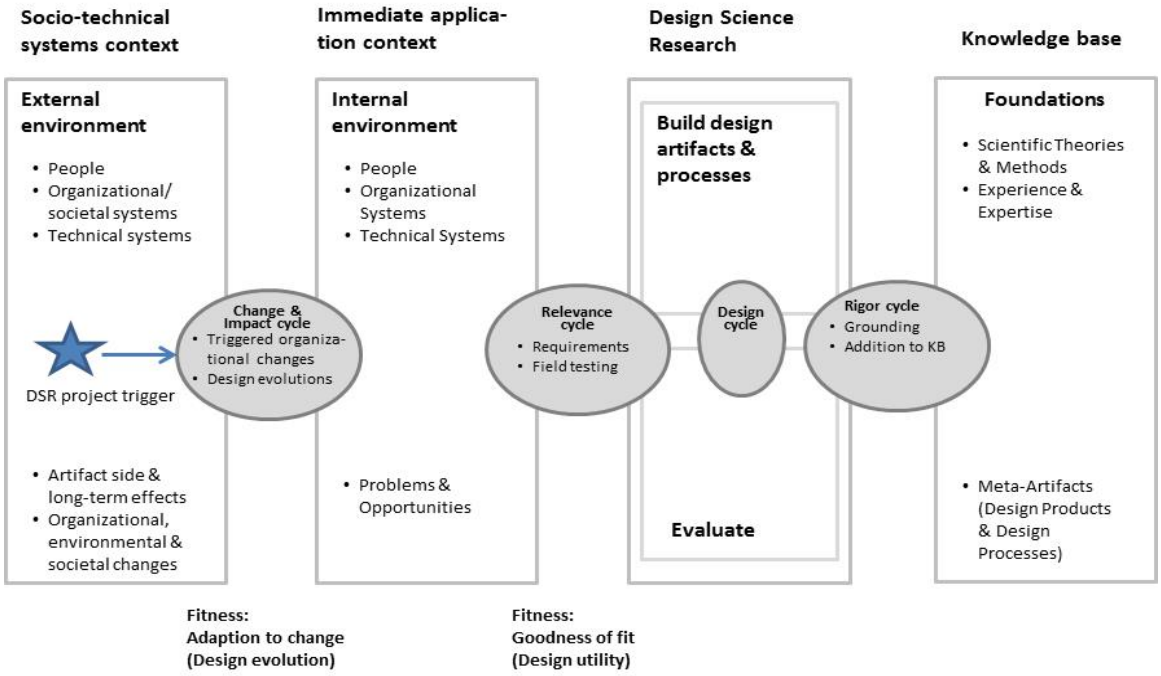

Figure 1. A four-cycle view of design science research. (Drechsler & Hevner, 2016, p. 5).

In this paper we focus on the change and impact cycle in Drechsler and Henver (2016). Using empirical data from an ongoing R&D project we analyze the internal and external environment in order to identify and understand problems and opportunities for ISDM training. This is also in line with steps 1-2 of the Design Science Research Method (DSRM) Process Model in Peffers et al. (2007). Next we describe the project of

study, including the planned design artifacts.

The CriseIT project

The presented case is the Swedish-Norwegian R&D project CriseIT – Preparing for Future Crisis Management. The project is financed by EU/Interreg and run by a multidisciplinary team of researchers from two universities in the border region of Norway and Sweden. The partnership is of quadruple helix model, including fourteen other partners from both countries. The project runs between Jan. 2016 to Dec. 2018 and the main target groups are regional and local government. The overall goal is to reduce cross-border barriers to crisis preparedness through developing collaborative networks, knowledge, methods and ICT tools for crisis management training and exercises. The border regions share common threats, e.g. flooded rivers, dam failures, and landslides.

In this project a DSR approach in line with Drechsler and Hevner (2016) is utilized, see Figure 1. A number of design artifacts are planned where one or several *ISDM training tools* are the most important ones. These should be generic enough to be useful in many organizations. Also, earlier studies show that it is vital to accompany the implementation of new IT with changes in the user context such as re-designed business processes (e.g. Alter, 2006). Other design artifacts to be produced in the project are therefore *business process models* – both for the as-is and the proposed to-be situation – and a *user method* with guidelines for planning and performing crisis training in ISDM. The latter is important since ISDM training will differ from traditional training practices.

In this first step we focus on establishing relevance by gaining knowledge about problems and opportunities experienced in the internal and external environment (c.f. Drechsler & Hevner, 2016). To ensure rigor in this phase two methods are applied, one for change analysis (the SIMMethod presented in Goldkuhl & Röstlinger, 2003) and one for analysis and design of work systems (The Work System Method by Alter, 2006). Design artifacts from this step will, for example, be an extended "snapshot" (Alter, 2006) summarizing important characteristics in the external and internal environment ("the work system"), and a problem diagram (c.f. Goldkuhl & Röstlinger, 2003) highlighting chains of causes and effects in the detected problems. Planned design artifacts from the next phase are *design principles* (c.f. Turoff et al., 2004) for ISDM training systems.

Among the scientific fields to be used for theoretical grounding of the artifacts are, except for crisis management and information systems development, also change management, e-learning, computer support for collaborative learning (CSCL), and serious gaming.

Data collection and analysis

Empirical data on problems and opportunities were collected through nineteen semi-structured in-depth interviews in the spring of 2016. The respondents represented 16 organizations: eight in Norway and eight in Sweden. The data collection aimed at creating an understanding of what Drechsler & Hevner (2016, p. 5) denote as the external and internal environment for the ISDM training tools and method to be designed. Therefore, the majority of the respondents belonged to organizations that are partners in the project, and also target groups of the planned artifacts. Also a few actors in the external environment were interviewed. The participants represented two national agencies, three county administrative boards, six municipalities, two NGOs and one SME delivering crisis training. In addition, representatives of the highest national authority in civil emergency management in each country were interviewed.

The respondents were active in planning, arranging and leading exercises. The interviews were semi-structured and included areas such as current training and exercise practices (incl. actors, business processes, problems, goals and strengths), IT infrastructure, and attitudes toward ISDM training. Seven interviews were held by telephone or videoconference, and the rest face-to-face. All but one interview was recorded. In two of the interviews 2-3 participants in the same organization and roles were interviewed simultaneously as requested by the respondents. The interviews lasted between 45 minutes and 2 hours. Each interview was summarized in an interview protocol, and analyzed in an iterative coding process (c.f. Miles and Huberman, 1994).

RESULTS AND ANALYSIS

In this section we present preliminary results and analysis.

The external environment

The national systems for crisis preparedness are organized at three levels of government in both Norway and Sweden; the national, regional and local levels. The civil emergency planning is coordinated at the national level by the Norwegian Directorate for Civil Protection (DSB) and the Swedish Civil Contingencies Agency (MSB)

respectively. National fundamental principles guiding crisis management are similar, as are national guidelines for planning and executing exercises. Also, the regional levels have comparable roles in supervising and coordinating local government agencies, arranging regional collaborative exercises etc. Furthermore, in both countries the municipalities have the primary responsibility of preparing for, and handling crisis. There are also some differences to be aware of, for example, in terminology and organization at an incident site.

There is a strong local autonomy in both countries, allowing the municipalities, for example, to decide what information technology to use. In both countries there have been national, custom-made web based ISDM applications offered for free to all municipalities for several years: CIM (Norway) and WIS (Sweden). The systems have functionality both for crisis response and crisis exercises. Their functionality for crisis exercises is, however, perceived as limited by some of the respondents, and CIM and WIS are not integrated with each other. Sharing information must therefore take place via other media such as telephone, e-mail or radio-communication. The two national radio-communication systems Nødnett (Norway) and RAKEL (Sweden) have recently been successfully connected and can thus be used in joint exercises. However, these systems primarily support spoken communication. Other types of information such as maps, photos, videos etc. are difficult to share. Our study indicates that Nødnett and Rakel are widely spread among rescue workers such as the police, firefighters and ambulance but not as common at the strategic level.

A cross-border civil protection counsel also exists in the studied region. The counsel arranges regular meetings between different crisis actors and a cross-border exercise approximately every fourth year. Their work is appreciated but does not reach out far enough into the municipalities according to the respondents.

Internal environment

People/Roles

The "People" element in Drechsler and Hevner (2016) was, in this study, interpreted as the concerned audience for ISDM training. These were found to be mainly twofold by the respondents: the crisis management team (as "trainees") and the security coordinators responsible for planning exercises (as "trainers"). The municipalities have security coordinators that plan the organizations' crisis training and often also lead the exercises. This can be a desolate role in smaller organizations where a single security coordinator might be solely responsible for planning and carrying out crisis training activities. Security coordinators in this study felt that they did not have time to plan and arrange enough exercises. Also, they thought they lacked the creativity and knowledge to design realistic, yet varied exercises. These problems are in line with the ones mentioned in Sniezek et al. (2002).

A common opinion among the respondents was that ISDM training is mostly relevant for the strategic level. The argument for this was, as Sniezek et al. (2002) point out, that there are few opportunities to get experience on the strategic level as both crises and exercises luckily are rare.

Organizational systems

In general, there is a strong engagement and interest in crisis exercises in the studied organizations. The organizations use different types of exercises such as single function exercises (e.g. the communication function), cross-functional exercises with the entire crisis management team, and collaborative exercises with several organizations. The exercise methods are table-top discussions, simulations with counter-acting and occasionally, full-scale field exercises. Individual training activities are rare but educational activities before exercises take place. Although time-consuming, the planning of exercises is often regarded as well-functioning today, as are the executions of exercises. More problematic is to learn from exercises. Most organizations said they lack systematic methods for improvements.

Some respondents from the local level wanted exercises to be as close to a real situation as possible while other respondents on higher levels, like Sniezek et al. (2002), stressed the need for learning generic problem solving skills and organizing rather than specific crisis scenarios. Also, some respondents expressed a desire to involve more (unfamiliar) actors, such as private companies, thus supporting the need to train collaboration (c.f. Bharosa et al., 2009). At the same time, several expressed that they wanted shorter exercises but more often. A combination of a few larger and many smaller exercises was seen as the best approach. A common opinion was that especially collaboration and communication (external and internal) need more training.

Technical systems

Almost all of the respondents use (desktop) PCs with Windows. Smartphones are also widespread. Tablets are used frequently in some organizations, and not at all in others. Usually the IT environment is controlled by the IT-department who decides if new software can be installed. CIM and WIS are used in most of the studied organizations but to a varying extent. The systems are more often used during a crisis than for preparedness/training. CIM seems to be comparably more used than WIS, perhaps due to directives on the regional level. It is not mandatory to use CIM, but more and more are expected to, according to a respondent at the local level. Representatives from the local level in Sweden claimed that there are directives that WIS should be used in real events although it was only sparingly used (even) in the great Swedish forest fire in 2014. When CIM and WIS are used, it is mainly for registration and logging of crisis events. An opinion expressed by several respondents is that the same technical systems should be used in exercises as in real events.

As in the study of Meum and Munkvold (2013) our respondents claimed that many (potential) users do not have the habit of using CIM/WIS as the municipalities cannot see the utility of them in their daily operations; "[we] do not know what we should use it for". One respondent thought that CIM is a good system but needs frequent usage. Also Nødnett/Rakel is used in several of the organizations. Except for CIM/WIS and Nødnett/Rakel there are occasional examples in the studied organizations of applications for sending out alerts, making digital maps, voice broadcast etc. As for planning and executing exercises some of the Swedish respondents mentioned using dedicated software for scenario planning, and MSB's "training web" with simulations of media and social media communication. However, office software such as MS Word, PowerPoint and Excel are the standard tools for exercise planning in most of the organizations.

Problems with current training practices

The most prevalent problems with current training practices mentioned were the lack of time and resources. Exercises are highly time-consuming to plan and execute for the trainers and also for the trainees, e.g. due to geographical distances and lengthy training sessions. As a consequence, almost all respondents believed that their organization did not train enough for crisis. There are nuances in this perceived shortage such as a lack of particular exercises or too little practice for specific parts of the organization.

Opportunities and risks with ISDM training

Overall the attitudes towards ISDM training are positive. ISDM training was thought to enable more frequent training/exercises, in shorter sessions. Also, the opportunities for trainees to participate in distributed exercises (c.f. MacKinnon & Bacon, 2012), perhaps even at different points of time (asynchronous), were regarded as important, as well as to get easy access to low-cost training tools, for example, via web applications. The ability to use smartphones or tablets for training was another opportunity mentioned. Other potential advantaged were to be able to get more data and a better overview of an exercise (in planning as well as during execution) as a trainer.

Another identified opportunity with ISDM training was to expand multi-agency collaboration, not only in exercises but also in planning and constructing exercises/training, as well as to include multimedia and tailor-make the content to individual roles to make training more fun and efficient. Both collaborative exercises and individual training for one's role were regarded as interesting. The latter was seen as particularly useful for preparing new employees. In addition, some mentioned the opportunity to practice individual decision-making and crisis events that are extended in time. All in all, increasing knowledge, competences, and risk awareness were the most frequently mentioned opportunities along with better support for exercise planning for security coordinators.

The respondents also saw potential disadvantages with ISDM training such as technical problems, or training collaboration with external actors. Some claimed that the IS need to be free of charge or low-cost to be adopted. Finally, several stressed that this type of training should complement, not replace, traditional training.

CONCLUSIONS AND DISCUSSION

The purpose of this study is to investigate perceived problems in current crisis training and identify opportunities for ISDM training in local and government agencies. The most important problems are connected to a lack of time – for both trainer and trainees. A majority of the organizations want more exercise but in less time-consuming and more flexible ways. ICT-based training is seen as bringing interesting opportunities such as more frequent, asynchronous and distributed training, organized in smaller modules/shorter sessions.

Our study indicates that especially two groups could benefit from ICT training tools. These are the crises

management team in local and regional government, and the security coordinators, i.e. the persons planning crisis training in the same organizations. It is reasonable to think that training is especially vital for actors on the strategic level, as these, in contrast to the operative level, seldom get to handle crisis in practice and therefore may have little or no experience. Moreover, the difficulty of scheduling traditional time-and place-dependent exercises may be especially prevalent on the strategic level as the team members often are managers and politicians with busy agendas. Crisis training planners/trainers in local and regional government often lack resources such as time and efficient ICT tools for planning at present. Planning tools exist on the market but may not match the needs or the budgets of smaller municipalities. Furthermore, several have expressed that they want to be able to collaborate and reuse exercises from other organizations. Training needs are often alike in different municipalities and constructing exercise scenarios is time-consuming.

All in all, no major differences between the countries were found regarding perceived problems and opportunities.

Implications for theory and practice

The organizations in our study give a coherent picture of needs and attitudes toward ICT tools. The user needs identified in this study could therefore form a basis for further testing/validation. Also, the design of the DSR project as a whole, to be further developed in forthcoming papers, could serve as inspirations for future studies.

We suggest that a systematic needs analysis should be performed in all ISDM development projects. Overall, our study indicates that there is an obvious need for improved ICT tools to complement traditional crisis training, both at the individual and the organizational level. Such tools should, if possible, allow crisis training planners in different organizations to collaborate and reuse exercises or parts thereof, thus removing the need to "invent the wheel" every time. The tools should also facilitate crisis training regardless of time and place to decrease limitations in the form of geographical distances and busy agendas. In addition, exercises should be divided into smaller modules, less time-consuming to execute. As cost is an issue in many public organizations, software vendors need to come up with cost-efficient solutions for the tools to be adopted. Preferably, these tools will facilitate also the ongoing operations in the organizations. Finally, it is important to consider "digital training" as a complement to, not a replacement of, traditional training.

Limitations

A limitation of the study is the relatively small empirical material and the fact that only a few members of the crisis management teams, one of the identified target groups for ISDM training, were interviewed. Another limitation, affecting mainly the generalizability of the results, is that most of the respondents were partners in the project and thus, from the start had a positive attitude towards ISDM.

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Getting Disaster Data Right: A Call for Real-time Research in Disaster Response

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ABSTRACT

In the response phase of disasters, minimal research has been conducted on the near real-time operational usage of social media. Research findings during this phase could provide evidence to the emergency management community that social media content can be retrieved, verified, and ultimately utilized in decision-making. This paper discusses potential strategies for conducting future research in near real-time during disasters to gain insightful knowledge rarely captured. Following the April 25, 2015, magnitude 7.8 Nepal earthquake, a team of 20 digital volunteers were virtually activated for 48 hours to extract medical-related information from multiple social media platforms and Internet sources. This practitioner insight paper examines methods applied to filter, classify, analyze, verify, and distribute the medical-related information in a timely manner. Association of past research studies are applied to the digital volunteer's experience within a case study framework, calling attention to the feasibility of digital volunteers as an information source in future research.

Keywords

Social media, digital volunteers, data collection and analysis model, human intervention, virtual activation.

INTRODUCTION

On April 25, 2015, Nepal was hit by a magnitude 7.8 earthquake killing nearly 9,000 people. Its epicenter was at Barpak, a village in the east of the Gorkha District. During large-scale disasters, such as the Nepal earthquake, identifying actionable social media content is challenging for practitioners due to the sheer volume of emerging information and misinformation. For researchers an authentic challenge exists in extrapolating real-time disaster information into theoretical research. Empirical evidence from twenty scientific assessments shows researchers are producing insufficient knowledge that is directly usable (Weichselgartner and Kasperson, 2010).

Practitioners have found it difficult to increase situational awareness and integrate analyses of social media content into operational activities. This is because of the intense workload from analysis, lack of resources to perform the task, and lack of mechanisms to verify the validity of content. (Diaz, et al., 2012). A viable option for practitioners to address these difficulties is to request assistance from a variety of available social media resources (Peterson, 2015). This paper presents a case study of the Montgomery County Community Emergency Response Team (CERT) virtual activation which aided several organizations responding to the earthquake.

The objectives of the case study are:

- Highlight the effectiveness of digital volunteer team methods used in real-time monitoring by sharing the data collection and analytical approaches used to classify, analyze, verify, and distribute social media information to decision-makers under time constraints.
- Correlate practitioner findings to those of researchers to increase and more effectively operationalize social media and other technologies in disaster response.

- Recommend strategies for conducting future research in near real-time during a disaster to gain insights rarely captured for benefit to both researchers and practitioners.

The structure of the paper follows. First, the case study briefly describes the primary organizations responding to the Nepal earthquake disaster that led to CERT's involvement. Next, it examines the data collection and analysis model used that includes references to several disaster research topics experienced during the virtual activation. The paper then discusses challenges and opportunities facing practitioners and researchers associated with social media. The conclusion then postulates an open call to the research community to improve the viability of social media within the practitioner environment producing opportunities for future research.

The information in the case study is based on the authors' firsthand experience, representing CERT and Humanity Road, in the aftermath of the Nepal earthquake disaster.

CASE STUDY

The day after the earthquake struck Nepal, a non-profit technology company, Kathmandu Living Labs (KLL[1]), initiated QuakeMap (Kathmandu Living Labs, 2015) to serve as an information hub for public relief urgent needs. More than 4,000 remote contributors from all over the world (Asher, 2015) plotted data on the map. Kathmandu locally-based multi-lingual volunteers reviewed cultural dialogues and coordinated with local officials and local aid agencies on the crisis mapping effort.

The emergency response and global health organization, AmeriCares[2], mobilized its medical teams to provide medical assistance and assess the status of damage to the health infrastructure within 48 hours of the earthquake (AmeriCares, 2015). AmeriCares had obtained baseline hospital map data from the World Health Organization on three heavily impacted areas of Nepal - Gorkha, Dhading and Sindhulpalchowk Districts. However, hospital addresses and contact information were missing from the baseline data.

Both KLL and AmeriCares contacted the 501(c)(3) volunteer-based public charity, Humanity Road[3] for assistance with their missions. KLL sought crisis mapping assistance and identification and coordination of urgent needs. AmeriCares sought assistance to aid in the identification of the missing hospital addresses and contact information, and assessing health infrastructure damage.

Humanity Road's overall disaster response activities involved multiple mission-specific projects that spanned 49 days. Some of the projects included producing general daily situation reports, conducting social media monitoring and amplification, serving as the QuakeMap afterhours platform administrator while KLL personnel rested each evening, and performing data mining in English and Nepalese languages supported by twenty five Nepalese diaspora and Nepalese translators. Additionally, Humanity Road provided information on hospital status, damaged items, availability of medicine and durable goods, and supply, fuel, generator, and medical staffing needs.

On May 1, 2015, Humanity Road requested assistance from their surge support partner CERT to aid in providing sustained updates to KLL and AmeriCares. Figure 1 represents the comprehensive workflow of organizations involved.

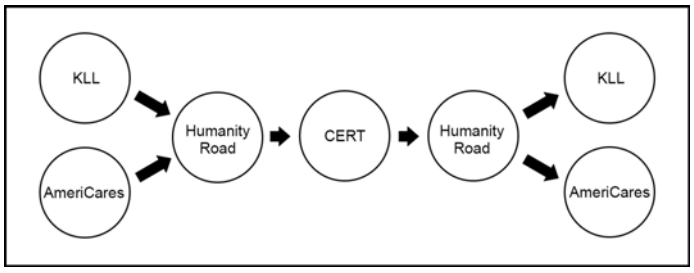

Figure 1. Comprehensive Organizational Workflow

[1] KLL is a non-profit technology company who works to enhance urban resilience and civic engagement in Nepal.

[2] AmeriCares is an emergency response and global health organization that works with a global network of local health care providers.

[3] Humanity Road is a 501(c)(3) volunteer-based public charity that uses the internet and mobile-based technologies to close communication gaps when natural disasters occur.

As described above, multiple organizations were involved in responding with various capabilities to the Nepal earthquake disaster. The remaining portion of this paper, however, will primarily focus on CERT's virtual activation experience and applicable disaster research topics.

CERT is managed by the Montgomery County Maryland Fire and Rescue Services and is comprised of over 500 volunteer members trained in basic disaster response skills, such as fire safety, light search and rescue, team organization, and disaster medical operations (FEMA, 2018). Since 2013, CERT has responded virtually to 21 natural disasters at local, state, national, and international levels. These assignments included developing situation reports, extracting urgent needs from social media platforms, crowd mapping, and social media data verification.

Upon receiving the request for assistance from Humanity Road, CERT leadership distributed an email to its membership base through a mass notification volunteer management system seeking volunteers. Twenty team members responded to the request. Members were divided into multiple teams and provided specific assignments while leadership oversaw the workflow during the virtual activation. Leadership remained available for members' questions or concerns, and also assisted with assignments that appeared to require special attention. Continuous leadership involvement supported test results of a study (Jenster and Steiler, 2011) which suggested virtual team leaders, during crises, be more active to increase team members motivation (Yu and Khazanchi, 2017).

Throughout the virtual activation period, daily conference calls were conducted enabling team members to share situational information from their assignments, ask questions, and discuss items of importance. Voice and data communication means used during the virtual activation included email, phone, conference calls, text messaging, Skype conversations, and Google collaborative documents. Concurrent sharing of information via multiple communication means allowed the team to make better decisions collectively based on improved situational awareness (Van de Walle, et al., 2016). For example, a Google collaborative document was constantly updated with valuable resources for all team members to consider for leveraging in their assignments. Further information on this collaborative document will be discussed later.

For the next 48 hours team members searched social media and Internet sources to identify medical-related urgent needs, hospital statuses, hospital addresses, and hospital points of contact. Factual information on damaged hospitals and clinics helped AmeriCares formulate a response at a time when there were few reliable information sources available other than personal observations at disparate locations. All identified medical-related urgent needs were plotted on QuakeMap by KLL for situational awareness or action by medical supply aid providers.

Midway through the 48 hour virtual activation, the direction for data analyses changed per the request of AmeriCares. Team members began seeking health and medical information on Village Development Committees (VDC) within three specific Nepal districts of Dhading, Gorkha, and Sindhupalchowk.

Figure 2 is an overview of the virtual activation, ranging from the initial request for assistance, to the operational processes implemented for extracting medical-related actionable information, to the closeout.

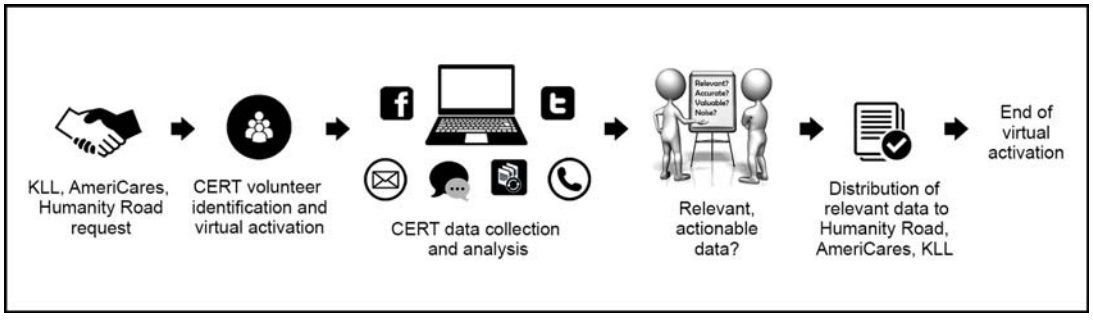

Figure 2. Virtual Activation Overview

Data Collection and Analysis Model

Prior to dividing up into teams, all team members were tasked to contribute pertinent medical- and earthquake-related keywords they individually believed may be of value for searching on social media. The generated list of 413 unique keywords was used to find medical-related urgent needs shared on social media platforms. Further information on how the keyword list was leveraged will be described below.

Next, one group of team members began searching for medical-related urgent needs within a dataset that contained 1.2 million tweets, retweets, shares, and posts. This dataset was categorized as having some affiliation to the

earthquake. Leadership was aware if members manually searched through this enormous quantity of data, compounded by time constraints, it would quickly lead to information overload. For this paper, information overload refers to information presented at a rate too fast for a person to process (Gonzalez, et al., 2016).

To avoid the risk of information overload, Humanity Road provided CERT with access to a social media analytics toolkit called Scanigo. Scanigo is designed for tactical real-time needs and implements an Ontology-Based Information Extraction (OBIE) technology to filter, categorize and rank social media within a collaborative user interface environment (G. Sikora, personal communication, 2016). OBIE is a discipline in which the process of extracting information from various information repositories (e.g., Twitter) is guided by an ontology.

The process of extraction of information involves multiple steps which include pre-processing the text into a machine readable form, and defining heuristics to identify the information to be extracted (Anantharangachar, 2013). A significant difference with this social media analytics toolkit versus others is that additional Natural Language Processing (NLP) algorithms are applied to a disaster response ontology that scores each tweet based on relevance and categorizes the tweets into mission-specific categories that are valuable to disaster response. For example, transportation, public health and medical services, search and rescue, public safety and security.

The disaster response ontology Scanigo used to score and categorize the tweets is comprised of over 2,000 concepts entity-modifier pairs (e.g., "person trapped", "need rescue"). The toolkit also gave the end user the ability to adjust the number of tweets to review based on relevance.

The organization of tweets into categories, specifically the medical-related category, allowed the tweet review workload to be reduced significantly, avoiding information overload risk. Nearly 80% of the original 1.2 million tweets, retweets, shares, and posts were eliminated from the analysis effort. Of the 1.2 million Nepal-related tweets, Scanigo filtered out irrelevant social media noise and classified the remaining relevant social media content into several mission-specific categories. A categorized dataset of 213,000 medical-related content was the end result of the filtering and classification. The dataset then was ranked by Scanigo, resulting in the identification of 2,132 ranked tweets.

Human intervention was required at this stage of the data collection and analysis effort. Team members searched the 2,132 ranked tweets for the 413 previously identified health and medical keywords. Previous research on disaster data (Vieweg et al., 2010) indicates that "a simple keyword or hashtag-search approach to tweet collection cannot guarantee extraction of only relevant tweets" (Verma, et al., 2011). This finding highlights the importance of incorporating sophisticated information systems, such as Scanigo or other data aggregation tools, into the data collection and analysis efforts to systematically identify, extract, and analyze social media data to improve information comprehension of the person performing social media analyses. Due to the data collection and analysis process method leveraging Scanigo prior to performing the keyword search, the chance of extracting medical relevant information improved significantly. Additionally, guidance on analyzing the 2,132 tweets was provided by leadership. Table 1 contains a sampling of questions recommended to ask while reviewing the 2,132 tweets for urgent health-medical needs.

Table 1. Sample of Social Media Verification Questions[4]

Question	Yes	No
Does it contain potentially urgent health-medical content?	Further research	Next post
Does it appear accurate and not outdated?	Further research	Next post
Was action already taken by an agency on the content?	Next post	Further research
Are clarifying facts[5] available?	Further research	Next post
Does it contain a photo or video?	Further research	Further research

Two examples of tweets during the analysis that qualified and did not qualify for forwarding for consideration of plotting on QuakeMap are below:

> *QualifyingTweet* - One tweet pertained to Kashigaon VDC Gorkha and an immediate need for doctors, medicines, relief, and volunteers. It qualified due to it being: recently published (not outdated); relevant

[4] Note: This is not an all-inclusive list of questions considered during social media analysis of disaster information.

[5] Facts can be obtained either through social media platform research, internet research, verbal or visual communications with trusted sources on scene, or other methods not described herewith in

to hospital/medical needs; geo-tagged from Nepal; and due to the user profile location being Bhrikuti Mandap, Kathmandu. Further research on social media platforms and Internet resources found no information indicating the request had been addressed

Non-Qualifying Tweet – One tweet pertained to a young child receiving medical treatment at a Dhading hospital. Although the tweet contained the keyword "hospital", the hashtags #Dhading, #Nepal, #Katmandu, and #Bhaktapurand, and included a photo, it did not qualify as it was irrelevant to hospital/medical needs assignment and was five days old.

Identified medical-related urgent needs were sent to leadership who double-checked the information for relevancy and accuracy who then sent them forward to Humanity Road. Humanity Road performed a second verification before relaying them to KLL for plotting on QuakeMap.

Figure 3 visually depicts the process of filtering through a high volume of social media content by integrating information systems and humans to capture relevant actionable health and medical-related urgent needs. The functions of the information system improved members' abilities to refine data into more manageable workloads.

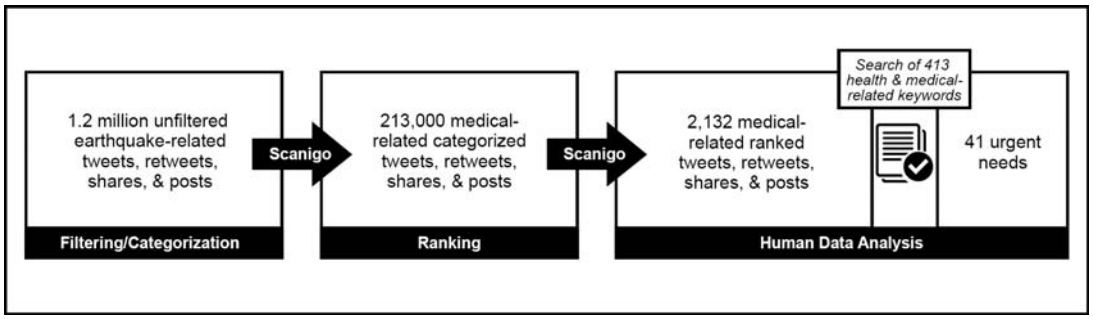

Figure 3. Health/Medical-related Urgent Needs Identification Process

As one group of team members sought medical-related urgent needs, another group scoured both social media platforms and Internet resources for the operational status of 177 pre-identified Nepal hospitals. They also sought the street address, points of contact, and district of each hospital. Every member was assigned approximately 20 hospitals to research. Dividing up the hospital assignment provided a seamless workflow that avoided work assignment fatigue and information overload. During the information gathering effort, a list of resources was developed by several team members to aid other team members in finding information pertaining to their assigned hospital. The list was created within a collaborative Google document, accessible by all, and continuously updated whenever a new valuable resource was discovered. Table 2 shows the various toolkits, social media platforms, fact sheets, websites, search engines, and news agencies used to search for each hospital operational status and other relevant information on each hospital.

Table 2. Data Collection and Analysis Resources

SM Platforms & Tools	News Agency Websites	Agency Websites	Search Engines
Twitter	BBC Sindhupalchok	WHO Fact Sheets	Google
Facebook	The Kathmandu Post	WHO Situation Reports	Bing
Twitterfall	The Associated Press	UNOCHA	
Scanigo	India Today	GDACS	
	eKantipur	OpenStreetMaps	

These same resources were used when the direction for data analyses changed midway through the 48 hour virtual activation and CERT began seeking health and medical information specific to the VDCs within the three Nepal districts of Dhading, Gorkha, and Sindhupalchowk.

Results

At the conclusion of the virtual activation on May 3, 2015, over 200 volunteer hours were logged by 20 CERT members. The following information was sent to Humanity Road who relayed it to AmeriCares and KLL:

- Hospital status updates (100)

- Medical-related urgent needs (41)
- Health and medical keywords (413)
- Health and medical information on Village Development Committees (85)

The delivered data was acknowledged by AmeriCares as valuable to their work in Nepal (R. Bram, personal communication, 2015). The 41 medical-related urgent needs were plotted on QuakeMap by KLL (Figure 4). As of May 18, 2015, over 1,800 reports on QuakeMap had been processed and routed to more than 50 military and civilian aid organizations, and over 65,000 people from 89 countries had visited the map (Humanity Road, 2015).

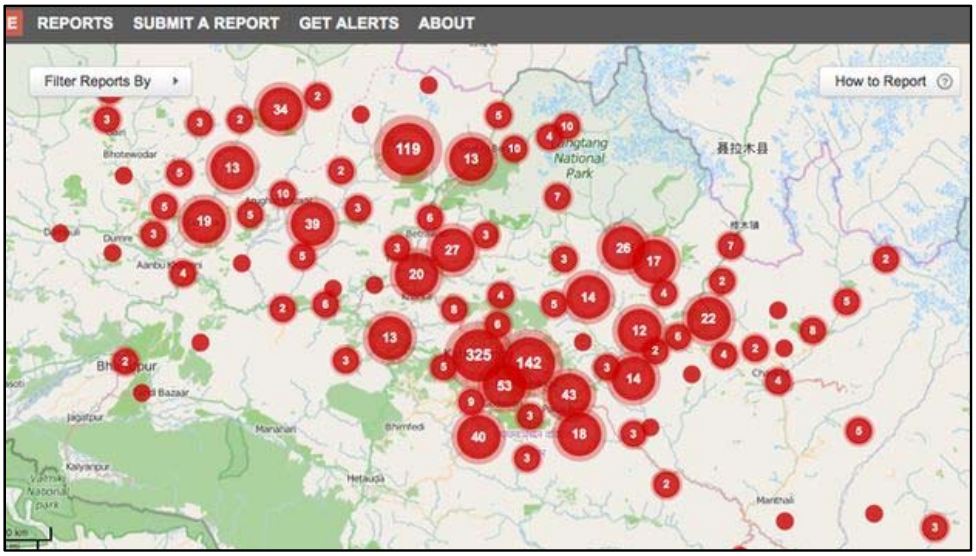

Figure 4. Screen Capture of the Nepal QuakeMap

The virtual activation produced timely, quality data indicating that traditional response and recovery could incorporate social media within operations to obtain actionable information. Further research, however, will be required to validate that the same model used to retrieve social media actionable health and medical information can yield identical positive outcomes for other disaster response functions (e.g., search and rescue).

The case study demonstrated overburdened local support networks can effectively call upon external support networks for assistance thus highlighting the importance of partnerships and also pre-confirmed digital volunteer teams (i.e., social media resources) can be enablers to operationalizing social media in responding to and recovering from large-scale disasters.

DISCUSSION

The spectrum of topics associated to disaster research is enormous and the case study featured only a small portion of those topics (e.g., human-computer interaction; information overload; team situational awareness). The virtual activation model demonstrates an opportunity worthy of consideration for future research. A similar virtual activation model was invoked less than two months earlier in response to Cyclone Pam which struck the Republic of Vanuatu (Thompson, 2015). *Could these models be applied to researcher planning for future studies?*

Recommendations

A gap facing disaster research and practitioners is there are not enough cases where research was conducted on the use of social media data during the response phase of a disaster. To strengthen the potential for such research, it is recommended a cohesive relationship between practitioner and disaster researcher be developed. Researchers may want to consider setting their research agenda and performing the research with input from practitioners (Weichselgartner and Kasperson, 2010). Research findings captured during this phase could help guide the emergency management community on how best social media content can be retrieved, verified, and ultimately utilized in decision-making.

The following set of questions were generated through the authors' experience gained from the Nepal earthquake virtual activation and analysis of past research findings. Answers to these questions would be relevant for both

the research and practitioner communities. By collectively answering the questions, it could initiate a dialogue on an array of topics that would be beneficial to future disaster research during the response and recovery phases. Additionally, joint answers would aid in a better understanding and awareness of the challenges each participant has in their respective field of expertise.

Questions include the following:

- *Can practitioner-researcher consensus be achieved to identify mutually beneficial measurable topics for future research conducted during disasters?*
- *Would conducting research within a time-sensitive accelerated and stressed environment, using the same methods of research conducted post-disaster, generate similar or different results?*
- *What (if any) are the similarities and differences between practitioner findings from social media usage during disasters, to research findings conducted post-disaster?*
- *Can research methods and data collection strategies be applied to practitioners' decision-making needs?*
- *Can the same prior research study conducted post-disaster also be applied during disasters in an effort to garner previously unknown, undocumented intelligence?*
- *Can social media disaster research be performed during a disaster which generates results that convince skeptical practitioners of social media applicability and value?*

Providing validity and confidence of the value of social media in practitioner decision-making is paramount and research efforts may be the catalyst to meeting this need. *Could this be addressed through a consortium of subject matter experts from both the emergency management community and academia? Who could identify specific areas of interest for further research based on mutually agreed-to objectives?*

The Nepal earthquake virtual activation model may serve as a foundation for future studies. Figure 5 highlights the target areas of the model where a research presence would be mutually beneficial, answering many of the questions posed above.

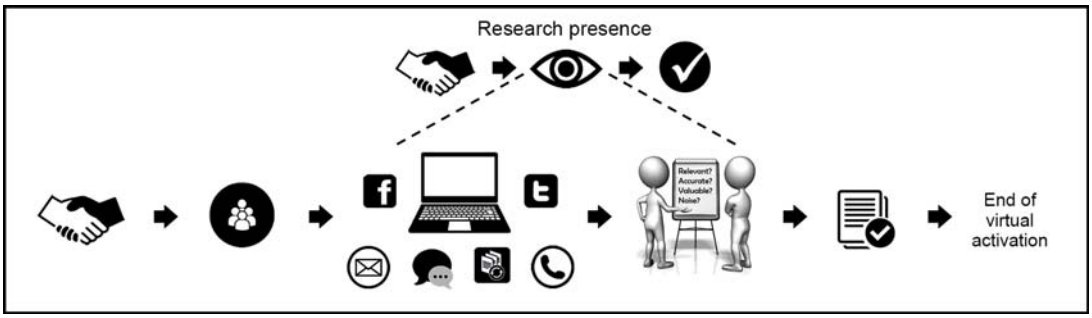

Figure 5: Virtual Activation Research Presence

CONCLUSION

By employing specifically designed technology for filtering social media noise and leveraging available social media resources (i.e., digital volunteer teams), the Nepal earthquake virtual activation model proved that near real-time mission-specific actionable information can be generated during disasters. The model demonstrated a singular effectiveness worthy of consideration for future virtual activations and provided insight into an avenue for academia to investigate as potentially viable for future disaster studies.

This paper brings attention to the need for further studies during disasters and recommends establishment of partnerships between the research and practitioner communities. Also, that studies be jointly developed during the preparedness phase of disasters.

The type of disaster chosen is a critical component of the partnership. It is expected real-time research will differ according to type of disaster (Callaghan, 2016). In determining the disaster type, consensus and understanding of the severity, scope, magnitude and complexity would help define the parameters of work to be accomplished.

The case study disclosed actionable social media content can be identified in a near real-time environment and provides an overview to the need of researchers to explore real-time research partnerships. Additional validation

by means of research studies and findings would enhance the practicality of further utilization of social media within operations. As a consequence, opportunities to gain insight rarely captured could be generated for future research into improving availability of real-time research results.

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Track 11

Community Engagement & Healthcare Systems

Information Requirements for Disaster Victim Identification and Emergency Medical Services: Hajj Crowd Disaster Case Study

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ABSTRACT

Disturbing crowd disaster incidents have been witnessed in every corner of the planet, which often lead to extensive difficulties, especially when they involve mass multi-nation casualties. When conducting Disaster Victim Identification (DVI) tasks, starting from finding the missing, curing the injured, and identifying the deceased, the challenge in such disasters is the lack of information to provide Emergency Medical Services (EMS) and conduct DVI in a timely manner. The literature presents fragmented solutions that can equip either post-mortem DVI or EMS with solutions to facilitate data collection and dissemination, but they do not consider a holistic solution that allows access to the victims' right information when needed. In this paper, we analyze information needs across multi-disciplines, as well as the requirements for technical support that can help manage the identification process. Recommendations should lay a sound foundation for future multi-disciplinary research in the areas of DVI, EMS, crowd disaster, health informatics, information security and software engineering in the health sphere.

KEYWORDS

Crowd disaster, Disaster victim identification, Emergency medical services, Hajj stampede, Information security.

INTRODUCTION

As the world's largest gathering (Ministry of Health (MoH), 2017), approximately 4 million pilgrims from more than 50 countries around the world travel to the holy city of Mecca to complete the Hajj rituals (i.e. Islamic Pilgrimage to Mecca). In these overcrowded conditions, human stampedes can occur, resulting in many injured people. Over the years, crowd incidents have happened on both a small and large scale during Hajj (Manoochehry and Rasouli, 2017). Moreover, being in a crowd is a situation that often cannot be avoided in our daily life. Some types of crowds are ad-hoc, such as riots or crowd attacks, but another type of crowd is voluntary, such as when someone is attending a football match or political event, during transportation or a funeral procession of famous people, or concerts in a large hall. Identifying the injured, dead or missing people in a crowd disaster is an elusive, complicated and time-consuming task. Many crowd studies have recognized that the forces of a massive gathering are almost impossible to control; fatal incidents occasionally occur, and the emergency response has been challenging (Ngai, et al., 2009; Santos-Reyes and Olmos-Peña, 2017).

The major challenge facing DVI and EMS teams in multi-national situations is the collection of the right information about the victims to find those missing, cure those found, and identify the deceased. Due to victims' demographics and the involvement of multiple stakeholders, governments are left with no option but to request help from external intergovernmental organizations, such as Interpol, to manage multi-DVI and EMS teams for each nation with victims involved. First and foremost, Interpol, as well as local police investigators, follow a traditional approach towards identifying missing persons in such open disasters, where families and friends report missing people by completing lengthy forms with fine-grained details about any identifiable information they can possibly record to help find them; examples in (Interpol, 2013a, 2017a). Some researchers have proposed a solution to address missing persons list identification and generation. Manoochehry and Rasouli (2017) suggested an early warning deployment of computerized software systems and camera monitoring, which can identify lost pilgrims, update their locations, and alert their group guide. However, those solutions are limited to the number they can manage at once. In addition, they are more victim rather than disaster-oriented, which renders them effective to search for a particular victim and it does not automatically generate a missing persons list for a particular disaster. Second, EMS provision for injured victims' needs to be done in a timely manner as time is critical. Therefore, paramedic teams need to access victim-related medical information immediately to provide healthcare services to victims; without these details, informed decisions (as simple as blood transfusion) cannot be made to decide the best way to save the victim's life. Therefore, several articles have suggested the enhancement of health and management approaches, such as an intervention (Salamati and Rahimi-Movaghar, 2016), health responses (Shujaa and Alhamid, 2015), and management of injured victims (Ganjeh and Einollahi, 2016). Third, DVI is "*the formal process whereby multiple individuals who have died as a result of a single incident have their identity established through the application of scientifically proven techniques*" (Victoria Institute of Forensic Medicine, 2014). Therefore, DVI plays a significant role in identifying deceased victims, where experts with different backgrounds and specialties need to collaborate in the case of a disaster.

When a major disaster occurs with mass fatalities, such as the Hajj stampede, the process of identifying victims is rarely possible by visual recognition (Interpol, 2017a), and thus often requires obtaining a conclusive identification through fingerprints, dental records, facial recognition, or DNA samples comparison with ones already stored in databases or taken from victims' personal belonging reference (Interpol, 2017a) and biological samples from the victims' families (Ritter, 2007). However, research is limited regarding DVI needs, and how to find information promptly on victims of Hajj crowd incidents. Currently ante and post-mortem information is, to a certain degree, still performed manually, and solutions in the literature mostly focus on helping post-mortem DVI teams in recording data collected from deceased victims' remains, such as in (Colville-Ebeling et al., 2014), but no research so far has focused on how to collect ante-mortem data and automate the comparison for the identification. Furthermore, some solutions are limited to a specific number of victims and are neither fast nor accurate, which renders them ill-equipped for investigations of mass fatalities incidents (Levinson and Domb, 2016). Finally, the lack of comprehensive solutions that would allow the availability of the right information for the DVI and EMS hampers them from achieving their tasks. Technology is one of the solutions that can mitigate the risk of deadly crowd incidents during Hajj, but the existing technology solutions are fragmented to focus on one team's needs, and lack a holistic solution that would equip DVI and EMS with the technology needed to achieve their goals in a timely manner.

In this paper, we use Hajj as a case study to investigate the information, as well as the technical needs for DVI and EMS teams to find the missing disaster-victims, cure the injured, and identify the deceased. The contribution of this paper is threefold. First, it identifies victims associated with a disaster, and classifies them into victims identification status lists. Second, it defines the set of information criteria required by the DVI and EMS teams for each victim status; Third, it identifies a set of required features of alternative technology to

accelerate the DVI and EMS tasks and minimizes casualties and loss and it assesses security and privacy risks that may arise due to the collection, processing and usage of the victim's data. The remainder of this paper is organized as follows. The Hajj Ritual section explains the basic information of Hajj rituals and common crowd disaster risks. The following section summarizes the literature review and methodology. The DVI current practices section presents the analysis of the information needs. The methodology section defines the research approach, following which, the results section presents the results from the analysis and lists the set of recommendations for future research. The following section, technical challenges, discusses in detail the opportunities proposed by seamless sharing, suggests information security risks, and raises privacy concerns at the same time. Finally, a conclusion is drawn in the last section along with suggestions for future research.

BACKGROUND AND LITERATURE REVIEW

Hajj Ritual Pathway

Hajj ritual involves ten tasks to be completed by all pilgrims in about four consecutive days in five different geographical locations (most of them are limited in terms of their space) representing a pathway: *Migat*, The Holy Mosque (also known as *Al-Masjid Al-Haram*), *Mina*, *Arafat*, and *Muzdalifah*. In order to illustrate the Hajj ritual process followed by pilgrims, we modeled their journey using Business Process Modeling Notation (BPMN). Figure 1 shows the Hajj ritual journey including: different sites, processes, order, and time restrictions for each move. Tasks are described in detail based on each day as follows:

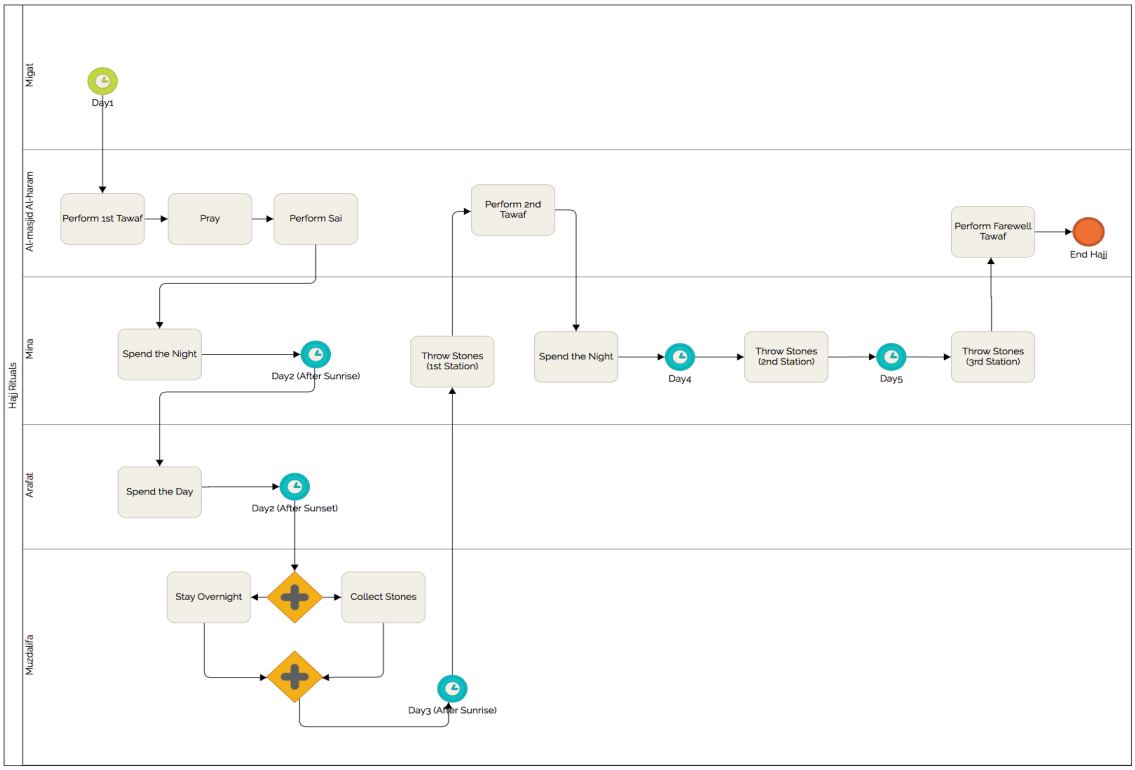

Figure 1 Hajj Ritual Journey

Day One

Hajj is initiated by reaching the *Miqat* before entering the holy city, Mecca. It is one of the points where the state of Hajj starts. Once pilgrims are ready, they head next to *Al-Masjid Al-Haram* to perform three tasks: Tawaf, (i.e. going around *Kabah* seven times in a defined manner), a prayer, and Sai (i.e. walking quickly between two small hills, *Safa* and *Marwah*). Thereafter, the pilgrims travel to *Mina* where they spend the night on this first day.

Day Two

Pilgrims travel 20 km by public transportation from *Mina* to the mountain of *Arafat* where they keep praying until sundown. After sunset, they leave for *Muzdalifah* and stay overnight to collect stones for their next tasks.

Days Three and Four

Pilgrims return to *Mina* to perform the symbolic throwing of stones at the first pillar representing the temptations of the Devil. Afterwards, the pilgrims return to Mecca to conduct the second *Tawaf*, return to *Mina* to spend the third and fourth days stoning the second and third pillar consequently, repeating the symbolic throwing of stones, and then return to Mecca for bidding farewell to *Tawaf*, before finally leaving Mecca.

During the Hajj, pilgrims are exposed to many risks and incidents, as a large number of pilgrims need to strictly follow the Hajj ritual journey at the same time. Risks and incidents include: fire incidents, crushes, injuries and stampedes, as well as infectious disease outbreaks (MoH, 2017). Two of the most prominent Hajj crowd incidents occurred in July 1990 and September 2015 (Ganjeh and Einollahi, 2016). In 2015, the whole world witnessed the deadly stampede incident which occurred in Mina when the pilgrims were conducting the stoning of the pillars; this killed a total number of 1,849 pilgrims (The_Guardian, 2015a), and that was not the first time Hajj had been marred by crowd-related accidents and tragedies (The_Guardian, 2006; 2015b). In 1990, a stampede happened inside a pedestrian tunnel leading out from Mecca towards Mina.

Religious Events and Crowd Incidents

Disasters during mass gatherings have repeatedly occurred throughout history. Soemaroo and Murray (2012) examine mass gathering disasters that occurred between 1971-2011. There were some major disaster crowds with mass casualties, such as a crush between fans entering and exiting an event venue; crowd surge and crushing; fireworks causing a fire; stairways fires in front of emergency exits; overcrowding of fans leading to a stampede. Crowd disasters frequently occurred in large events such as football matches, Olympic games, music festivals, firework events, and religious events, such as Hajj. The reasons for the mass casualties were various, but Soemaroo and Murray (2012) conclude that there are five categories of the causes of crowd disasters: overcrowding and crowd control, event access point, inadequate fire safety measures, medical unpreparedness and slow emergency response. Overcrowding could happen because of tickets being oversold for big events, such as football matches and music festivals, poor estimation of crowd numbers, and efforts to control crowds using tear gas leading to panic and human stampedes. Sometimes, crowd disasters are caused by a lack of safety measures, such as fire protocols or delays in emergency response (Soemaroo and Murray, 2012). At times, EMS could not access the disaster site causing response delay, such as in the Ramstein airshow disaster (Martin TE., 1990), or there were no routes available for the responders to reach the stampede location.

Religious events and crowd incidents such as Hajj crowd disasters have been the subject of scientific investigation related to crisis management (Helbing et al., 2007), which is considered equally as important as other crowd research on religious gatherings, such as the stampede case in the Kumbh Mela (Greenough, 2013), or examples of various human stampede cases during religious festivals in India (Illiyas et al., 2013). The Hajj disaster in 1990, causing the death of 1,426 pilgrims, occurred when they spontaneously rushed to leave Mecca via one exit. Such major crowd disasters have occurred many times and there are similarities in these major events, i.e. missing people or fatalities.

Numerous studies suggest the use of technical solutions to improve the management of Hajj or to better prepare in case of disaster, such as: crowd-sourced data collection and context aware services, big data cloud computing, intelligent shelter allotment for evacuation planning, pilgrimage tracking using both RFID and mobile systems/wireless devices, and multimedia surveillance event detection. Ahmad et al. (2014), for instance, suggest a spatio-temporal ritual service *HajjNUmrah* framework that exploits smartphone sensors to locate pilgrims, sense the environment, geo-tag people with severe health issues and social networks tailored to the Hajj ritual. In a normal situation, such applications may enable people stay connected and allow them to call in case of emergency, but they are not at all effective in identifying the injured or deceased in a crowd disaster. *SmartCrowd* (Ali et al., 2015) is a mobile cloud computing system that offers information and communication services during the Hajj. The data from pilgrims' smartphones can be used for locating high-density concentration points to be analyzed and mapped. However, there is no further information on the implementation part of *SmartCrowd*. Similarly, multimedia surveillance event detection is suggested as an alternative technology by Al-Salhie et al. (2014). A smartphone-based *Hajjlocator* (Mantoro et al., 2011) is proposed to solve the issue of missing pilgrims. The prototype of the mobile application is designed in such way that one can track and monitor individuals in a crowd. Both *SmartCrowd* and multimedia surveillance are useful features that allow EMS to remain alerted regarding potential crowd disasters from different areas with

high-density locations. Likewise, tracking people is possible through *Hlocator* and this is mostly useful for groups conducting Hajj together. Other solutions focus on wireless communication sensor networks to provide assistance to pilgrimages (Alwakeel et al., 2014). A crowd controller has been proposed (Yamin and Albugami, 2014) for monitoring transportation, health care services, ritual services, security services and improvement of Hajj management. Meanwhile, intelligent shelter allotment for emergency evacuation has been proposed (Yang et al., 2015) for pre-planning under various evacuation scenarios, which will contribute significantly towards improved emergency management. However, in the literature, how to improve victim identification when disasters actually occur remains unsolved.

DVI, Forensic Practices and Technologies

Although there is extensive literature focusing on how to improve crowd Hajj management, there is very limited research dedicated to DVI on large-scale crowd tragedies such as in Hajj or other religious gatherings, even though both issues are equally important. DVI is part of humanitarian and legal responsibility where investigators should identify every individual, when possible, so that the victims can be returned to their family to help with their grief (Interpol, 2017b). Victim identification is, indeed, part of forensic medicine and crime investigation. However, there were variations from time to time regarding how victim identification should be conducted, as explained by De Alwis (2011). There was a period where the post-mortem identification was not performed in the field, and should only be performed by a medical officer. Later, on-scene investigation was introduced where the expert (a medical officer) would observe the scene, take notes and photographs, and carry out basic medico-legal investigations, but not carry out the post-mortem examination. Afterwards, the first personnel to arrive at the scene where a dead body is lying are specially trained police officers to preserve the scene and conduct relevant investigations until the arrival of senior police investigators, the magistrate, medical officer and forensic scientist. Most of these techniques are valid for individual forensic investigations. The DVI for mass causalities was introduced later, which means that in previous mass tragedies involving numerous victims, such as tsunami disasters, airplane crashes, and crowd tragedies, the majority of victims were not identified.

Modern technology introduced new techniques, such as photographic evidence, X-ray for mortuary, DNA technology and other means for identification, such as fingerprint, eye print, handprint, leg-print. Post Mortem Computed Tomography (PMCT) scanner (Morgan et al., 2014), radiography and fluoroscopy (Viner et al., 2015) are used for mass casualties. Dental radiographs/forensic odontology is a robust alternative for human forensic identification (Rindhe and Shaikh, 2013), used when other information is not available. In forensic odontology, the victim identification is performed based on dental features, as teeth are parts of the human body that are not easily damaged, and this is considered as a reliable tool for DVI. There are numerous suggestions introduced to improve forensic odontology. Debbarma and Nath (2014), for instance, suggest a contour and skeleton-based shape extraction used in matching algorithms for dental radiographs. The DVI has recently gained more attention as part of forensic techniques. However, in the existing literature, how resource and time intensive DVI can be applied during mass fatalities such as the Hajj crowd disaster remains unresolved. In the following sections, we briefly introduce the development of DVI and existing standards and regulations.

DVI Current Practice

The Hajj stampede, similar to many other large-scale crowd disasters, is a subject of international investigation as the victims are often citizens from multiple countries. The International Criminal Police Organization (ICPO) or Interpol, is an intergovernmental organization facilitating international police cooperation, making it the world's largest international police organization, bringing 192 members to represent their countries under its umbrella (Interpol, 2017c). When a major disaster occurs, one country alone may not have sufficient resources to deal with mass casualties. In some cases, the incident may have damaged or destroyed the country's existing emergency-response infrastructure, making the task of victim identification even more difficult. Therefore, Interpol established the first working party on DVI in 1982 to tackle this challenging issue (Interpol, 2017a). The first Interpol DVI Guide was issued in 1984 and was subsequently revised over several years, and the most recent one was published in 2014 (Interpol, 2017a).

DVI is the formal process whereby multiple individuals who have died as a result of a single incident have their identity established through the application of scientifically proven techniques (Hallam et al., 2005). Therefore, DVI plays a crucial role in law enforcement criminal investigations and interrogations. When a major disaster occurs with mass fatalities, the process of identifying victims is rarely possible by visual recognition (Hallam et al., 2005), and thus DVI often requires obtaining a conclusive identification. Furthermore, DVI teams work collaboratively, in an interdisciplinary manner, engaging the services of experts in various disciplines towards the identification of victims. DVI teams are encouraged to cooperate with other national DVI teams. Currently,

the basis for coordination and response that require DVI includes: first, Legislation, Jurisdiction and National Conventions; second, Interpol DVI Standards; and finally, Command and Control arrangements. The DVI process consists of four phases (see Figure 2):

Phase 1- Scene

The team investigates the human remains and property at the disaster site.

Phase 2- Post-Mortem (Victim Data)

The team conducts a detailed examination of human remains in the mortuary. It collects detailed data, such as fingerprints and skeleton sketches, in addition to the data that are collected during Phase 3 (See Ante-Mortem data).

Phase 3- Ante-Mortem (Missing Person Data)

The team collects missing person data from various sources. This task is initiated with collecting and recording all information related to individuals who may be regarded as potential disaster victims (Interpol, 2013). This process starts only when a victim has been identified as missing. The data can be collected from the missing person's family, relatives, and/or friends.

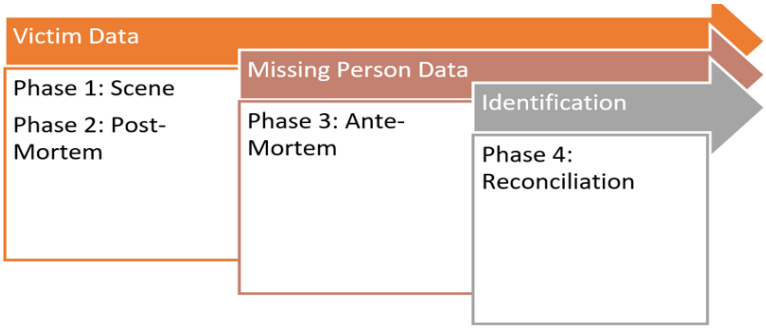

Figure 2. The DVI Process (Interpol, 2017a)

Phase 4- Recognition

The DVI teams match/cross reference post-mortem and ante-mortem data. The combination of Victim Data and Missing Person Data will lead to Identification, and conducting recognition. Victim Identification is done by preparing a list of special Ante-Mortem and Post-Mortem key markers for bodies using only particularly noteworthy features of a missing person or body recorded in a list.

DVI teams consist of the following experts:

- Photographers, Radiologists and Interview Teams
- Property Managers
- Scene and Post-Mortem Recorders and Quality Assurance Teams
- Evidence Collection and Management Teams,
- Mortuary Managers
- Investigators, Logistics, Liaison and Missing Persons Officers
- Information Technology Specialists

According to Interpol (2014), disasters can naturally be classified as open or closed, looking at it from the DVI's perspective. On the one hand, an open disaster is a catastrophic event resulting in the death of unknown individuals for whom no prior records or descriptive data are available. The Hajj stampede is an example of an open disaster. A closed disaster, on the other hand, is an event where there has been the death of a number of individuals belonging to a fixed, identifiable group (e.g. aircraft crash with a registered passenger list). DVI in an open disaster is more challenging and requires both technology and experts' support.

In Europe, the FP7 EU funded project FASTID has introduced an international Missing Persons and Unidentified Dead Bodies (MPUB) database in Interpol secretariat (Interpol, 2013b). FASTID was created due to the unavailability of a centralized database at both regional and international level. Even if the data existed in

some regions, the database was not interlinked. MPUB database allows for searching of items such as DNA and dental records. It also integrates its interface with other databases, such as fingerprints (Interpol, 2013b), which greatly supports the DVI tasks. However, in crowd incidents such as the Hajj, the situation is more complicated as there are many nationalities involved, and thus the biometric data is not always available in such databases for all countries. Also, the victims could be from countries that have no link to MPUB.

Current Forensic Practice in Saudi Arabia

Concerning the legislation related to forensic identification process in Saudi Arabia, Alqahtani et al. (2017) identify that there are two relevant government agencies involved in such cases, i.e. The MoH and The Ministry of Interior (MoI). The MoH, on the one hand, is the main regulator of forensic issues and the party responsible for the technical supervision of forensic activities in the country. The Ministry issues a set of instructions and procedures to guide the doctors performing forensic duties. On the other hand, the MoI conducts the investigations, arrests the perpetrators, and establishes the claims before the courts. However, they work exclusively, where each department establishes its own protocol in dealing with the forensic investigation. Alqahtani et al. (2017) list several issues regarding current forensic practice in Saudi Arabia:

- No clear national guidelines or protocols for personnel dealing with forensic cases (photographs, radiographs, descriptive report or methods to be used).
- No protocols in the hospitals on reporting or documenting cases that arrive during the emergency.
- No standardized report forms to describe the detailed cases to the court and typically they are sent directly to the judge without the need for the expert witness to attend.
- No references and limited accuracy.
- No minimum and maximum range of age estimation reports or the method used to reach that estimation.

In addition, when applying forensic odontology techniques, official forensic forms that document oral findings are available in Arabic only, and do not include the complete dental status. Tooth abbreviations, color distinction, supplementary examination, types of radiographs taken and methods used in the analysis are not documented. In brief, there are huge challenges in handling mass fatalities as DVI is not fully supported by current legal practice, and can lead to inefficiency in the DVI workflows.

Finally, this section clearly identifies the number of fragmented solutions that can equip post-mortem DVI to help with the data collection and dissemination. It also identifies the gap in the literature that needs to be bridged with a holistic solution that allows for victims' appropriate information to be accessed by the right team member at the right time.

METHODOLOGY

Initially, the information requirements identification for DVI and EMS followed the requirement elicitation and analysis cycle in Figure 3 (Sommerville, 2016). This requirement elicitation and analysis cycle involved stakeholders with different areas of expertise to discover, classify, organize, prioritize, negotiate and specify these requirements.

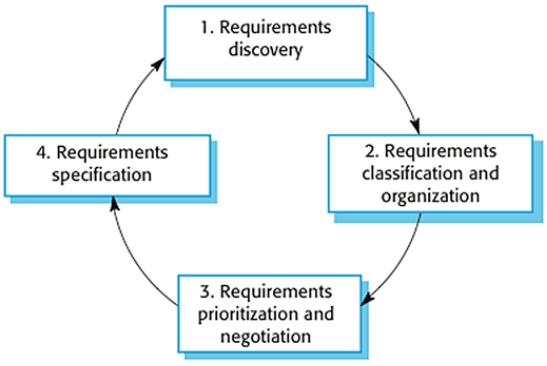

Figure 3. Requirement Elicitation and Analysis Cycle (Sommerville, 2016).

The methodology involved the following key phases:

- Define the complete Hajj process in terms of activities, locations, users, and information requirements.
- Design and model the scenario of the Hajj ritual using BPMN to illustrate the process and the challenges it includes (see Figure 1).
- Classify victims in a disaster into four scenarios based on the identification stage lists: Alive and Well, Alive and Injured, Indirect Confirmation through an emergency contact, and Missing person.
- Discuss and revise challenges for each class of victims as seen by DVI and EMS teams in worse case scenarios.
- Identify the gap.
- Validate the requirements.

Within discussion groups, the initial requirements were refined to generate the requirement specifications. A total of at least sixty-seven hours of brainstorming sessions were conducted jointly and individually with experts in thirty-three fields over the course of sixteen months distributed as listed in Table 1 and 2:

Table 1 Fields of Expertise

Total Fields of Expertise	**Team Member Expertise**	**Total number**
33	Physicians	2
	Health informatics experts	2
	Information security experts	4
	Computer scientists	8
	Saudi Red Crescent authority representatives	7
	DVI Dentals team members from Saudi Arabia, Italy, Australia, and Brazil.	4
	Disaster Mortuary Operational Response Team (DMORT) members from USA	2
	Members of Interpol and one forensic deontologist.	4

Table 2 Contact Hours with Discussion Groups

Discussion Groups		
Total hours	Specific hours	Specific Team
67 h	34 h	EMS
	33 h	DVI

These results include a set of information requirements for DVI and EMS to allow them to find the missing, rescue the injured, and identify the deceased.

RESULTS

This section summarizes the results from the analysis and synthesis we performed on the primary and secondary data collected from the experts in eight different fields. The results present the classification of victims, as well as the classification of information required by the DVI and EMS teams in Hajj crowd incidents and discusses the technical challenges.

Victims Identification Lists

According to the Interpol guide (Interpol, 2017a), missing persons' lists cannot be confirmed until forty-eight hours from when the disaster happens. Therefore, and in order to generate a final missing persons list for DVI teams, a list of victims in an identified disaster must be added to one and only one of the following four lists shown in Table 3 below.

Table 3 Victims' Lists and Descriptions

No.	List Name	List Description
1	**Alive and Well List**	Victims who are found alive within the first 24 hours and do not need any medical attention.
2	**Alive and Injured List**	Victims who placed an S.O.S. call within the first 24 hours and need medical treatment.
3	**Pending Confirmation List**	Victims who did not place an S.O.S call within 24 hours, and before the following 48 hours pass, an emergency contact is contacted to request the whereabouts of the identified victim and his/her health status. If the emergency contact has already responded and supplied updated information about the targeted victim, this is listed in this list.
4	**Missing Persons List**	Victims who were neither reached within the first 48 hours nor their emergency contact reached, are considered missing.

Information Requirements for DVI and EMS Teams

For each victim in any of the three lists, specific information needs to be accessed by either the DVI team or EMS team. This information is classified based on the task needed for the victim's case, whether because he/she is missing, injured, or deceased. This is shown below in Table 4.

Table 4 Summary of Information Requirements for DVI and EMS Teams and Access Control Rights

Information Required	Victim's case task			Task Purpose	Access Control Rights
	Cure the found	Find the missing	Identify the deceased		
Medical records	✓			Medical treatment, first aid	EMS teams
Blood type	✓			Medical treatment, first aid	
Family members	✓	✓	✓	Help find victim and/or return them to the family	
Affected person lists	✓	✓	✓	Medical treatment, first aid	
Alive/injured list	✓			Help responding to victims within 24h	
Pending confirmation lists		✓	✓	Contact next kin if no response after 24h-48h	DVI teams: law enforcement officials, deontologists, DNA and fingerprint specialists
Missing person list	✓	✓	✓	If no response from victim and next of kin after 24-48h, missing person will be listed as missing	
Victim's registered information (dental x-ray, dental work, fingerprints)			✓	Post/Ante-Mortem	
Basic information of the victims			✓	Ante-Mortem	
Body description (weight, height, eye colors)			✓	Post/Ante-Mortem	
Pathology			✓	Post-Mortem	
DNA (blood from the core of the body, deep muscle tissues, bones or teeth)			✓	Post-Mortem	
Skeleton sketch			✓	Post-Mortem	
Original medical/dental record, medical practitioners and dentists consulted by missing person			✓	Ante-Mortem	
Blood samples from parents/children of missing persons			✓	Ante-Mortem	

Technical challenges: Security and Privacy Risks

Table 4 shows the information criteria required and the access rights for the EMS and DVI teams which could be used as guidelines for the list of features required, including functional and non-functional requirements for software and technical solutions of mobile applications on mobile or wearable devices to connect victims with DVI, EMS, and rescue teams in real time to allow them to find the missing, cure the injured, and identify the deceased. For the different actors, the tasks and information needs are as follows:

- Victims; place an S.O.S emergency call in the event of an incident.
- Rescue teams; access a list of injured victims and share their geo-location and medical information with the local rescue team to prepare for EMS who provides medical treatment.
- DVI teams; access a list of victims "last seen" within a close range of the identified disaster and share it along with their geo-location with the local DVI teams to try to find them and have access to their essential identifiable information to speed up the identification of victims.
- EMS teams; access list of injured victims and their medical information.

Access Vs. Privacy

Although the above solution encourages openness and seamless sharing to paint a full picture that would allow each team to perform their tasks, it nevertheless raises information security and privacy concerns that could hinder its adoption. As mentioned above, different teams require specific victim-related information at various victim identification stages. Even though the need for personal identifiable information may improve the quality of DVI work, the digitization of such information poses new privacy and security threats. Such threats include, among others, first, improper disclosure of sensitive information by privileged DVI professionals. Second, there is the threat of unauthorized access to personal information by persons taking advantage of the DVI environment, and finally, cyber criminals could gain access to valuable data such as health information.

Information security and privacy are major concerns for individuals and DVI team members worldwide. For instance, if we consider the medical information of victims (shown in Table 2), Vodicka *et al.* (2013) carried out a survey on online access to patient records and found that approximately one-third of participants were concerned about the security and privacy of their health records, particularly regarding who should have access to which item of health information. Furthermore, according to a survey by *IBM* and the *Ponemon Institute* in 2017 (US Department of Health and Human Services, 2017), many breaches involve personal information, such as protected health information theft, loss or improper disposal of medical records, and unauthorized access to, or disclosure of, health information. The above-mentioned findings demonstrate that it is essential to address security and privacy concerns regarding personal information. Furthermore, there is global governing legislation with which such a solution must comply. Such legislation has defined access restrictions to protect patient privacy and means of processing health records securely. Moreover, the "Health Insurance Portability and Accountability Act" (HIPAA) is an American legislation to ensure that health information is protected adequately while allowing the necessary flow of health information for providing and promoting high-quality healthcare (Nosowsky and Giordano, 2006, U.S. Department of Health and Human Services, 1996). Furthermore, Europe has similar legislation, including the EU directive (EU Directive 95/46/EC) (Directive, 1995) on the protection of individuals with regard to the processing of personal data and the free movement of such data. The General Data Protection Regulation (GDPR) (European Commission, 2016), adopted in April 2016, will supersede the EU Directive 95/46/EC and will be enforceable from 25 May 2018. Such standards and legislation also provide security and privacy suggestions to address the need to protect personal information.

However, to establish more secure and readily available services to DVI and EMS teams, there are many security and privacy challenges to overcome in the technical solution. Among those challenges are:

- User privacy and data protection
- Authentication and identity management
- Trust management and policy integration
- Authorization and access control

A number of concerns would be raised by the proposed solution, and so it is important to ensure secure use and sharing of victims' personal identifiable information. This is particular to such solutions when diverse stakeholders need access to fragmented, confidential information in a timely manner to gain a holistic view of cases under investigation. A major concern would be how to prevent privileged DVI teams from disclosing sensitive information improperly. A second concern regards to malicious users taking advantage of the DVI environment by having unauthorized access to personal information such as health information, among others. Improper disclosure or unauthorized access may occur when someone within the DVI team accesses shared

information for unethical reasons, for instance, accessing a victim's health information for personal gain. In overcoming authorization and improper access matters associated with DVI, access control models, such as role-based access control (RBAC) (Ferraiolo, et al., 2001), attribute-based access control (ABAC) (Hu, et al., 2015) and others, may prove to be the answer. Access control is critical to the successful adoption of this solution to manage problems related to unauthorized and improper access.

CONCLUSION AND FUTURE WORK

Disaster incidents have been witnessed in every corner of the planet, and the world has mourned for victims affected by crowd and natural disasters, as well as acts of war and violence. Crowd disasters with mass multi-nation casualties often lead to vast difficulties and challenges, especially when conducting DVI tasks starting from finding the missing, curing the injured, and identifying the deceased. Frequently, such mass gatherings involve multiple citizenships, such as in the largest annual gathering, the Hajj, which is much more complicated to manage in the case of a disaster. Unlike closed gatherings, such as an airplane crash accident, for instance, when passengers are mostly well registered and accounted for, the main challenge in crowd disasters is the lack of medical information for rescue teams to provide EMS in a timely manner, as well as, identifiable information for ante- and post-mortem DVI teams of police investigators, DNA and fingerprint specialists, and odontologists to perform their tasks to bring justice to victims and closure to their families. This makes it an elusive, complicated, and time-consuming task that leads to the increasing number of causalities in such urgent situations, when time is critical to disaster victims. Practitioners have acknowledged the need for technical support for victim identification in such multi-nation mass casualties, especially in Hajj.

The literature offers a number of fragmented solutions that can equip either post-mortem DVI or rescue teams with solutions to assist with data collection and dissemination, but they do not consider a holistic solution that allows for victims' relevant information to be accessed by the right team member at the right time. In this paper, we used requirement engineering and business process modeling notations to analyze information needs across multi-disciplines, as well as the requirements for technical support that can help manage the identification process and analyze certain practical challenges that face such solutions with the benefit of insight gained from the Hajj case study. The requirements were refined with experts in nine specialties to identify: the information criteria required by DVI and EMS teams from each victim stage, the set of required features of a supportive technology to speed-up tasks and minimize causalities and loss, and the security and privacy risks. Results show that victims in the Hajj crowd disaster could be classified into either missing, injured, or deceased. Furthermore, each of those classifications represents a case which requires specific information that must be granted to a specific team in order to achieve the goal of that particular case. However, access control is critical to the successful adoption of this solution as a holistic view is required on each victim under investigation. A set of features is required by the DVI, EMS and rescue team to operate. For each DVI and EMS team member, information disclosure should be carefully studied to ensure they only retrieve the required information at the time they need it. Finally, the set of recommendations outlined in the results should lay a sound foundation for future multi-disciplinary research in the areas of disaster victim identification, medical emergency services, crowd disaster, health informatics, and information technology in the health sphere. Suggested future work includes the use of the requirements identified in this research to develop an alternative technology that can support faster response? in mass casualties such as the Hajj crowd incidents. With such a tool, the security and privacy risks could be identified, as a technical concern should also be considered to facilitate the implementation of a solution and overcome the current technical challenges. The solution should mainly focus on the technology that can help the EMS and DVI teams to respond faster in terms of finding the missing, curing the injured, and identifying the deceased.

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Detecting & Visualizing Crisis Events in Human Systems: an mHealth Approach with High Risk Veterans

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ABSTRACT

Designing mHealth applications for mental health interventions has largely focused on education and patient self-management. Next generation applications must take on more complex tasks, including sensor-based detection of crisis events, search for individualized early warning signs, and support for crisis intervention. This project examines approaches to integrating multiple worn sensors to detect mental health crisis events in US military veterans. Our work has highlighted several practical and theoretical problems with applying technology to evaluation crises in human system, which are often subtle and difficult to detect, as compared to technological or natural crisis events. Humans often do not recognize when they are in crisis and under-report crises to prevent reputational damage. The current project explores preliminary use of the E4 Empatica wristband to characterize acute aggression using a combination of veteran self-report data on anger, professional actors simulating aggressive events, and preliminary efforts to discriminate between crisis data and early warning sign data.

Keywords

mHealth, mental health crisis, computational psychology, wearable sensors, aggression, veterans.

INTRODUCTION

This project applies general crisis theory to psychosocial crisis events in US military veterans (DiGiuseppe and Tafrate 2003, Novaco and Chemtob 2015). After serving in the military, many veterans experience several psychosocial disruptions at once, ranging from post-traumatic stress disorder (PTSD) to learning how to fit into civil society (Semaan, Britton et al. 2016). Here, we are focused on one specific form of personal crisis, the expression of intense interpersonally directed anger – often referred to as rage to denote its ferocity and acute onset. These angry outbursts occur in the home, in the workplace, or in college for veterans returning from military service. Such issues are often an emergent property of PTSD and can profoundly damage important social relationships, paradoxically the very relationships that are critical to helping the veteran adjust to post-military life (Semaan, Britton et al. 2017). As such, developing systems that detect and inform rapid mental health crisis intervention for veterans is of utmost importance.

At every level of human experience, crisis situations defy simple solutions because of their complex, interlocking nature. What appear to be dissimilar events, like major natural disasters and individual mental health (MH) crises, actually share important characteristics (Franco, Hooyer et al. 2016). These include: 1) pre-existing system vulnerabilities which may be known or unrecognized (Lipscy, Kushida et al. 2013); 2) early warning signs that are difficult to detect against background noise (Saleh, Saltmarsh et al. 2013); 3) cascading impacts as resources and options degrade (Berariu, Fikar et al. 2015); 4) a point of criticality beyond which degrees of freedom to act are profoundly constrained (Sornette 2002, Arnal 2015); 5) a clearly recognized crisis event (the period beyond the point of criticality) which requires significant external resources in order to recover or restore order (Quarantelli 1985, O'Sullivan, Kuziemsky et al. 2013). True crisis events have proven quite difficult to accurately predict and intervene on before the point of criticality using human intelligence or computational methods (Boettiger and Hastings 2012). Moreover, failures in crisis alerting in healthcare (i.e. false positives or false negatives) can lead to complex legal, ethical and clinical problems (Drake 2013, Cajita, Gleason et al. 2016).

Multiple sensor networks in an Internet of Things (IoT) environment, including wearable and/or mobile devices, can be used to develop a much more detailed view of the behaviors that precede MH crisis, the moment of crisis itself, and its immediate aftermath. Anger is one of the least researched emotions in psychology, and sensor driven research for this emotion has the dual pay-off of examining human systems crisis and also more deeply informing a detailed behavioral picture of anger. PTSD associated anger and aggressive outbursts plague a subset of veterans trying to reintegrate into civilian society (Novaco, 2015). This subgroup, i.e. veterans with anger management problems, is targeted because of the comparatively high base rate of future anger episodes (Hartl, Rosen, Drescher, Lee & Gusman, 2005). This elevated base rate for overt aggression (i.e. vocalized, physical expression of anger) makes the immediate research goals feasible, as the number of crisis and early warning sign observations are maximized.

Despite the advantages of examining human systems crises through this lens, several theoretical and procedural issues remain to be solved. We address several of these issues here: First, a very brief summary prior work that informs the current project; Second, data from focus groups with high risk veterans is presented; Third, preliminary laboratory simulated aggression scenarios with actors wearing the E4 Empatica wrist band are discussed; Fourth, several practical, ethical and theoretical problems for crisis research in this context are identified as one form of results from this work; Fifth, based on these problems, a proposed method for improved marking of crisis events in humans is offered. Finally, we discuss this work as it relates more broadly to the various types of crises, and how interactions between human systems level crisis and larger scale crises may interact.

PRIOR WORK

This effort builds on our ongoing work describing a collaborative mobile health (mHealth) design process with veterans. The community partnership responsible for this effort, the existing Quick Reaction Force (QRF) smartphone application, and the collaborative design approach used to construct this existing system are briefly summarized here to set the stage for the current work which moves us toward more complex, IoT based real time crisis detection. All work described here received IRB approval for human subjects research.

Veteran Community Engagement for Research

This work is driven from a Community Based Participatory Research (CBPR) perspective. We have partnered with Dryhootch of America, a non-profit veteran led, veteran serving community organization headquartered in Milwaukee, Wisconsin for about 5 years to develop a smartphone app to support veteran-to-veteran mental health intervention. Dryhootch leaders and faculty from the Milwaukee VA Medical Center and the Medical

College of Wisconsin. Descriptions of this community-academic partnership, the Dryhootch Partnership for Veteran Health, its formation, and lessons learned are detailed elsewhere (Franco, Logan et al. 2016). One common area of interest within the partnership was improving outreach to younger veterans returning from Operation Enduring Freedom (Afghanistan) and Operation Iraqi Freedom (often referred to as "OEF/OIF veterans") using technology. OEF/OIF veterans have different expectations about connecting with systems of care often preferring technology mediated contact as compared to veterans from prior US military service eras.

Dryhootch QRF Smartphone App

The Dryhootch QRF smartphone application was developed to mimic a human-to-human peer support model for veterans struggling with civilian reintegration, with US military veterans participating in an intensive, multi-month collaborative design process to provide initial user requirements and interface ideas, ongoing feedback for app refinement, and finally to recruit veterans to use the system. The app and design process are detailed elsewhere (Rizia, Johnson et al. 2014, Rizia, Franco et al. 2015, Rizia, Franco et al. 2015). Figure 1 depicts the (a) veteran app used to collect basic self-report information using an Ecological Momentary Approach and (b) the peer mentor version of the app, which visualizes this self-report data to facilitate intervention decisions are shown in Figure 1.

a) Veteran app interface b) Peer mentor app interface c) Veterans using the QRF app

Figure 1: QRF Smartphone App Development

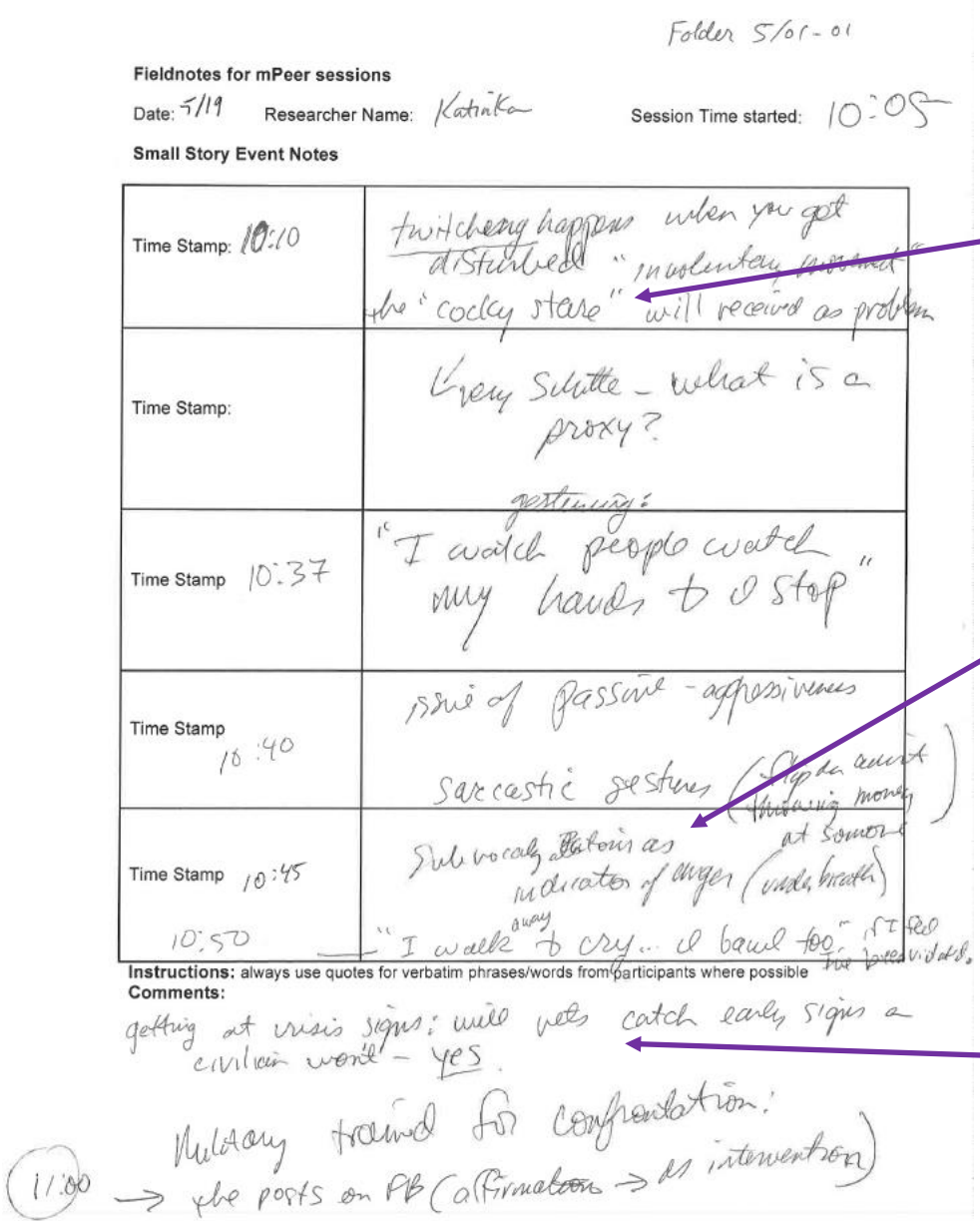
METHOD

Once the QRF app was built, the veteran MH peer mentors asked if it would be possible to use onboard sensors to also collect information that could be used to deepen our insight into early warning signs and crisis events that the veteran might not self-report. Thus, we focus here primarily on our initial efforts to capture meaningful sensor information about angry outbursts. Broadly, our research goals are to use a "bottom" up approach (Landgren 2010) to understanding veteran crisis through the lens of behaviors that can be captured by IoT sensors, to optimize the detection of these behaviors through machine learning techniques, and ultimately to reliably discriminate these behaviors from sensor signatures that are similar, but do not represent human crisis events (i.e. to minimize false positives). Our initial work unfolded in three stages: 1) ethnographic research from small focus groups with high risk veterans to examine "lived experience" of veterans with anger problems; 2) exploring the potential use of sensor systems through simulated aggressive crisis events, data visualization, and computational approaches. This phase involved working with professional actors as part of the research team to carefully simulate rage and other high emotional intensity events in the laboratory with the E4 Empatica sensor wristband; and 3) developing an approach to maximize real world crisis observation in an IoT environment with veterans using a 360-degree evaluation design, integrating psychometric data, self-report, observer-report (e.g. family member, other veterans, etc.), and sensor data.

Focus Group Data and Analysis

Preliminary information was collected via weekly focus group sessions (45-60 minutes each) with three at-risk veterans. In these sessions, the social scientists used open-ended interviews to elicit the contexts and bodily experiences leading up to angry outbursts. During these interviews, the entire study team used "small story" (Georgakopoulou 2007) field note worksheets to document warning signs, triggers and social contexts of anger with these veterans. After seven focus groups saturation of data was reached. Saturation was determined through ethnographic analysis identifying recurrent topics in language and actions.

From the field notes, the anthropologist on our team used descriptive coding to develop a list of dimensions to design a general taxonomy of warning signs (scenarios, social settings, and gestures). This taxonomy was further developed in detail by the entire team by reviewing and commentary on the fieldnotes (Figure 2). We classified the various types of cues leading up to an angry outburst in each of the general categories, both social (external) and individual (internal). A selective summary of these data are offered here and data analysis continues **(table 1)**.


Folder 5/01-01

Fieldnotes for mPeer sessions

Date: 5/19 Researcher Name: Katinka Session Time started: 10:05

Small Story Event Notes

Time Stamp: 10:10	twitchiness happens when you get disturbed "involuntary movement" the "cocky stare" will received as problem
Time Stamp:	Very Subtle – what is a proxy? gesturing:
Time Stamp 10:37	"I watch people watch my hands to d stop"
Time Stamp 10:40	issue of passive-aggressiveness sarcastic gestures (flipping the bird / throwing money)
Time Stamp 10:45 10:50	Subvocalizations as indicator of anger (under breath) at someone "I walk away to cry... d bawl too" (I feel the loss/victim)

Instructions: always use quotes for verbatim phrases/words from participants where possible

Comments:

getting at crisis signs: will vets catch early signs a civilian would – yes

Military trained for confrontation!

11:00 → the posts on FB (affirmation → as intervention)

Veterans noted subtle, involuntary movements as one precursor to anger. Also noted were dominance behaviors like "cocky stare". None of these early warning sign behaviors are easily detected by wearable sensors.

Subvocalizations and sarcastic gestures noted as early warning signs for explosive anger

Veterans note that other veterans are probably better at human driven detection of anger precursors than civilian observers.

Figure 2. Small Story Fieldnotes Captured by Study Team.

In the analysis of the focus group data, we consistently found that some early warning signs for aggression were not active behaviors, but rather the veteran's attempt to bring impending aggression back under control. Interestingly, this gets at the definitional aspects of aggression taken from the psychological literature: *aggression* can be viewed as the uncontrolled behavioral expression of the emotion of anger; in contrast, *anger* is the emotion itself, not a set of behaviors (Deffenbacher, Oetting et al. 1996).

Attenuated Behaviors - Angry Crisis Warning Signs	Low Level Aggressive Crisis Behaviors	High level Aggressive Crisis Behaviors
Involuntary • Shaking • Facial twitch • Stiffening body	***Throwing gestures*** · Money on bar · Keys on table · Phone across table	***Grand gestures*** · Sweep obj. off table · Flipping table over · Throwing lamp
Voluntary • Cocky stare • Posturing (widen stance) • Stillness	***Hand Gesture*** · Knife hand · Pointing · Middle finger · Making a fist/fist in air	***Melee*** · Throwing bottle · Throwing bar stool · Throwing people · Chasing people
Vocalization changes • Talking louder • Talking over someone • Muttering under breath	***Foot gestures*** · Tapping · Shaking leg · Kicking object	
Social Withdrawal • # of phone calls • # of texts • TCP/IP meta data	***Physical contact*** · Poke · Push · Enter other's personal space	

Table 1. Early warning signs leading up to angry outburst

Thus, the early warning signs for aggression may be less expressed as overt behavior, but rather the individual's attempts to *disallow these behaviors* until some threshold is met. In our multidisciplinary discussion during the focus group sessions, these attenuated behaviors (see Table 1) were a constant area of concern as it became clear that many of them were at or beyond the physical limits of what the sensor on the mobile devices could detect and record. For example, one of the veterans reported that he routinely used dominant behavior when he was very angry (but not yet aggressive), that included staring at the person he was angry with, physical posturing (e.g. widened stance), and physical *stillness* (as opposed to action) to express intimidation (Carney, Cuddy et al. 2010).

Simulated Aggressive Crisis Events

Next, based on the summarized information about aggressive gestures, professional actors (also part of this research team) were asked to act out the gestures in a series of simulations. One actor wore the E4 Empatica device, while another actor made provocative statements for the first actor to respond to. The discrete low-level and high-level aggressive gestures were performed repeatedly as a first step. Gestures involving feet were omitted because of the focus on the E4 wristband as the data source. In order to provide both richer data and also to make the E4 data conform more closely to real-life, we next asked the actors to perform three brief (5-7 minute) formal, scripted interactions using Shakespeare and modern theater scripts.

These scenarios involved one high intensity anger condition, one graduated anger condition, and one non-anger but intense emotion condition. During both anger conditions a third actor prompted the two acting out the script to systematically incorporate all anger related gestures if any were missed. However, the actors were also free to use other gestures and were encouraged to improvise.

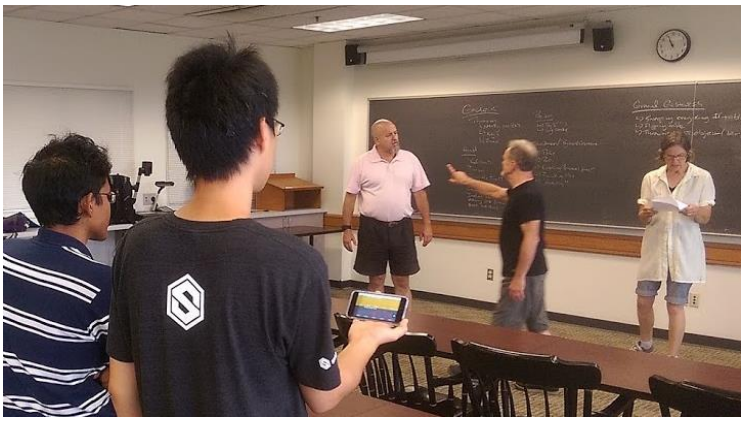


Figure 2: Actors performing aggressive gestures with real-time data capture from E4 wristband

Laboratory Data Capture Limitations

Issues that arose initially with this approach included concerns such as the need to have time-synced video matched to the physiological data feed from the E4, a constraint that would not be surmountable with actual veterans in real-world data capture situations outside of the laboratory. Additionally, the raw data from the E4 onboard sensors sampled data at different rates, requiring sampling normalization to occur as a pre-processing step before any other analyses could be performed. Finally, during the focus groups, the veterans repeatedly underscored the importance of sub-vocalizations, changes in vocal pitch, and changes in volume as key to understanding the transitions from aggression early warning signs to crisis. However, we did not attempt to integrate data from another device (e.g. a smartphone's microphone) as part of this initial pilot work.

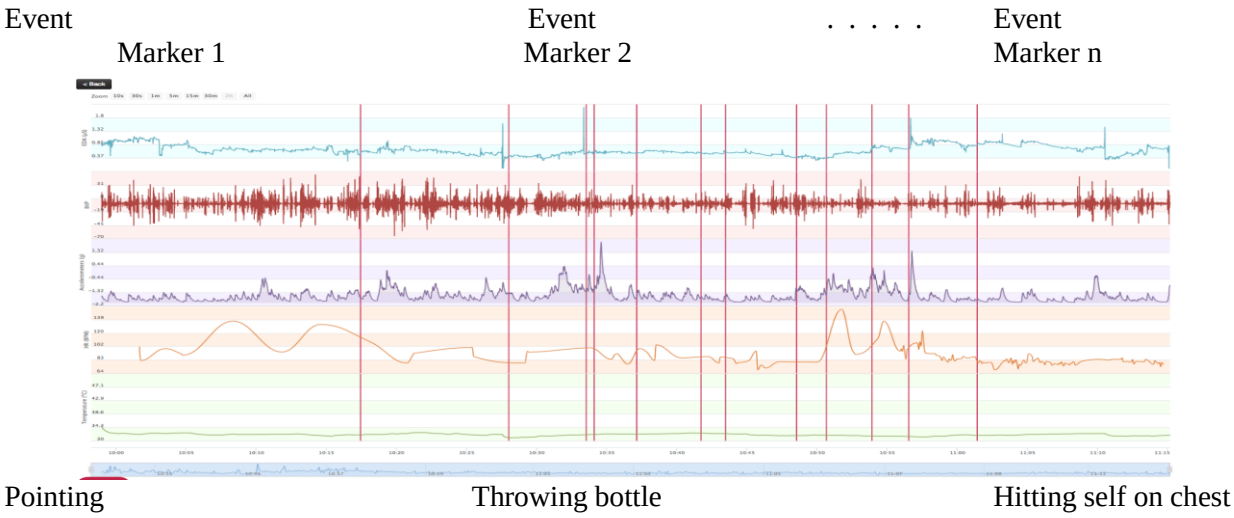


Figure 3. Real-time data from E4 wristband including accelerometer and physiological data

RESULTS

Computational Analysis

The project focused on semi-supervised machine learning approach to detect gesture clusters from the data set. Over 11,000 data points were collected from the accelerometer sensor. Each data point consisted of the three axes (X, Y and Z) coordinates. The data points were labeled with the twelve respective gestures performed by the actors. Once the data captured from the E4 wristband was normalized the labeled data stream from the accelerometer sensor was fed to the expectation maximization (EM) machine learning model. The EM model is

an iterative artificial intelligence (AI) technique that evaluates the log-likelihood based on the existing value of the parameters. A 75:25 split was done for training and testing the AI model to find a cluster pattern. Knife Hand, pounding fist, pointing, Italian street talk and throwing keys were the five gestures among twelve that were successfully detected from the clustering model. Figure 4 below shows five clusters in colors deep blue, red, light green, cyan and pink respective. Five clusters 0 through 4 were detected with accuracy above 80%.

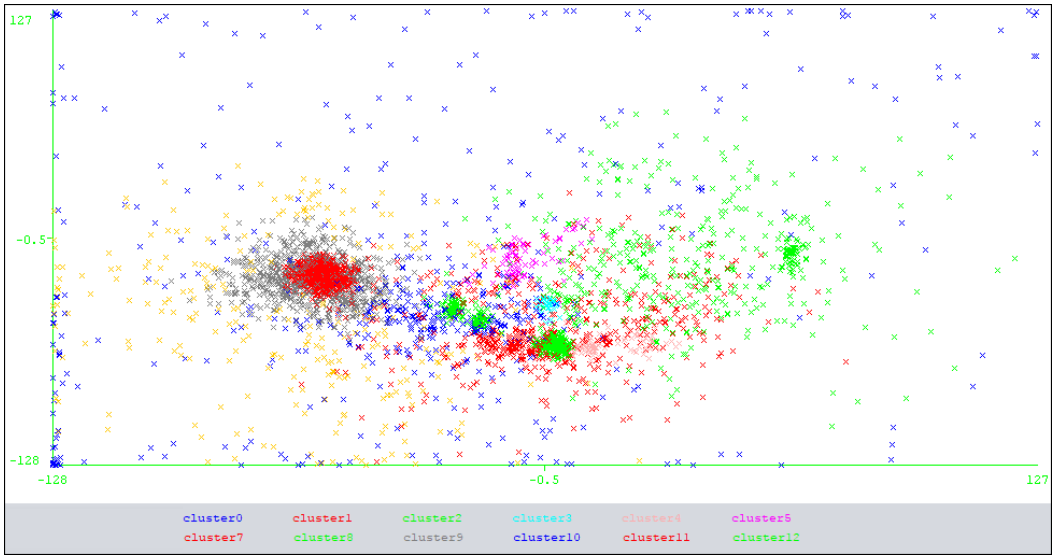


Figure 4: Expectation Maximization Model for Angry Gestures

Process Results: Some Reflections

Theoretical or atheoretical approach?

Not surprisingly, as part of a mixed social science and computer science team, each group brought with it its own disciplinary views and methods. The social science view of this problem was largely regarded through a theoretical lens, first examining the emotion of anger, and next the expression of uncontrolled anger through aggressive behaviors. The social science team sought to build up a body of academic knowledge, lived experience from veterans with histories of aggression, and to systematically characterize the specific behaviors that were assumed to be associated with early warning signs and crisis events in this population.

In contrast, the computer science team viewed the problem as one that should be approached from an atheoretical, data-driven perspective, using machine learning approaches to search for early warning signs after crisis events had been clearly marked in the data. While neither approach is right or wrong, searching for ways to more effectively combine these theoretical/atheoretical approaches may yield important insights, and the divide in our thinking illuminated three other key considerations in this work:

Which Comes first? Crisis or Warning Sign?

While the answer to this question is clearly that by definition early warning signs precede crisis events, as we considered the situation of aggression the edge between these phases of crisis became fuzzy. The simplest example is the distinction between a physical contact that expresses aggressive crisis versus a physical contact that is an early warning sign. For instance, some punches may be thrown to signal that a crisis is about to ensue, while the individual is not fully committed to following through to serious aggression. Other punches may be thrown in the midst of fully engaged melee combat. Questions arose about the ability of sensors to discriminate between these two types of activity without additional contextual information. Numerous other examples of events that could, in one view, be taken as a crisis, while under another view be seen as an early warning sign.

Can humans be trusted to mark their own crisis events?

While detecting crisis events in most non-human systems is typically straight forward (i.e. once the point of

criticality has been reached the crisis is observable and obvious), humans typically do not want to disclose that a mental health crisis event has occurred, and memory or reporting biases often result in under-reporting (O'Leary and Williams 2006, Bone, Gelberg et al. 2016). This fundamental problem has historically plagued efforts to therapeutically address these crises after the fact, and is a problem that must be solved before advances in computational psychology to address these problems through predictive analytics can be achieved (Poikolainen 1985). The computer science team assumed that the event marking button on the E4 Empatica wristband would be used by the veterans to mark crisis events in real life situations. However, through the focus group with veterans it became apparent that humans – even if they were willing to disclose that a crisis is occurring – do not always recognize the crisis event as such *in the moment*. In fact this issue goes to the heart of the problem: those who experience aggression are often initially not able to put words to their emotions and are so wrapped up in the aggression that they are unable to distance themselves from the emotion enough to reflect and take more productive actions. Similarly, the professional actors became so wrapped up in the simulations that they forgot to stop and mark events using the E4 event marker button, even though they understood the value of doing so and there was no social stigma in disclosing this contrived crisis event. Thus, the very intent of the system we are attempting to design must be to provide support to both help the veteran identify that a crisis may be occurring, and use the friction of this "check in" to learn more about what true positives (crises) and false positives (non-crisis, but anomalous data) look like. The system ultimately has to support crisis event detection independent of the human because of the inherent limitations of human systems in recognizing and responding to these events.

Legal and Ethical Considerations

Working with high risk populations presents several complex legal, privacy and ethical considerations in the context of mHealth application design. In particular, while incremental progress toward identifying mental health crises and early warning signs was seen as acceptable by the computer science team, the practical and legal considerations around false positives and false negatives had to be concretely brought into the discussion (Klinkman, Coyne et al. 1998, Lalkhen and McCluskey 2008). For example, in real-world use, a false positive (i.e. an indication of a crisis event is immanent or occurring) would likely require a crisis response protocol be initiated, potentially requiring a phone or in-person check-in between the veteran and a licensed mental health provider (e.g. a clinical psychologist or psychiatrist) to ensure that the veteran was not a threat to themselves or others. With an insufficiently accurate machine detection approach, the veteran could be receiving many unnecessary, unwanted contacts to check on their status. Conversely, if the system fails to detect crisis events when they are in fact occurring, the veteran would be left without intervention, raising the risk of legal action against those designing and deploying such a system. Even in the context of research, both of these problems are vexing and raise serious concerns.

At the veterans' request the initial QRF app was designed with an embedded privacy framework that anonymized data stored for research purposes, while making the veteran's identities available to veteran peer mentors (mentor phones re-coupled names and IDs using a local database on the mobile device). However, with the addition of behavioral data directly seeking to understand and identify high risk behaviors, the team came to the conclusion that any future work would require veterans to be consented to use a system that provided the research team with full access to their identities in the event that a crisis occurred and required emergency intervention. With this decision also comes the burden that very intrusive data about routine daily activity at a very fine level of detail, coupled with identity and psychological functioning information could be breached.

Methodological Results: Improvements in Human Crisis Marking

After considerable back-and-forth between the social science/computer science teams, we abandoned the idea that veterans would be able to reflect on their own high-risk behavior in the moment. We saw even with the professional actors that the dialogue with another person (i.e. the target of aggression), self-involvement with the emotion of anger, and the physicality of the expression of anger all made actively marking moments of personal crisis nearly impossible even in the laboratory environment. These constraints would likely be exacerbated in real-world settings with high risk veterans because their ability to even recognize emotion and aggressive crisis events as such is likely limited (Laser and Stephens 2011). An alternative strategy that avoids the problems associated with self-report in a much later clinic visit (i.e. days or weeks after an aggressive episode has occurred) was clearly needed.

EMA+360-Degree Assessment

After discussion, a new procedure was mapped out with all parties (veterans, computer science, social science team), leveraging the existing QRF smartphone app for use with high-risk veterans. This proposed approach

would involve 1) a single item question delivered daily via the QRF app asking the veteran, "Were you angry any time today?"; 2) a positive screen will result in an alert to their veteran peer mentor via the QRF mentor app, prompting a telephone base check-in; 3) during the telephone based check-in the veteran peer mentor will probe for the context the anger arose in, if it resulted in aggression, and if aggression was present a time point when it occurred; 4) in order to capture other moments of anger or aggression that may be missed in daily EMA, the veteran will complete a weekly reflection log on anger/aggression, asking the veteran to reflect on any incidents that came up for each day of the last week; 5) the veteran peer mentor will respond to a similar log, noting any incidents they are aware of for the veteran which the veteran may not be thinking of as rising to the level of crisis; 6) Finally, all of the available information from the logs will be discussed in a group meeting with the veterans, peer mentors, and social science team to carefully review for any unmarked moments of aggression, and also to determine level of intensity of aggressive acts using available dynamic risk assessment tools for aggression (Figure 5).

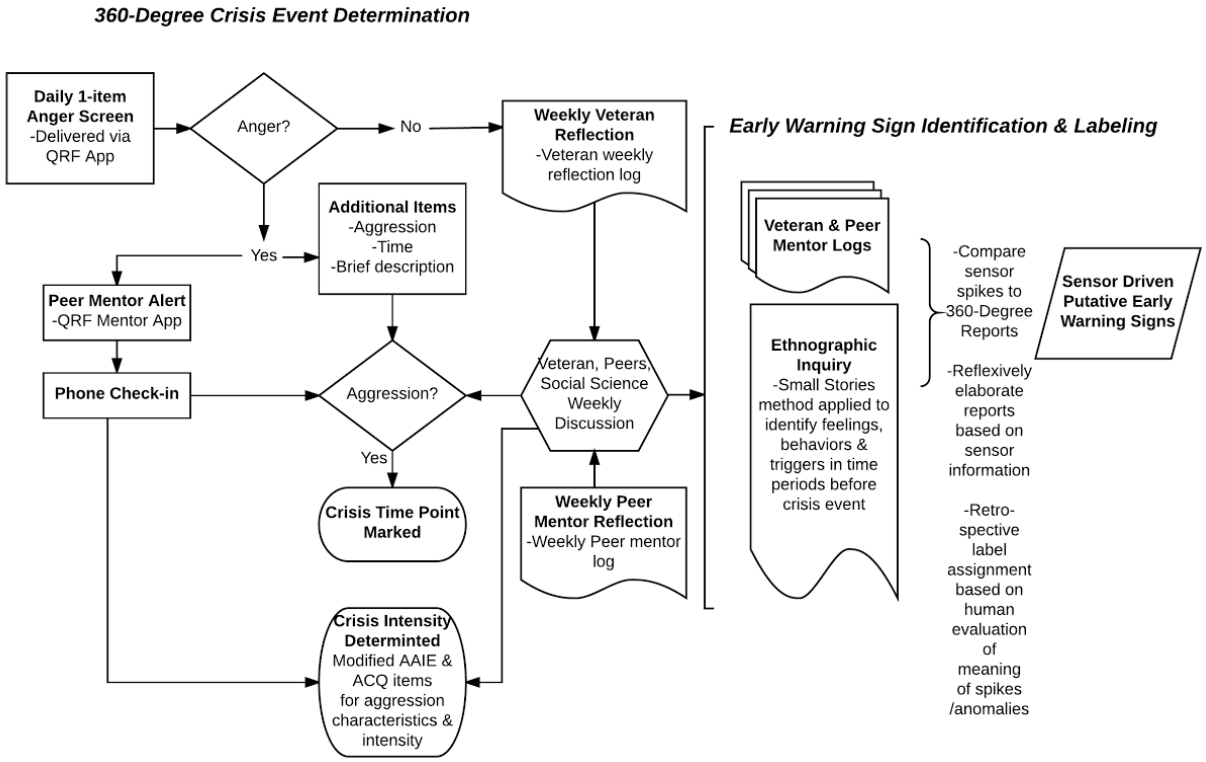


FIGURE 5. 360-DEGREE CRISIS EVENT DETERMINATION STRATEGY WITH HUMANS-IN-THE-LOOP

CONCLUSION

Most mHealth applications, particularly for mental health conditions, implicitly attempt to prevent crises from occurring in individuals. However, most first generation systems have focused on relatively simple tasks such as patient education, mobile resource and referral, or as supplemental support to traditional clinical care. We argue here that addressing mental health emergencies requires a much more comprehensive approach, one that can be particularly well addressed by IoT based sensor systems. To accomplish this, three things will be required: First, a deliberate effort to explicitly address mental health problems through the theoretical lens of crisis management; second, a social view that involves the patient, non-professional or para-professional social supports to the patient; and three, applications that leverage a wide range of data available from worn, in-home, vehicle, and other ambient sensor sets. Optimally such approaches will ultimately address not just population normative mental health crisis management strategies, but a *personalized behavioral medicine* strategy that is capable of identifying warning signs specific to each person.

While seemingly straight forward, our attempts initial pilot work in identifying methods for using IoT systems to assist in the detection of mental health crisis with US military veterans presented a number of challenges. In particular, addressing the natural, human filters that mask when mental health emergencies occur using robust, time intensive and expensive approaches may be initially required in order to build sufficiently accurate learning

data for computational approaches to be useful. Relying solely on clinical or self-report well after the fact will obscure critical weak signals. Further, we have identified some important limits of existing sensor based approaches for primary data collection of attenuated or subtle behavioral markers, for example staring or subvocalized epithets may require alternative sensor set-ups. For instance, use of wearable eye trackers or miniature microphones placed on the throat or near the mouth might assist in detection of subtle anger cues. Overall, our approach emphasizes the importance of combining ethnographic and machine learning techniques. To accurately re-create veteran lived experience in a controlled, laboratory environment, we incorporated skilled actors as part of the study team to re-create scenarios. This, in our view, allowed us to generate very high quality training data, and timestamping through review of video also enabled granular markup of these training datasets for supervised and semi-supervised machine learning. The importance of ethnographically driven ISCRAM research has been suggested previously (Landgren 2010), and this effort attempts to embed them specifically in a machine learning context.

We have proposed an approach to assist IoT based mHealth systems obtain accurate crisis marking data for one type of mental health crisis. The approach likely can be generalized to other human systems crisis events, and the observations and reflections offered can inform a broader discussion on the theoretical aspects of crises and early warning signs, as well as the practical implications of detecting these phenomena in complex, real-world settings.

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Inter-Agency Communication and Information Exchange in Disaster Healthcare

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ABSTRACT

In a disaster, the main agencies of healthcare and relief are usually health and disaster management organisations. Although these two disciplines share the same vision of care provided to disaster victims, post-disaster studies have shown that poor communication between them can negatively impact the collaboration needed to ensure the quality and coordinated delivery of effective healthcare. This paper presents the current findings of an on-going investigation to determine and reduce the barriers to smooth and effective communication and information exchange. The long-term aims are to establish joint agency training to improve communication and to specify the requirements of a knowledge-based system based on the timely exchange of information contained in dynamic datasets defined by inter-agency needs.

Keywords

Disaster healthcare, disaster e-health, disaster management, disaster medicine, e-health

INTRODUCTION

Disaster management[1] agencies have a broad remit for dealing with the mitigation, preparedness, response, and recovery phases of a disaster. Their responsibilities include infrastructure, transport, resources, supply chains, and related domains, as well as the safety and general well-being of disaster victims (International Federation of Red Cross, 2017). The healthcare of those affected by disasters is a more focused range of activities delivered by public health professionals, paramedics, and disaster medicine specialists using rigorously defined protocols and clinical competencies (Subbarao et al, 2008).

Despite many common values and similar operational characteristics, disaster managers and health professionals have frequently failed to share their tools and personnel (Bissel, 2005; Fountain et al, 2013; Russo, 2011), a circumstance that can lead to delayed, substandard, and even unavailable healthcare. This paper describes a study to identify some of the communication-related issues that can impact the fundamental characteristics of effective healthcare, *viz* care quality, patient access and safety, and cost-effectiveness (WHO, 2010), and its delivery in disaster situations. The categorised issues have been used as a framework for semi-structured interviews with disaster managers and clinical personnel to understand their key needs for information exchange. The long-term goals are to use the findings to develop training that reduces barriers to communication, and to specify the requirements of an information system that can be used to facilitate inter-agency collaboration and coordinated action.

[1]We use the term ‘disaster management’ instead of the more common ‘emergency management’ for consistency with the phrase ‘disaster medicine’. The term ‘emergency medicine’ is avoided since it is commonly used for mainstream (ER) care.

METHODOLOGY

A comprehensive literature study was undertaken to reveal the obstacles that hinder information exchange and seamless collaboration between agencies responding to the health demands of disaster victims. The review attempted to answer three main research questions; What are the barriers to effective communication between clinical and emergency personnel during disasters? What essential information do these practitioners need to communicate in emergency situations? How can communication between emergency management and emergency medicine practitioners be improved?

Databases searched included TRACIE: Healthcare Emergency Preparedness (Information Gateway), Disaster Lit: The Resource Guide for Disaster Medicine and Public Health (National Library), The International Disaster Database (EM-DAT), Google Scholar, Scopus etc. Journals consulted included The American Journal of Public Health, International Journal of Emergency Management, American Journal of Disaster Medicine, Disaster Medicine and Public Health Preparedness, Prehospital and Disaster Medicine etc. Grey literature used involved government reports, policy statements, etc. The search also covered websites of international humanitarian organisations including IFRC, UNOCHA, and WHO.

Search keywords such as *cross-agency collaboration*, *information exchange*, *disaster medicine* and *disaster management* revealed 56 relevant articles from different disciplines including information and communication technologies, healthcare, humanitarian relief and public policy. Analysis of the articles extracted re-occurring themes that researchers report as having a significant influence on inter-agency communication and representing potential barriers to concerted action.

Semi-structured interviews were then held with disaster managers and disaster-healthcare practitioners to discover their perception of the identified themes (see below). Interviews (15) lasting typically 60-90 minutes were recorded with six senior health disaster personnel with extensive expertise in disaster preparedness and response, and eight disaster managers across various governmental agencies and non-governmental organisations. Types of disasters to which participants responded ranged from the Christchurch earthquake in 2011, the Syrian War, and the West African Ebola virus epidemic. One interview was also conducted with a United Nations special representative to gather the views of a senior decision-maker from an international humanitarian organisation.

THEMES THAT NOTABLY INFLUENCE INTER-AGENCY COMMUNICATION AND INFORMATION EXCHANGE

The themes that emerged from the literature review fell into five broad categories; authority and leadership, culture and trust, situational awareness, technology and legislation. These categories are used here to summarise the results. Full details are available elsewhere (Abbas et al, 2018).

Authority and Leadership

A potential cause of sub-optimal collaboration between disaster management and health professionals is the different authority structures that determine operational modalities and the way each agency responds to crises (Abbas et al, 2016) Disaster managers have traditionally been trained according to a military command-and-control model but there is increasing awareness that this model has limitations in situations that demand rapid, adaptive decisions (e.g. between civil defence, fire fighters and clinicians) and coordinated responses between the responding groups. Similar limitations apply to planning, which is often intra- rather than inter-agency (Local Government New Zealand, 2014).

Whilst disaster medicine (often seen as a poor relation of mainstream emergency medicine (Hayes et al, 2012; Smith et al, 2012) is based on multi-disciplinary teamwork, it is extremely hierarchical and less familiar with the need to collaborate in real time with agencies external to its domain. These distinctions can lead to different priorities and territorial misunderstandings making it difficult for disaster victims in need of treatment to receive seamless care. Moreover, authority differences can impose a leadership conflict when responding collectively to critical situations. For example, who is responsible for declaring a state of emergency (MCDEM, 2012)? Uncertainties can still occur even when plans to resolve this difficulty are in place.

Culture and Trust

Disaster management is a comparatively new discipline with a necessarily pragmatic approach to evolving situations. In contrast, disaster medicine is a scientifically based domain very conscious of its academic credentials and focused on strict, set protocols. The way each domain perceives information depends on the tasks it has to perform. Medical responders have their own evidence-based criteria for ranking emergencies whereas disaster managers have to correlate diverse information from multiple disciplines such as geography, geology, and meteorology. It is therefore probably naive to expect the two sectors to communicate smoothly without efforts to resolve issues that may stem from their different cultural origins.

A critical factor for successful cross-agency collaboration is trust (Zaheer et al, 1998). Mutual trust implies that collaborators will observe agreements and ethical principles (integrity), willingly share, rather than withhold, information, and contribute their resources and competence to the collaborative relationship in a complementary way (Dubai School of Government, 2009). Trust eases the need for controls and monitoring tasks that can waste critical time in disaster stations, and encourages flexibility and a focus on goals rather than processes (Zaheer et al, 1998).

Situational Awareness

Situation awareness (SA) is about knowing and recognising what is going on around us (McIlvaine, 2007). In Endsley's seminal work (Endsley, 1988), SA comprises three elements; perception (understanding the importance of information about a given situation), comprehension (how the perceived information is combined, interpreted, stored, and retained), and projection (the ability to forecast future situations from current and previous ones). Whilst each person in a team needs to have some level of SA to perform their allocated tasks, concerted and appropriate decision making and action are only possible if they have a shared understanding of these situational elements and an awareness of other team members' requirements and the tasks they perform.

Situational awareness is critically dependent on information flow and the realisation that data items of limited value to the members of one domain can be crucially important to their counterparts in other areas. Thus, clinicians may need disaster managers to list for them the numbers and type of particular injuries suffered by disaster victims so that care personnel can determine the numbers of doctors and nurses, and the extent of equipment and medications, that are needed. Similarly, if an environment becomes unsafe, clinicians may need to advise responding managers that evacuating some critically ill patients is more dangerous than letting them remain.

Technology

The previous sections spotlight human and organisational issues that hinder or expedite communication in disasters. Much of this communication, however, is facilitated by information technology particularly in the first few hours after a disaster event occurs; a critical time for making decisions such as triage evaluation (Donner et al, 2012). Underutilisation of ICTs in disaster response by both the disaster management and medicine sectors almost certainly reflects understandable concerns about the costs and complexities associated with their adoption, application, and likely impact on practitioners and victims (Kabashiki, 2013). Technical interoperability between agencies is a significant concern due to potentially incompatible systems and access restrictions based on information security and perceptions of data ownership.

Overcoming these technical barriers through a collaborative approach based on multiple information channels, better ICT preparedness, and public education on the use of alternative communications channels during an emergency, provides numerous benefits. These include avoidance of misleading information, enhanced health information management, access to health records regardless of time and geography, improved communication between both healthcare providers and consumers, and better use of scarce commodities (Coiera, 2015).

Legislation

Information sharing is closely related to trust. However, in the healthcare context, there is also a legal dimension to information sharing that stems from the need to protect patients' privacy and confidentiality. Health practitioners may be unwilling or unable to share patient medical records even between members of the same agency let alone cooperate with other professional organisations (Lips et al, 2011). Other issues arise when agencies have different interpretations of privacy legislation and how it should be applied, and when government agencies deal with non-governmental organisations (NGOs) and community-based service providers that are not covered by government exchange protocols. A trade-off between protecting patients' confidentiality and achieving a flexible level of information sharing that enables cooperation is crucial to the success of cross-agency collaboration.

Thus, there is a need to emphasise legal interoperability, and with it, accountability, in a collaborative disaster response. Legal interoperability covers laws, policies, procedures, and cooperation agreements needed to allow the seamless exchange of information between different organisations, regions and countries (EHealth Governance Initiative, 2012).

INTERVIEWS TO DETERMINE INTER-AGENCY COMMUNICATION AND INFORMATION EXCHANGE NEEDS

This section describes preliminary findings of the interviews carried out to discover practitioner requirements for inter-agency communication and information exchange in disasters. Interviewee comments are paraphrased and woven into the text using italics. The Discussion section suggests early recommendations from the outcomes.

Although the context of the interviews was disaster healthcare, many of the issues raised are common to other

disaster situations. Moreover, whilst the presentation here endeavours to group themes according to the categories identified earlier, the findings revealed that the perceived category of a theme could vary depending on both a practitioner's experience and the context of an interview. Thus, a theme seen as a leadership problem in one interview could be better understood as a cultural issue in another, or even seen in a further interview as a legal issue with overtones of authority. This multi-dimensional aspect is evidently a consequence of the complexity of disaster situations and the ways in which those involved struggle to make sense of them.

Many of the communication issues raised by interviewees concerned aspects of authority and leadership. These covered the lines of command between local, regional, and national agencies, often noting '*a misperception of what it is that agencies deliver*' and '*the confusion that comes from what they all mean, the differences between them and how they work together*'. A common problem was '*knowing who to talk to*', an issue not confined to relevant contacts in key agencies such as Civil Defence or health organisations, but extending to knowing which agency to refer to when an unusual event requires specialist action. An example quoted was of an agricultural corporation now brought into the emergency strategy to deal with food safety matters.

One interviewee spoke of the '*family of disaster management disciplines including process and risk communication, crisis management, business continuity management, risk management, emergency management*' which emphasises that '*the perception that there is always going to be one leading agency is not correct*'. There was general acceptance that the specialised nature of responses, e.g. fire and healthcare services, required multiple leadership but regret that '*there existed no all-government centralised contact list*' that could help to coordinate action.

The cultural and trust issues indicated by the interviews paralleled closely those found in the literature review. There is '*no single voice guiding disaster management professionals on what best practice means in emergencies*', a comment lamenting that disaster management '*doesn't have the recognition*' that is self-evident for disaster medicine because '*we haven't set it up for ourselves*'. A consolation was that '*the profile of disaster management has been raised over the past eight or so years in organisations and agencies in the health sector*' and '*we are slowly getting there*'. This improvement in status is facilitated by '*regional disaster management advisors who work, train, and help medical personnel in the disaster management aspect'*, a collaboration that '*builds relations enabling disaster managers to identify clinical directors and health officers during response'*. A note of caution was, however, noted in another interview which observed that the reverse process, in which disaster managers are trained by health-sector staff to go back to their agencies and train their own staff, '*doesn't work when people don't want it to work*', suggesting a trust issue.

Trust is a key component of both resource and information sharing. Different agencies collect and '*own*' the data they need to perform their main responsibilities but, in an emergency, data owned by one agency may become critical for another agency to function properly. Territorial 'data ownership' can therefore lead to sub-optimal responses including healthcare. The scope of the data that health professionals need from other agencies is normally quite limited concentrating on '*how many are injured, the priority of injury types, where patients are sent, and when discharged*'. In return, health organisations routinely share '*GPS locations of facilities, and resource data such as staff and bed numbers'*. Other data exchange themes arising from the interviews concerned patient privacy and confidentiality, and the desirability for data to be handled electronically rather than manually.

When asked about formal mechanisms for improving situation awareness (Endsley, 1988), interviewees pointed instead to effective information exchange as the key requisite – '*it's actually knowing that you need to talk to people and knowing what you need to talk about'* as well as sharing timely information across a system designed to build a dynamic, holistic picture of a disaster event. Systems of this type, known as Common Operating Picture (COP) systems (HFIDTC, 2009), collect and integrate data from automated sensors, satellite feeds, and geospatial and mobile systems. Even so, COP systems requirements must involve all disaster stakeholders if hey are to meet the challenges confronted by responders. These requirements echo the value of cross-agency, or even better, joint agency, training to engender shared situation awareness.

Another aspect of situation awareness that drew attention in interviews was the difficulty of media communication in disaster situations. '*It's problematic to give out misleading information to the public'* and to the broadcast media, so '*be first, be right, be credible'*. The same question of control arises with social media both with regard to spreading false news and advice, which may have unforeseeable consequences such as patients using inappropriate medical interventions when normal clinical guidance is unavailable. Nevertheless, interviewees saw many situational awareness benefits to social media; timely information, alerts to find help or minimise threats, ability to gauge public opinion and adjust recommendations, check understanding etc. *'Social media exchanges are so much part of modern society that they should be central to the development of disaster response strategies'*.

Interviewees were vocal in underscoring the crucial role of information technology in disaster management and disaster healthcare but equally critical about the design and performance of current systems. Interoperability and

scalability of different agency systems were seen as troublesome issues as were flexibility – '*in any given moment, I might like pure numbers and figures in a spreadsheet but then I'd like this shown to me in a graph and I'd like that graph to be interactive so that I can drill down into it to find the* data' and usability – '*we've got to scroll through massive documents and situation reports when all we really want to know is a couple of quick numbers to help us make a decision'*. The target is a single, usable, knowledgebase system, that is dynamically updatable, and accessible to every disaster agency providing them with customised and interactive data. In this respect, the concept of minimum datasets (MDS) attracted considerable interest. An MDS is a minimum set of data elements used by several countries for mandatory collection and reporting in a selected health area of interest (AIHW, 2017, Svensson-Ranallo et al, 2011). Many participants felt that specialised MDS could be useful for disaster healthcare (Borsato et al, 2000) and the notion of separate dynamic MDS for baseline (i.e. demographic), healthcare, and humanitarian purposes attracted a lot of discussion and encouragement for further development.

Other noteworthy topics mentioned by practitioners were the need to use data systems not just for disaster responses but for forecasting and preparedness planning (e.g. by using epidemiology data), and, by contrast, to see graphical information systems (GIS) not just as a '*planning and intelligence tool*' but as a '*huge communication tool'*.

Many countries have robust legislation to preserve patient privacy and confidentiality during information exchange (Yarmohammadian et al, 2010). However, the legislation is typically designed to provide safeguards under non-disaster settings when data availability is guaranteed and exchange processes are rarely time-constrained. The chaotic conditions and urgency attending disasters are very different; priorities can change rapidly, putting pressure on the delicate balance between confidentiality, informed consent, and intervention. Interviewees were largely comfortable with their current systems which didn't '*touch the privacy code area'* but there would seem to be value in studying the extent to which a code could be relaxed in a crisis and how circumstances could be normalised thereafter.

Another legislative area of interest to practitioners related to the '*knowing who to talk to*' theme mentioned earlier. It was suggested that there should be an '*all-government centralised contact list'* that legislated who must be contacted in a given set of circumstances, what information should be exchanged, and what to do with it. This directive alludes back to the minimum dataset concept mentioned above and suggests a fruitful avenue of research. Finally, an interviewee pointed out the need to consult with agencies such as the Red Cross when aspects of international humanitarian law and aid were involved.

DISCUSSION

As explained, this paper describes an on-going study to identify the barriers to smooth and effective communication and information exchange in disaster healthcare. Although the findings are preliminary and subject to more detailed analysis, we can see how they can contribute to the long-term goals to develop training and systems that reduce these barriers and yield better healthcare in disaster scenarios.

A central, recurring theme in the interviews was the '*knowing who to talk to*' requirement aimed at ensuring that responders always have access to the information they need to perform their assigned tasks. Practitioner responses regard this obligation as so critical that they recommend it is supported by legislation or comprehensive regulations that prescribe a centralised contact system with clear, even automated, instructions on who to communicate with, what information to exchange with them, and how to act on it including who else to contact.

Respondents were highly supportive of joint agency training co-designed by civil defence and health authorities as a way of ensuring that disaster managers and clinicians and other health personnel were made aware of the information needs of all responders (Hayes et al, 2012). The consequent improvements in situation awareness would enhance collaboration and coordinated action.

Many comments highlighted the importance of information exchange that was restricted to essential data elements eliminating unnecessary data that could become a fatal distraction in the stressful environment of a disaster. As mentioned, this idea prompted the suggestion of an information exchange system built around customised and dynamic minimum datasets. In a fully-fledged form, such a system would collect multimedia data from sensors, feature COP and GIS components, and use adaptive artificial intelligence algorithms to route extracted information between appropriate contacts and agencies.

CONCLUSIONS AND FUTURE WORK

The authority, cultural, situation awareness, technical, and legislative challenges identified in this study have revealed a wide range of issues that impact inter-agency communication and information exchange in disaster healthcare

Whilst the literature review and interviews were rigorously planned and executed, the findings presented here represent only a preliminary analysis. Future work will therefore further mine the rich datasets from the interviews to refine and expand the results.

The expanded results will then be used in a Delphi study to add granularity that was not sought at the initial stage. Examples include questions designed to:

- identify themes associated with other phases of the disaster cycle, especially preparedness planning;
- elucidate themes that may depend upon the type of the disaster, e.g. floods, terrorism, epidemics;
- ascertain themes that are applicable across a range of disaster scenarios;
- consider privacy and confidentiality issues associated with inter-agency communication and information exchange;
- study the role of social media to harness its benefits and reduce the drawbacks;
- investigate the potential of minimum datasets as the basis of an efficient inter-agency, information exchange system;
- develop a prototype information exchange system and study the implementation issues need to realise the goals described in this paper;
- explore the design, content and delivery of a joint, postgraduate, disaster healthcare course for disaster managers and health professionals.

The outlined plan forms part of a programme to produce an extended road-map that is designed to support training for, and the delivery of, better healthcare in all phases of the disaster cycle. Such improvements will provide many human and economic dividends.

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Citizens Communicating Health Information: Urging Others in their Community to Seek Help During a Flood

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ABSTRACT

When wide-scale flooding occurs in a community not accustomed to floods, health concerns emerge. While official organizations tasked with communicating emerging health information exist, the proliferation of social media makes it possible for average citizens to participate in this conversation. This study used a combination of semi-structured interviews and photo elicitation techniques to explore how citizens used private social media sites to share health information. We found two main categories of health concerns: existing medical conditions and water-created. We further identified six themes that describe the common approaches average citizens used to share health information: Narrating a personal experience, presenting it as a Public Service Announcement, downplaying the contribution, bringing a credible source into the conversation, including external links and sources, and using humor. Together, these findings suggest that citizens need health information during a flood disaster, and when they do not have it available from official sources, they use their private social media to tap into a shared community identity and carefully help one another.

Keywords
Disaster, crisis communication, health information, community, social media, flooding, credibility, identity.

INTRODUCTION

Floods are the most common natural disaster around the world (Doocy, Daniels, Murray, & Kirsch, 2013), and when they affect an entire community, they can cripple the official emergency response (Fritze & Kray, 2015). Formal official responses often assume that responding organizations are known ahead of time, have trained together, and are available when needed (Bigley & Roberts, 2001). Despite the existence of extensive training, and bureaucratic structures, when the authority structures break down, so do the formal plans (GAO, 2005). In 2005, the response to Hurricane Katrina had provided evidence that many Americans lack the means to adequately address their medical and sheltering needs during a disaster, particularly among vulnerable communities (Eisenman, Cordasco, Asch, Golden, & Click, 2007). The unanticipated flooding of entire communities during Hurricane Katrina caused systems to break down (GAO, 2005), and this appears to have happened when the flooding that resulted from Hurricane Harvey and affected the greater Houston, Texas USA area.

Healthcare systems, including entities responsible for sharing information with communities, are not immune to the

catastrophic effects of wide-spread floods (Ryan et al., 2016). Emergency workers in affected areas often need to care for their own crisis-stricken families, making coordination and response difficult (Majchrzak, Jarvenpaa, & Hollingshead, 2007). Yet, when citizens believe they need health information, and they do not receive it from official sources, they find other ways to reduce their uncertainty and get that information (Auf der Heide, 1989). Understanding how citizens communicate health information to one another is the focus of this research.

It's my Group so I Need to Help

Online and private social networking sites are often composed of groups of friends, family and co-workers who make a conscious effort to stay connected (Robertson & Kee, 2017). While the terms social networking site (SNS) and/or social media are often used interchangeably, here we concentrate on the networking component of social media because our questions center on what people share through *private, not public* online media.

Social identity theory (SIT) was originally developed to explain how groups interact (Tajfel & Turner, 1979), and it rests on the idea that the "extent to which people identify with a particular social group determines their inclination to behave in terms of their group membership" (Ellemers, Kortekaas, & Ouwerkerk, 1999, p. 372). One "group" where this theory has been applied and extended is in studies of organizations (e.g., Ashforth & Mael, 1989; Stephens & Zhu, 2016; Zoller, 2003). In their summary of existing research literature on organizational identification and health, Stephens and Zhu (2016) found five reasons that identification can serve as a form of glue when communicating about health: identification is linked to persuasion, can influence health information sharing at work, can help community groups reduce turnover, can work in conjunction with technologies to influence health outcomes, and is often connected to emotions. While their work was specific to an organizational context, there are many reasons to believe that online social media sites, like Facebook, can function to bring people together into groups where identification is salient.

For example, one study exploring how social media sites can be used to communicate health messages at work found that when an organization has highly identified members, these sites can be used effectively to communicate about non-stigmatized illnesses like skin cancer (Stephens, Goins, & Dailey, 2014). These scholars explain that the theoretical mechanism at play is that a social medium—i.e., Facebook—can heighten the salience of organizational membership through visible shared symbols, like logos, and through other member's comments. Furthermore, when these organizational members were more identified, they also felt less overloaded with the health information being presented. It was as if "identification buffers the overload individuals experience when they consume health information" (Stephens et al., 2014, p. 406). Overload is highly salient when communicating health information because people feel heightened uncertainty when there is medical jargon and ambiguity present in health messages (Thompson et al., 2011); a similar reaction people have when they experience a disaster.

Having the ability to share information—a common feature of many social media platforms—has been shown to be important for disasters (Murthy, 2013; Vieweg, Hughes, Starbird, & Palen, 2010) and health communication (Southwell & Yzer, 2009). Sharing health information leads to positive outcomes like providing opinion verification, improving self-esteem, and facilitating shared personal goals (Southwell & Yzer, 2009). Furthermore, when the shared information matches the needs of others, they can continue to pass it on and broaden the reach (Rioux, 2005). Past research has shown that the level of identification with an organization also influences how people share health information with others (Crook, Stephens, Pastorek, Mackert, & Donovan, 2016).

Individuals incorporate those organizational membership cues into their construction of personal and social identity, which ultimately influences their attitudes and behavior (Larson & Pepper, 2003). Furthermore, during disasters like floods, people often feel a need to help others, a concept referred to as a culture of responsibility (Marincioni, 2001). But we know very little about the health information that concerns citizens the most during a widespread flood disaster. Therefore, our first research question asks:

RQ1: What are the primary flooding-related health concerns raised by citizens on their private social media?

Murthy (2013) argues that the dissemination of health-related information on social media suggests our society has shifted to one of an "update culture," where individuals have a frequent desire to share content about health on their personal social media pages as soon as new information arises. This desire is heightened during a disaster, and these same citizens may want to move beyond simply sharing information and instead prompt others to take action.

In the health education and communication research literature, the concept of mobilizing information is defined as a type of information that can prompt individuals to action in response to a particular health threat (Damond, Winters, Jack, Cropper, Londono, & Stoddard, 2003). The concept is derived from mass communication research (Lemert,

1981), but it could be an especially helpful concept in a disaster context because it compartmentalizes specific content that needs to be included in messages to move publics to action: location, identification, and tactics. Perhaps multiple groups—including citizens—are using mobilizing information to cue their community members to take action to protect their health. While past research often focuses on posting and sharing, it has not explored if and how citizens share information in ways that can motivate others to take action. Thus our second research question:

> RQ2: What communicative strategies do citizens use when sharing health information through their private social media?

METHOD

This study is part of a larger project examining social media use and rescues during Hurricane Harvey. Here we focus specifically on community members who communicated health information through their private social networks.

Data Collection

Participants were recruited from one heavily flooded community in the greater Houston, Texas area. They were invited to participate in one-on-one interviews that lasted 20-80 minutes and were organized around using a photo elicitation (Harper, 2002) approach. This form of data collection assumes that images—defined as photos and textual posts—and people's decisions to share those images, are a richer form of data than simply responding to interview questions. Visual social media research moves beyond text-based analyses and includes images as important parts of the communication process (Vis, 2013). However, including images in data analysis can be quite time consuming, methods for analyzing these data are only now developing (e.g., Murthy, Gross, & McGarry, 2016), and virtually all studies have only included publicly available images. The protocol used in this study was unique because our IRB and commitment to the funder of our research was that we ask people to share private data, not simply social media data posted to public sites. This meant that our team needed to build close relationships with the participants and thus we focused on specific communities where members could help facilitate a meaningful and trusting snowball sample. To build this trust, we spent weekends volunteering in this community, as well as identifying opinion leaders. These community engagement practices, well as our interview guide and photo elicitation techniques allowed our team to become part of the communities we studied, and community members became part of the research by sharing and describing their lived experience through their personal photos, videos and social media posts. This created a unique environment in preparation for, during, and after the interviews (Ahmed and Palermo, 2010; Ahmed et al., 2012). Finally, we carefully explained—in the informed consent document and verbally—how we would redact private data and use pseudonyms. All but one of our interviewees voluntarily shared photos and private social media posts.

Our semi-structured interview guide contained six primary questions with multiple probes, and one set of demographic questions. The questions asked how people became involved with the rescue, how they used social media and mobile devices during rescues, the emotions they experienced, and their communication successes and challenges. As people shared the stories of how they were involved in rescues, they also showed text and photos that they posted on social media such as personal Facebook profiles, community Facebook groups, private community Facebook groups, private NextDoor neighborhood groups, private WeChat group messages, and images downloaded from news media and government websites that they forwarded and shared with their own private networks. As they showed photographs and text, the interviewer asked permission and took screen shots of those posts, or the participant emailed or texted their social media posts to our dedicated project mobile device.

We completed 17 interviews and collected 485 images (containing photos and textual posts) for this analysis of our work-in-progress study. Nine people from this community participated as volunteer rescuers, seven were rescued from their homes, and one person in this study was a Public Information Officer for a local emergency response organization, but he was also a member of the affected community. The participants were predominantly white (88%) had an average age of 38, and lived in an upper to middle-class community. Two of the rescuees reported their income as less than $40,000 USD, but all other participants made over $75,000 USD.

All interviews were audio recorded and transcribed with pseudonyms. The data were analyzed by listening to audio recordings, reviewing field notes, and coding all the images. Our research team examined the images—photos and captured textual posts—and looked specifically for those that addressed the research questions. We coded those images by discussing the data in team meetings and identifying what was physically present in the photo. For example, Figure 5: medicine bottle and prescription. Then, in the textual component of that post, Figure 6, we coded it thematically: medical problem, public service announcement, persuasive communication. We also examined the interview conversation pertaining to the post, and coded that data thematically as well. We used Owen's (1984) criteria of recurrence, repetition, and forcefulness to identify key themes that addressed our research questions. For example, Figures 4 and 6 are different posts that were coded as containing many of the same themes. At the conclusion of the coding process, we re-examined our research questions and used the coded data to respond. The interview data

and direct quotes, serve as important context that helps understand the value of collecting and analyzing multiple forms of data.

FINDINGS

Research Question 1: What are the health concerns raised by citizens in a flood disaster?

To address research question one, we examined our interview and photo data and found that health concerns fell into two primary categories: *existing medical conditions* and *water-created health concerns*. Within water-created health concerns, we found they could be further categorized into: *dirty water*, *immediate physical dangers*, and *emerging health concerns*. This research question is more descriptive and categorical, so while we present these findings here, we elaborate on them when addressing research question two.

Existing Medical Conditions

The flooding in this community was pervasive. Flood waters lasted almost two weeks affecting at least 25% of the buildings and shutting down transportation (Moravec, 2017). The severity of the flooding meant that healthcare facilities were flooded as well as the homes of healthcare providers. This is important context information because a key concern among people who evacuated was how to get a fresh prescription of the medication they left behind when they were evacuated from their homes. In many cases, their best bet at getting the medication they needed was to return to their flooded homes, go into the medicine cabinet, and be escorted—often by boat—back to safety. In some areas medical needs were prioritized along with pets (see Figure 1), but in other areas, people had to cajole the National Guard or private citizens with boats to help them retrieve their medication.

Figure 1: Sign Located at the Entry of a Neighborhood

When interviewing a middle-aged woman who had survived multiple hurricanes, she mentioned that in her prior job she worked as a call taker for a mail-order pharmacy. Her comments provided helpful context concerning the medicine needs of flood and hurricane evacuees. At her company, they were allowed to put some medicine orders through early, before the official date when the medicine could be refilled. She explained: "If they were in a flood zone zip-code, and we anticipated a hurricane, no matter what [we put their refill through]. Because if you didn't have the hurricane, you had an extra supply of medicine." Her company had learned this strategy over time as she explained:

> Basically, we heard from them, "I ran out" or "I evacuated," or "I ran out in the middle…what can I do? I can't go back to the house to get my medicine." Or "the medicine spoiled." Or "The electricity went out, the refrigerator stopped." I feel bad now if they just can't get an extra supply. You can't say [to justify the refill] it's a "vacation supply," because a hurricane is not a vacation. You have to ask for an emergency supply. We had a special code for emergencies.

Water-Created Health Concerns

The second core health concern centered around the fact that there was water throughout this community during the flooding and it lasted for days and even weeks in some areas. The first sub-category in water-created health concerns was the *"dirty water."* What started as fairly clear water that resembled a lake out of its bounds (see Figure 2) quickly became "dirty" water, muddy brown sludge that was everywhere once the water rose and wastewater treatment plants could not handle the overflow (see Figure 3).

Figure 2: Early Flooding

Figure 3: The Dirty Water

Members of these communities in the greater Houston area shared these photos, and similar photos were also on the news, because most the evacuations occurred when people could not see their feet due to the "dirty" water. We use the word "dirty" because that was the term most frequently used on the social media posts we captured.

The second sub-category in water-created health concerns was *immediate physical danger*. While we elaborate these in the second research question, they ranged from concerns that animals might harm people during the evacuation, to fears that objects under the water—e.g., manholes, fire hydrants, curbs—could cause people to trip or hurt themselves.

We differentiated immediate physical dangers from the third sub-category of *emergent health concerns* because it was after individuals were rescued, or they rescued others, that people who had been in the water began to see new health concerns emerge. They had rashes on their bodies, felt sick at their stomachs, and some people realized that getting Tetanus shots might be prudent considering that the water was contaminated with fecal and decaying matter.

RQ2: How do citizens communicate health information through social media?

The descriptive findings from research question one informed the analyses we conducted to address research question two. There are six themes that describe the approaches average citizens used to share health information: *Narrating a personal experience, presenting it as a Public Service Announcement, downplaying the contribution, bringing a credible source into the conversation, including external links and sources*, and *using humor.*

Narrating a Personal Experience

As a part of narrating their rescue and recovery experiences, many people simply made comments that speculated about health concerns and they shared the actions they took. Jason commented about the dirty water and how he could not see his own feet. This is how he explained the actions he took because he was in the dirty water.

> "And I was like God forbid they go far enough down there to where the water like sweeps them away like trash. We don't know what's in there, and it's just like it was like scary because you don't know what's in this water and you know all these things that people have been like in the water, like people could get sick now because it was like fecal matter and all this crazy stuff. And you know, I even went to the doctor because I know I was like that one guy on the first night who was walking around in it, and I know and I was like OK, I mean probably go get blood tests and all that stuff just make sure I'm not sick or anything like that.

The personal experiences were especially vivid when the people who had to evacuate from their homes had chronic health conditions like diabetes. These evacuees were not only concerned about their fitness to evacuate—e.g., did they have the endurance to walk through flowing water, did they have open wounds that could get exposed to dirty water—but legitimate stories of alligators, rodents, and reptiles in the water compounded their stories. Ann Sharp was one such evacuee:

> I keep looking back and I was telling my friends to stop but I said I thought about that alligator. I said that alligator gonna get me on my way back to my home. And I got to walk through this water. It's scary because you had to feel your way around. I knew if I really didn't know that apartment where I was I probably would have fell down. Because that water was coming in, so I was with my hands in the air, and I'm diabetic, I knew I was gonna fall anyway. He was telling me I gotta keep up walking. I was saying, No I got it. I got it. I got to feel my weight. I know what a sidewalk is. And I know it's a step down. Yeah. And if I step down, I might fall.

While these two examples were shared during interviews, many of these same types of stories were posted on social

media. The data we share next will illustrate how this theme also emerged in social media posts. The difference between what was said in the interviews and what was posted on social media was that chronic health conditions were not mentioned as frequently in social media posts. The fears people put in writing related to falling, drowning, animals, and getting sick from the dirty water.

Presenting Private Comments as a Public Service Announcement

Public Service Announcements (PSAs) are "designed to inform or induce certain behavior in specific audiences, generally for noncommercial profit using mass media approaches" (Bator & Cialdini, 2000, p. 527). PSAs are a central part of health campaigns around the globe and as the technology landscape changed in the early 2000's, researchers began studying their use in user-generated media like YouTube (e.g., Walther, DeAndrea, Kim, & Anthony, 2010). Health PSAs are normally crafted in advance and some use health communication theory principles to guide their content creation (e.g., Walther et al., 2010). So when the acronym, *PSA*, began appearing in private social media posts, our team dug into these more deeply.

Shared health information that was prefaced with *PSA*, contained several features of other private social media posts concerning health, but the details moved beyond description and reflected the persuasive goals to induce behavior change. It is difficult to know if the citizens truly designed their posts with these persuasive goals in mind, and it even appears that *PSAs* might be a way for these citizens to communicate their desires to share information without sounding pushy. Despite their intentions, these posts contained many compelling persuasive components of actual PSAs. For example, Figure 4 is a photo of a private Facebook post where a community member presented the information she was sharing as a PSA. Notice that the crafting of the PSA utilized persuasive wording and provided a specific call to action.

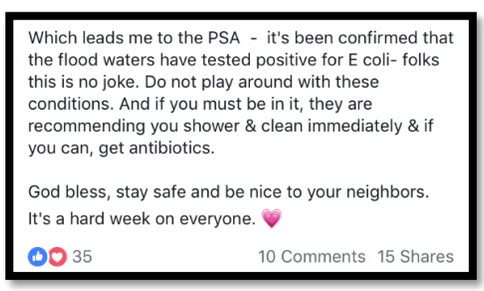

Figure 4: A Public Service Announcement

In other examples of posting a citizen-created PSA, the message contained elements of narrating one's experience that was woven into the information shared and cemented a connection back to the community. The stories contained narrative fidelity and probability (Fischer, 1985); the details are sufficient to convince a reader they are true and if people lived in flooded areas, the narrative could convince them that the same issues could happen to them. Second, the posts referenced medical sources like physicians, and not only did the person posting the information visit a healthcare professional, but they also repeated things they said the physician told them to do and shared that with others. Third, there was a call for action—often multiple calls—with specific instructions for what to look for and when and how to seek help. Finally, by including images, the persuasive elements of the post got an added boost: they showed the medications prescribed by the physician. See Figures 5 and 6 for the photo and the text that appeared in one of these Facebook posts.

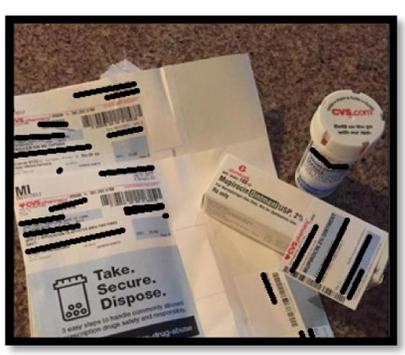

Figure 5: Image of Medicine Prescribed by Physician

PSA for those who have been in the flood waters...

I got bitten by something (probably some fire ants), and noticed swelling and redness. Normally I would have treated it at home but given I spent a number of hours in toxic flood waters (as SOOO many did), so I went to have it looked at. I'm glad I did! They gave me a shot, antibiotics and cream. It definitely was infected, and would have definitely escalated quickly if left untreated.

The Doctor did urge anyone who has been in the water to watch yourself very carefully for the next few days. The toxicity Sunday and Monday was less intense than as time went on (hence the beautiful brown color). Sharing for those who would normally tough it out. Just go get checked out!

Figure 6: Persuading Though a Personal PSA

Bringing a Credible Source into the Conversation

Several people who posted health information on their private social media sites appeared to want to increase the impact of their message by reposting, or sharing a message communicated by a health expert. For example, one citizen who had contributed substantially as a behind-the-scenes rescue support person, seemed to use a strategy of priming people in her social media feed, supporting her claims by posting a comment made by a nurse who was her friend, then reinforcing the nurses comments. She brought in this outsider—a nurse—to help her better persuade her Facebook followers that floods heighten specific health considerations. See Figures 7 and 8.

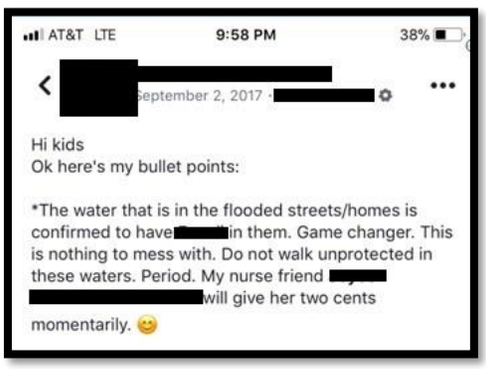

Figure 7: Priming Followers

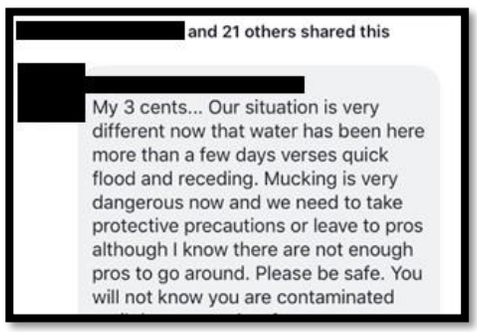

Figure 8: Bringing in Nurse for Credibility

Downplaying the Contribution

In both of the posts found in Figures 8 and 9, the citizens were trying to persuade, but they also downplayed their contributions. The most common way this happened was with introductory phrases like "My 3 cents…," "Just my opinion," or "I think this might help." Note that the comment that began, "My 3 cents," was written by a nurse. She was not posting as part of her official job, but her friend introduced her in an earlier post and even said she would "give her two cents…" There are other hedging comments found in many posts: tentative statements, vague comments, and warnings advising others to double check the information they post.

Including External Links and Sources

In some posts, it was obvious that the citizen wanted to demonstrate the veracity of a statement because along with the statement, there would be a hyperlink or the name of an organization where they retrieved the information. They were citing their sources, even in a private social media friend and neighborhood group. One woman in our sample who used external citing extensively said she did this "because I didn't want people to doubt me. We didn't have time for people to be bothering me with lots of questions, that is why I primarily posted on Facebook. People who don't know me, might question my information and I wanted them to act and appreciate that I had done the background research to help people who needed it the most."

Using Humor

One final way that citizens shared health and safety information was through humor, but they also including images that depicted the humorous danger as real. Past research on visual social media has also reported humorous depictions (e.g., Murthy & Gross, 2017), but here we find a mix of emotions and sources of the humorous information. For example, the local news channel posted a photo of a snake climbing up the side of a home. Individuals in the Facebook message thread viewed the photo as frightening, but also made it a bit of a joke concerning snakes also wanting to escape the rain. The citizen who shared the post captioned this with "Hell no!" See Figure 10 for this example.

In a related feed, posted by a connected friend, they were also discussing snakes in the water. One commenter joked about the colors that snakes do not like, and a third commenter lightened the mood. Note that humor was emphasized further by using the smiley face emoji. See Figure 11 for this example.

Figure 10: Reposting of Photo of a Snake

Figure 11: Humor about Snakes in the Water

DISCUSSION & CONCLUSION

The communicative strategies citizens used to share health information through their private social media accounts reflect their knowledge that they are a part of an online community where they have a sense of shared identity. Furthermore, these are their friends and neighbors and they want to provide information that helps others in their personal networks improve their health. While we used theories of identity and identification to explain why citizens might engage in this health information sharing behavior, the findings further clarify how communication, credibility, and online community identification work together to prompt people to be cautious, caring, and as accurate as possible when they attempt to share and persuade others during a disaster. Prior research suggested that different communities will prioritize hazards differently and agencies must be responsive to this dynamic (Wells et al., 2013). But in addressing health information during Hurricane Harvey, dirty water and physical danger were top concerns over the flooded communities.

Private social media communities are composed of friends and neighbors—not necessarily people we like—but still people we know and people with whom we have ongoing relationships and conversations. One participant explained this well when she said, "I told a newcomer to our neighborhood that we would not flood. I feel so bad, I guess she has forgiven me because she still speaks me when we see each other on the street. " In contrast to her verbal assurance to her neighbor, the general tone of these posts was one of cautiously sharing health information without overstating claims and without creating panic. In this way, members of these private social networking groups drew upon their shared social identities to be responsible with the information they shared. This sense of responsibility is illustrated further when people asked credible experts, nurses, to make a supportive post and then they primed their friends and shared that credible health information. Even the details in their narrated experiences displayed a tone of credibility.

Credibility is a well-studied communicative construct that consists of trustworthiness, expertise, competence and goodwill (McCroskey & Teven, 1999; McCroskey & Young, 1981). The last component, goodwill, was added more recently as a component of credibility, and it means that someone has others' best interests in mind when they communicate. The findings from this study strengthen the value of including goodwill as a part of credibility, and that is why we labeled this overarching finding credibility instead of trustworthiness.

In linking the identification components of their group membership along with their sense of responsibility to provide credible information, it is difficult to determine causality within this variable mix. The value of qualitative work is to unearth these variables and it will be worthwhile for future researchers to build on these findings by designing experiments and careful surveys to elaborate on these relationships. While prior visual social media research examining Instagram images cross-posted to Twitter during Hurricane Sandy revealed humorous, deceptive, and misleading images, their research also revealed that people were "meaningfully narrating one's disaster experience visually in real-time" (Murthy & Gross, 2017, p. 127). What we see in this private social media data does not contain many erroneous posts and exaggerations—not much fake data. Our findings suggest there is social pressure that keeps most of these community members in line, on line.

CONCLUSION

When the citizens in this study used their private social media to post health information relevant to the flood, they were clearly communicating to the online community where they felt like they belonged. These posts reflect a tone that was caring, cautious, and as accurate as they could be when trying to educate and share health information. Our data suggest that citizens had many questions about the safety of the dirty water, and how to handle the myriad health issues that arose when they were functioning in the middle of chaos. Not a single interviewee, including emergency management personnel said they saw official information posted from Health and Human Services or other health-related agencies. Two people mentioned hearing this discussed on TV, and people said they knew they needed to "protect themselves" by wearing waders, but their flood-specific health knowledge was vague. These findings should provide healthcare organizations and health and safety agencies a bit of a push to plan their health messages in advance and disseminate them much more widely in future flooding disasters.

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Track 12

Designing for Resilience

The lack of preparedness for payment disruptions in local community core businesses

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ABSTRACT

One of the most important infrastructures for society is the payment system. If this system malfunctions, it can lead to disruptions in other critical infrastructures. By developing resilience i.e. the ability to recover or resist different disruptions in complex dynamic systems, as well as analyzing and raising awareness about it, such events can hopefully be handled better. The purpose of this study is to gain an insight into the different sectors' ways of dealing with disturbances in the payment system. Six participants from the food, fuel and bank sectors were interviewed using semi-structured questions. The interviews were conducted and data was analyzed using a thematic analysis approach. The results indicate a low level of resilience maturity among these organizations when it comes to handle long-term disruptions in the payment systems. The results provide valuable input to the project and a better understanding of payment infrastructure resilience.

Keywords

Critical infrastructure, resilience, payment system, food distribution, fuel distribution

INTRODUCTION

Recent cyber attacks have shown how vulnerable many critical infrastructure systems in society are. Ansell et al. (2010) argue that our infrastructures become more and more entangled, and resilience of these systems increasingly depends on collaborative responses from actors with diverse backgrounds that may not be familiar with cascade effects into areas beyond and outside their own organisation. The payment system is no exception to this as it is increasingly dependent on digital services from a variety of providers to function. In many countries, there is a clear decline of cash payment, and in some early adopter societies, like Sweden, cash payment is virtually gone and replaced by card and/or smartphone-based payment options. Further, shopping in general is moving online, especially concerning retailer products such as clothes, electronics etc., where payment exclusively is done via card or other digital services. Businesses of central value to society, such as groceries, medicine, and fuel are still mostly procured in traditional stores or petrol stations, but payment is mainly card-based or based on other online payment methods. But to what degree are such businesses prepared for longer disruptions in the payment services?

Despite the work of identifying, analysing and understanding risks and developing routines for preventing and mitigating serious disruptions in the payment system in Sweden, there is still a lack of insight into how the proposed action plans exactly need to be executed and how numerous other actors in society (e.g. citizens, food stores, petrol stations, voluntary organizations, and so on) will act in case of a temporary or complete breakdown of the payment system. For instance, several key actors in the payment system have in earlier studies expressed that they will take a larger responsibility than their formal responsibility (MSB, 2009), but it is not clear what this means exactly and whether these organizations actually will do that when crisis hits.

This paper is part of a larger project (Creating Collaborative Resilience Awareness, Analysis and Action for Finance, Food and Fuel Systems in INteractive Games, CCRAAAFFFTING) aiming to develop a simulation gaming environment (a combination of role-playing games and computer simulation) that can be used to better understand how resilience is achieved and maintained during disruptions in the payment, food, fuel and finance system (Laere, et al., 2017). The ultimate purpose of developing the gaming environment is to provide team-training to decision-makers in handling crisis situations in a multi-organisational context. Gaming-simulation (Laere, Vreede, & Sol, 2006) aims at representing reality and enabling an individual actor or a group of actors to experience the dynamics of the simulated system with purpose of increasing overall organisational resilience. The goal and overall design of the crisis response simulation and scenario development is described in detail in Laere et al. (2017).

The purpose of this paper is to investigate in what ways local businesses in the core sectors banking, food- and fuel distribution are prepared to handle disturbances in the payment system. This will be done by utilizing a model from resilience theory, the Systemic Resilience Model (see below), to see what strategies these businesses have in place for upholding their businesses, and thereby their societal function, in the case of a disruption in the payment system. This knowledge is needed in the CCRAAAFFFTING project in order to support simulation and scenario development to be used in the crisis response training environment. The results will be used to improve the design of the scenarios used in the interactive simulation games. It will also be utilized to modify the implementation of the computer simulation to better reflect the dependencies between actors that have been identified in the interviews. Six interviews with representatives from various businesses have been conducted and analysed. The outcome of these interviews will be presented below.

RESILIENCE AND THE PAYMENT SYSTEM

Digital services are often discussed in terms of how "secure" they are, i.e. to what extent they can continue to function during various forms of attacks. From a business point of view, the ability to uphold function (too keep providing goods and do transactions) is often referred to as "business contingencies" or "resilience". Literature describes the payment system as an "inverted pyramid". At the top of the inverted pyramid is the broad base of economic actors whose daily activity in the market economy gives rise to payment obligations. This base of economic actors consists of individuals who use retail payment services provided by banks, and a variety of business enterprises in the goods and service industries. The next level includes very specialized firms, such as brokers and dealers, involved in the money, capital and commodities market, which also rely on bank payment services. (Blommstein & Summers, 1998, p. 27). The payment system is thus what the connections in the financial system that is the fundament of its very existence. Without transactions, or at least the potential for transactions, finance stops and becomes pointless. *How* transactions are made have however differed greatly during the last century, moving from transactions of noble metals, cash, paper documents to digital transactions and trade. All implementations of payment systems have their strengths and weaknesses. It is fair to say that the financial system never has been so interconnected and so dependent on a multitude of actors to provide services in order to function. Resilience is a systemic approach to understanding how systems critical to society, such as industry, infrastructure, finance, or ecology, can absorb changes or disturbances and still persist (Holling, 1973; Foster, 1993). The term has been interpreted in many different ways in different domains and may refer to: bouncing back to a previous state, or bouncing forward to a new state, or both; absorbing variety and preserve functioning, or recovering from damage, or both; and being proactive and anticipating, or being reactive (when recovering during and after events), or both (Bergström, van Winsen & Henriqson, 2015; Lundberg & Johansson, 2015). It is a well-known fact that the financial system is surprisingly robust when considered over a longer time-period, but also that it is sensitive to local or short-term disruptions (Helbing, 2012) that at times have proven to cause severe cascading effects (Pescaroli & Alexander, 2015) that have impact even on a global level. Improving resilience of the financial system, or parts thereof such as the payment system, is therefore of great importance to society. Basole and Rouse (2008) looks at how "service value" can be created in a network context and how the structure and dynamics of the network, as well as customer expectations influence the complexity of the service eco system. Their approach aims to describe the nature, delivery and exchange of service value and direct and indirect relationships between value network actors, as in the payment system. Johansson, van Laere, and Berggren (2017) have developed a network-based approach for describing how actors in the payment system can create and consume resilience in a network based on the work of Basole and Rouse (2008).

The Systemic Resilience Model

Resilience for crisis management and response is a wide area (Williams et al., 2017). Lundberg and Johansson (2015) made an effort to merge and compile different points of view in the field of disaster and crisis response resilience (see for example Comfort, Boin & Demchak, 2010) into one systemic model, the *Systemic Resilience*

Model (SyRes). The SyRes model departs from the idea that the coping with an unwanted event can be seen as a downward spiral activating certain basic resilience functions (anticipation, monitoring, responding, recovery and learning) and their associated strategies (where the strategies are the actual manifestation of the functions, or their 'form', which may differ from system to system). The SyRes model consists of four different sections: Event-based constraints, Functional Dependencies, Adjustment of capabilities and Strategy (see **Figure 1**). Functional dependencies refer to a set of functions needed to create a resilient system. The event-based constraints describe how the event to be handled put different constraints on the responding system during different phases of the event. The functional dependencies point to the core functions that must be maintained. Adjustment of capabilities refers to different approaches to shape how the functions are executed. Strategy, in turn, refers to different ways of coping with an event – in many cases these strategies are visible in terms of actions taken to keep a system out of harms way, such as constructing barriers (immunize) or creating response systems (control) (Lundberg & Johansson, 2015).

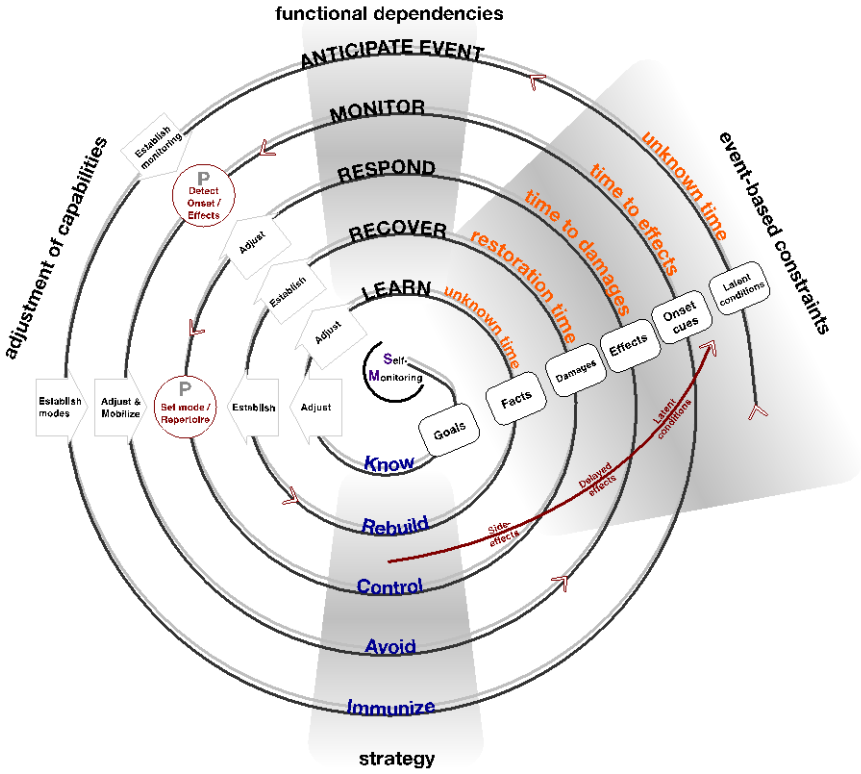

Figure 1. The systemic Resilience Model (Lundberg & Johansson, 2015. Used with permission from the authors).

"Functional dependencies" describes a number of such "core resilience functions": *Anticipate, Monitor, Respond, Recover, Learn, and Self Monitor*. Each function can be seen as holding the potential to cope with an undesired development – for example, if a threat is anticipated, it may be mitigated or prevented from happening at all. Likewise, if monitoring is directed in such a way that threats can be detected, harm can potentially be avoided. Response takes place as a consequence of anticipation or the detection of a threat, or even as a reaction to an event that is discovered first when it is already ongoing. Response involves an effort to control the situation and minimize or avoid harm to the own, or other core, system(s). If the system takes damage in some form, recovery comes into place in order to re-construct the system after the event. Learning steps in as an essential function needed to improve the resilience of the system by adapting ways of working or creating new means to avoid similar events in the future. Finally, self-monitoring is a continuous process needed to assess if the current way of working is appropriate to maintain an acceptable level of safety and resilience in the system (Lundberg & Johansson, 2015). In the context of this study, it is the manifestation of these functions, i.e. the strategies developed, or suggested, by actors depending on the payment systems that are of interest. A lack of strategies corresponding to the core resilience functions (Anticipating, Monitoring, Responding, Recovery, and Learning) indicate a potential lack of resilience, and hence capability to detect and cope with disturbance in the payment system. This study aimed to identify and describe strategies used in the payment system to uphold the resilience functions described above. By identifying such strategies, or lack of such strategies, training scenarios can be designed to challenge the participants in such a way that they are forced to reflect upon how they apply anticipatory strategies, monitoring strategies, strategies for response, response strategies, and learning.

METHOD

A semi-structured interview technique was used in this study, based on the suggestions by Howitt (2010). All interviews were recorded and transcribed. The functions described in the SyRes model (Lundberg & Johansson, 2015) were used as guidance when creating the questions used in the study.

Participants

All participants were recruited from the same municipality in Sweden with the ambition of having representatives from major grocery and fuel chains/banks in the study. The municipality is a mid-sized Swedish town with strong presence of both industry and academia. Six persons from three different business types participated in the study. Two participants came from grocery stores, two from banks, and two came from fuel distribution (petrol stations).

The participants from the grocery stores both worked for supermarkets belonging to large chains that have presence in most Swedish cities. Both participants had extensive experience from this type of business having worked for 25 and 20 years. They were both in managerial positions.

One of the participants from the banks was an office manager with 20 years experience. The other was an expert on digital payment methods with 10 years of experience.

Both participants from the fuel distribution sector were petrol station managers with 8 years respective 9 years of experience from the sector.

All participants were recruited via e-mail or telephone contact. They were also provided with an information leaflet describing the project and a consent form. All interviews except for one were conducted face-to-face. The other was performed using telephone.

Material

A set of 11 overarching questions were prepared and used for guidance during the interviews. Most questions were complemented with a set of sub-questions that could be used as back-up in case the interviewee did not provided enough information. The overarching questions were:

1. Could you describe your role at your work place?
2. For how long have you been working here? What is your professional experience?
3. How many persons work here? What type of employees do you have?
4. Could you tell me about an actual event/disturbance in the payment system where you had to adapt to changes that were beyond your control?
5. Is there anyone you can contact to get support in case of major disturbances?
6. If we imagine a scenario where the payment system is disrupted for a longer period such as 6-7 days, can you describe what you would do?
7. Can you describe the measures you would follow to solve a problem in the payment system before you make a decision or take action?
8. Who is responsible for making decisions regarding payments, and how?
9. Do you have any examples of situations of what you would do if you were unable to reach other core actors such as banks, fuel distribution or others?
10. What would you describe as your most important goal in the case of a disruption in the payment system?
11. What kind of equipment do you need to be able to continue working?

Apart from the questions, the information leaflet mentioned above was used also as a consent form.

An Apple Iphone 6 was used as the recording device during the interviews.

Analysis

All interviews were transcribed according to the schemes described by Howitt (2010) and Linell (1994) prior to analysis. Transcriptions were performed on a basic level, not including for example pauses or overlapping

speech. However, orthographic transcription was applied, where the way utterances were made are reflected, i.e. accent etc (Howitt, 2010).

A thematic analysis was then performed on the transcribed material. The analysis consists of six steps that serve the purpose of moving through the process of getting acquainted with the data to identifying and describing the themes (Braun & Clarke, 2006). The steps are: 1.) Familiarise yourself with your data, 2.) Generate initial codes, 3.) Search for themes, 4.) Review themes, 5.) Define and name themes, and, 6.) Produce a report. The first stage thus consist of the process of establishing a thorough understanding of the transcribed material by generating initial codes. Such codes are more numerous than the actual themes. Once these two steps have been conducted, the actual themes usually emerge. These may have to be iterated before they are saturated and consistent. After this, they can be assigned with appropriate names and used to create a report, in this case the results section of this paper. Themes can be identified in two ways, either by empirically guided analysis or by theoretically guided analysis. Each theme should contain data that reflects essential aspects of the research questions (Braun & Clarke, 2006). In this study, a bottom-up approach to analysis was applied, meaning that the empirical material guided analysis, although the questions asked to the participants were guided by theory. The themes were thus identified based on the analysis performed on the transcribed material, although the researcher conducting the analysis to some extent was trying to identify resilience-related aspects such as "core values".

RESULTS

From the analysis described above, seven themes emerged:

- Limited payment solutions and options
- Communication with the customer
- Protect goods, customers, trust and safety
- Dependent on many actors
- Depend on others to solve the problem
- Preparations and training of staff during a crisis
- Depend on the internet and electricity

The identified themes applied in slightly different ways to the participants in the study. Naturally, there were some differences between the banks and the stores/petrol stations as they provide somewhat different services to their customers. Below, we will discuss each theme and the potential consequences for the payment system. All excerpts presented have been translated from Swedish. For original language, please refer to Jaber (2017).

Limited payment solutions and options

The participants were asked to reflect upon how they would handle a disturbance in the payment system. Something that quickly became obvious was that there are very few payment options in today's society. Neither banks, grocery stores or petrol stations would be able to maintain operations without the card payment technologies. The only realistic option mentioned were cash. However, most participants estimated that the cash available in local ATMs would run out within one hour. Cash would thus only be an option during very short disturbances in the payment system. In general, cash usage is in strong decline in Swedish society. As one participant stated (supermarket manager):

> I have checked and it is around 10-20% of my turnover that is cash

One participant had real-life experience of a short disturbance in the card payment system. In that case, the staff in the supermarket adviced their customers to go and get cash from an ATM. This was, as predicted, only a temporary solution.

> We adviced people to withdraw cash from the ATM outside the store so many went there to get money, but after a while the ATM run out of money and yes then we could not really do very much so we simply had to eh, yes the customers had to leave and walk away you could say

The participants were asked to reflect on how they would handle a disturbance in the payment system. In summary, their consideration was that there does not exit many alternatives to bank cards. Banks, grocery stores, and fuel distributors would not be able to maintain operations if ATMs, card readers etc would stop

working. If a power failure would occur, things would be even worse as pumps, freezers, and refrigerated counters would stop working as well. Smaller shops with fewer customer, such as petrol stations, may be able to cope somewhat longer than large supermarkets. One petrol station manager stated that:

> What we usually do is to write down the name and say can you come by tomorrow for example. It is a pretty small place where the petrol station is located. So that works when you have many customers nearby that you even recognize.

Communication with customers

To inform the customers is a major concern to all participating businesses. Without customers, the services would not be needed. In line with what Basole and Rouse (2008) express, it is important for the service-based system that the customers are happy. As such, the customers' attitude is of great importance to the businesses, including to have a relation with the customers and to preserve trust. The most common way to inform customers seem to be to distribute papers at the entrance to make the customers aware of what has happened. One of the store managers stated that:

> My mission as store manager is to make sure that everything works, if it does not work then I have to solve it as good as possible, then we have to write big signs by the entrance, if it would not be working for several days. Unfortunately something has happened that makes it impossible to pay by card, then we need to inform all customers that they need to bring cash in order to shop.

Protect goods, customers, trust and safety

If a disturbance does occur, the different businesses seem to prioritize differently. Banks prioritize the customers and their trust towards the bank, while grocery stores focus on the goods. However, customers are highly ranked by all participants, as well as security during a crisis. All participants mentioned that disturbances lead to insecurity for both customers and personnel. All businesses wanted to run their dealings as long as possible to maintain the customer relation, but if security is at risk and they cannot be paid then operations are closed down. One of the bank employees stated that:

> First and foremost we prioritize service, we will make profit during the journey anyway. But if something happens, then it is service to the customer, in order to solve the customer's problem or situation that is the most important issue when something occurs, that is a crisis.

An important difference between the banks and the supermarkets was that the latter also prioritized their goods. If power should fail or cash registers stop working, they still need to take care of their perishables.

> Trying to save perishable goods since it is so darn much money. In the store you go out and look what we have you will find millions on the shelves and the dates are ticking away quickly, especially on perishables.

However, service was found equally important to the supermarket managers.

> Firstly one would want to prioritize to run the business to the customer as a service. And make some money as well but firstly you want to survive this period that you may think will not last that long or at least not more than 7-10 days that you know or hope will not be much longer than that. So you can always increase speed after that. In such a case it is important to maintain a good relation with your customers. But you also need to think about your personnel and so so that they not, because it can be pretty chaotic in a situation like this, so that they do not get into a bad situation.

The managers thus express that they would like to continue operations, both in order to get rid of perishable goods and to maintain their reputation and relation to their customers. At the same time they are worried about the wellbeing of their employees as they potentially could end up in a bad position having to manage angry customers that cannot shop as expected.

Depend on many actors

The included businesses are part of large, complex networks with many dependencies to each other. If one actor in the network would stop providing their service, for example if a transport to a grocery store wouldn't show up on time this would have cascade effects in a domino like fashion. Hence, if a critical infrastructure would collapse all of society would suffer from this. Many grocery stores receive supplies daily and keep minimal stocks. This means more complex dependencies, while at the same time leading to a more effective and cost-effective production and distribution of services and goods. However, this type of on-demand supply chain also causes brittleness on the societal level. A store manager stated that:

> Today, we received 65 pallets of goods, they need to be put on the shelves and if there are no new goods then my store would be empty in a few days in case I did not get new deliverances. So there is a lot to rely upon.

The petrol stations are perhaps even more dependent on others to run their business. Communication with other suppliers is crucial as the amount of fuel available is calculated on average sales. A petrol station manager described a scenario where a lorry moving a large piece of machinery came by and filled up 2000 litres of diesel, equal to the sales of an entire day. This forced him to call the supplier and order an additional delivery.

> The guys who plan the deliveries they plan perhaps 2-3 days ahead, they always look and then I called directly you know I have a name that I can call. So I called and said now this happened, now you need to re-plan and they said great that you called. The entire thing was moved one day and he checked it out and then they turned it around so I got the delivery the next day instead of two days later as planned.

The bank employees stressed the fact that they are more or less completely dependent on other actors to run their operations. For example, the ATMs are owned and operated jointly by several banks. There are also many sub-contractors that are needed to provide basic services to customers. As one bank employee stated:

> It depends on the type of system, each system has one, we are a very complex organisation and there are many different systems involved to handle payments and the person in question has mandates for acting within ones own area or responsibility…… It is usually not just one person you have to turn to in order to make a decision about what to do, that is why we are working as a team where we have members from many different areas in the bank in order to be able to solve problems.

Depend on others to solve the problem

All participants claim that they will call a service person who will "solve" the problem. For every malfunction in the system this approach has been successful, and mostly the problem is solved quite quickly.

> We have a service desk or help desk or what you want to call it. When we have problems, no matter what it is or some IT related stuff, we call the service desk and they connect immediately. And mostly, nine out of ten times, they can resolve it like that *snap with the fingers*.

As this approach has worked, most participants hadn't even considered alternatives. A longer disturbance was hard to imagine, as it had never occurred previously (most disturbances were solved after an hour or so).

> We have a department that take handle these things, so if something doesn't work it does not take long before it is working again. It can take maybe a morning or something like that. The longest disturbance I have experienced has been for a couple of hours and then things are working.

The stores managers could not provide any input to solve a disturbance in the payment system, as these were outside of his/her control and they have to rely on others.

> I haven't thought much about this, one relies on that things will work. And at the occasions when things haven't worked someone takes care of it. And then the problem might be that you aren't prepared to

> take care of things yourself (when it happens). […] I haven't experienced anything major, during the smaller disturbances I call someone at once and things have worked out. It might be wrong at times but then you just call and they fix it.

Preparations and training of staff during a crisis

All business in the study are dependent on that other actors solves the problem. These actors do not have the competence or means to solve a disturbance in the payment system. Being part of a complex network, one of the few possible actions the involved actors can take are to inform the responsible problem solver. In addition, they can try to continue operations, even if this means degraded performance. If this is not possible shutting down is the only option. The local businesses do not have any strategies to solve the problem apart from calling someone else.

> You could say that we have trained them and they know who to contact and they can contact me if I'm not at my desk.

Among the respondents from the bank business, there is a difference in concern and approach as all personnel are trained and the banks have a plan for how to deal with a crisis situation, should it occur.

> Yes, oh yes, everyone knows that. They are trained.

> There are exact contingency plans for what to do when something unexpected occurs, who does what.

It is very clear that everyone in the study knows exactly what to do, and that there is a lot of person trained to handle unexpected events. However impressive this is, this raises some concerns. The plan is to call the help desk. How the help desk can or will handle an unexpected disturbance is not clear though. Another interesting inconsistency is in what way the very "exact contingency plan" can address unexpected events.

Depend on the internet and electricity

A disruption that blocks internet or stops electricity from running would put a halt to society. All participants say that they cannot continue operations under such circumstances. They cannot charge the customers, they do not know the price of the products, light, ventilation, heating, and cooling does not work. All information is located in systems dependent of Internet and electricity. Equipment and previously used methods are not available any more. If they were available, the younger parts of the workforce do not have the required skills, and would need training to be able to use the equipment. As more and more of the operations are digitalized and automated, requiring both electricity and the Internet to function. As the store managers put it:

> We are extremely vulnerable, we are depending on power and that technology works. Technology is fantastic but it is, if it breaks down then it is tough.

> If the electronics do not work, sure I can barter, you can trade a milk for 10 kronors[1], but that does not work. If I have two, maybe two and a half, two thousand customers a day then I cannot sell things to the customers manually. We do not know the prices of our goods either. Even if I let them in the store with flashlights to shop, we would not know the price of our stuff. Everything is in the computers. So society is incredibly vulnerable.

A petrol station manager made a similar statement:

> Yes we are depending on very many systems to maintain our system. Large heavy IT organisation, we are depending on our machines, systems and we are depending on people that can operate these systems.

CONCLUSION

Firstly, it should be noted that the sample in this study is fairly small and sampled in a single municipality.

[1] Swedish currency.

However, we still believe that the observations made are transferable to Swedish society in general as the type of stores, petrol stations and banks are very common and can be found in most Swedish cities. There is no obvious reason for thinking that this particular municipality would be a unique exception. Further, it should be taken into consideration that we have not addressed governmental organizations responsible for crisis response, such as the Swedish civil contingencies agencies or municipal crisis response teams, although we have not found any evidence in literature or in official sources indicating that a societal capability to cope with a supplying the nation, or even a part of the country, with food and fuel exist.

The conclusions that can be drawn from the results described above are that the food, fuel and bank sectors are not prepared for a longer disruption in the payment system. The actors interviewed in this study trust others (mainly IT support functions) to solve problems in the payment system for them. They also assume that the disturbances probably last as long as a few minutes or hours before the IT support solve the problem. There is little or very limited planning or strategies to deal with disturbances. Because there is no plan, the most common response of the actors is that they are likely to shut down their business if the payment system is not working for a longer duration.

The Systemic Resilience model (Lundberg & Johansson, 2015) has proven to be a valuable tool for understanding the potential resilience of the actors included in this study. If we depart from the functions described in the Systemic Resilience model, we see that no strategies related to the functions *anticipation* and *monitoring* could be found in this material. The strategies related to the *response* function mainly concerns calling other actors to solve the problem, or simply abandoning or shutting down operations entirely. The systems in operation among the actors in this study seem very robust, but the businesses in themselves are probably fragile disturbances occur in spite of this robustness. The *recovery* functions were not really discussed in the interviews, other than the fact that it is important to maintain good relations with customers in order to continue business once the problems are solved. It is hard to draw any conclusions regarding the *learning* function as no events of the kind discussed in this study have occurred. From this point of view, the crisis response training environment that is being developed in the CCRAAAFFFTING-project may prove valuable as they allow for learning in a controlled environment. *Self-monitoring* seems to be largely absent. The complexity of the actor networks also imply that even if some of the concerned actors would be able to make some degree of self-monitoring, no one has a complete overview of the entire system. This suggests that emergent effects in the network of actors could cause disturbances that could strike across the payment system, which in turn would be caught off guard. It is clear that both grocery stores and petrol stations are highly depending on logistics and that all actors are depending on functioning IT and communications to run operations. A disturbance in the card payment system would strike against all actors participating in this study, as well as society in general.

For the CCRAAAFFFTING project, this study have contributed with valuable information for the design of the simulations going to be used in the planned crisis response training as well as a better understanding of the payment system domain in general. The interviews have shown that providers of food, fuel and banking services have a need for improving their preparedness and capability for coping with payment system disturbances.

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Evaluating Team Resilience in Simulator-Based Crisis Management Training

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ABSTRACT

Currently, there is a lack of assessment approaches for evaluation of resilient capabilities in simulation games. This paper presents work-in-progress to create such an instrument to be used in crisis management simulation games for the fuel, food, and finance sectors. The "Team Resilience Assessment Method for Simulation" (TRAMS) is based on the Systemic Resilience Model and departs from the assumption that resilient crisis management teams will be able to develop strategies for assuring that anticipation, monitoring, response, recovery, and learning are established and maintained in their respective organizations as well as in the crisis management team. A prototype version of the TRAMS, based on the experiences of representatives from the involved sectors and firmly related to resilience theory, is presented and discussed. The TRAMS instrument will be tested in 30 planned simulations games including participants from the fuel, food, and finance sectors.

Keywords

Team resilience, assessment, simulation games, training, Systemic Resilience Model

INTRODUCTION

This paper presents work conducted in a project called Creating Collaborative Resilience Awareness, Analysis and Action for Finance, Food and Fuel Systems in INteractive Games (CCRAAAFFFTING). The goal for this project has been to develop a simulation-gaming environment (combining role-playing gaming with computer simulation) to present a context where the payment system is represented and where dependencies between different actors become evident. This system can be used to better understand how resilience is achieved and maintained during disruptions in the payment, food, fuel and finance system (Laere, et al., 2017). The purpose of developing the gaming environment is to provide team-training to decision-makers in handling crisis situations in a multi-organisational context. Gaming-simulation (Laere, Vreede, & Sol, 2006) aims at representing reality and enabling an individual actor or a group of actors to experience the dynamics of the simulated system. In this case with the purpose of increasing overall organisational resilience. The development and design of the crisis response simulation and scenario is described in detail in Laere et al. (2017). The project started in 2016 and initial data collections based on document studies, interviews and workshops with experts from the food, fuel and financial sectors reveal seven challenges for collective cross-functional critical infrastructure resilience that need to be dealt with: 1) Shortage of food, fuel, cash, medicine; 2) Limited capacity of alternative payment solutions; 3) Cities are more vulnerable than the countryside; 4) Economically vulnerable groups in society are more severely affected; 5) Need to maintain trust and prevent panic; 6) Crisis communication needs; 7) Fragmentation of responsibility for critical infrastructures across many actors (Laere et al, 2017).

Applying a systemic resilience approach to this allows for assessing and understanding the impact of the simulation-gaming upon resilience, and organizational resilience in particular. Hence, this paper presents an

approach for evaluating systemic resilience in collectives of crisis responders engaging in simulator-based training sessions in the fuel, food, and finance sectors.

RESILIENCE IN THE FINANCE SYSTEM

Without transactions, or at least the potential for transactions, businesses as well as finance stops and becomes pointless. *How* transactions are made have however differed greatly through history, moving from transactions of noble metals, cash, paper documents to digital transactions and trade. All implementations of payment systems have their strengths and weaknesses. It is however fair to say that the financial system never has been so interconnected and so dependent on technical infrastructure and a multitude of actors providing various services in order to function. From a business point of view, the ability to uphold function (too keep providing goods and do transactions) is often referred to as "business contingencies" or "resilience". Literature describes the payment system as an "inverted pyramid". At the top of the inverted pyramid is the broad base of economic actors whose daily activity in the market economy gives rise to payment obligations. This base of economic actors consists of individuals who use retail payment services provided by banks, and a variety of business enterprises in the goods and service industries. The next level includes very specialized firms, such as brokers and dealers, involved in the money, capital and commodities market, which also rely on bank payment services. (Blommstein & Summers, 1998, p. 27).

Resilience is a systemic approach to understanding how systems critical to society, such as industry, infrastructure, finance, or ecology, can absorb changes or disturbances and still persist (Holling, 1973; Foster, 1993). It is a well-known fact that the financial system is surprisingly robust when considered over a longer time-period, but also that it is sensitive to local or short-term disruptions that at times have proven to cause severe cascading effects that have impact even on a global level. Improving resilience of the financial system, or parts thereof such as the payment system, is therefore of great importance to society.

A crisis event is rarely handled by a single individual (Johansson, 2005). Depending on the type of crisis there may exist prepared structures for coping with the crisis, such as professional crisis response organisations. However, other types of events may occur where there are no prepared measures for coping. In such cases, an ad-hoc team of actors usually handles the crisis event. A team is "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/object/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership" (Salas et al., 1992, p. 4). An ad-hoc team is a temporarily organized team where members are included because of their organizational background and experiences and where the team members might not have met prior to being part of the team. For the purpose of handling a crisis situation, these teams are often formed rapidly to deal with a difficult and complex situation in the short-term. In an educational context, ad hoc learning-teams develop by proceeding through stages (Fransen, Winberger, & Kirschener, 2013). To assess learning it is important to define criteria that relate to concepts important for the team task. Berlin and Carlström (2015) showed that by strengthening the collaborative components of exercises, the participants' perception of actual emergency work can be advanced.

Simulation-based crisis management training

Gaming-simulation is defined as a specific form of simulation. Simulation in general aims at designing a model of a system in a complex problem area in other to be able to experiment with the model. Deeper insight in the behavior of the system is created by evaluating various operating strategies against each other in one ore multiple scenarios. Gaming-simulation differs from other forms of simulation in that it incorporates roles to be played by participants and game administrators, implying that people and their (goal-directed) interactions become part of the simulation (Laere et al., 2006). In addition to role descriptions and interaction formats, simulation-games can also include a physical simulation model (a board game, a mock-up, a computer simulation, or any other representation of a physical reality) that the game participants need to interact with. It is important to understand that both the changes and impacts of changes to the physical simulation model in the simulation-game and the interaction between the participants (often negotiation processes about what to change and how to interpret changes in the physical simulation model) are part of the simulation-game and object of study (Mayer, 2009). Gaming-simulation is especially relevant when the "*how and why*" of the interaction processes between the participants are of interest and when these interactions cannot easily be incorporated in computer simulation models. In addition, it creates a deeper learning opportunity, as simulation-game participants literally are active participants in the simulation, rather than passive observers of a computer simulation.

Caluwe et al. (2012) and Daalen et al. (2014) discuss extensively how simulation games successfully have been used to study the interaction between stakeholder decisions in complex design problems. Simulation-games can

be used for exploring the feasibility of future policy alternatives, for studying and motivating organizational change, and as research tools to study the processes or organizational change, policy-making and stakeholder interaction. Borodzicz and van Haperen, (2002; 2003) and Laere et al. (2007) discuss how crisis management simulations can be applied to generate learning at the individual, group and organisational level. Learning in crisis simulations is seen as reflecting on collaborative practice, grounded in theories like experiential learning (Kolb, 1984) and single and double loop learning (Argyris, 1977).

With respect to resilience of the payment system, a few simulation-based approaches have been reported in the literature focusing on the banking sector, and thus not incorporating interaction with the fuel and food sectors. For instance, Bedford et al. (2004) exploits a simulation framework for assessing the worst-case impact of operational incidents in large-value payment systems where a typical incident is the inability of one part to send and receive payments. In their approach, the liquidity of the banks is simulated through transaction delay factors which increase in the case of liquidity drops, making the approach similar to causal map modelling. Another related approach is presented in Galbiati and Soramäki (2011), modelling banks as agents in a multi-agent system and simulating how these banks, as artificial decision makers, minimize their own costs due to delays and liquidity acquisition resulting in game-theoretic equilibriums. However, attempts on relating the payment system to the fuel and food systems in a simulation environment is lacking.

CHALLENGES IN EVALUATING SYSTEMIC RESILIENCE

Given the variety of interpretations of resilience (Bergström, van Winsen & Henriqsen, 2015), resilience is hard to operationalize into useful strategies and measurable indicators. Lundberg and Johansson (2015) have therefore proposed the Systemic Resilience Model (SyRes) model as a way to describe process, functions and strategies on a conceptual level in an effort to synthesize different perspectives in the field of resilience research. The SyRes-model will be used to guide the simulation approach so that all core functions of a resilient system, as well as coping strategies, will be addressed in the gaming sessions.

The Systemic Resilience Model

Lundberg and Johansson (2015) made an effort to merge and compile different points of view in the field of disaster and crisis response resilience into the SyRes model. The SyRes model departs from the idea that the coping with an unwanted event can be seen as a downward spiral activating certain basic resilience functions (anticipation, monitoring, responding, recovery and learning) and their associated strategies (where the strategies are the actual manifestation of the functions, or their 'form', which may differ from system to system). Crises are commonly described in terms of three phases: pre-event, event, and recovery (before-during-after) (Shaluf, Ahmadyn & Said, 2003) and the SyRes model roughly follows the same logic. The SyRes model consists of four different sections: Event-based constraints, Functional Dependencies, Adjustment of capabilities and Strategy (see **Figure 1**).

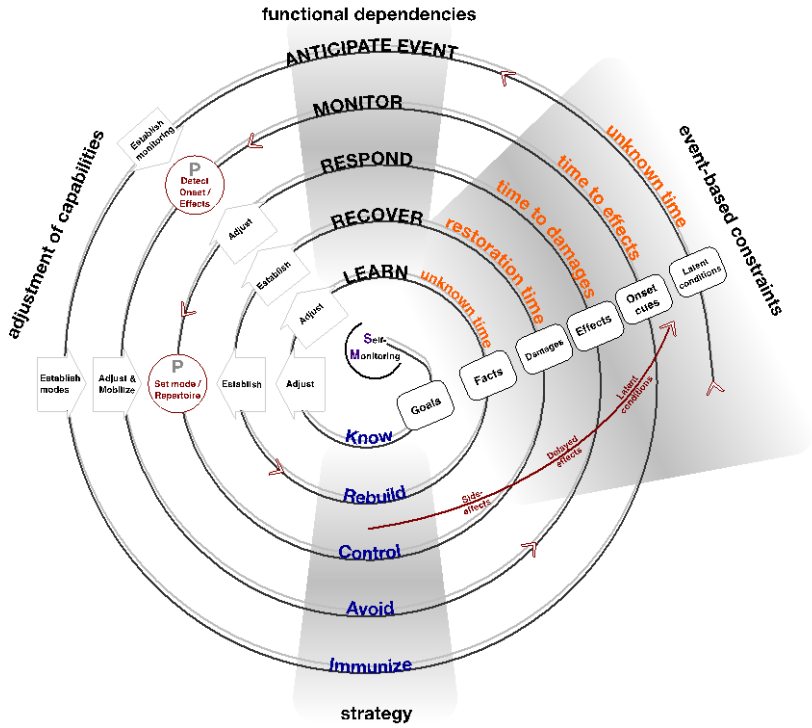

Figure 1. The systemic Resilience Model (Lundberg & Johansson, 2015, used with permission from the authors).

Functional dependencies refer to a set of functions needed to create a resilient system. The event-based constraints describe how the event to be handled put different constraints on the responding system during different phases of the event. The functional dependencies point to the core functions that must be maintained. Adjustment of capabilities refers to different approaches to shape how the functions are executed. Strategy, in turn, refers to different ways of coping with an event – in many cases these strategies are visible in terms of actions taken to keep a system out of harms way, such as constructing barriers (immunize) or creating response systems (control) (Lundberg & Johansson, 2015).

"Functional dependencies" describes a number of such "core resilience functions": *Anticipate, Monitor, Respond, Recover, Learn, and Self Monitor*. Each function can be seen as holding the potential to cope with an undesired development – for example, if a threat is anticipated, it may be mitigated or prevented from happening at all. Likewise, if monitoring is directed in such a way that threats can be detected, harm can potentially be avoided. Response takes place as a consequence of anticipation or the detection of a threat, or even as a reaction to an event that is discovered first when it is already ongoing. Response involves an effort to control the situation and minimize or avoid harm to the own, or other core, system(s). If the system takes damage in some form, recovery comes into place in order to re-construct the system after the event. Learning steps in as an essential function needed to improve the resilience of the system by adapting ways of working or creating new means to avoid similar events in the future. Finally, self-monitoring is a continuous process needed to assess if the current way of working is appropriate to maintain an acceptable level of safety and resilience in the system (Lundberg & Johansson, 2015). In the context of this study, it is the manifestation of these functions, i.e. the strategies developed by actors depending on the payment systems that are of interest. A lack of strategies corresponding to the core resilience functions indicate a potential lack of resilience, and hence capability to detect and cope with disturbance in the payment system.

What to assess?

Assessing resilient performance is challenging as there are few descriptions of what successful resilience *is*, how it manifests itself in terms of strategies and behaviours, apart from what can be found in different definitions such as to "recognize and adapt to handle unanticipated perturbations" (Hollnagel, Woods & Leveson, 2006). A well-known paradox in all contingencies planning and related activities is that what can be assessed before a critical event always has to be the *potential* for coping with an event as it by definition is impossible to say if implemented measures are going to make a difference before an undesired event actually has taken place. In

real-world situations, manifested resilience can naturally be assessed post-facto, but such an assessment may not be very informative as there always will be a high degree of uncertainty in relation to how similar future events will unfold. Simulation games offer a unique opportunity in this respect as they allow us to confront participants with unusual and challenging situations without having to suffer the consequences of erroneous actions or lack of preparedness (Johansson, van Laere & Breggren, 2017).

The ability to have prepared strategies for coping with a crisis, or rapidly develop such strategies, is thus a potential assessment point. For example, if there is a lack of strategies on any of the functions in different phases of a crisis, this could be seen as a potential for improving resilience.

Another challenging aspect is to determine what "good" performance is from a resilience point of view? To successfully cope with an unwanted situation is naturally a potential indicator but avoiding the situation altogether would be an even better outcome. Success must always be related to some form of criteria. Using the SyRes-model and the concept of core values as a point of departure, we can conclude that a system can be seen as resilient if it can uphold its core value(s) by implementing successful strategies before the situation spirals out of control. This suggests that in order to assess resilient capability, even in a simulation, a thorough understanding of what a system must protect and preserve must be achieved when designing the simulation and the scenarios used in it.

The SyRes model addresses functional dependencies (Anticipate, Monitor, Respond, Recover, Learn, and Self Monitor) in terms of strategies that are suggested to be assessed. This is done using the TRAMS approach (see below).

The Team Resilient Assessment Method for Simulation (TRAMS)

In line with the SyRes model presented above, and the challenges associated with assessing resilience in teams, we have developed an assessment method for resilience in simulation games called "Team Resilient Assessment Method for Simulation" (TRAMS). This assessment approach is founded on the premises that actors from different organisations not normally working together (cf. ad-hoc teams) team up to cope with a disturbance in the payment system, as outlined in the CCRAAAFFFTING project (Laere et al., 2017) described above. In simulation-based gaming for improving team resilience scenarios must present events that *challenge the participating actors in such a way that they are forced to engage in collaborative problem-solving*. In typical training or exercise scenarios, participants are encouraged to apply known procedures or skill sets. This would not be the case when training to become more resilient. Instead, each gaming session should be divided into distinct phases based on events designed to challenge the participants' resilience. In line with the SyRes model and crisis research, at least three phases should be used for assessment; before, during, and after a disturbance. During the *before* phase, the participants in the gaming simulation can be evaluated in terms of their ability to anticipate the development of the crisis as well as their ability to direct attention to and monitor important parameters associated with the anticipated development. In the *during* phase, the ability to avoid or cope with the disturbance can be analysed. Finally, in the *after* phase, the ability to learn from the event and adapt existing strategies in order to better cope with similar events, can be evaluated (see Figure 2. below).

The TRAMS assessment has been developed into an observation-based instrument intended to be used by researchers and training facilitators during gaming simulations. This instrument aims to support the identification of strategies developed, and used by, the participants in a gaming simulation and departs from the SyRes functions. The overarching purpose is to assess whether the participants are able to develop strategies to cope with the disturbances they encounter in the simulation and if these strategies actually lead to positive outcomes for the participants. The instrument is summarised in table 1 below, which will be explained further.

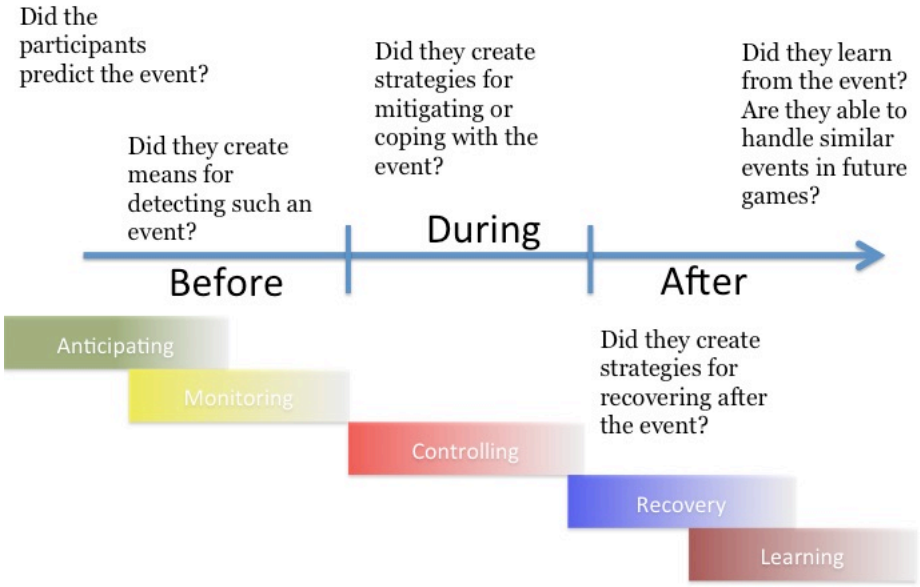

Figure 2. The SyRes functions related to the three phases of a disturbance in the gaming simulation.

Table 1. The TRAMS instrument.

SyRes core functions	Strategies in phases 1---N	Related core value	Developed by…	Involved actors	Expected effects	Implementation	Simulator outcome
Anticipating							
Monitoring							
Controlling							
Recovery							
Learning							

SyRes Core functions

In the first column, we find the SyRes core functions. These are intended to be used as guidance for identifying strategies used and developed in the various phases of the gaming simulation (see below). *Anticipating* strategies can for example take the form of prognostics used by the participants, such as brainstorming, analysis of available data, consulting experts etc. All such efforts that are possible to identify should be noted. *Monitoring* strategies are usually based on earlier experiences (such as previous gaming simulations) or anticipating strategies that direct monitoring efforts. Monitoring strategies can for example be that resources are allocated to observe certain phenomena that are deemed interesting for being prepared before a disturbance or for understanding an expected disturbance better. *Controlling* strategies concern measures for mitigating or coping with a disturbance that is expected or has occurred. *Recovery* strategies can be created based on what is anticipated, what is currently happening or after something has happened. For example, if a disturbance in the supply chain is expected, the grocery stores may stock up to avoid running out of goods to sell. Disturbances in the card payment system may be less severe if all ATMs are prepared with enough cash to support such payment etc. *Learning* strategies can for example be creating incident reporting systems, knowledge databases or assuring that experiences made during an event is incorporated in staff training.

Strategies in phases 1---N

The phase columns reflect the events in the gaming simulation. These are normally known to the researcher/training facilitator and can be described in the instrument (rather than simply providing a number). Strategies identified should be noted in the corresponding phase. Doing so makes it possible to track what strategies that where developed in the different phases. Note that several strategies may be developed in certain phases while other phases may include no strategies. This depends entirely on the participants and the outline of the scenario used in a particular gaming simulation.

Related core values

An assumption in the SyRes model is that all resilient systems are based on a set of *core values*, which may or may not be explicit (Johansson, van Laere & Berggren, 2017). A resilient system must be able to maintain core values also when situations occur that disrupt existing functions. For example, a business must be able to continue generating revenue even when payment systems fail, or at least assure that existing assets are not depleted and that readiness exists for rapid re-establishment of payment processes. Obviously, it is not always possible to infer to what core value a specific strategy relates, but if possible this should be noted in this column. For example, assuring that there are sellable goods available by stocking prior to an existing disturbance in the supply chain is an example of protecting the core value of making revenue. An organisation's core values are identified through focus group interviews with high-level managers and strategists in that organisation.

Developed by

This column should be used to describe from whom a specific strategy originates. Was it a collective decision within the team, or did an individual participant suggest it? This information can be used to assess how well collaboration between the different participants work, who (what participant) is taking initiative, and if a certain organization is more prone to pushing strategies.

Involved actors

The implementation of a strategy will normally involve several actors, both within the participating team and "external" (simulated) actors in the gaming simulation. If possible, these should be noted in this column.

Expected effects

Often, the participants express what kind of effects they believe the strategies they implement will have on the outcome of the gaming simulation. If this can be captured, it should be noted here. This information can be used to analyse what kind of understanding (mental model) the participants had of the scenario and their actions.

Implementation

This column is used to describe if a strategy actually was implemented and if so in what way? These details of the implementation can mostly be captured from simulation log files, so the description should be kept on a general level.

Simulator Outcome

This column can be used to provide a short description of the actual outcome of the implemented strategies, which can be utilized in analysis and de-briefing sessions. Extensive discussions have been held at several of our design workshops and in intermediate work group meetings considering what indicators are most relevant and appropriate to visualize performance in the various sectors of society. Currently, three major performance areas have arisen: 1) payment options, 2) good flows, and 3) security.

Available payment options are statistics on the actual use of each of the four different payment types over time, or the amount of stores (proportion of total number of stores) where they each option is available.

For goods flow the main indicators is "disappointed customers" over time (the simulation counts the number of arriving customers that cannot fulfil their purchase for any reason). Additionally, it is shown how many stores currently are closed (in %), which groups of goods currently are out of stock, how many perishable goods are destroyed over time, and how many planned deliveries that fail (due to fuel shortages).

Security related indicators are amount of cash in stores (implying increased robbery risk), number of shop lifting

incidents, and the number of security guards per store.

From a collaborative resilience perspective, the challenge for simulation participants is to be resilient on all performance areas, rather than optimizing one.

Additional measures

In addition to the assessment of resilience functions, the team will be assessed regarding workload (Helton, Funke, & Knott, 2014; Funke et al., 2012), team member exchange quality (cf. Willems, 2016; Seers, Petty, & Cashman, 1995), and shared understanding (Berggren, Johansson, & Baroutsi, 2017; MacMillan et al., 2005).

Team workload has an impact on team performance (Funke et al., 2012). As the team is part of a system that, during crisis, is striving to uphold performance and as the team members are less familiar with each other (i.e., an ad-hoc team) it is important to assess team workload to be able to understand the outcomes. The same argument is true for the shared understanding in the team (Berggren et al., 2016); when team members have a lower shared understanding of the team's goals it is harder to adapt to and support each other in order to maintain performance.

Team member exchange quality (Willlems, 2016) indicate the quality of social interactions, for example high team member exchange quality suggest that the team members communicate openly, support each other, and provide constructive feedback These are traits that are seen in more mature teams (cf. Tuckman, 1965).

Humphrey and Aime (2014) suggested a multilevel, multi-theoretical, and multi-period framework can provide a better understanding of the system and team. This framework can also direct the data collection. Considering individual, team, and system level will offer a more comprehensive result. Collecting data regularly and repeatedly will ensure that a single moment in time is not a deviation vis-à-vis system outcome. This also allows for following trends over time. Using a multi-theoretical framework for interpreting results provides a richer understanding of the phenomena.

Workload, team member exchange quality, and shared understanding are all rated by the participating team members. The quickest and easiest approach is by including a questionnaire addressing these aspects. In addition, questions about how much a participant has learned and to what extent the organization has changed should be asked. All these questions (workload, team member exchange quality, shared understanding, learning, and change) provides a basis for feedback and reflection as well as possible explanation and understanding of the resilience outcomes.

DISCUSSION

The TRAMS (Team Resilience Assessment Method for Simulation) instrument has been used in a pilot study within the CCRAAAFFFTING project. The TRAMS instrument satisfies several criteria for assessment, namely: validity, reliability, theoretically grounded, useful, cost-effective, meaningful, and sound. During the pilot study the TRAMS instrument was tested and evaluated as a tool for assessing systemic resilience. The purpose was to eliminate problems and errors. After this initial iterative development, the instrument will be used during the main data collection of the CCRAAAFFFTING project lifecycle.

Utilizing a simulated environment further allows for investigating the relationship between potential resilience and manifested resilience. It can naturally be argued that simulations never will be able to reflect the intricate complexity of real-world situations (Brehmer & Dörner, 1993). However, claiming that simulated environments are useless for investigating how resilience manifests itself in different situations is also flawed. Rather, it is the model underlying the simulated environment and the participation of relevant stakeholders that decide what conclusions that can be drawn from findings from such studies (Johansson, Berggren & van Laere, 2017).

Expected added value of using TRAMS

The existing body of resilience research has not presented sufficient methodological suggestions for assessing collective resilience, especially regarding how individuals and teams contribute to the collective resilience. The literature on teamwork and collaborative practice is rich. However, the connection between collective resilience, teamwork approaches, and collaborative practice literature is still limited. The TRAMS instrument provides a structured way of assessing systemic resilience and related team concepts in socio-technical systems responsible for handling disturbances that requires collaboration between ad-hoc constellations of actors. By utilizing the instrument, actors from the fuel, food, and finance sector will potentially increase their awareness of how dependencies between them, the payment system, and how they ought to coordinate their actions with other stakeholders in the system to prevent for escalation of a disruption. Utilizing TRAMS during sessions in the

gaming simulation will generate knowledge on how the large variety of actors together can develop a collaborative response that prevents escalation, rather than individual responses which might counteract each other. These insights can be used to communicate proposals for action to respective stakeholders. In this respect, TRAMS offer possibilities for organizational learning in that it creates a sound and replicable basis of indicators for both systemic resilience functions and team aspects. These can be used for feedback and reflection, a requisite for organizational learning. As the organisations develop and change they become more able to handle disturbances and be more resilient, hence are able to perform even under stressful conditions.

Future work and recommendations

The TRAMS assessment approach will be tested in the CCRAAAFFFTING project. A series of 30 simulation games with practitioners from the fuel, food and finance sectors are planned. The TRAMS assessment approach will be evaluated continuously along with the simulation game until a usable, valid and reliable version has been defined.

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Evaluating Platforms for Community Sensemaking: Using the Case of the Kenyan Elections

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ABSTRACT

The profusion of information technology has created new possibilities for local communities to self-organize and respond to disruptive events. Along with the opportunities, there is also a series of challenges that need to be addressed in order to improve societal resilience. One of these challenges is to make sense of the continuous stream of information to create a coherent understanding and improve coordination.

The research presented in this paper focuses on the socio-technical requirements of IT platforms that support sensemaking and coordination. Using a comprehensive evaluation exercise based on real data from the 2017 Kenyan elections, we examine the development, workflows and use of this shared situational awareness in a group decision making process. In this manner, we identify requirements for resilience platforms and identify further research directions.

Keywords

Sensemaking, community engagement, evaluation, requirements, resilience

INTRODUCTION

Disruptive events, irrespective of their nature, often exceed the capacities of professional authorities – leading to institutional voids and giving rise to localized response activities (IFRC 2016). At the same time, the situation is often highly uncertain. Through the proverbial 'information firehose' decision-makers and affected communities are confronted with conflicting or redundant information, and actionable information is increasingly hard to find (Van de Walle and Comes 2015).

Given the uncertain and chaotic nature of these disruptive events establishing an understanding of the crisis, and attributing meaning to what is happening are crucial for the response (Weick 1993; Weick 2010). *Sensemaking* process is a continuous process of information collection, enactment and retainment (Sharoda and Reddy 2010). While this sensemaking process has been studied extensively for responders, such as Search and Rescue teams (Muhren and Van de Walle 2009), disasters coordinators (Weick 2010), and emergency services (Kuligowski 2011), there is limited research in sensemaking and decision-making at the community level.

However, communities play an important role in the response to disruptive events. The World Disaster Report 2013 by the International Federation of the Red Cross, highlighted that: "90% of the people saved in a disaster are saved by local people" (IFRC 2013). Communities are not only the first on-site, but also have access to local resources and capacities that can be deployed immediately. For sensemaking, particularly the legacy or 'sensemaking trajectories' (Muhren et al. 2008) of the local communities are highly relevant.

The increasing importance of mobile technology and social media has given communities more options to create, share and analyze information. Increasingly, communities use collaborative platforms to self-organize. These can be neighborhood apps fostering communications, or dedicated tools and platforms for crowdsourcing (Shanley et al. 2013) or crisis mapping. One of the most recent examples has been provided in the 2017 Harvey Hurricane response (Sebastian et al. 2017).

This paper sets out to study the impact of collaborative platform on community sensemaking and decision-making. In this paper we present the initial findings from an extensive evaluation session, based on a real-world case. In the next section we explore the theoretical background related to the community sensemaking and

decision-making. This background informed both the setup of our evaluation as well as the approach to collecting data. Next, we present the results from our various data collection efforts, including surveys, self-reporting and group discussions. We conclude the paper by discussing these results, the methodology used, presenting the key findings and future research opportunities.

BACKGROUND

Resilience

A widely used definition of resilience sees it as 'systems ability to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner' (UNISDR 2009). However, many other definitions and insights have been developed. This includes discussions on whether resilience is the ability bouncing back to a previous state as predominantly used in engineering (Bruneau et al. 2003; Comes and Van de Walle 2014; Comfort et al. 2010; Madni and Jackson 2009; Zobel and Khansa 2014) or an adaptive process of change and transformation as is typical for the socio-ecological school of resilience and complex adaptive systems theory (Filatova et al. 2016; Folke 2006; Jerneck and Olsson 2008; Klein et al. 2003). The later emphasis the transformative nature that disruptive events have on communities and socio-ecological systems, requiring them to not only deal with the consequences of a disaster ('bouncing back') but also reflect on the causes of such an event and implement measures to reduce future risk ('bouncing forward'). Increasingly we see the latter approach be part of disaster risk reduction strategies, often referred to as 'building back better' (Fan 2013) and strengthen the affected communities capacities (Almedom 2008).

A different, but related debate is the discussion whether resilience is linked to tangible assets and characteristics of a community as argued by Norris et al. (2008), or rather a process (Brown and Kulig 1996). However as illustrated by Giddens (1979), the two aspects are linked: certain characteristics, infrastructures and/or assets of a community can enable or hinder the community driven resilience process.

The recent survey on urban resilience of Meerow et al. (2016) highlights particularly well how fragmented the field of resilient is with respect to the definition and scope of the term; the only consensus that they found was that resilience is something positive. Maybe most important from an information system and ICT perspective is the missing combination of the engineering and design thinking of resilience with the adaptive and transformative theories that come from the socio-ecological systems, thereby expanding the scope of the analysis to complex adaptive socio-technological-ecological systems. We discuss here specifically the role of information sharing platforms for community resilience, thereby making a headway in bridging the gap between (ICT) design and resilience in disaster response.

Community

As illustrated, communities play a pivotal role in dealing with a disruptive event. These disruptive events test the resilience of a community and reveal shortcomings. As such, communities are not only at the heart of responding to disruptive events, but also benefit from understanding how they can improve their resilience when disruptive events affect them.

Communities can be identified by three characteristics according to Frankenberg (1966): common interests among people; or common ecology and locality; or a common social system or structure. This definition implies a shared responsibility and interest in the resilience of their community and in dealing with disruptive events. This shared responsibility among everyone in the community has been described by Ronan and Johnston (2005). Moreover, communities are also driven to develop mechanisms to improve their resilience, whether pre- or post-disaster (Kendra and Wachtendorf 2007; Taket 1999).

Theories on social capital in resilience stress the importance of social interaction in terms of networks and information flows for collective action (Adger 1999; Pelling and High 2005). Besides keeping links to their close families or within their neighborhood ('bonding' social capital), the networking capital stresses the importance of external links that a community has, governed by economic or legal relations (Adger 2009), where the latter are particularly important in institutional 'voids', marked by an absence of governmental actors (Klievink and Janssen 2014). Extending these concepts Szreter and Woolcock (2004) define linking social capital as "norms of respect and networks of trusting relationships between people who are interacting across explicit, formal or institutionalized power or authority gradients in society". This is particular important as in disasters, the ability to connect quickly to professional decision makers and public authorities for coordination of relief efforts can be crucial (Aldrich and Meyer 2015; Aldrich and Sawada 2015).

Coordination

In the response to disasters, communities and professional actors hence need to work together, pooling their knowledge, resources and response capacities. Accordingly, coordination in the context of disasters entails information sharing, collaborative use of resources or expertise, joint policies and definition of responsibilities (Comfort 2007). Information and communication technologies empower new actor groups to self-organize and engage, taking on new roles and responsibilities.

At the same time, particularly the early chaotic phase of disasters is subject to 'severe' or 'deep' uncertainty (Comes et al. 2015). The combination of uncertainty, time pressure, and proliferation of technology has wide implications for coordination. The widespread access to data and analysis tools gives rise to an unprecedented number of forecasts, predictions and analyses at any level, adding noise and uncertainty. Particularly, the problem of politicizing data and the link between information and power has been increasingly in focus recently (Comes and Adrot 2016).

The increasing pressure for accountability and transparency can lead to stalemates and long decision processes. But the longer it takes to decide the more likely it is that, given the pressure to respond, reactive measures have already been implemented locally. This lacking coherence increases the risks of decisions being rendered obsolete or seriously flawed even before they are implemented. Under the pressure to respond and given disrupted communication lines, in these settings localized response efforts emerge, making it particularly challenging to coordinate and align their efforts. Nevertheless, coordination is a critical success factor in effective disaster response as the situation is often so overwhelming not a single actor is able to deal with the situation single-handedly (Bharosa et al. 2010).

Sensemaking & Information

Sensemaking is the process that individuals go through to develop an image of what is happening or what people are doing (Weick 1995). This -iterative- process is a collaborative effort by different actors to develop a shared awareness. While this sensemaking process has been studied extensively for responders, such as Search and Rescue teams (Muhren and Van de Walle 2009), disasters coordinators (Weick 2010), and emergency services (Kuligowski 2011), there is limited research in sensemaking and building situational awareness at the community level. However, over time different platforms have emerged that support responders in supporting this process, including crowd-sourced information, for example during the Kenyan Elections (Goldstein and Rotich 2008).

Before, during and after elections a custom-build web platform called Ushahidi was used to collect reports from the public through different channels, including SMS and submissions on a web page (Okolloh 2009). The resulting information from this platform provided both government agencies and individual citizens with an understanding of the unfolding situation. It has been studied how these crowdsourcing platforms support mandated responders in their sensemaking process for example after natural disaster such as the Earthquake in Haiti 2010 (Gao et al. 2011; Heinzelman and Waters 2010) or conflict situations such as the Libya crisis (Stottlemyre and Stottlemyre 2012) or Kenya elections (Meier and Brodock 2008). However, it is there has been limited study how such platforms and the resulting information support sensemaking at the community level.

Research gap

Building resilience is a process that is targeted at and - more importantly- driven by communities. Building resilience enables communities to reduce the impact of disruptive events and supports them in dealing with the resulting effects. Especially in these circumstances communities are dependent on themselves. If we are to encourage the community resilience process, supporting sensemaking at the community level is an essential step. Nevertheless, the currently available platforms mostly support the sensemaking process of formal (mandated) responders, but they could also support the communities in their collective sensemaking process (Comes et al. 2017). However, to date no research focused on investigating if this is a valid assumption and how platforms should be designed to encourage such community sensemaking process. This paper aims to address this research gap. In the study presented here, we use a comprehensive evaluation approach to examine the contribution of (augmented) crowdsourcing platforms to the sensemaking process for non-mandated responders in disruptive events.

METHODOLOGY

When designing an evaluation to examine the above mentioned effects, there are several considerations (Link et al. 2014; Meesters 2014) First and foremost, we need to design the content, this encompasses not only the

objective, but also the tasks to be executed. Those *objectives* and tasks stem from the research objective outlined above: Sensemaking in a disruptive event by non-mandated (experienced) responders. This is then translated in specific *tasks*. Next, we consider the *delivery* of the evaluation; how the evaluation is framed and presented to participants. This includes the *scenario* and *background* introduced to the participants as well as the *workflows* and *tools* at the disposal of the teams. Finally, data has to be collected during the scenario exercise in order to evaluate the initial (research) objective.

Evaluation Design

To examine if the platform and services offer sense-making support, the scenario would have to fulfill the following criteria: (1) provide an unknown context to the participants, (2) provide a clear objective that encourages participants to common to a situational understanding, (3) provide sufficient data to enable participants to reach that objective (4) provide a comprehensive and realistic scenario. The participants were students with various backgrounds in Technology and Management, with a common interest and some introductory lectures on the design of participatory systems. A total of twelve students joined the evaluation.

Evaluation Delivery

The Kenyan elections, which initially took place on August 8, 2017, were highly disputed and have led to several eruptions of violence. The results of the elections were also disputed and eventually annulled by the supreme court of Kenya, leading to another election cycle held in October 2017. As part of the government's effort to make the elections more transparent, the Uchaguzi[1] initiative was re-launched. The goal of the initiative was: "... to help Kenya have a free, fair, peaceful, and credible general election in 2017." Uchaguzi aimed to support this objective through a broad network of civil society and citizen observations. It provided a platform which enabled citizens to report, with any technology available to them, any incidences significant to the election.

Fig 1. Real-world Uchaguzi workflow

This scenario was a good fit with the criteria outlined above: the participants were not closely familiar with the specific background and context of the Kenyan elections. Furthermore, the scenario provided a clear objective: mapping the reports of voting incidents and irregularities to support the Kenyan election board in assessing the validity of the elections as well as support the security & safety forces in containing the violence. Additionally, access to sufficient data was provided to create a comprehensive and realistic scenario that enabled enough depth for the participants to play their role and complete their objective. Finally, the validity of the scenario was ensured by being based on the Uchaguzi deployment which was part of the real elections with proven results.

Scenario

Using Uchaguzi as inspiration the scenario was adopted for the evaluation. The participants took on the role as

[1] Uchaguzi 'Election' in Swahili https://www.ushahidi.com/uchaguzi-support/what-is-uchaguzi/uchaguzi-2017-overview-and-background

members of an 'Election Observation Mission-team', send from the European Union in response to a request made by the Kenyan government. In this scenario the participants support the election observation mission by collating, processing and analyzing the data send to them by other observers in the team, closely resembling the real-world mandate, process and workflow of Uchaguzi. Aside from the participants themselves, the evaluation included several role-players to provide realism and support to the participants, without breaking the scenario:

- **Head of mission:** The head of mission provided the participants with the required objectives, necessary information and mandatory tasks. This included the data collection tools showed in the next section.
- **Kenyan Election Board:** This player of the Kenyan Election Board, would inform the participants about the impact of their work, provide general updates on the unfolding situation and respond to country-specific inquiries if needed.
- **IT Support:** IT support provided the role-players with their own 'digital workspace', including dedicated email accounts, a shared workspace for their team on Google Drive, the pre-configured Ushahidi platforms and a Slack channel were the support was offered. Most importantly, IT support would also provide daily data updates (injects) to the participants.

The data provided to the participants was created specifically for this exercise *using the real-world data* from the Uchaguzi deployment. A representative sample for the evaluation was made from the complete data-set, ensuring a similar ratio of 'published' (indicating verified and useful reports) and 'unpublished' (indicating were valuable reports). The data-set also had the same distribution across distinct categories as the complete real-world data-set. The timestamps of the reports were updated to match the dates of the evaluation period.

Participants were divided in three groups and worked in their own environment. In their role of 'digital election observers', the participants received a briefing at the start of the evaluation outlining their mandate, mission objective and tools at their disposal. Each group was provided with their own 'digital workspace' as described above.

This platform was augmented with several services developed as part of the COMRADES research project. Using these tools, the team would receive, process and publish the 'reports' (data) received from the observers. While the participants were free to determine their own workflow, a generic daily workflow would encompass receiving data (daily), cleaning & importing it, processing it, and publishing the results to the public.

Data collection

The data collection was carried out using three approaches: surveys, mission reports and group discussion. The *surveys* focused on an individual participant while the *reports* had to be filled by the whole groups. In fact this was aimed at making the group work together and summarize their collective perspectives and situational awareness. Eventually, the *group discussion* was a collective meeting of all groups to determine if the single teams shared a common understanding of the local context, and if, given the same roles and data, could come up with a common decision.

The repetition of surveys and reports over time was aimed at tracking changes in the perspectives of the participants. To achieve that, three surveys and two reports were filled in and written by the participants at different times along the evaluation. Table 1 illustrates the schedule of the evaluation, including the main objective (task) for that day, the in-person meetings and the data-collection for the evaluation. This schedule was presented and monitored by the head-of-mission role-player. The next sections show the content and structure of the surveys, reports and group discussion.

Table 1 Schedule of the Evaluation

Date	Mission	Participant Task	Team Meeting	Eval. data collection
Day 1	Preparation	System test	Briefing & Tutorials	1st survey
Day 2	Preparation	System test		
Day 3	Election	Process observation reports	Q&A Session	
Day 4	Election	Process observation reports	-	
Day 5	Election	Process observation reports		Intermediate Report
Day 6	Election	Process observation reports	Q&A Session	2nd survey
Day 7	Election	Process observation reports		
Day 8	Debrief	Process observation reports		Final report
Day 9	Debrief		Presentation / Debrief	3rd survey

Surveys:

The surveys aimed at evaluating Situational Awareness of each individual participant and were structured according to the Situational Awareness Rating Technique (SART) as suggested by Selcon and Taylor (1990). This approach uses ten questions based on a 7pt Likert Scale, aimed at investigating three components of Situational Awareness: Situational Understanding, Attentional Demand, and Attentional Supply. Situational Understanding represent the confidence a participant has that the situation at hand is completely understood. Attentional Demand relates to how challenging the current set of events is in terms of Instability, Variability and Complexity. While Attentional Supply applies to the amount of effort a participant is investing in understanding the course of events.

Reports:

The reports were aimed at collecting open feedback from the teams. The participants were given a predefined structure to be filled in. The structure was divided in two main parts: one was a Situation Report as part of the scenario exercise and the second one was aimed at gathering feedback on the evaluation exercise itself, but also on the platform. The situation report included the following sections: workflows, IT tools, current situation, and advice on the election validity and recommendation for security force allocation. For this purpose, a template map was provided to the students to report Security, Staffing and Voting Issues.

With regards to the security force allocation, participants had to come up with a final decision in terms of the allocation of three police forces within the most affected areas of Kenya. This had to be included in the final report. The report included also the reasoning behind the above-mentioned choice based on their situational awareness. In the Evaluation section, participants had to provide feedback based on the following elements: Mission and Objective (e.g. feasibility of the exercise), Workflows and Team Organization (e.g. critical perspective on the flows chosen by the team) including IT Systems and Services used.

Group Discussion:

Once the final report was delivered, the group discussion phase was implemented. This section was structured in the following way. First, the participants presented their map with the final decision and related argumentations. The groups then discussed to come up with a joint decision. This discussion was facilitated by the researchers.

RESULTS

Based on the data collection strategy shown above, several results were gathered for each of the data collection tools. Table 2 summarizes the results, while the following sections provide more details.

Table 2 Summary of Results for each of the Data collection tools adopted

Data Collection Tool	Evaluation Dimension	Results for Situational Awareness	Other Results
Surveys	Individual Participant	Increasing over time, affected by continuous information inflow.	N.A.
Reports	Within Group	Different Prioritization of Areas	Similar workflow for separate groups, need for contextual knowledge, Socio-Technical Requirements
Group Discussion	Among Groups	Different prioritization of Areas, Different Interpretation of Information	Need for contextual knowledge, Socio-Technical Requirements

Results of Surveys

Situational Awareness seemed to increase during the simulation and reaching a plateau between the second and the third survey. As far as the components of situational awareness are concerned Situational understanding increased over the simulation but reached a plateau between the second and third surveys. Attentional demand increased considerably between the first and second surveys. The demand kept rising the second and third survey, but with decreased momentum. Attentional Supply increased over time almost steadily. Table 3 shows the results from the surveys.

Table 3 Results of the Surveys averaged per group and for all groups (overall average)

Group Average	Survey	Attentional Demand	Attentional Supply	Understanding	Situational Awareness
Group 1	S1	4,0	3,6	3,3	**3,0**
	S2	4,6	4,4	4,0	**3,9**
	S3	4,8	4,5	4,2	**3,8**
Group 2	S1	3,7	4,4	3,5	**4,2**
	S2	4,4	4,8	4,7	**5,1**

	S3	4,8	5,0	4,4	**4,6**
Group 3	S1	4,6	4,8	3,4	**3,6**
	S2	5,6	4,3	3,8	**2,5**
	S3	5,7	5,1	3,7	**3,1**
Overall Average	S1	4,1	4,3	3,4	**3,6**
	S2	4,9	4,5	4,2	**3,8**
	S3	5,1	4,9	4,1	**3,8**

Results of Mission Reports

In addition to the surveys, each group also produced two reports: an intermediary report (approximately halfway during the evaluation) and a final report (at the end of the evaluation). The participants described the workflows they used throughout the evaluation period. This workflow involved processing the incoming data and using the various systems at their disposal. Based on these descriptions, it became clear that all groups followed the same approach: 1 or 2 persons in the team would be responsible for uploading the data in the platform, after which all the group members would go over the results and fine-tune the entries on the platform as needed.

The Participants were asked to provide advice to the *Kenyan Government* based on the data they received and analyzed. They were also asked to describe how confident they felt in the recommendation and feedback provided in the report. For the final report only, the participants had to provide a final decision in terms of validity of the elections and resources allocation. The results of resources allocation showed that the groups prioritized different areas in terms of intervention of three different police forces (see figure 2). Also, the decision on the validity of the elections was different for the groups.

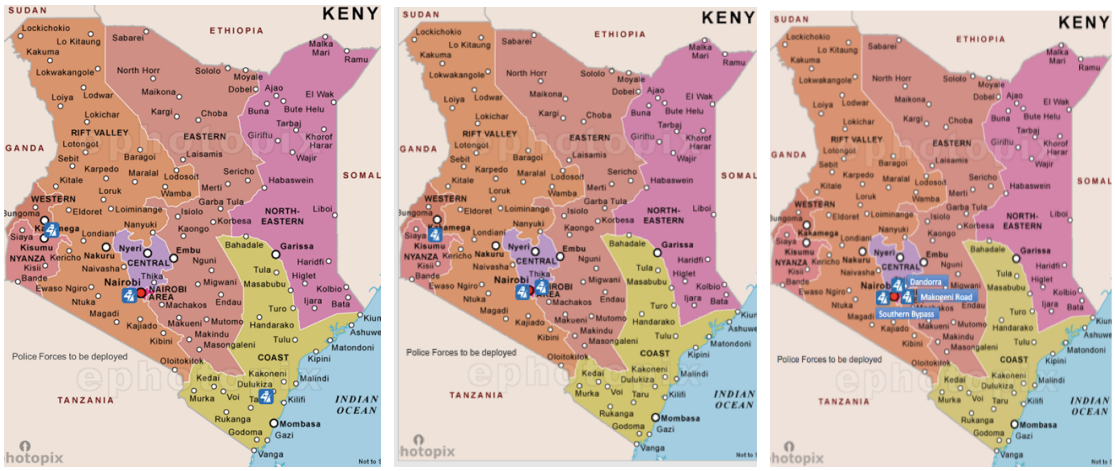

Figure 2 Comparison of Police forces allocation among the three groups of participants. While there seems to be some agreement on Nairobi, there are different opinions on Kisumu and Mombasa.

Results of the Group Discussion

During the discussion the participants showed to have a collective understanding of the local context and could discuss the topic using the same terms. Nevertheless, their presentation of final decisions showed a different prioritization of areas as in the final reports (see fig. 2). The group discussion revealed that participants had different interpretations of the available information despite having the same role in the simulation. This led to the difficulty of finding a common decision. Differences among groups rose based on different prioritization of areas, or the trustworthiness of the information from specific sources.

DISCUSSION

Combining the results from the individual surveys, the group reports and the joint discussion with all participants, findings related to different topics emerge. First, we discuss the use of the platform and its features by the participants. Secondly, we examine the way that the participants handled, processed and interpreted the data provided to them. Next, we zoom more specifically into the relation between the data and the sensemaking process. Finally, we reflect on the evaluation method itself.

Platform evaluation & socio-technical requirements

The platform to process and share data played a vital role in the evaluation setup. This platform, along with new

features designed to support communities in their sense-making process, was used by the participants to enter and map the incoming reports. Our evaluation proved useful to *collect socio-technical requirements* for the further development and deployment of this platform. The feedback given by participants in the surveys, reports and group discussion emphasized the *importance of training*. This training related to the technical operation of the platform, as well as the workflows within the team.

Some of the feedback produced by participants was also more technical and directly related to possible *additional features for the platform* they used. This feedback included improvements in the user-interface, the ability to process data in a more structured manner, and integrations with other services and platforms. Some of these elements were directly implemented by the developers of the platform, while other are in the list of possible improvements for the future. This ensures direct applications of the findings from research and gives importance to the HCI component of a platform, which could ultimately affect the goal of stimulating a shared situational awareness and cooperation among stakeholders (Streefkerk et al. 2014). This direct feedback loop also highlights evaluation approach as a tool for direct and actionable feedback to developers of these platforms.

Information processing & sensemaking

Even though the situation evolved, and new events started to emerge, the participants felt more confident in their tasks. This was also indicated by the reduced need for external services that supported participants in understanding specific keywords (places, names, terms, etc.). Participants indicated in both the surveys and reports that the usefulness of services decreased. By working with the data over a longer period, they implicitly built up their tacit knowledge to understand the situation, essentially supporting their own sense-making process. However, in the group discussions participants also mentioned that as the evaluation progressed they felt the need to classify the information in the initial (pre-defined) categories in the system, even though they were free to adapt them to their needs. This desire to fit the data to certain categories, trends and previous findings indicated the risk of *confirmation & fitting* (Comes 2016)

Furthermore, in the final report and group discussions, the participants seemed to mainly focus on the latest data received. Rather than building a comprehensive evaluation, including all the data gathered and processed throughout the evaluation, participants focused on the issues that the latest update revealed. The historical data (and underlying trends) was selectively used (or even discarded) in the final reports to highlight these issues, essentially displaying an *immediacy effect* (Anderson 1965; Huber et al. 2011)

In the reports the participants noticed the reliability of their self-reporting and stated that they felt confident in the data they had processed and their analysis but *lacked the contextual knowledge to assess how their 'internal' findings related to the real-world*. Specifically, in relation to media reports, public awareness and -most importantly- as historical baseline, for example from previous elections. Participants indicated that this information and contextual knowledge would enable them to better frame and interpret the results from their data and better cater to the needs of the requesting agency. This contextual knowledge is especially relevant to identify abnormalities (baseline), or to give meaning/value to certain signals presented in specific messages.

Methodology

The evaluation setup and scenario provided the participants with an in-depth experience of handling crowd-sourced information during a disruptive event. None of the participants had any prior experience with the crowd-sourcing information in general or with these situations specifically. Moreover, during the briefing the participants indicated that they were not familiar with the details of the scenario, other than what had been reported in the news. While the participants were not directly affected by the event, these properties are similar to communities who aim to understand and make sense of a unknown situation.

The participants indicated in the group discussion that they felt the scenario was comprehensive but that a clear motivation was needed to feel (continuously) engaged. As they were not (in reality) affected by the elections or had another incentive, motivation was at times suboptimal. Additionally, the extend time-period of the evaluation also proved challenging for them to stay involved and motivated. While the participants found the case interesting as an introduction into this field, a more compressed, relatable case would have kept the engagement stronger over the longer period of the evaluation. These findings emphasize the importance of reciprocity for information systems aimed at communities, as illustrated in the socio-technical requirements found within the COMRADES project (Piccolo et al. 2017).

Despite these improvements, the evaluation methodology provided comprehensive feedback on the platform, the use of information, and the sense-making process of non-professional responders at the community level. It also demonstrated that the use of platforms and -more importantly- *working directly with information*, supports the community in building an understanding of the ongoing situation. However, there are caveats and biases that

have to be taken into consideration and studied in more detail.

CONCLUSION

Various situational awareness platforms are now available to deal with social unrest resulting from conflict situations. Nevertheless, these platforms are rarely evaluated scientifically in order to assess their actual support (especially for communities) and which requirements are key for their design. Effectively evaluating these platforms during real crises is impractical, therefore scenario evaluations are needed. One of the challenges related to the development for scenarios, consists of the creation of realistic settings, able to emulate reality as much as possible in order to provide scientific ground for the evaluation.

One key finding of this study is that it is possible to transform data recorded from a real situation into a scenario for the evaluation of a situational awareness platform. The proposed methodology was used to set up a scenario with social media data from the Kenyan election of August 8th, 2017. The course of the election was stretched from one to nine days, in order to adapt the workload to the number of participants available compared to the real case. Moreover, the purpose of an extended schedule, was aimed at giving the participants time to fill in the intermediate surveys and write the intermediate report. Given the limitations above, the findings of this research approach have to be considered as the qualitative results of an exploratory study.

The methodology still provided us with a tool to analyze the ability of the platform to create a shared situational awareness and a coordinated approach among stakeholders, but also some directions for future research. As far as this is concerned, we were able to create a collective understanding even for people who were not initially familiar with the context. This only solved part of the problem. The participants *interpreted* the situation differently, due to their background, bias, etc. Therefore, even though we established a common narrative and vocabulary that could be used to communicate effectively, additional efforts are needed to translate this into a coordinated approach among different stakeholders.

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Crisis Cleanup: Creating a Virtual Command Post to Support Relief Organizations on the Ground

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ABSTRACT

We report on an initial assessment of a grassroots tool developed within the Volunteer Organizations Active in Disaster (VOAD) community to support the coordination of efforts between the diverse network of relief organizations on the ground following a disaster. We look first at the problems that led to its development and the volunteer principles embodied in the tool. We then present an overview of the primary workflows and processes used to capture and manage work orders within this system. We discuss some of the benefits of centralized coordination of work across this network, opportunities for future growth, and some of the barriers that are inhibiting further growth of this tool. Finally, we conclude with opportunities for future research.

Keywords

Disaster recovery, disaster volunteers, volunteer coordination

INTRODUCTION

Effective response to large-scale disaster and crisis events requires the collective effort of a diverse community of groups and organizations, each filling important gaps and addressing the critical needs of communities in the aftermath of disaster (Dynes 1970; Tierney et al. 2001). Citizens are often the true *first responders*, initiating search and rescue efforts and providing medical attention until emergency personnel arrive on scene (Dynes 1970). In the warning and most acute phases of an emergency, formal emergency response organizations work to address the immediate impacts, minimize threats to life and property, and to restore critical infrastructure. Even in small to medium-sized events, formal response organizations may not be able to address all the needs of a community. Thus, citizens and community organizations play a critical role in filling gaps and organizing medium to long-term recovery efforts (Fritz and Mathewson 1957; Hunt et al. 2014; Voorhees 2008; Wenger 1991).

After the initial threat of the hazard has passed, Voluntary Organizations Active in Disaster (VOAD)[1] converge to form a coalition of *second responders* assisting survivors in the initial phases of recovery. These organizations serve an important community need in helping to bridge the gap where federal funding and assistance ends and community recovery begins. They also help to foster resilience by helping survivors mitigate some of the immediate impacts of the disaster more quickly than they could potentially accomplish on their own. However, as these volunteers converge to help after a disaster, researchers (Barsky et al. 2007; Schmidt et al. 2017; Voorhees 2008) have noted significant challenges to volunteer coordination, communication, information sharing, and integration within the formal response efforts. In this paper, we present a case study of an online application—*Crisis Cleanup*—designed and developed within the VOAD community to overcome many of these challenges.

VOAD

There are multiple definitions of the term VOAD ranging from a conceptual framework, to the ongoing organizational networks, to the physical and local implementation of volunteers in disaster. In this paper, we define VOAD as the broad, informal network of volunteers on the ground after a disaster. The size and diversity

[1] https://www.ready.gov/voluntary-organizations-active-disaster

of this network varies depending on the size and magnitude of the event. It may include established VOAD organizations (e.g., the American Red Cross, United Way, Habitat for Humanity, Amateur Radio Emergency Service, etc.) as well as spontaneous community organizations that emerge to provide assistance. VOADs operate in parallel with one another and members cannot activate, supervise, or direct one another except as defined by special agreement.

Use of Online Tools in Disaster Response and Recovery

The use of online tools and technologies to organize disaster response and recovery efforts has grown significantly in recent years. Numerous studies look at the use of social media and information communication technologies (ICTs) to organize globally distributed, digital volunteers to aid efforts on the ground (Hughes and Tapia 2015; Majchrzak and More 2011; Palen et al. 2015; Reuter et al. 2015; St. Denis et al. 2012; Starbird and Palen 2013; Zook et al. 2010). However, research looking at the potential use of online tools to coordinate the on-the-ground response of volunteer organizations is limited (de Lanerolle et al. 2010; Schmidt et al. 2017; White and Palen 2015), particularly the coordination of work across volunteer relief organizations and emergent community groups. To fill this gap, we provide an initial assessment of Crisis Cleanup—an online application designed to make visible the needs of communities impacted by a disaster and the coordination of cleanup efforts across the loosely organized network(s) of volunteers on the ground. We look specifically at the evolution and use of this tool over 7 disasters for insight into implications this has for the future evolution of Crisis Cleanup and other applications designed to coordinate volunteer resources in the recovery phase of disaster. The content of this paper is based on information gathered during a series of informal interviews with the founder and creator of Crisis Cleanup. It is also based on printed and online content provided by the creator.

CRISIS CLEANUP BACKGROUND

The creator of Crisis Cleanup conceived of an online framework for coordinating the cleanup efforts of volunteer groups on the ground after working as a volunteer following Hurricane Irene in New Jersey, USA in August 2011. As a member of a faith-based volunteer group, he was struck by the overall inefficiency and disconnection in the process. Volunteers, eager to help, would congregate at various locations and often spend hours waiting for a work order. Once completed, they either travelled back to the command center or contacted the coordinator for a new assignment. Communication break downs and time spent standing around resulted in significant attrition among volunteers because they either thought there was no remaining work or they grew frustrated with the wait time. Additionally, no mechanisms existed for incorporating assessments and information gathered in the field back into the volunteer framework. With numerous organizations working in parallel, multiple groups often canvased the same neighborhoods while others were completely ignored. Finally, there was no efficient way to funnel and manage the help requests from the 2-1-1 Helpline Centers to the volunteer organizations on the ground. The 2-1-1 Help System is a reserved number in the United States and Canada that provides free, confidential information and referrals at the community level[2]. During a disaster, they work with emergency management to offer support and disseminate information. Crisis Cleanup's creator saw the potential for a solution that could 1) provide an effective mechanism for capturing information and requests from those affected by a disaster event, 2) share the big picture across the loosely coupled network of organizations and volunteers, and 3) empower individual volunteers and organizations to use this information to organize and inform their response.

The initial prototype of Crisis Cleanup was deployed for the first time following a destructive windstorm in June, 2012 in Southern New Jersey. Members of the public called the New Jersey 2-1-1 Call Center where operators created work orders that were then copied to a map. Cleanup crews claimed work orders electronically and began work based on their schedule and availability without having to coordinate with a central command center or work coordinator. This simple workflow helped to organize and coordinate the work of over seven hundred volunteers and to aid several hundred impacted residents. Operators within the call center also used the map to check the status of work orders and provide that information back to the affected residents.

The system was used four months later to support cleanup efforts following 2012 Hurricane Sandy, where it was used by over 120 voluntary relief organizations (Titus 2017). During Hurricane Sandy, a team of software developers expanded this concept. They re-wrote the platform to further automate the workflow and to make the code and interface more robust and stable. Since then, Crisis Cleanup has been used to manage seventy-eight disasters in thirty-four states and six countries.

[2] http://www.211.org

OVERVIEW OF CRISIS CLEANUP

What makes Crisis Cleanup interesting is not the underlying technology, but rather the principles of volunteerism and cross-organizational coordination supported by its simple interface. The interface is designed to support several key principles of volunteerism. First, it provides equal access to big-picture information across all active relief organizations and the means for members of this group to update relief data as they gather new information or complete work. This mechanism ensures that all organizations and volunteers have the most up-to-date and complete picture of the relief effort. Second, volunteer organizations operate independently from one another, even though they often work towards the same goals, so the system must allow volunteers to organize themselves and solve problems in their own way. Finally, the system must empower the community to help itself and support the spontaneous volunteer groups that emerge within the chaos on the ground.

Crisis Cleanup supports two primary workflows. The first is the assessment process. This process lets volunteers gather information about needed work, contact information, and location information used to pin the work order to the Crisis Cleanup map. The map interface supports work order management (see Figure 1). The symbols and color of work orders on the map indicate the type of work and current status. Volunteers can view, claim, un-claim, or change the status for a work order by selecting the work order icons on the map.

Managing Work Orders

As assessments are completed, new work orders are pinned on the incident map with the icon depicting the type of work and the color indicating the current status (Figure 1) Volunteers can claim an individual work order that matches their skills or a type of work within their local work area. As work orders are claimed and completed, the system updates the work order status. Volunteers staffing the 2-1-1 Helpline and the Crisis Cleanup Hotline can check on status of the work orders.

At a higher level, organizations can target areas where they are most needed and avoid duplication of effort with other organizations. They can also download a report of the Crisis Cleanup work orders claimed by their organization to coordinate their work and document their efforts.

Figure 1: Sample Crisis Cleanup Map with Legend

Building the Local Relief Network

A new relief network is constructed for each deployment of Crisis Cleanup. Membership is open to any reputable relief organization, provided they meet the following criteria. First, the organization must have a physical presence in the disaster area or interact directly with those affected by the event. Second, they must perform relevant operations, such as canvassing, assessments, cleanups, muck-outs, or rebuilding. Finally, organizations must be reputable and have no financial interest in the cleanup (e.g., contractors or construction agencies). The network includes both established relief agencies and emergent community groups. Inclusion of emergent community groups is critical to local community response, giving community members a broad picture of what is needed and the means to organize their response and long-term recovery.

A local coordinator or a designated local agency oversee the vetting and approval of new organizations. They

are not officially "in charge" nor do they manage and assign work orders. They have the vital knowledge and insight to make sure that only voluntary relief organizations active on the ground are admitted to the network.

New organizations are added to the network after they have been vetted to confirm that they meet the criteria given above. Once accepted, the initiating contact logs in and invites trusted colleagues from within their organization to be part of the cleanup. Crisis Cleanup has a workflow that allows coordinators to onboard volunteers quickly. Once in, volunteers can begin to organize and plan their efforts self-sufficiently.

Performing Needs Assessments

Needs assessments are performed both over the phone and in person. When requested by local relief organizations, Crisis Cleanup opens a toll-free hotline staffed by virtual volunteers from participating organizations. These volunteers answer calls from home, often in multiple states. For example, during the height of the 2017 hurricane season, this hotline fielded 60,000 calls, and up to 3,000 calls per day. Survivors can contact either the Crisis Cleanup Hotline or the local 2-1-1 Helpline to request assistance. The Crisis Cleanup Hotline and local 2-1-1 helplines are staffed by trained volunteers who capture relevant work details from survivors and create new work orders (Figure 2). Relief organizations continue to canvas neighborhoods on foot and can create work orders as well. The traditional practice of canvasing neighborhoods on foot still takes place, but now organizations can clearly see which areas have been canvased and avoid duplication of effort. Additionally, volunteers can also input work orders directly from the field as they identify gaps in the cleanup process and new areas of need.

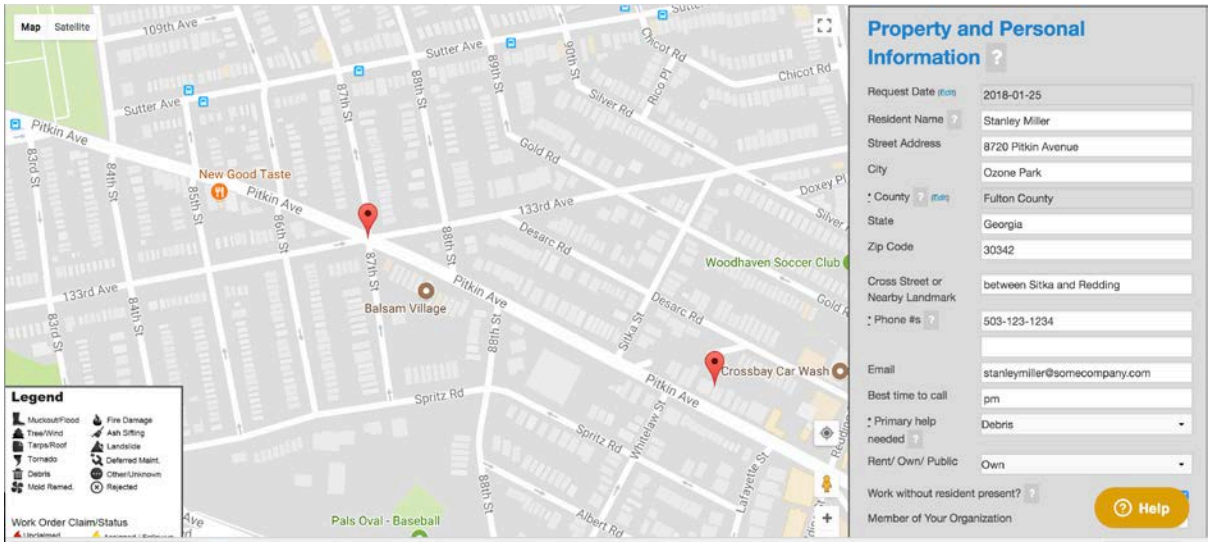

Figure 2: The Crisis Cleanup Work Assessment Form

Protecting Survivor Information

The vetting process of Crisis Cleanup is meant to limit the collection of survivor data and to limit exposure to only reputable relief organizations and vetted volunteers interacting directly with survivors. Data collection policies are meant to protect exposure of this vulnerable population even further. Data collected during the needs assessment focuses primarily on property information. Ideally, only basic contact information or key pieces of information may be noted in the work order. This information is used to prioritize the request and may include data about whether the resident is elderly, without insurance, or a first responder. Volunteers are trained not to collect sensitive data, such as date of birth, immigration status, social security numbers, race/ethnicity, religion, profession, income level, insurance settlements, or personal health status. The assessment form can be modified or customized, but organizations are asked to think carefully about whether the information collected is necessary to prioritize, prepare for, or execute the work order. Data collected by Crisis Cleanup volunteers is never monetized or sold.

While maintaining the privacy of survivor information is a critical consideration, Crisis Cleanup developers recognize the value of sharing carefully de-identified information with a broader audience. Consequently, the information displayed on the public maps only shows the type of work, and the location of the work order has been randomized within the local area so that the exact location cannot be identified. In the future, developers would like to support more diverse levels of data access (see Table 1).

Table 1: Future Data View/Access Levels for Crisis Cleanup

Access level	Data access	Description
Recovery	Access to client database and maps	Organizations that *interact directly* with survivors either doing assessments or cleanup work
Coordination	Access to client database and maps claimed or reported by affiliates	Organizations that *do NOT interact directly* with survivors but *directly supervise* organizations that do
Situation Awareness/ Preliminary Damage Assessment	Access to damage assessment and situation awareness data without personally identified information	Organizations that *do NOT interact directly*, but need general situational awareness and statistics
Public	Access to de-identified public maps and data	Members of the public/general audience

DISCUSSION

Crisis Cleanup is an interesting system because it was started by volunteers who recognized a need. Since its original proof-of-concept in 2012, the system has been adopted widely and deployed in 75 events to date. It functions as a virtual command post coordinating the efforts of the broad network of relief agencies and volunteers on the ground. It was designed to address some of the key inefficiencies inherent in coordinating the efforts of a diverse and independent network of relief agencies working independently but towards the same goals. While Crisis Cleanup is unlikely to fully replace volunteer command posts on the ground, it has been shown to be an important complement to on-the-ground work. In the remainder of this discussion section, we start by identifying some of the benefits provided by this online system. Next, we offer ways that this solution could be extended and some of the barriers preventing further development. We conclude with some of the key questions we would like to address moving forward.

Benefits

The clearest advantage that Crisis Cleanup provides is the shared big-picture view of what is needed and what is happening on the ground. The relief agency and the volunteers themselves collectively build and maintain this informational picture in real-time. Individual agencies decide where to position themselves, allowing them to avoid both duplication of effort and provide assistance more evenly across affected areas. Volunteers no longer have to waste time waiting for the next assignment and the inefficiency of traveling back to the command post. They can claim a work order and coordinate directly with survivors. When a work order is complete, they can claim another within the area they are working. This improvement alone likely results in more work being completed more quickly. It may also minimize attrition since volunteers can see what remains to be done and are empowered to step in and perform the work. Volunteers also contribute to the big picture by submitting new work orders based on needs assessments done in the field and updating the status as they claim and complete work. Another key advantage is that volunteers staffing the Crisis Cleanup and the local 2-1-1 help lines can work directly with survivors to create work orders that are shared across organizations. There is no guarantee of assistance, but sharing maximizes visibility of the request and optimizes chances that someone will claim and complete the work order. Finally, this system captures and reports on both the current needs of the community and the support provided by relief organizations in a unique and comprehensive way. During the immediate response and recovery efforts, this comprehensive picture is potentially valuable for identifying important trends and gaps that require the shifting of resources and creative community solutions. Longer term, detailed damage information may help communities plan better for future events and may help researchers better understand the complex relationship between social decision-making and the impacts of a disaster.

Future Enhancements

The developers of Crisis Cleanup have identified several ways to extend Crisis Cleanup in the future. For example, Crisis Cleanup currently only works through a web browser and the system would be more flexible if it could also be used as a smart phone or tablet application in the field. The underlying database design and analytics tools also need improvement. Additionally, the developers want to create an application programming interface (API) to support communication with other programs and systems involved in the response effort. This

API would also provide the ability to import data from other sources directly into Crisis Cleanup and export cleanup information for integration with other maps and websites. Developers would also like to add a phone interface that would allow survivors to log requests for assistance and check on the status of the requests themselves.

Moving forward, the creator of Crisis Cleanup wants to construct a trusted relationship directory that is collectively maintained and work through issues related to data sharing so that other agencies and collaborators can view the appropriate level of information related to the relief effort. He would also like to explore extending Crisis Cleanup for longer-term recovery and rebuilding operations.

Challenges

Crisis Cleanup is an open-source software package intended to help survivors of a disaster. Its use is free to volunteers and organizations contributing to the relief effort. However, the nature of its use precludes monetization. Members of CrisisCleanup.org have raised limited funding from within the VOAD community to support the tool, but not enough to accomplish some of their broader development objectives. It is unlikely to attract government funding because Crisis Cleanup starts where the government scope of responsibility ends. While the services may be invaluable for a disaster survivor, it does not save the government money, nor can Crisis Cleanup provide any sort of guarantee about services provided. Crisis Cleanup grew out of grassroots efforts from within the VOAD community and it remains to be seen if this application can attract the sponsorship it needs to grow into a more robust solution.

Future Research

We see Crisis Cleanup as a potential rich site of study to understand how online tools enhance on-the-ground coordination of volunteer work. More research is needed to understand both the strengths and weaknesses of recovery work managed through a virtual command post model. Crisis Cleanup appears to work best when disaster spans a large geographic area and there are many relief agencies responding. However, the completion rate for work orders can vary widely, which is illustrated by two recent disasters. Hurricane Irma and Hurricane Harvey were both highly destructive events that covered a wide geographic area and prompted strong response from the VOAD community. However, the reported completion rate for claimed work orders for Hurricane Harvey was considerably higher than it was for Hurricane Irma. As a next step, we plan to perform a detailed workflow analysis of these two events as well as interviews with users of Crisis Cleanup to better understand the factors that influence the completion of work.

CONCLUSION

Crisis Cleanup is an innovative grassroots solution that explores the use of online tools to enhance the productivity and coordination of highly local volunteer work in response to a disaster event. It strives to enhance rather than replace inter-organizational communication and collaboration. Successful use on over seventy-five disasters demonstrates that the use of a carefully designed inter-organizational information sharing and collaboration platform is a critical component of a successful on the ground response.

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Identifying Traces of Resilient Performance in Incident Management Systems using Episodes

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ABSTRACT

In order to cope with increasing complexity of catastrophic disasters, resilience is considered an essential capability of an incident management system (IMS). As resilience is manifested during systems operation, a naturalistic observational study was conducted to understand how resilient performance dynamically takes place in this domain. The study results were presented using the concept of episodes, each of which uncovers a trace of such resilient performance following an information input called an inject. The episode analysis also facilitated the identification of complex and dynamic interactions among human and technological agents to satisfy work demands, representing work-as-done (WAD) in large-scale emergency response operations.

Keywords

Resilience Engineering, Incident Management, Episode Analysis, Cognitive Systems Engineering.

INTRODUCTION

Adverse events such as technical, natural, or civil disasters have revealed limitations in managing risks from various threats and have challenged society's capabilities of preparing for, responding, and recovering from such events (Mendonça, 2007). This challenge has been reflected through responses to several recent disasters, for example, the Deepwater Horizon oil spill in 2010 (Birkland & DeYoung, 2011; Sylves & Comfort, 2012), Hurricane Katrina in 2005 (Comfort, Birkland, Cigler, & Nance, 2010; Wise, 2006), and September 11 World Trade Center (WTC) Attack in 2001 (Comfort, 2002a, 2002b). In order to address these challenges and reduce impacts of the adverse events on human lives, social and environmental infrastructure, various incident management systems (IMSs) were developed and put in operation. Generally, an IMS is designed to manage adverse events of varying scales that involve multiple agents, agencies, jurisdictions, organizations and disciplines. These events also include emergency, disaster, catastrophe and even planned events (e.g., sports games). Moreover, an IMS is responsible for all the mission phases such as prevention, protection, mitigation, response and recovery (Keybl, Fandozzi, Graves, Taylor, & Yost, 2012).

An IMS is a complex socio-technical system (STS) in which human practitioners (e.g., incident managers and operators) work with technological artifacts within and across boundaries of a social structure (Qureshi, 2007). The boundaries of an IMS may lie across organizations (i.e., one fire department to another), geographical areas (i.e., from rural to urban area), dissimilar cultures (i.e., bureaucratic to generative (Westrum, 2004)), and time periods (i.e., day shift to night shift) (Carayon, 2006). Within the IMS, there are complex and dynamic *'interactions'* among human and technical agents, hazardous tasks and a built/natural environment that surrounds them (Wilson, 2000).

In order to address the increasing complexity of STSs, Resilience Engineering (RE) has emerged as a new safety

paradigm (Hollnagel, Woods, & Leveson, 2007). RE views success and failure as different outcomes of the same system's adaptation process of coping with real-world complexity (Dekker, Hollnagel, Woods, & Cook, 2008). Resilience, however, does not simply mean changing system's performance reactively given a certain demand. Resilience is "the intrinsic ability of a system to adjust its functioning prior to, during or following change or disturbance, so that it can sustain required operations under both the expected and unexpected conditions" (Hollnagel, 2011, p. xxxvi).

Disasters and catastrophes impose severe disturbances that require continuous change in incident management performance. In this context, resilience is considered a crucial capability of an IMS during emergency response and recovery (Boin, Comfort, & Demchak, 2010; Caldwell, 2014; Comfort et al., 2010; Harrald, 2006).

BACKGROUND

There have been continuous efforts to conceptualize and define resilience in incident/emergency management in the literature. Weick (1993)'s seminal work offered four dimensions of resilience that facilitate sense-making through a scrutiny of a wildfire at Mann Gulch, Montana in 1949 that took 13 smokejumpers' lives. Those four potentials are improvisation, virtual role system, attitude of wisdom, and respectful interaction. Improvisation means a capacity to rework knowledge in a novel way for problem-solving. Virtual role system helps maintain a role structure in individual's mind if a certain role becomes unavailable. Wisdom is an attitude that doubts exiting skills, belief and knowledge whether these are true and valid. Respectful interaction includes respecting other's report as well as one's own perception and reporting honestly to others. Subsequent work was conducted in more specific aspects of emergency response operations: role performance, resource management and communication/ information management.

With respect to roles in disaster responses, Mendonça and colleagues identified characteristics of improvised cognitive and behavioral events in the bombing of the Alfred P. Murrah Federal Building in Oklahoma in 1995 and the attack on the World Trade Center (WTC) in New York in 2001 (Mendonça et al., 2014). The results of this study showed that about 10 to 13 percent of the emergency responder's behaviors were improvised, and procedural improvisation that refers to a departure from a normally prescribed way of performing a role was most predominant. Lundberg and Rankin (2014) unveiled instances of role change, negative impacts of taking new roles and ways to improve resilience. For example, the authors suggested that it would be necessary to include improvised roles during regular exercises to foster resilience skills (Lundberg & Rankin, 2014).

With regards to resources management efforts, research was focused on an adaptive use of materials. Kendra and Wachtendorf (2003) conducted a timely on-site data collection after the WTC attack to capture elements of resilience in New York City's Emergency Operations Center (EOC). The authors examined how a new EOC had been reestablished and run after the initial EOC, located inside the WTC, was demolished. According to Kendra and Wachtendorf (2003), the elements of resilience in that restitution process include adaptive performance of incorporating resources, for example, physical facility, personnel, equipment and supplies necessary to operate the EOC. Webb (2004) found out that changing equipment usage was the second most common behavior following procedural change, supporting Mendonça and colleagues (2014)' study. Mendonça and colleagues proposed two types of instances that entail resilience when: 1) the use of available resources at-hand is blocked, and 2) necessary resources are not available (e.g., too far to obtain) (Mendonça, 2007). In order to address this challenge, the authors developed a decision support tool that is able to generate alternative resources and investigated its effect on 5-person team's resource allocation decision-making processes (Mendonça, Beroggi, & Wallace, 2003; Mendonça & Wallace, 2007).

Another major process of emergency response organizations is communication and information management (Comfort, 2007) A study performed by de Carvalho and colleagues (2018) highlighted how standard operating procedures of Brazilian emergency responses framed as work as imagined (WAI), are realized into actual practices or work as done (WAD). The study revealed that the WAD is the outcome of team adaptation through communication among team members under complex emergency situations (de Carvalho et al., 2018). Rankin and colleagues (2013) identified communication and information flow of improvised role incumbents of a Swedish Response Team and presented such work flow in several episodes, a chain of communication sub-events that are bound together for a common meaning.

The existing literature on resilience in the emergency domain indicates that, for large-scale incident management operations, activities such as management of resources, information or communication, are distributed among multiple actors, and developed with their respective manner and tempo (Woods, 2017). Thus, interactions among different human and technological agents within an IMS are an essential aspect of a system's resilience (Nemeth, 2008). To that end, this study aims to use episode analysis to model a continuum of such interactions that take place in the course of satisfying demands from an incident.

METHOD

Research Setting

The present work employed a naturalistic observational study in high-fidelity emergency response simulation provided by the Emergency Operations Training Center (EOTC), managed by Texas A&M Engineering Extension Service (TEEX)[1]. EOTC training programs impose realistic work demands on participants allowing for observations of resilient performance in the context of a realistic emergency response. Each training course invited 40 to 45 trainees under the supervision of about 20 highly skilled instructors in a simulated Incident Command Post (ICP). Two training courses were selected for data collection: one in June and another in August, 2017.

Participants

Participants in this study were recruited on the first day of a scheduled training course in the EOTC. A majority of participants had moderate to high level of emergency operations experience. For the first observation, 39 out of 44 trainees consented, and 32 out of 46 consented to participate in the second observation. All instructors participated in both studies. Participants were diverse in terms of their discipline (e.g., firefighting, law enforcement, emergency medical) and their geographical location (e.g., different States and municipalities). The research protocol obtained pertinent approval from authors' Institutional Review Board (IRB) for the compliance with research ethics and for the protection of human subjects' right (IRB No.: IRB2016-0489D).

Equipment, Facility and Scenarios

The training facility is equipped with laptop and desktop computers, telephones, printers, photocopiers, white boards, large displays, microphones and two meeting rooms. In particular, a proprietary intranet software named EM*ES (Emergency Management * Exercise System) was used to help participants communicate each other (e.g., bulk email, event log, incident map). Overall, four incident scenarios were given during each training course: three half-day sessions and one full-day session. Three half-day scenarios were identical for both observed courses, namely: Columbia State University (mass shooting), Needland Tornado (hurricane), and El Diablo (a plane crash into a stadium). The full-day scenario differed (the first study: earthquake, the second study: civil disturbance). In order to make these exercises more immersive, experienced and skilled role-players provided 'injects' that were pieces of virtual incident information fed into the IMS (e.g., fire containment status, number of casualties, request for perimeter setup, a report from field observation, and a call from the mayor). Scripts for injects were prepared in advance but they were often adapted to match with situations as they evolved.

To collect sufficient data, multiple technologies (e.g., iPad application, camcorders, voice recorders, screen capture tool) were used to record interactions among participants and technical artifacts. These interactions were observed and coded with respect to 'three C's': Context, Content and Characteristics as shown in Table 1.

Table 1. Three C's of Interaction

Context			Content	Characteristics	
Initiator	Receiver	Technology		Frequency	Duration
Who initiates an interaction?	With whom?	Which technology is used in that interaction?	What is communicated for what purpose?	How often does the interaction occur?	How long does the interaction occur?

Materials and Procedure

Participants attended a simulated incident management training course for three and a half days. In the morning of the first day, an instructor held an instructional session to provide participants with training tutorials, objectives, expected learnings, and overall incident management and planning processes. The instructor also explained roles and responsibilities, and forms and technologies to be utilized. After lunch on the first day, the first incident scenario began at 1 p.m. Initially, another instructor gave the participants an incident briefing for the scenario and assigned them to each of five sections of an ICP, namely, Command, Operations, Planning,

[1] For more information, visit http://teex.org

Logistics and Finance/Administration. The main scope of the study was the Planning Section because it was primarily in charge of communicating incident information within the ICP. Once the participants were gathered at each section, two other instructors provided specific tutorials for the objectives and functions of the section and the description of each role. The instructors gave additional instruction when the participants needed to learn how to use the software. Participants were encouraged to ask questions from instructors and also the instructors often approached participants to instruct role performance or to check in for the work progress. In the morning of the second day, the second incident scenario began at 8 a.m. without providing any additional instructions.

At the first scenario, an instructor presented an incident briefing for the different scenario and assigned the participants to different sections. The assignment was not random because the EOTC staff considered assigning them to a different section from the previous sessions to increase the level of exposure to various roles. Upon the assignment, instructors gave specific tutorials for the section and each role in the section. This process occurred in a very similar way for the third and the fourth scenarios. Camcorders and screen capture recordings were started before the training session began not to interrupt the training. Voice recorders were put on participants' vests once their roles were determined. Four to six trained observers (three undergraduate and three graduate students) conducted direct observation after roles were assigned. Observers recorded interactions between participants, both verbal and material as well as working with technical artifacts.

Data Analysis

Multiple audio/video recordings obtained from each exercise were synchronized using Adobe Premiere Pro CC 2018. Next, trained undergraduate research assistants began transcribing participant's actions and communications. The transcribers also measured time taken for each episode, an initiator and a receiver of such actions and communications, and a technological device used in these where applicable. The iPad application was used to capture moments where such episode began and finished.

To analyze communications and interactions that occur among multiple agents, an episode analysis similar to (Korolija & Linell, 1996) is used. In incident management operations, such episode is translated into a series of actions from the reception of an incident data input to the dissemination of the processed information to other members. Figure 1 depicts how an episode can be composed of interactions among different human and technological agents. It involves human-to-human interactions that have direction (from a white box to a black solid box), duration and frequency of those interactions, and a type of technology used in that interaction. In addition, this episode incorporates actions performed by single personnel with a technological device (a gray box). Consequently, episodic time (T_e) is obtained by measuring time when an inject is given (T_i) and time when its related demands are met (T_d). The outcome of these episodes is the dissemination of processed information displayed in an event log. The number and quality (e.g., accuracy and currency) of information threads in that event log are also used to assess the system's performance output.

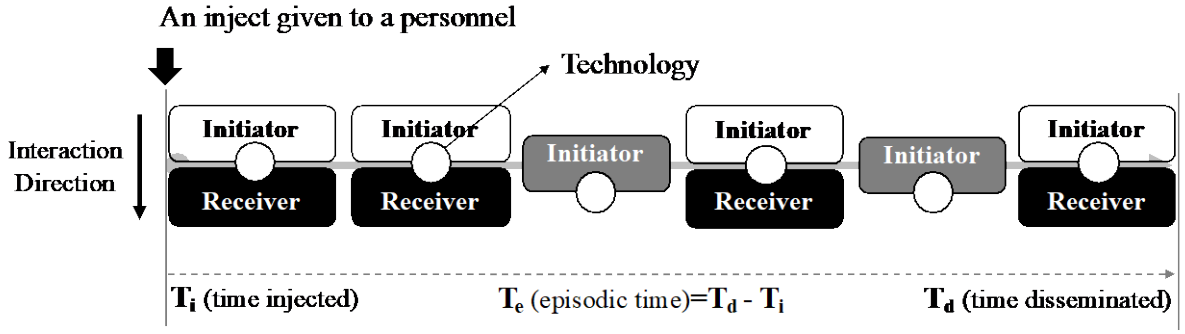

Figure 1. Schematic of Episode Analysis

PRELIMINARY RESULTS

While transcription and episode analysis are ongoing, in this paper we present two episodes to discuss our theoretical model of emergency response episodes. Figure 2 and Figure 3 respectively illustrate each episode following an initial inject given to Information/Intelligence Unit Leader (I/I Lead) in the Planning Section. During the exercise of El Diablo (Figure 2), a virtual character, role-played by a skilled staff, reported a field observation that contains incident information (e.g., location and consequence of the incident). This communication occurred via Telephone. Next, I/I Lead took some follow-up actions, for example, taking a note

of what he heard from the field observer (on Paper), communicating it with another I/I agent (Face-to-face), and making copies of what he wrote down (Photocopier). Following this, I/I Lead delivered each of the copies (213 GMs[2]) to other roles that he considered may need such information such as Documentation Unit Leader (DOCL), Situation Unit Leader (SITL), Public Information Officer (PIO), Operations Resource Specialist (Ops Res.), and Operations Section Chief (Ops SC) through various technologies and artifacts. In another exercise of Needland Tornado (Figure 3), a similar pattern was observed.

For example, following an initial field report that notifies degree of damage in different locations, I/I Lead had a verbal dialogue with another I/I agent, printed copies of the field report (213s), and handed them over to other roles. These patterns are marked as dotted boxes (e.g., red, blue, green and purple) that indicate sub-episodes. For example, after having conversation with a field observer (red), I/I Lead had internal communication within other I/I agents (blue). And then, I/I Lead made copies of a message that contain incident information (green), and disseminated the copies to other roles (purple). The episodic time was 11 minutes and 58 seconds for the first episode and 23 minutes and 35 seconds for the second one. This indicated that the second episode was twice as long as the first one. With respect to frequency of interactions, eight human-to-human interactions among eight roles and two human-to-technology interactions were captured for the first episode whereas 12 human-to-human interactions among 10 roles and one human-to-technology interaction were identified for the second episode.

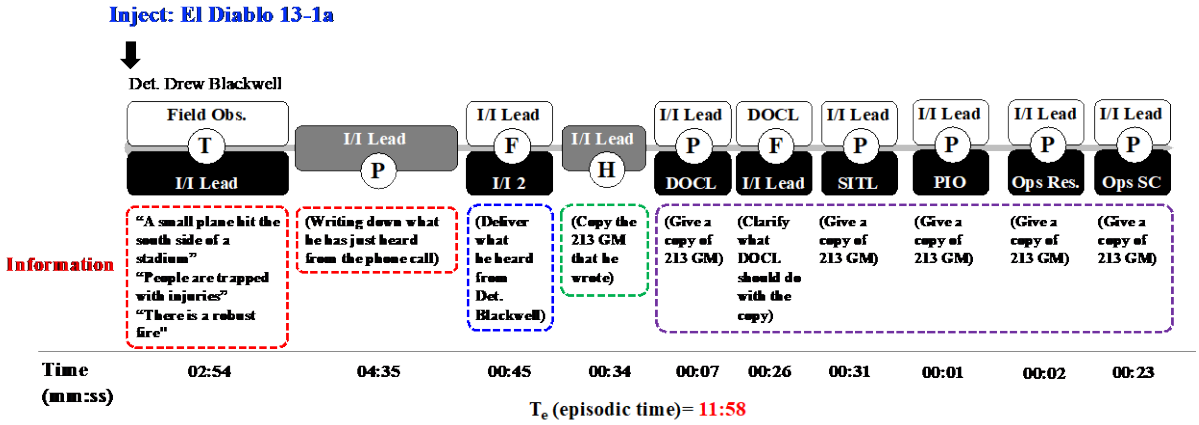

Figure 2. Episode after Inject El Diablo 13-1a

Note: a white box: initiator, a black box: receiver, a circle in the middle: technology, a gray box: working alone, a dotted box: sub-event with a recurring pattern.

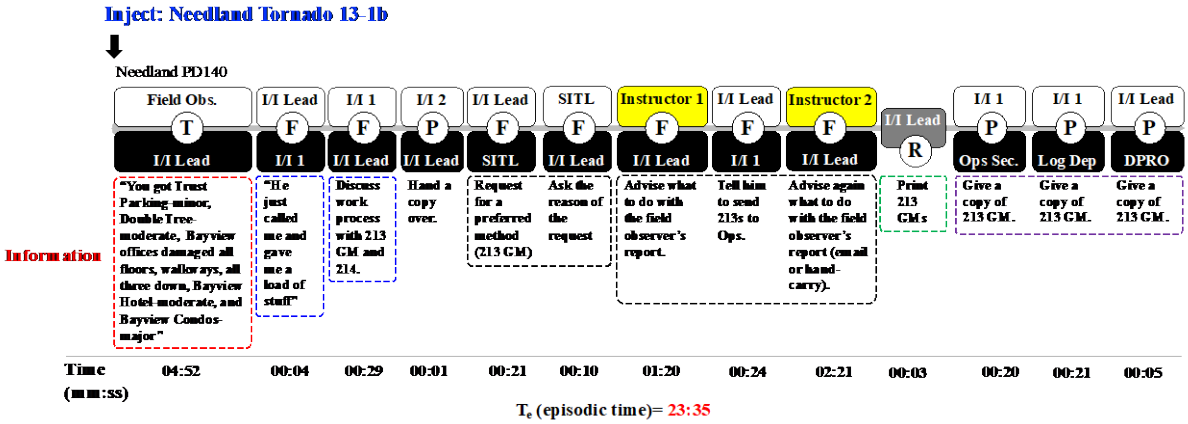

Figure 3. Episode after Inject Needland Tornado 13-1b

Note: a white box: initiator, a black box: receiver, a circle in the middle: technology, a gray box: working alone, a dotted box: sub-event with a recurring pattern.

[2] A 213 GM is one of standard forms included in FEMA Incident Command System (ICS) which is used to document incoming messages.

DISCUSSION

Tracing Resilient Performance

The findings from the current study showed a non-linear, dynamic process of 'compensating' demands within an incident management team of distributed multiple roles. As Woods (2006) noted, resilience of a system may not be manifested until it encounters disruptions, which may fall outside design capacity (Woods, 2006). Hence, the episode analysis was conducted to understand the information handling function of the IMS following an inject composed of various incident data. From the preliminary extraction of two episodes, some similarities and differences were identified. The major difference between two episodes is that I/I Lead in the second episode interacted with SITL and two instructors to discuss a preferred method of communication on whether it should be emailed or hand-carried. This might be reflected in the longer episodic time and a higher number of interactions. In a similar vein, the measures in episode analysis may show promise as a diagnostic method to investigate interactions in a team environment in which multiple human and technological agents function together.

Measuring Resilient Performance

Resilience is known to be a difficult concept to measure, and even systematic attempts to measure it in unplanned-for situations (e.g., disaster, catastrophe) were severely limited (Mendonça, 2008). Features of episodes, for example, time taken to cope with injects, duration and frequency of actions and communications provide measures for resilient performance of an IMS. It is important to note that being resilient does not mean making faster and shorter paths of compensation of work demands (Woods, 2006). Rather, it means how the system absorbs a shock, reorganizes its functions and how interactions occur across different levels to achieve system goals (Mendonça, 2008). Hence, our suggestion for future research is to characterize differences in those work demands as well as in subsequent organizational behaviors. Furthermore, it is worth understanding how four processes of resilience, namely, Monitoring, Anticipating, Responding and Learning (Hollnagel, 2011) occur in incident management operations.

Limitation

While this study is the first attempt to systematically analyze resilient performance following an external input to an IMS, several limitations need to be addressed in the future research. First, in this study, data were collected in a simulated setting. While EOTC environment is similar to real-world emergency response operations in many aspects, evaluating models of derived from this high-fidelity simulation setting against real response scenarios is warranted. (Mendonça, 2008), it is necessary to validate, or at least support, such findings with real-world evidences. In addition, more episodes are required to provide more reliable and generalizable findings that enable statistical analyses. Furthermore, the present work did not examine the effect of different technology on the information handling performance. Work is in progress to examine how different technologies are used in those episodes.

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The *Digital Crow's Nest*: A Framework for Proactive Disaster Informatics & Resilience by Open Source Intelligence

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ABSTRACT

The research on technology-assisted crisis management has primarily existed for two decades since 9/11. Although, the focus of technology research has been centered around tools to assist the response phase after a disaster. There has been a lack of emphasis on the role and design of technologies to assist the other phases of the crisis management cycle, particularly preparedness and mitigation phases to lead towards the vision of building resilient communities. In this paper, we first identify resilience characteristics of a community from the prior literature. We then analyze a co-occurrence network of concepts in the ISCRAM publications to validate the gap in relating technologies to resilience and conduct an indicator analysis of factors for proactive disaster informatics via a case study of recent disaster. Our analysis leads us to propose a conceptual framework "*Digital Crow's Nest*" based on Open Source Intelligence to improve the technology design for community resilience.

Keywords

Resilience, Emergency management, Crisis Management, Indicator Analysis, Open Source Intelligence.

INTRODUCTION

When standing to watch on a ship, a sailor looks both internally and externally to assess risk to the vessel. Internally, a watch will assess the ship's systems, status of the crew, and the integrity of the vessel. Externally, the same watch monitors navigation, the relative location of other vessels, broadcasted weather conditions, visible weather conditions, and the sea state. A Crow's Nest is the highest position on a sailing vessel where the watch has the broadest view of activity (Rouach and Santi, 2001). This long view in conjunction with continually monitoring of the immediate environment, allows sailors the greatest vantage point in their attempt to be proactive regarding the safety of the ship. Any change in the normal status is assessed for risk to the crew and vessel. When the watch stands down, all pertinent information is shared with the next watch during transition and the process begins again. This analogy has profound implications for disaster informatics to prepare emergency services of future resilient communities.

Consider the most active year for natural disasters in its history — 2017, the US territory of Puerto Rico remains in a state of crisis after hurricane Maria devastated the island in September of 2017. When the hurricane struck the island it had already endured two near-misses in the previous month. While it is tempting to lay blame on hurricane Maria alone, there were numerous factors that contributed to Puerto Rico's already weakened state. In 2006, the US Congress ended tax breaks that helped Puerto Rico's struggling economy (Greenberg and Ekins, 2015). Given the loss of income and the loss of 10 percent of its population fleeing to the US mainland for employment during the Great Recession, Puerto Rico was unable to fiscally recover and took on more debt as it tried to regain control over its finances (Alvarez, 2017). Such factors are often unaccounted in the disaster informatics solutions.

Likewise, during the time prior to hurricane Maria, the island was facing a problem of aging infrastructure. Fallout from the financial crisis resulted in the electrical grid - already known for higher rates, slow repairs, and minimal maintenance - not being properly maintained (Vives and Hennessy-Fiske, 2017). As a result, the Puerto Rico Electrical Power Authority declared bankruptcy in July 2017 ('Puerto Rican Power Utility PREPA Files

For Bankruptcy', 2017), months before the series of hurricanes passed through the Caribbean. And while a nearly Category 5 hurricane will always pose a heightened level of risk to any area, knowledge of certain areas of Puerto Rico's overall state might have provided a greater level of awareness where the risk was greatest throughout the island. A severely weakened electrical grid was all but destroyed with little skilled labor to repair it and no funds for replacement, hindering the islands' resiliency and capability for recovery. As of November 2017, direct deaths from the hurricane stood at 54 persons, while indirect deaths as a result of the cascading effects are speculated to be over one thousand (Santos-Lozada, 2018).

Given the state of the island's finances, labor pool, infrastructure, and the persistent issue of its location to the US mainland, by summer of 2017, Puerto Rico was already exposed to danger where any of the much weaker hurricanes or even tropical storms might have caused the similar catastrophic outcome. As Wybo and Lonka (2002) note, "emergencies become crises if the system's resilience and emergency preparedness is insufficient to manage the event response and recovery." Cracks in Puerto Rico's systems were largely known and the data was immediately available. The point of failure lies in no one taking a comprehensive look at the proverbial signposts and assessing the overall risk to the island and its citizens.

While risk management and analysis has been discussed in crisis management literature, the crisis informatics (Palen and Anderson, 2016) research has mainly focused on the use of ICT technologies for better emergency response, understanding public behavior in the response, and the design of efficient response technologies. The areas of technologies range from big data analytics to human computer interaction including information and knowledge management, machine learning, information retrieval, data mining, network science, social media mining, simulation and modeling, and information visualization across a genre of structured to unstructured big data sources (Castillo, 2016). Likewise, the existing tools are available as open source as well as proprietary emergency management platforms. However, the intended use-case of such existing technologies and tools has been centered around response and relief coordination after a disaster event (Hristidis *et al.*, 2010; Purohit *et al.*, 2013; Imran *et al.*, 2015; Li *et al.*, 2017; Reuter and Kaufhold, 2018). There is a lack of research interest on technologies to assist different phases of crisis management and also evaluating the cross-phase uses of the response-driven technologies, particularly, as exemplified by the illustration of hurricane Maria, there is a lack of technology use to create more resilience for a community.

If resiliency is the process and ability of a community to restore function after a disruption or disaster event (Patel *et al.*, 2017), then forewarning of the potential impacts of a crisis event is critical to the endeavor of recovery. Community resilience has characteristics that are not just specifically related to the long-standing research domain of risk management but rather have a relation to a comprehensive set of domains that also incorporate the elements of technology design. Therefore, this paper seeks to show that a proactive awareness of ground conditions and risks as "intelligence" prior to any inclination of a potential crisis is a part of the preparedness process and contributes to a community's resilience. Such awareness and intelligence can be thought as a foundation towards designing technologies for resilience. This is distinct from the phenomenon of situation awareness studied in recent years with a primary focus in the literature as a tactical, reactive awareness to crisis events after they occur, and not predictive. To this end, we pose the following research questions:

RQ1. What is the current state of the art regarding the technology-assisted community resilience and preparedness in the disaster informatics research area?

RQ2: What is the role of open data sources and technologies in preparing the emergency services of the future resilient communities?

To address RQ1, we demonstrate the lack of emphasis on the role of technology for resilience and preparedness by performing co-occurrence network analysis of concepts in the scholarly data of all publications in the ISCRAM conference series on crisis management. For RQ2, we conduct an indicator analysis — a structured analytical technique — using open source data to help determine the level of risk or emergency prior to the onset of a crisis.

The rest of the paper is organized as follows. We first discuss the background on resilience characteristics for a community and open source intelligence, followed by our scholarly data analysis method to analyze the existing literature on resilience. We then describe an indicator analysis with a case study and present the design of our proposed framework "Digital Crow's Nest".

BACKGROUND AND RELATED WORK

We have two focus areas in the related work for this research: community resilience and open source data.

Community resilience has a comprehensive coverage in terms of the range of areas it is connected to and those required to understand it holistically (Patel et al., 2017; Comes and Van de Walle, 2014), including public

communication and risk monitoring, local knowledge, community networks and relationships. While there is no common, agreed upon definition for resilience across the world and the different practitioner and research areas, it is ".. a highly sought after by disaster-response professionals, government officials, and academics. .." (Patel et al. 2017). The key goal of community resilience identified across the different definitions focuses on increasing local capacity, social support and resources, and decreasing risks, miscommunication, and trauma. The common characteristics identified across the different definitions for resilience include a proactive approach to policy, governance, community management and lastly, the information and communication technologies. Although there is a gap in understanding the design of such ICT technologies and how the state-of-the-art methods for data sourcing and analytics can support such design. It is essential to understand the technology design requirements that would serve the key characteristics and goals of community resilience.

Open-source data has recently become a state-of-the art resource to discover hidden patterns and exploit intelligence that can help address the technology design needs for resilience. Particularly, Open-source Intelligence (OSINT) is a national security term whereby OSINT is relevant information collected from "overt collection." (Lowenthal, 2003) That is, any publicly available source collected and used in an intelligence context. For the purpose of this study, we refer only to data that may be collected via the World Wide Web. Sources range from traditional news media and their websites, social media, commercial data, professional and academic publications, government reports, or any verifiable source identified publicly or online.

Information from online data can be extracted and assessed with regards to any intelligence question. Despite certain inherent risks such as issues of trust and credibility of sources, the vetting process of most sources aside from social media is routinely accomplished in a more objective ways in various intelligence-driven processes. Thus, we argue that the open-source data analytics can be leveraged for timely informing or at least partially meet the needs of the technologies for community resilience.

Table 1. Analytical summary of the dataset collected from ISCRAM digital library for the period of 2004 to 2017.

	Counts
Number of library records with abstract metadata	1323
Number of nodes and edges in the concept network	250 concepts, 13956 relations
Number of modular communities in the concept network	5
Illustrative top-ranked concepts per community (ranked by PageRank score; colored in consistence with figure 1)	c1: {*ict, city, preparedness, hazard, power, earthquake, natural disaster, threat, communicate, resilience*}, c2: {*disaster management, gis, geographic, behavior, humanitarian, automatic, twitter, situational awareness, volunteer, technological*}, c3: {*cis, emergency, environment, crisis management, emergency management, simulation, fire, awareness, architecture, adapt*}, c4: {*efficiently, casualty, casualty incident, organisational, mass casualty, mci*}, c5: {*public, responder, mobile, sensor, phone, alert, timely, deployment, internet, video*}

DATA AND METHODS

We take a mixed-method approach in this paper to address our research questions on the role of technology for designing resilient communities. First, we present the co-occurrence network analysis of concepts in the ISCRAM publications. Second, we describe an indicator analysis via case study of Santa Rosa wildfires to discover the patterns of information needs and available indicators in the open data.

Scholar Data Analysis: Concept Co-occurrence Network

The ISCRAM library is a premiere avenue for disseminating research on information systems for crisis management. So, we collected all the publications from its digital library. Table 1 provides a summary of the

collected dataset. We extracted all the abstracts from the collected publications and then, constructed a concept set of interest by removing all the stopwords, extracting both unigrams and bigrams with minimum frequency 3, and ranking terms by the popular *tf-idf* measure of term importance in a document corpus. We then created a co-occurrence based network for the nodes as the top ranked 250 concepts (for computational tractability, given the large number of edges) and used Gephi open-source tool for network analysis.

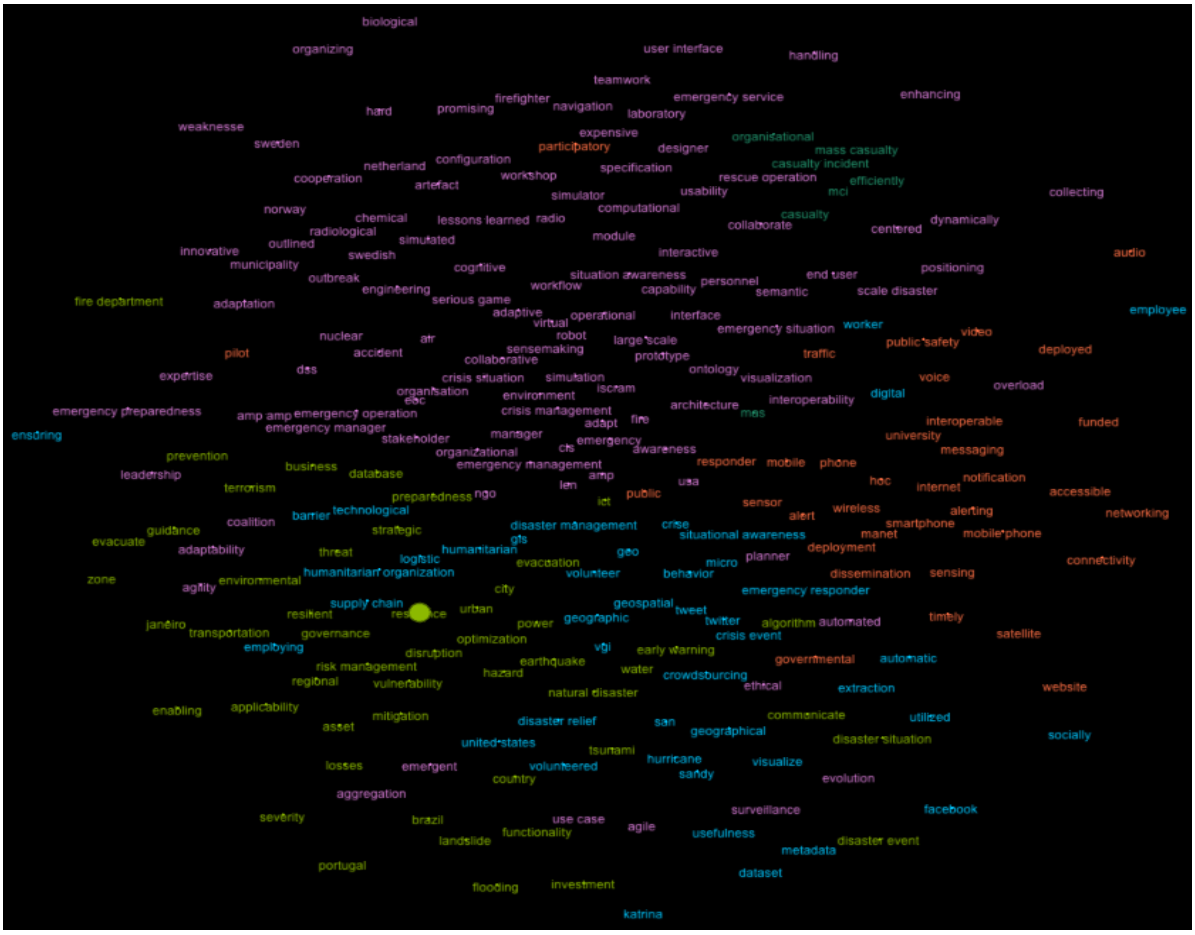

Figure 1. Concept communities detected from the co-occurrence network extracted from the ISCRAM publications. Green colored community contains the resilience related concept and depicts a lack of focus on discussing concepts of technology design and development for resilience.
[color view recommended]

Measures:
We adopt the following network analysis metrics (Newman, 2010) for this study: a.) Modularity of network for community detection, b.) PageRank of a node for concept importance. Modularity measures the strength of dividing a network into modules or clusters, which implies that high Modularity networks will have dense communities separated by sparse connections across the communities. PageRank is a variant of eigenvector centrality of a node that computes the relative importance of a concept node in the network, implying such high centrality nodes will have a critical role in communication within a community. We used these two measures to generate communities of concepts and rank concepts within the communities by importance as shown in figure 1 and table 1.

Observations:
We can observe a number of patterns in the co-occurrence network (see figure 1 and table 1). First, a visualization of detected communities shows that for the 'resilience' concept (member of the green colored community c1), there is a lack of concepts related to technology factors in its community c1, while all other communities represented by other colors have some aspect of technology either as a solution or a barrier. Second, the identified top concepts connected to the resilience include 'preparedness', 'threat', 'power' and 'city' as well as 'risk management', 'investment', and 'vulnerability', which as anticipated, forms the foundation for the discussion of resilience in the existing literature. However, these concepts primarily relate to

the management, policy, and governance domain than actually the technology design and thus, support our argument for the need to understand technology factors associated with the resilience. Next, we conduct an indicator analysis in the context of a recent disaster.

Indicator Analysis

Indicator Analysis (IA) is a structured analytical technique used in Intelligence analysis by US national security agencies (Heuer & Pherson, 2015). The method tracks and maps pertinent historical and current data in the effort to expose patterns and trends that indicate a significant shift in an area of interest. When employed successfully, the technique reduces biases and provides documentation for forecasting events.

IA develops a matrix for analysis that includes scenarios, categories, factors, and indicators (explained next). The matrix is dynamic and fluid; while scenarios and categories may not often change, the factors and indicators are persistently evolving and therefore, require persistent monitoring and revision. This means that factors for analysis are unique by location, type of possible event/scenario, and may change according to the time of year.

A *scenario* is a customized estimate of possible specific outcomes that could result from a category for improvement or destabilization. Usually these scenarios are based on the current events of the factors involved in that category. Consideration of various types of scenarios to encounter are expected by an emergency manager that helps determine the broad categories of events used for consideration. A *category*, in essence, is the broad aspect of the potential scenario that merit individual scrutiny in order to understand the entirety of a situation. A *factor* is a subset or granular events occurring within a category. It is understood that factors and categories are interconnected, meaning that individual events can have cascading results affecting other categories. Factors are gleaned by the information extracted from online, publicly available sources. An *indicator* is a trigger event and can be assessed at geographically and temporally varied levels.

With regards to crisis management research, in the US, emergencies are managed locally, regionally, and also at a state or federal level. As such, indicators can be categorized according to their respective pertinence to a given level: local (micro), regional/state (meso), or federal (macro) level. Further, indicators can be assessed by strategic, operational, and tactical areas. Strategic indicators are those that cover large geographic expanse (national, global) and occur over long periods of time. Operational indicators are more limited to state and regional geographies and occur within weeks and months. Tactical indicators occur in immediate areas such as counties, cities, and towns, and are immediate - within hours down to minutes. Tactical indicators typically serve as triggers, meaning their mere presence can begin a series of events leading to an acute phase of a crisis.

Lastly, is the application of indicators. Indicators can be single events or actions within a factor that signify a major shift, affecting conditions in the rest of the category or other categories. Indicators can also be a combination of events that serve a similar function in conjunction with each other. IA is most successful when indicators are not only identified, but when a pattern of activity is also determined. Much of indicator analysis is not only looking for the specific indicators that will signal a potential upheaval, but tracking how factors change over time resulting in more useful trend analysis.

It is important to note that IA pre-supposes a crisis event. That is, IA is a proactive activity to monitor a current status in any context. At such time indicators show a pattern that a current state of something is changing, for example, a pending natural disaster, then the state shifts from proactive to reactive as the prodromal stage of a crisis evolves, thus requiring a different type of monitoring activity and response.

Case Study: Santa Rosa, California

We analyze the Northern California wildfire event using our IA method. An accepted assumption in the disaster management community is that no two crises are ever the same. The unique conditions of time, space, people, institutions, weather, and other factors associated with an event implies that each event requires its own set of unique considerations that inform the response. Because of this, events such as the wildfires that occurred in Northern California during October of 2017 would have required a radically different response from the wildfires that occurred in Southern California during December of the same year.

However, risk may be a factor that the events could conceivably share. When we consider the worst-case scenario prior to an event, it better informs prevention, preparation, response, and ultimately, resiliency of a community. We present the indicator analysis matrix in table 2 for the case of Santa Rosa and present the details of in-depth context of the indicators and activities happened during this event in the following.

Under normal conditions, California has a history of being well-prepared for fire events, however, evolving weather, climate, social, economic, and government conditions created an underlying risk that was not considered and resulted in the death of 42 residents, and the destruction of over 8400 structures. The cost of over

USD 1 billion in damages made it one of the worst natural disasters in California history (Winton and Grad, 2017). The town of Santa Rosa alone lost 32 residents and over 3000 homes.

Weather conditions. After experiencing severe drought for over four years, California received a respite during the winter of 2017 with significant amounts of snow and rainfall (Rogers, 2017b). Despite increasing reservoir levels throughout the state that alleviated much of the drought (United States Geological Survey, 2017), the period of a wet winter and dry summer, resulted in an abundance of dried-out, low-lying vegetation alongside 80 million dead trees. The dead trees had perished during the previous four years, creating a large amount of dormant fuel. During the early fall, wildfire season began as expected with several small fires occurring throughout the northern portion of the state (Sorci *et al.*, 2017). However, also as expected, the Diablo Winds, a hot, dry, offshore wind from the Northeast, began to sweep through the San Francisco Bay area (Shepherd, 2017). Above-average temperatures with extremely low humidity (Accuweather, 2017), combined with steady and persistent dry wind as well as the abundance of dried vegetation created ideal conditions for large-scale wildfires.

Climate conditions. During the last 25-year period, the effects of climate change began to show in the area. Parts of the wine country that did not traditionally experience wildfires began to see an increase, as winters became wetter and summers longer and drier. This change in climate shifted the fire danger zones throughout the area, placing Santa Rosa within one such zone. However, construction ordinances failed to address this shift, so new construction did not mandate fire-resistance building practices (Payne, 2016).

Social demographic conditions. Santa Rosa, California is a mid-sized city centered in California's wine country. Since the 1990s, the population of the city grew from 120 thousand to over 170 thousand by 2015. The population segment most increased was an older, upper-middle class to wealthy demographic (Payne, 2017). In the deaths that followed, the majority of the deceased in Santa Rosa were older persons who likely experienced a normal decrease in hearing and smell thus not likely alerted to or sensing the danger, and in the end, lacking the speed and mobility with which to escape their homes (Jaffe, 2017).

Infrastructure and governance conditions. The socio-economic conditions of the area led to a building boom during the early 2000s in both commercial and residential real estate. This also led to more residential houses being constructed on previously unoccupied land increasing the Wildlife-Urban Interface (WUI) significantly. Within and outside the city limits, this urban sprawl led to overdevelopment of the area and drove increases in real estate prices. The final result was a persistent affordable housing shortage for lower to middle class residents (Hart, 2017).

Economic conditions. A slow recovery of state finances from the Great Recession of 2008 resulted in budget cuts. Combatting ever-increasing incidents of wildfires increased the need for money (Gorte, 2013) to support prevention activities, just as state and local municipalities gutted prevention budgets (Board, 2017). Additionally, wage stagnation affected the profession of wildfire fighters as wages topped out, on average, at slightly above state minimum wage standards (Calfas, 2017). This happened while also reducing the funding for volunteer fire departments, which were established to help lower costs of firefighting.

Government conditions. Further exacerbating all of this, murky cooperation agreements between federal and state agencies, and local union infighting, resulted in large-scale disagreements over who is responsible for combatting which fire and at whose expense (Gabbert, 2017; United States Department of Agriculture, 2013 & 2015). However, when disaster strikes, and all grievances are temporarily placed on hold, there is still the reality that due to a high level of WUI, the different types of firefighting converge, and yet it became clear that wildfire specialists are not trained at urban firefighting and vice versa (Rogers, 2017a). And city firefighters are certainly not trained, staffed, and resourced at a level capable of managing multiple structures burning at once. Lastly, because of the systemic issues across the state at a time of numerous wildfires occurring at once, traditional resource sharing is impossible because resources are spread too thin (Calfas, 2017).

Taken into context all the factors prior to the wildfire event, Santa Rosa was already at a heightened level of risk simply requiring one or two triggering events to create an immediate, full-scale emergency. Over time, these same conditions also mark the city as incredibly non-resilient.

Observations

Considered temporally, Santa Rosa possessed different levels of concerns over strategic, operational, and tactical time frames. Strategically, or over the long-term, climate change, infrastructure, demographics, and economics all contributed to the level of loss and destruction, as shown in table 2. Operationally, or in the near-term, weather patterns and lack of resources both human and material contributed to a less-effective response. Tactically, the series of small wildfires converging due to a normal wind event created the trigger for the disaster to occur.

Nearly every indicator for risk and triggering events, were discoverable through open source data analytics methods with the potential for extracting relevant information for analysis with some uncertainty. The only indicator not meeting this criteria in this case study were the cross-training issues between urban and rural firefighters. However, now known, this is an indicator that could be incorporated into future risk assessment scenarios.

Table 2. Santa Rosa case study - Indicator Analysis. *[color view recommended]*

Category	Type	Level	Indicators	Risk Score	Source
Strategic	Climate	Macro	Climate Change	3	NOAA, NWS
	Government	Meso	State/Federal turf wars	3	News
	Government	Meso	Murky Cooperation agreements	3	USDA, NFS
	Economic	Meso/Micro	Rising Costs of Wildfire Protection	2	News
	Economic	Meso	Decreased volunteer fire fighter budget	4	News, State & Local
	Economic	Meso	Drained prevention budgets	4	News, State record
	Government	Macro	Interstate union fighting	3	News
	Government	Micro	Lax regulation on fire proof housing	4	Local Record
	Government	Meso	Overdevelopment - Wildland Urban Interface	4	NFS, CalFire, News
	Government	Meso	Interface issues with firefighter training	2	
	Infrastructure	Macro	Evolving fire zones due to climate change	3	NOAA, NWS, State
	Social	Micro	Aging Demographic	1	Census Data
	Economic	Meso	Lack of Affordable Hosing	1	News
	Economic	Meso/Macro	Professional Jobs - Minimum wage	2	Labor Statistics
Operational	Government	Meso/Macro	Capability - Resources spread thin	5	News
	Climate	Meso/Macro	Resevoir Conditions	1	USGS
	Weather	Meso/Macro	Drought	5	USGS, NOAA
	Weather	Meso/Macro	Temperature	4	NWS
			Risk Score	*54*	
Presense of Triggering Mechanism					
Tactical	Event	Meso	Multiple wildifres in the region	Y	CalFire
	Weather	Meso/Macro	Weather Event: Diablo Winds	Y	NOAA, NWS

5	Serious Concern
4	Substantial Concern
3	Moderate Concern
2	Low Concern
1	Negligible Concern

On the micro level, at the individual sites, the fires arrived unexpectedly in the middle of the night. The victims who perished were mostly aged and elderly, and lacking the ability to identify the risk or escape, thus it would be unfair to attribute hubris or optimism bias on their behalf. However, the reality of an aging demographic does require a strategic and operational level risk assessment on behalf of local and regional emergency managers.

The meso-level experiences most of the level of responsibility for risk assessment with regards to the Santa Rosa disaster. This is due to the fact that there are local and regional governments to consider and the majority of the risk indicators apply here. Issues in training, wages, agreements, housing, and budgets are all problems than can be remedied. In not only recognizing, but solving these issues, this risk level possesses the greatest chance at increasing resiliency. At the macro level also, state and federal governments, climate change, and weather conditions are also factors beyond control, thus, when it comes to resiliency, this level can only be recognized and have proper corresponding actions to mitigate the indicator.

Sadly, even after destruction from these fires, the onset of steady rain, and the process of rebuilding has begun. The town still conceivably exists in a state of high-risk should the underlying conditions that exacerbated the loss of life and property not be mitigated.

It is interesting to note here that social media did not appear as an early indicator data source. This may be attributed to the fact that social media possibly only becomes active when a known event will occur but is not yet occurred. It implies that active social media streaming may itself be an indicator for an event being no longer just theoretical and the volume itself becomes an indicator that a crisis may be in its prodromal stage.

Next, we propose a framework (see figure 2) as a key lesson based on the main observations of the two types of analyses — lack of research on linking technologies to community resilience and the need for proactively tapping open-source data for indicators of predictive intelligence for disaster informatics.

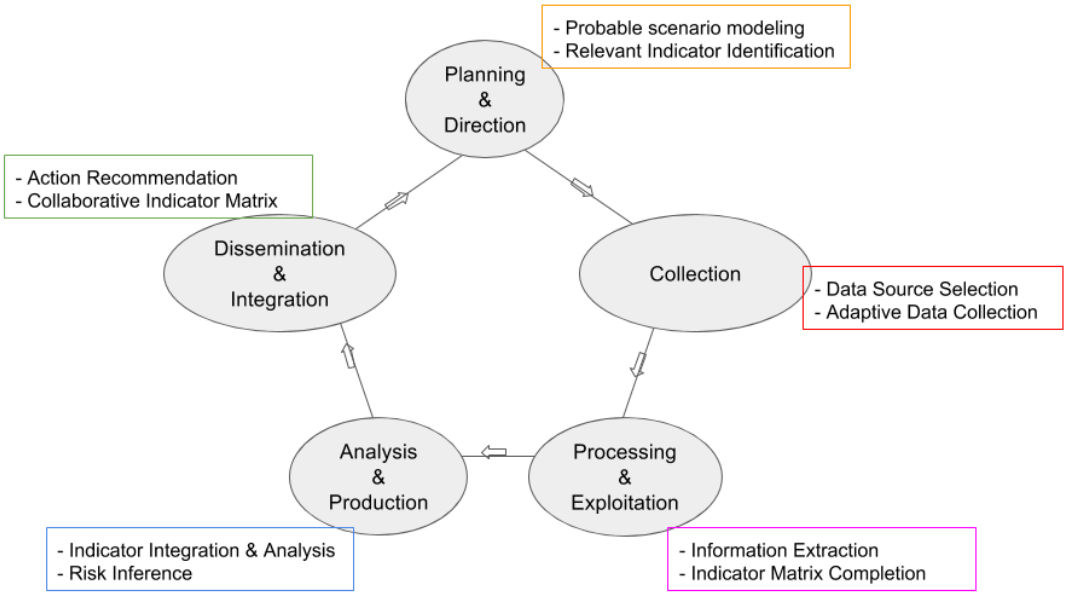

Figure 2. Summary of the proposed framework to inform technology design for community resilience.

LESSONS LEARNED: *DIGITAL CROW'S NEST* FRAMEWORK

The proposed framework for the *Digital Crow's Nest* seeks to assess a status of risk at any given time with or without the presence of an impending crisis. This allows emergency managers to proactively monitor and prepare for crisis scenarios in hopes of mitigating the effects of an emergency when it occurs. The framework proposes five areas of activity: Planning and Direction, Collection, Processing and Exploitation, Analysis and Production, and Dissemination and Integration.

Planning and Direction: This phase begins with analysts developing conceivable scenarios that a given area may experience. By considering past and probably future scenarios, this allows analysts to develop a list of activities to monitor. If there are arguments or biases over an issue, the indicators may help to depersonalize the argument by referring to a list of objective criteria.

Collection: Once indicators are established, analysts then identify appropriate sources for data and information. Digital collection methods of data is determined by the form of the data. The regularity of collection may be automated and the frequency determined by analysts. Given the growing open-source data sources, this component requires an adaptive design towards data collection technologies.

Processing and Exploitation: Within the indicator matrix, several steps must be accomplished before analysis. The data and information gleaned must then be categorized. Analysts must assign temporal aspect: strategic (long term), operational (near term), tactical (immediate). A short description of the type of data is also assigned (i.e. Government data, news report, crowdsourced/ social media, etc.). The level of data (micro, meso, or macro) refers to whether this is an issue within local, state/regional, or federal control. A short description of the indicator may assign or refer the title of the data report or news item. A risk score is then assigned on a scale of 1 (negligible) to 5 (Serious). Also, the source of the data will also be listed. Lastly, an analyst should determine which indicators serve as a triggering mechanism - an indicator, whose mere presence, serves as a main alert for trend analysis. Normally, a tactical level activity serves as this mechanism.

Analysis and Production: Analysis may be performed by the presentation of each indicator for manual assessment, or by an automated method where rudimentary risk is assigned and either confirmed or reevaluated by the analyst. The culmination of the risk factors should be constantly maintained, and a threshold risk score established. Any score above the threshold will indicate high exposure to the state of risk independent of any triggering mechanism. Presence of a triggering mechanism, regardless of the aggregated risk score, may also determine risk exposure.

Dissemination and Integration: Ideally, the indicator matrix should be maintained and shared across all levels of concern (micro, meso, macro) in a preferred form that is mutually agreed upon, however, a data-driven alert technique may be optimal as written reports lack the ability of online semantic integration and collaboration

across systems. As scores of information pertinent to a given level are presented, they may also be revised if a more nuanced understanding of the information is available. Collaboration in the maintenance of this matrix also enhances consistent communication across levels.

The proposed framework is an easy technological solution for analyzing resilience related information from open-source data and can be implemented in an offline or online interface of a software.

DISCUSSION

When events from the Santa Rosa fires are deconstructed (see Table 2), what we see is a systemic failure to identify risk from a meso and macro level - the levels occupied by governments. Local, regional, state, and federal concerns have top-down and bottom-up effects. No one level only affects their own sphere, thus a uniform and comprehensive approach is required when performing risk assessment. When the perception of risk remains only within one sphere of concern, and other spheres are not considered, it is easy to see how risk can become normalized and the proper level not assessed.

Using the same technological approach as the Santa Rosa fires, we could observe similar indicators in Puerto Rico as discussed in the introduction, where conceivably, an earlier state of emergency might have been declared allowing the state and federal governments to mobilize resources for mitigation.

There are a few limitations to this research. The proposed framework is dependent on a given geographical area having no legal restrictions that may hinder collaboration and cooperation between stakeholders. Further, the implemented framework must be designed in such a way as to accommodate the technical systems of all stakeholders, highlighting the interoperability challenge. We plan to address these concerns in our future work.

CONCLUSION

This paper presented an analysis on the lack of research in linking technology design to community resilience aspects of crisis management, given the major focus of prior works in disaster informatics on the response phase only. We described a novel framework Digital Crow's Nest based on open source intelligence as a solution towards the design of technologies with a proactive disaster informatics approach for resilient communities.

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Track 13

Open Track

Co-Designing a Virtual Training Tool for Emergency Management

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ABSTRACT

Responders and decision makers can be trained through simulation tools where participants learn how to deal with an ongoing crisis and make decisions through a realistic, simulated environment using a game or gamification approach. Training through a simulated, virtual crisis tool would be a more affordable way of conducting a drill, as a supplement to field drills. In this paper, we describe the requirements' elicitation process for co-design of a virtual training tool for emergency management. The cooperative design process included researchers and end-users together to generate potential solutions for a defined problem. The elicitation process involved brainstorming, interviews and a workshop together with representatives from emergency stakeholders. A systematic qualitative data analysis was conducted. The paper reports our analysis results which serve as a basis for further development of an emergency management virtual training tool using an extreme weather scenario.

Keywords
Emergency management, co-design, training tool planning, extreme weather.

INTRODUCTION

One of the most challenging parts of responding to a crisis is to understand precisely when each actor should start taking action at each stage of the crisis development, without ignoring the standard procedure of crisis response. Sometimes, improvisation is needed in the initial phase of a crisis due to unknown threats ahead, before the first responders can follow pre-defined plans. Field drills are an essential part of crisis responder training and contribute to comprehending timely actions needed in a crisis. However, field drills are time-consuming in terms of preparation, resource-intensive in terms of recruitment and coordination of all the players and logistics, and also financially expensive. In addition, the opportunity to train inexperienced staff to become more experienced decision makers in different roles is very limited. An alternative way to train responders and decision makers is through simulation tools where responders learn how to deal with a crisis and make decisions through a realistic, simulated environment using a game or gamification approach. Training through a simulated, virtual crisis tool will be a more affordable way of conducting a drill, as a complement to real field drills.

Serious games (SG) have been used in different organizational contexts as a means for training. Several studies have initiated and proposed to use serious games for emergency management as an approach for conducting training (Di Loreto, et al., 2012, Di Loreto, et al., 2013). The application areas for SG are wide, including military training, organizational education, medical care emergency services, politics, business, and many other sectors of society. There is also a slight disagreement on the definition and coverage of SG (Boyle, et al., 2016, Djaouti, et al., 2011), with different game-like experience terms in use: *Game, Serious Games, Simulation, Gamification* and *Game Inspired Design* (Marczewski, 2015). Most authors refer to SG as games intended for non-entertainment purposes (Metello, et al., 2008), such as education (Linehan, et al., 2009). Promoting learning and education, participation, and behavioral improvement are the core of the SG (Seaborn and Fels, 2015).

The advantages of a gaming approach are numerous. It is a less costly alternative for training activities that can complement field training or as an alternative to the table-top exercise, and allow intended trainees (e.g. emergency management personnel and decision makers) to train more often than they would otherwise be able to do

in field-based exercises. Adequate training games can replicate conditions in various scenarios, allow organizations to record logs, and store the actions for later review, debriefing or repetition. Moreover, games are a less risky environment to train new personnel rather than exposing them to risk (Radianti, et al., 2017).

Even though SG is gaining popularity as an alternative for crisis management training, Di Loreto, et al. (2012) indicate that there are several missing elements in SG for crisis management: 1) connection with an actual territory (i.e., the game takes place in an abstract environment); 2) possibility to play with roles; 3) emphasis on the importance of the debriefing phase, and 4) support for coaching during the playing sessions. The KriseSIM project reported in this article aims at developing an emergency and disaster Virtual Training Tool (VTT) prototype that address several of these elements. Important questions addressed in this project are: how to gather the requirements and design of the VTT from the end-user perspective and tailor this into a VTT tool? What kind of user interface requirements will be useful and understandable for the end-users? How can such a tool be made relevant for various emergency stakeholders?

The paper describes the co-design process (Martinez, et al., 2016) carried out for the development of a virtual training tool linked to the Norwegian crisis management context. Co-design refers to a cooperative design process where researchers and end-users together generate potential solutions for a defined problem. This method has already been used in the emergency management domain (Cinderby and Forrester, 2016, Hughes, 2014, Munkvold, 2016, Petersen, et al., 2015), as an iterative approach with participants representing various stakeholders whose degree of participation varied depending on user needs and stage of the design process.

The paper is organized in six sections. The next section presents relevant literature on co-design and the approach employed in this work. The third section describes the methodology of the elicitation processes. The fourth section elaborates the results of the co-design, followed by a discussion of the findings, including challenges and opportunities. The final section concludes the paper, also presenting implications for future work.

CO-DESIGN METHODOLOGY

Relevant Literature

Co-design refers to a cooperative process between stakeholders involved in an enterprise. The undertaking is usually developed on a particular domain or field, such as information and communication technology, health or marketing, with a specific purpose: to cooperatively design a solution related to a specific pre-described problem or case involving target users of such a solution (Sanders and Stappers, 2008). Co-design was initially invented in the Nordic countries (Bødker, 1996), with the purpose of allowing the employees to take part in the decision and control of their production means. Co-design has been used in information and communication technology to transform end-users into active contributors of a technology solution design for and with them (Martinez, et al., 2016). In this way, it is the end-users who describe their needs with their own voice. Co-design gathers representatives of end-user groups in the same place at the same time, facilitating a common understanding and prioritization of needs that will be later translated into functional and non-functional requirements and look and feel of the desired system solution.

Co-design has been used in different ways and areas, such as building community participation in community strategy (Leicestershire, 2017), governance (Hill, et al., 2007) and developing regions (Ramachandran, et al., 2007). However, a common underlying principle is that the method requires the recruitment, consent and interaction of the representatives of the user groups for whom a solution is intended. The word solution means that there is a problem or scenario to which co-design participants are usually confronted, immersed or described. The problem or scenario may or may not be familiar to participants. The key is that the co-design sessions may stimulate the imagination, cooperation and dialogue between participants to find a solution for the problem (Martinez, et al., 2016). The participants are then responsible to explain and present what they mean by their suggestions and propositions, and why these may be important for them and others.

There is evidence in the literature about the use of co-design and analogous methods, such as co-creation (Prahalad and Ramaswamy, 2004), user-centred design (Vredrenburg, et. al, 2002) or participatory design (Hughes, 2014) used to co-design technology solutions involving end-users. Examples of studies that involve end-users for disaster and crisis management can be seen in the literature. For instance, community participation in the form of a collaborative action-research method by the Tasmania fire service to transform community education (Middleton and Leahy, 2017), governance to solve policy issues on tension between the government agencies and local companies (Hill et al 2007), and investigation of technological solutions in the domains of communication, microfinance and education in developing regions such as India and Uganda (Ramachandran et al 2007). While participatory or user centric designs have been adopted for the crisis management domain, reports on the involvement of stakeholders in actual co-design of technological tools for disaster management is still limited (Akama and Light, 2012, Lundberg, et al., 2012, Petersen, et al., 2015). Several factors may explain why. In the first instance, the recruitment of end-user representatives from emergency organizations requires resources and

time available to free them from their work, which may be challenging due to their required permanent availability to assist if an emergency occurs. In the second instance, the unpredictability of certain disasters and crisis may hinder the appropriate selection of user-group representatives.

Basically, there is low tolerance for errors in this kind of technology support, so include all stakeholders' needs is one of the reasons for implementing co-design process. Further, co-design of emergency management requires users who are familiar with coordination and communication tools, limiting then the range of stakeholder representatives potentially selectable for the process.

Our Approach

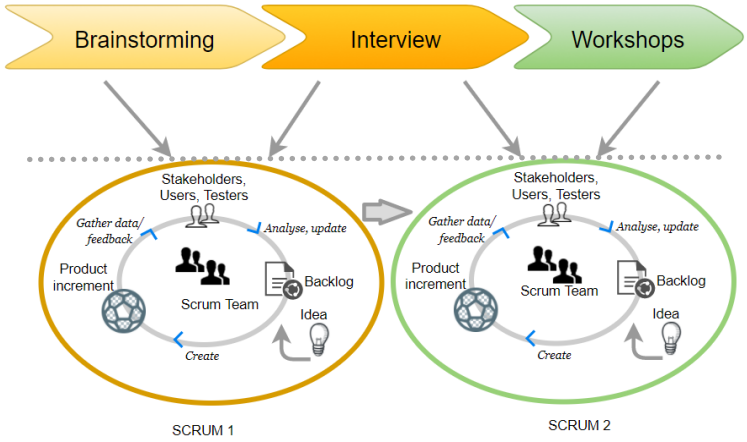

Figure 1. Two-levels of Co-design Processes

In this project, the co-design processes were iterative and occurred at two levels, as seen in Figure 1: First, at *the general level* where the research team interacted with the stakeholders to discuss general requirements. The co-design process was conducted as a combination of brainstorming, interview and workshops. The focus group discussion (FGD) was used in all these subsequent processes at the general level. FGD involves the use of in-depth group interviews focusing on a given topic, in which participants are selected with the recommended number of participants between six to eight (Rabiee, 2007). This technique is unique due to its ability to generate data based on the synergy of the group interaction, to discuss differences between participants and to tackle abstract and conceptual subjects (Ritchie, et al., 2013).

Second, at *the technical level* of developing the VTT, which entailed another iterative co-design process adopting the Scrum method (Cervone, 2011). The participants of the Scrum were grouped into different roles: *product owner* (who maintains the product backlog, prioritizes product requirements, defines features of the product), *Scrum Master* (a leader of team members responsible for running daily Scrum meetings) and *Scrum Team* (the developers). The workload was split into several *sprint cycles*, always starting with an agreement on the tasks to do. Each cycle was split further into main tasks and subtasks. At this technical level, we have conducted two Scrum processes where each scrum was divided into seven and six stages respectively.

The brainstorming results were sent to the Scrum Team in the first Scrum stage, which focused on prototyping and developing a proof-of-concept product. During the development cycles in Scrum 1, we also included the iterative co-design processes of testing, discussion and collecting feedback from the stakeholders. In the workshop, we conducted a more detailed information gathering to allow us to adjust the VTT prototype into the next level, i.e. a usable, realistic training tool. All results obtained from the second workshop were fed to the second Scrum stage**.** In this paper, however, we mostly report on the result and analysis of the co-creation process *at the general level*, and not at the technical/ Scrum processes.

ELICITATION PROCESS

Brainstorming

The participants in the brainstorming were representatives from the following emergency stakeholders: fire brigade, police, municipality, hospital, and Red Cross. In addition, four researchers from the university participated, and two persons in addition taking notes and photos (eleven in total). This session consisted of two themes: 1) General discussions on the proposed project and comments from the stakeholders related to their current emergency management practices, and 2) Brainstorming using the mind mapping technique. In theme 1, we mostly discussed the general issues, especially making all participants familiar with the project ideas and building a shared understanding of the local emergency management practices and current training situation. In theme 2, we went deeper into the main concepts of the VTT features. The brainstorming process was a way to collect spontaneous ideas from the experts/stakeholders on a specific problem. Our goal was to elicit some keywords that were considered essential as elements for developing VTT as a SG. This elements are taken from design framework proposed by Van Daalen, et al. (2014). As the term serious game was also new to the participants, we started with predefined SG elements to be explored further.

To elicit information from the stakeholders, we designed the brainstorming session as an interactive mind mapping session. Mind mapping is considered a highly effective way of getting information out of our brain and can quickly map out our ideas (Davies, 2011). The predefined serious-game elements mind map was displayed on the wall. Using sticky notes, each stakeholder was asked to suggest important scenarios and detailed elements needed to be taken into account to build a game that can help to train in decision-making processes. The workshop focused the following main issues:

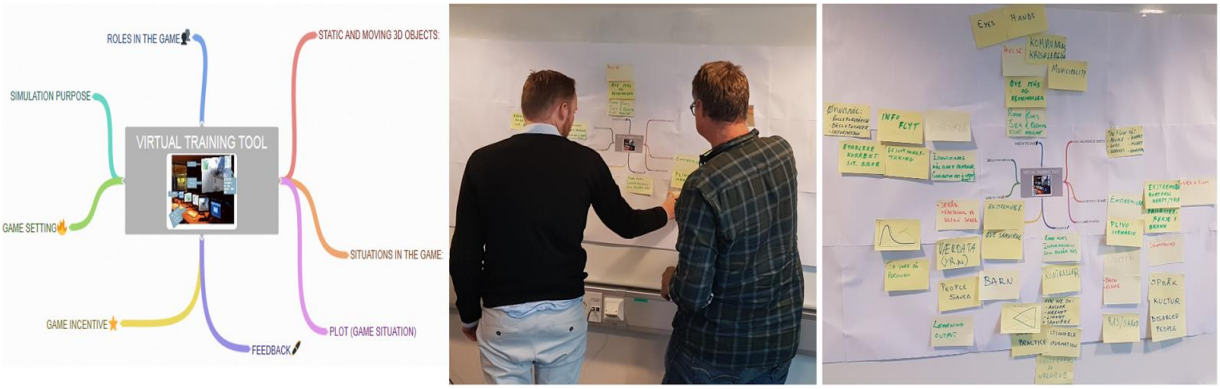

Figure 2 Mind-Mapping Sketch (left), Brainstorming Process (middle) and the results. See Table 1 for detailed information from this activity

The mind mapping process is illustrated in Figure 2. The participants were asked to provide as many ideas as possible within 3 minutes for each branch in the mind mapping sketch in Figure 2 (left). This process took approximately 30 minutes, and then each of them explained their ideas briefly. All elements in the mind-mapping sketch and the results in Figure 2 are summarized in Table 1 (Brainstorming Results Section).

Workshop

The workshop involved eight participants representing the fire services, the county governor's office, the Red Cross, and the university. All participants from emergency stakeholders had extensive experience with emergency management practice. The workshop lasted four hours and focused on the following main issues:

1. Participants' overall expectations from the project.
2. Discussion on what scenario(s) that would be most useful to include in a virtual crisis game.
3. Information requirements for the VTT user interface (UI), as perceived from the different stakeholders.
4. Based on 4), sketching a UI considered useful for the purpose of the emergency management training.
5. Discussion on target user groups and possible role of a facilitator for the VTT.

Figure 3 Figures presented in the Workshop to trigger ideas and elicitation process

The workshop was videotaped, and the audio was fully transcribed. As a basis for issues 2-5, an initial prototype of the VTT was presented. Figure 3 is the illustration of a user interface sketch to trigger discussions and facilitate elicitation in issue 4. The workshop provided detailed suggestions in terms of information requirements from the different stakeholders and also important considerations for how to make the tool relevant for different user groups. The key results of the workshop are presented in the following Results section.

We also conducted interviews as part of the planning work. The role of interviews in this co-design process was a supplement or an alternative, such as when we found doubtful issues on the project process, new questions along the way, or whether the expected key stakeholders would be hindered from coming to the planned workshop. In fact, we interviewed police personnel on the training requirement and other issues that are critical in the decision-making process. The interviews were audiotaped and fully transcribed.

Data Analysis

The data analysis was done by examining, categorizing and recombining the evidence to achieve our research goals, as suggested by Yin (2013). This includes managing the information, making sense of the content, and discarding irrelevant information (Rabiee, 2007). To minimize the potential bias, Rabiee (2007) also pointed out the importance of conducting analysis in systematic, sequential, verifiable and continuous ways. This means that systematic analysis requires a protocol that follows a predetermined and verifiable set of sequential steps in advance of the group discussion. While continuous means that the analysis can be started during the focus group discussion, which can be done by asking more questions if vague issues are detected. This activity continues after the discussion through the transcription process and deeper text analysis.

Our raw data consisted of key concepts written in sticky notes and transcribed text. For data treatment, written information in the sticky notes were grouped into similar themes, while the transcribed text was annotated by highlighting the relevant ideas for the project goals in short phrases. Subsequently, we developed a thematic framework by looking closer at the main ideas and concepts arising from the text, and began to develop categories. Afterwards, indexing was done by shifting the data, sorting out quotes and making comparisons among different themes and point of views of the different participants.

RESULTS

Brainstorming Results

As a basis for the brainstorming, we adapted the SG design framework proposed by Van Daalen, et al. (2014). We listed all ideas collected during the brainstorming process, as seen in Table 1. The goal was to identify main features that would be good to incorporate into the VTT tool development, and an interesting scenario that would be relevant for all parties. The results in Table 1 show very broad ideas. However, the most critical features as a basis for working further are the ideas listed under the "the situation in the game" and "the game setting". From the word frequencies under these two themes, "extreme weather" and the use of weather data were the most frequently mentioned. In addition, there were some ideas that could be associated with the extreme weather scenario, such as flood, loss of power and telecommunication infrastructure, and landslide. The stakeholders also indicated a preference for a large scale scenario where each emergency unit could take part and make decisions in the game.

Table 1 Results from the Brainstorming Session

Elements	Ideas
Static and moving objects	The flow of people, goods, money, information, services and energy
Situation in the game	Extreme weather, passengers trapped in a ship fire, flood, loss of power and telecommunications infrastructure, Plivo (*Pågående livstruende vold*—a Norwegian term referring to a situation with life threatening violence), dilemma, landslide/ avalanche
Roles in the game	Municipal crisis management, health, staff and rescue management, Red Cross's search and rescue, crowd of people, children and old people needing help, gestures (eyes, hand, brain)
Feedback	Information that concerns Red Cross, controller, how the crisis management actors conduct: responsibility, closeness, equality and cooperation (In Norwegian: *ansvar, nærhet, likhet, samvirke*); actionable information, consequences of a choice, best practice feedback in the game on an unknown situation, multilingual alerts
Game purpose	Cooperation training, understanding of information flow, understanding of the role, decision making, establishing appropriate situation description, coordination, taking care of personnel
Game setting	Extreme weather, the use of weather data
Game incentive	Identify measurable factors (what does it mean to be good?), people saved, learning output

Based on this analysis, selecting extreme weather as the scenario could apparently cover most of the ideas generated in this brainstorming, as this could also include cascading effects such as a fire in the electricity power grid due to fallen trees and dilemmatic situations such as several events appearing simultaneously and requiring priorities to be made. The rest of the elements mentioned in Table 1 served as feature ideas that could be inserted gradually during the VTT development. One of the challenges from the results was defining "the role in the game". Each actor mostly suggested a role that was in line with their own role in real life, resulting in broad variations with respect to the roles in the game. We brought these brainstorming results into a proof-of-concept tool development process, i.e. the first, and tried to start with developing an extreme weather scenario. We selected the extreme weather named 'Synne', that occurred in Eigersund, Norway in 2015, as a reference case to ensure the realism of the VTT development. While we do not discuss the development process in this paper, we could mention that the product of the first Scrum process was shown in the next workshop (see Figure 1) as an inspiration for getting the right information required for the project.

Workshop and Interview Results

On Technology and Crisis Management Issues

In this section we provide the background information taken from the discussions in the brainstorming and workshop that we would use for developing the SG. In the workshop, there were several problems identified as current crisis management issues, one of these being the lack of communication between the municipality and the police. Communication from the municipalities is defined in the emergency plans, but does not work well the other way. On technology, the need for better map support was raised. The municipality has a crisis communication technology today, but this does not include any common platform for electronic maps, as the map module from the technology provider is still considered too expensive. While there exist other map sources such as used by the regional power company for showing power outages, and the road authority map showing real-time information on closed or damaged roads, none of these maps are interconnected.

Another technology discussed was drones, which have been used for some purposes. However, the local responders currently only hire external services for drones when needed, or use them for testing purposes. The energy company that is a critical stakeholder often deploys drones for inspecting power lines. In a search and rescue operation, the responders may deploy a helicopter with an infrared camera that is very effective at finding people. This could also be done by deploying a drone. In the local Red Cross, the use of drones for emergencies so far only results from individual initiatives, and there is yet no national initiative. The stakeholders considered this as a characteristic for emergency preparedness in general, that often is fragmented and lack of coordination.

On Defining the Training Context

In line with the issue of communication challenges raised earlier, the stakeholders argued for the importance of realistic training in terms of using the actual communication solutions in use. They considered it useful to offer training in collecting the required information for establishing a situational picture in the municipality context. Further, they also pointed to the large differences between collecting information on a sudden onset event, e.g. a terrorist attack, and extreme weather forecasted five days ahead. The game should have different levels depending on whether the responders are in an operations central or the municipality, and who should be contacted. The game should have a system for 'picking' resources, as the participants often struggle with getting the right resource. In short, from the municipality perspective training in communication was repeatedly mentioned as necessary to be included in the VTT. While from the police perspective, training in decision making based on the flow of information was considered critical for effective emergency management.

In the current practice, emergency management actors learn from the evaluation reports produced after different events. However, there are two different practices for making an evaluation in the focused region, consisting of two counties. One county would run a series of exercises, and then the municipalities involved in each exercise would write the evaluation report with all learning points, self-assessment, and send this back to the county governor's office. This would then be used for quality assurance and ensuring that the emergency actors grasped the exercise goals. In the other county, the county governor's emergency management team themselves would write the evaluation reports, presenting to the municipalities what needs to be improved. In our VTT training design, these top-down and bottom-up approaches will be incorporated: on one hand, the players can derive the learning points by themselves for generating discussions with other players. On the other hand, the players can communicate the results and disagreements with more professional tutor. In other words, the planned VTT will accommodate possibilities for both self-learning and guided-learning.

On the Virtual Training Tool Design

As an introduction to the discussion on the VTT design, the facilitator explained the use of the event-based design for the VTT and how understanding the timeline of a crisis was important. In fact, the different stakeholders operate with different timelines in terms of their perceived role and when each stakeholder should start taking action. The left sketch of Figure 4 shows how the resources from the rescue efforts (police, firemen and health services) peak quickly in the acute phase of the crisis (thick line), while the municipality resources will peak after the acute phase (thin line), when other units are demobilized. The middle figure illustrates the *Information* vs. *Opportunity* where in the emergencies, the opportunity space for making decisions will shrink when the information level increases. The left triangle portrays the opportunity of decision making while the right triangle is the information level that starts accumulated over time. Figure 4 (right) matches the timeline suggested by the municipality, but is less steep in the beginning, as the preparation stage comes into the picture.

When such an emergency timeline is transferred into the VTT, the stakeholders agreed on the importance of presenting a correct timeline in the game, showing the actual delays between calling for resources and getting this in place, especially from the perspective of the fire services. However, if we think of the municipal crisis management, it needs to be considered how advanced this timeline should be, as it could also include affected

areas such as water and sewage, home nursing, etc. With an extensive design, the crisis management stakeholders could play with their entire organization. But the stakeholders also expressed a need to limit the scope of the graphical visualization in the VTT, as the information was perceived to be the core. As an example, if it is reported that water is rising and the municipality forgets to close the road so that some cars are trapped, then it is perhaps not necessary to show this in the game but just present it as vital information.

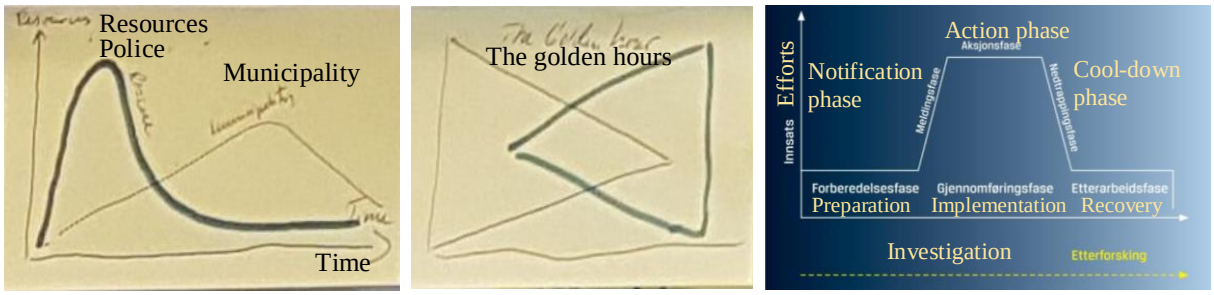

Figure 4 Crisis escalation over time and response as suggested by the municipality. *Left*: Resources dedicated for rescue (thick line) and municipality resources (thin line) as the crisis is evolving. *Middle*: The chart depicts how the opportunity space will shrink when the information level increases. *Right*: Crisis timeline as suggested by the police.

The firefighter argued for the importance of the first responders sharing information early to the municipality, the mayor and the councilman, and that this should be included as part of the game: "share the information you know, don't wait till you get all the pieces". The representative from the county governor's office mentioned that social media is currently not being used in emergencies, and that the county governor's office does not have a need for "every person's information" as they are only responsible for coordinating the information from the different relevant organizations. But he also pointed out that other stakeholders such as the municipality, the police and the fire department will have more need of such information. In short, with respect to the use of social media there were still differing opinions on the need of adopting it into their working procedures. Based on this opinion, we will treat the social media as an optional or a part of "nice to have" requirement in the VTT design, as for the training purpose, it is always good to have a possibility to make use of the new thing.

User Interface Suggestions

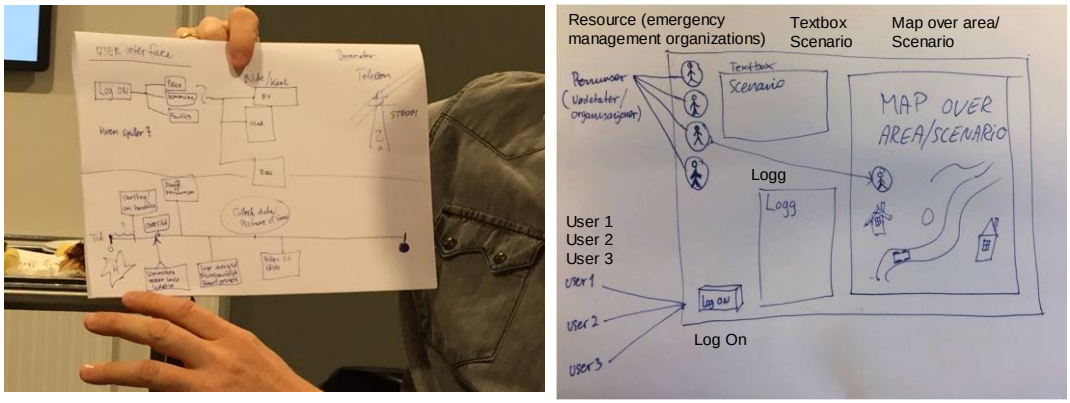

Figure 5 User interface elicitation. *Left*: a stakeholder presenting his idea. *Right*: example of a user interface idea

We conducted one round of exercise on the possible user interface that would be useful or in line with current practice for the different participants. As a starting point, we provided an illustration to trigger ideas, as shown earlier in Figure 3 in the Methodology section. Each stakeholder drew elements they considered would be necessary to appear in the VTT. Figure 5 presents results of the user interface elicitation.

The local Red Cross suggested an overview where one could get a good situation picture, but this should not be too complex. For example, for all kinds of vehicles (police cars, fire trucks, rescue boats, snow vehicles etc.), the number of vehicles and the crew for each of these should be listed. One also should know how many people have engaged in a rescue operation, and make sure that everyone returns safely. In the case of a volunteer organization, someone can join for two hours while others can join for two days. In bad weather, they have to know who is out there. In short, the Red Cross should be able to keep track of personnel including their volunteered time and material resources, which can be incorporated into the VTT design.

From the perspective of the fire services, the main collaborator in an extreme weather scenario will be the civil

defense, and the 110 Alarm Central (monitoring several municipalities) would be a branch that could provide resources for the fire services. Thus, the user interface would need an overview map with the ability to zoom in on actual buildings with flooded basement areas, so that one will know the affected area and the water level. Responders may have a dilemma in a flooding situation whether they should prioritize between evacuation from a parking basement or a nursing home with older people. If a fire is involved in the situation, data on weather and time is very relevant, as the firefighters aim to be ahead of the fire instead of running after it. In line with the responders' challenges in the field, the following elements were suggested to be included in the user interface: 1) *Weather data*: forecasts, wind directions and intensity, and its changes; 2) *Own Resources*: available resources and the number of deployed teams; 3) *Log of tasks*: completed tasks, new tasks, what is urgent and what can wait. A situation picture was considered essential. In practice, the fire services also need to balance between securing life and health of the victims and their own response personnel.

From the municipality perspective, their emergency management team would be put in operation when the they consider it is necessary. They create an overview, situation picture and focus areas to solve the event. The municipality will collect data such as images of the site from the media, for a better common situation picture. Moreover, there are some key parameters such as the kind of emergency situation, whether or not telecommunications and power are still available, etc. Thus, based on the log-on, the user interface will be adapted to who is playing the game: the police, fire fighter, heath service, municipality or volunteers. The map is vital for knowing the relevant area to manage. We also need a screen that can show the resources, emergency services and login button on who are the users. If it is the municipality who logs in, one gets a situation and can choose equipment, call resources, decide who will use it, which would be the same for the other responders. The decisions made can be updated continuously. There should also be an area in the interface that can show the new tasks and events continuously scrolling across the screen in relation to what has happened and being reported.

As we also considered the possibility to combine the VTT tool with some information flow into the game, we conducted a brainstorming to know what information would be important. The following data sources and technologies were mentioned in the workshop: GPS tracking of resources, interlinked-controlled swarms of drones to take comprehensive images, social media monitoring tools with a map interface, 3D video from smart glasses, weather information, and analyzed big data. In addition, satellite data such as from Copernicus, map with position, an overview of the resources and other data related to storm and flood threats are important. Lastly, on the choice of scenario the participants considered that extreme weather would provide possibilities for many different events that occur concurrently or as cascading effects. In fact, for local responders, there is currently limited competence in handling this scenario.

On Diverse Aspects of Training

There were some aspects discussed such as how the VTT should operate: whether the tool would be self-explanatory, or whether one should be able to stop during the game play for evaluation of decisions made, and then start again. For the latter design, the training would require a facilitator. The participants also discussed who should be the target users. One of the suggestions was that the tool should cover the full interplay between the different crisis organizations, to enable learning about the work methods of other parties. This because today, emergency responders work in a rather isolated way, sitting in their own "glass-bowl". In other words, a role-play type VTT was proposed where someone from each response unit can play, change role (login as another organization), and do joint evaluation afterwards. In this way, each actor can learn about the perspective of other emergency responders.

Finally, the suggested role of the VTT is to provide a kind of "theoretical exercise" that can support field exercises, and is thus not intended as a substitute for field exercises. For example, the VTT could be used before a full-scale exercise to ensure that the exercise focuses on the right things. And it could also be used after a full-scale exercise, for training in particular areas where a need was identified.

DISCUSSION

Challenges

In the elicitation process, we identified that each emergency responder organization has different challenges and goals in a crisis. The main challenge is how to accommodate different perspectives and needs from various actors and express them into manageable and doable tasks within the project timeline and available resources. Thus, careful design is needed to enable the research team to include as many needs as possible, and do the prioritization on "must have", "good to have" and "may have" features.

For the methodological part, the time allocation between the different activities were the main challenges. A couple of themes planned in several sub-sessions were discussed already before the intended sessions. Thus, we used shorter time to cover all planned themes. In contrast, the user interface elicitation proved challenging and

took longer time than planned as the stakeholders needed concrete example to be able to contribute ideas. Thus, we skipped an additional planned co-design activity, i.e. to provide color-coded labels on pre-prepared alternative user interfaces for indicating the importance of various elements. However, in general we achieved most of our goals, but we learned that flexibility and having backup plans are key for a successful co-design workshop.

Opportunities

Over the last 20 years, we have seen a development in game engines and what they are capable to do. As they have matured, they have broadened their scope from games for entertainment to include serious games, and training and e-learning applications. It is this development in game engines that have made it possible to develop a VTT, with limited resources, that includes realistic 3D surroundings, easy to use interfaces and multi-player possibilities as an alternative design to answer the competing goals issues of different stakeholders as described in the Challenges section. The new modern game engines have the tools available to create a virtual world that can potentially contain all the elements of what takes place in a real-world scenario.

The idea with serious games is to take the enthusiasm and fun factor from entertainment games and combine it with a purpose of learning a certain skill or master a certain situation. The use of different e-learning tools and techniques is expected to have a tremendous growth in the years to come (EU, 2014) and e-learning is expected tol grow to cover 30% of all educational provision before 2024. Through observation at our university we have seen that the use of multimedia and e-learning can both motivate and enhance the learning experience for our students. We believe that we with our VTT have accomplished a first version of a game that can actually ease the training and understanding of how to work with a crisis for different stakeholders. However, we should emphasize that the VTT is intended to complement real field drills, by training cognitive, analytical and critical skills. Field drills still represent a higher degree of realism for training contextual decision-making and coordination in time critical situations.

Lessons Learned

- *On the project goal*: the stakeholders thought it would be useful if the project could produce a tool that enables learning on the different emergency response organizations' working methods.
- *On the involvement of experts from different domains:* while the stakeholders represented have different roles in emergency management, their perceived need for improving communication between actors and coordination of resources enabled a common focus for the game. Thus, emphasis was given on interaction across the domains, rather than requirements specific for each domain.
- *On the requirements collection*: we managed to collect both high-level and detailed requirements that can be transformed into VTT tool features. We also have an overview of necessary and less important features, e.g., not all elements should be visualized into 2D or 3D objects, as text information is sometimes adequate.
- *On the elicitation method*: There were slight discrepancies between the plan and implementation as mentioned in the "Challenges" sub-section. However, we mitigated these issues by improvising during the workshop to ensure all points were discussed. The audio-video recording was very useful for extracting the most relevant information from the workshop.

CONCLUSION

The discussions with regional emergency management stakeholders in our project have revealed different perspectives and considerations regarding aspects that still need improvement in current emergency management practice. Training in decision making and communication are two elements that were emphasized, and information required in the VTT user interface and future use of the VTT has been identified. The results provide a strong basis for future research on the further development of Virtual training tools for emergency management. In particular, we identify five potentially fruitful avenues of development: (1) how to tailor necessary components into the tool; (2) information available in the VTT for the different players; (3) training guidelines with or without a professional mentor (4) usability testing; and (5) possibility to handle multiple roles as suggested in the brainstorming, with a multiplayer game as a potential future direction.

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An Architecture for Simulating Drones in Mixed Reality Games to Explore Future Search and Rescue Scenarios

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ABSTRACT

The proliferation of unmanned aerial systems (i.e., drones) can provide great value to the future of search and rescue. However, with the increase adoption of such systems, issues around hybrid human-drone team coordination and planning will arise. To address these early challenges, we provide insights into the development of testbeds in the form of mixed reality games with simulated drones. This research presents an architecture to address challenges and opportunities in using drones for search and rescue. On this architecture, we develop a mixed reality game in which human players engage with the physical world and with gameplay that is purely virtual. We expect the architecture to be useful to a range of researchers an practitioners, forming the basis for investigating and training within this unique, new domain.

Keywords

Mixed Reality, Drones, Games, Simulations, Disaster Response, Search and Rescue.

INTRODUCTION

As unmanned aerial systems (i.e., drones) proliferate, we expect them to be of great value to the future of search and rescue (and disaster response, in general). Such devices have started to be used in disaster, often controversially, raising concerns around privacy violations and safety regulations (Wall 2013; Lidynia et al. 2017). As these scenarios materialize, there will be a need for researchers to develop and test designs, as well as for practitioners to train with them. To develop, test, and train for hybrid human-drone team scenarios in search and rescue, we expect to the following issues will arise:

*Play & Interactive Experiences for Learning Lab, Department of Computer Science
†Knowledge Representation, Logic, and Advanced Programming Lab, Department of Computer Science
‡Perception, Action, & Cognition in Mediated Artificial & Natural Environments Lab, Department of Psychology

- **Team Configurations**: concerns around how best to construct cooperating teams of humans and drones to maximize effectiveness (e.g., what is the right ratio of humans and drones?, what are their roles?, what types of drones and sensor payloads are most effective?);
- **Search and Rescue Methods**: the incorporation of drones will alter how search and rescue is performed (e.g., how do we use drones to find victims?, how do we use drones to assess structural stability?, what search patterns do we employ?); and
- **Device Configurations**: attention must be paid to how to design sets of devices that enable mobility while providing sufficient control of drones (e.g., how do we best direct teams of drones?, what is safe and effective in the field?).

To address these issues, we are developing testbeds in the form of mixed reality games with simulated drones. The games are *mixed reality* because one or more humans play these games in physical reality to which a virtual reality is connected. The virtual reality contains a game scenario and one or more drones, which do not exist in the physical reality. The simulated drones operate in an existing open-source robot simulator (Gazebo[1]) (Figure 1) that can recreate a number of drone configurations and accurately simulate various sensor payloads.

The present research develops an architecture in which human players (e.g., trainees, researchers, practitioners, study participants) engage in a game that combines work in the physical world with gameplay that is purely digital. The human players are equipped with wearable computers and sensors, enabling the digital game to track their location, context, and activities. Drones are completely simulated and do not exist in the physical world, enabling developers to address the above issues without concerns about public safety due to drone mishaps or aviation rules.

In the remainder of this paper, we synthesize a brief background on disaster response and provide deeper insight into drones, games, mixed reality, wearable computers, and prior disaster response simulations. We then explain our proposed architecture that facilitates simulating drones, developing mixed reality, and collecting data. As a parallel thread, we describe our game design for exploring search and rescue drone applications; while we expect to develop multiple designs in future, we present our current version here. We then discuss the benefits and drawbacks of using mixed reality for this purpose and close with our expectations for future work.

BACKGROUND

Disaster response is a complex set of activities to mitigate the effect of a critical incident (Toups, Hamilton, et al. 2016). The term *incident* refers to "An occurrence, natural or manmade, that requires a response to protect life or property..." (U.S. Department of Homeland Security 2008, p140). *Responders* are people who contain the impact of disasters and prevent further loss of life and property. Such response is crucial, because disasters cannot be prevented entirely, but their impact can be contained and reduced. We draw on our prior research around disaster response teams (Toups and Kerne 2007; Toups, Kerne, and Hamilton 2011; Toups, Hamilton, et al. 2016) to drive the design of our mixed reality game and wearable system.

Search and rescue is a disaster response operation to locate persons who are in distress or imminent danger, aid them (e.g., medical, food), and move them to a safe place (Department of Defense 2006). There are different types of search and rescue operations (e.g., urban search and rescue (US&R)[2], mountain rescue[3]). Time is a critical factor in search and rescue operations, any delay might result in loss of the persons, therefore, using technology such as drones, in these operations could help to minimize the time needed to find persons who are in distress (Waharte and Trigoni 2010).

Drones

The term *drone* refers to an unmanned aerial vehicle (UAV) that can be controlled remotely (Chang et al. 2017; Barin et al. 2017; Jones et al. 2016), and is a subset of unmanned aircraft systems (UAS) (Austin 2010). Drones come in many sizes from micro drones (e.g., those that fit in a human palm) to large drones (e.g., military drones the size of small fighter jets). Flight type (e.g., quadcopter, hexacopter, fixed-wing) impacts what work a drone is capable of (e.g., fixed-wing cannot hover, but might be able to move quickly) (Vergouw et al. 2016). Payloads are the equipment that drones carry to perform useful work (Austin 2010). In search and rescue, payloads are various sensors (e.g., camera, thermal imager, GPS), though future scenarios might include effectors (e.g., to support delivering materials). Drones are expected to play a crucial role in search and rescue and are already involved in the

[1] http://gazebosim.org
[2] FEMA's Urban Search & Rescue page: https://www.fema.gov/urban-search-rescue
[3] Mountain Rescue Association: http://mra.org

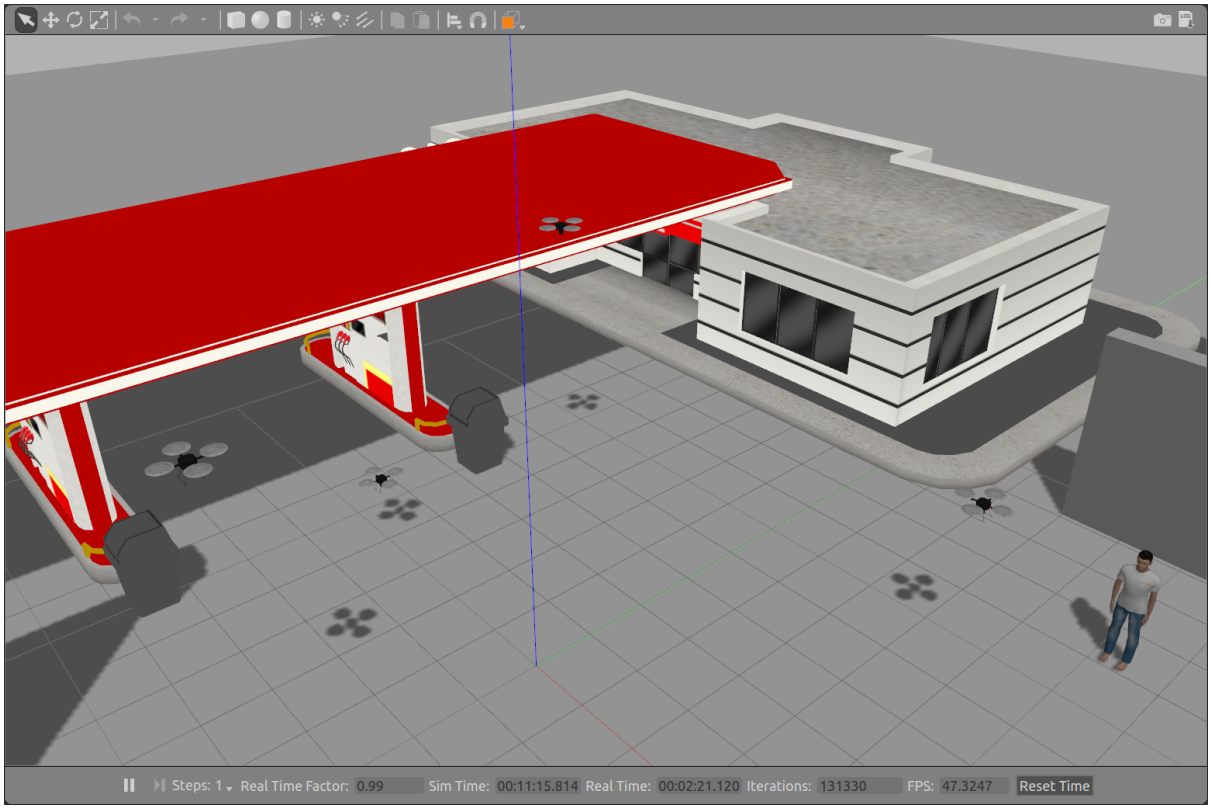

Figure 1. Multiple drones simulated in Gazebo.

field (for better or worse). For example, drones were, controversially used in search and rescue during Hurricane Harvey in summer 2017 (Hutson 2017; ABC News 2017). Drones were used to to create a 3D map of the flooding and the damage that helped first responders in rescue operations.

Mixed Reality and Wearable Computers

Systems that connect virtual and physical reality in some meaningful way through the use of networks, sensors, and databases are *mixed realities* (Milgram and Kishino 1994). These range from augmented reality, in which conformal 3D imagery is integrated with a perspective on the physical world, as with most aircraft head-up displays to augmented virtuality, in which physical-world artifacts and spaces are integrated into a virtual world (Sharma et al. 2017; Alharthi, Sharma, et al. 2018). The present research is concerned with systems between these extremes, mixed realities, in which we integrate virtual reality with physical reality without the augmented component. That is, simulated drones will be able to send data to a player in the physical world, but the player will not be able to see the drone. Later extensions of this work could include an augmented component to enhance immersion.

Wearable computers are computing devices and sensors that can be worn on the different locations of the human body to provide context-sensitive information support while working in the physical world (Barfield 2015; Mann 1997; Starner et al. 1997). Wearable computers are an enabling technology for mixed reality. Wearable devices establish a constant interaction between the user and the environment, and often form their own network of intercommunicating effectors and sensors. These devices provide a different range of affordances compared to other device types (e.g., desktops, laptops, smartphones) (Barfield 2015) owing to their form factors (e.g., smart glasses, smartwatches, smart rings), input modalities (e.g., speech commands, touch screens, air-based gestures), and output modalities (e.g., display, audio, vibration). These input and output modalities allow the user to monitor and control other devices. As these devices proliferate, we expect them to be extremely valuable in search and rescue contexts. The present research aims at creating testbeds for configurations of wearable devices in the context of working with drones.

Game Design

Games are framed as a combination of rules and play, involving designed game mechanics, through which players make choices (Salen and Zimmerman 2004). *Rules* are the structures of a game that constrain player choices,

while *play* is the freedom to make choices within those constraints (Salen and Zimmerman 2004). These logical procedures or mathematical formulae frame the choices to which a player has access. Rules define the outcomes of choices, resulting in new, observable game states. To that end, play is the essential experience of the system that the rules create. The combination of rules and play leads to designed moments of choice for players: *game mechanics* (Salen and Zimmerman 2004; Adams and Dormans 2012; Juul 2005). Game mechanics are defined by the designer and are decision points at which players trade-off various possible outcomes. In digital games, these choices may be very fast, occurring in the order of milliseconds. The *core mechanics* are the choices that players make repeatedly, forming the essence of a game (Adams and Dormans 2012). The present research develops a set of game mechanics for simulating drone interactions with wearable computers in a mixed reality.

Prior Disaster Response Simulations

Prior disaster response training simulations address a wide range of skills including team coordination (Toups and Kerne 2007; Toups, Kerne, and Hamilton 2011), decision making (Silva et al. 2012), and planning (Toups, Hamilton, et al. 2016; Alharthi, Torres, Khalaf, Toups, et al. 2018; Alharthi, Torres, Khalaf, and Toups 2017). Supporting team coordination and decision-making training through the use of a scenario-based mixed reality simulation has been used, allowing responders to coordinate with each other in real-time, face-to-face and remotely, to mitigate a simulated disaster (Fischer, Jiang, et al. 2014; Alharthi, Sharma, et al. 2018). These types of live mixed reality simulations also provide training opportunities for human-agent coordination and collaboration (Ramchurn et al. 2016; Fischer, Greenhalgh, et al. 2017), helping responders to build advance coordination skills. Advances in personal computers and wearable technologies have the potential to enhance the design of mixed reality experiences and training (Feese et al. 2013). All of these prior studies provide innovative approaches to the design of disaster response simulation, pushing forward the adoption of advanced technologies to support training.

ARCHITECTURE FOR SIMULATING DRONES IN MIXED REALITY

We have developed an architecture designed to incorporate drone simulation with multiple physical-world wearable devices and planners; Figure 2 provides a diagram explaining the architecture. Its primary components include a *request handler*, which manages goals and drone state in communication with the planner. The *planner* is responsible for identifying which drones will respond to a request and how. Once a plan is formed, the *action processor* manages communication either directly with the drone controller or with specialized components that are purpose-built for particular actions. The *drone controller* then interfaces with the virtual world to simulate drones. In the remainder of this section, we provide more detail on the architecture, beginning by explaining the Robot Operating System (ROS)[4].

The simulation is realized using Gazebo Simulator 7.0 with a drone model developed by Meyer et al. (2012)[5]. We use the ROS Kinetic Kame to manage a number of components, including Gazebo. Components running under ROS are called *packages*, and each package may contain multiple *nodes*. A node is a process that performs computation. ROS manages nodes and provides communication between them.

Figure 2 shows a high-level view of our architecture where blocks are nodes. Apart from normal blocks, there are two other types of blocks: stacked blocks and blocks with dashed-lined border. Stacked blocks represent multiple node instances running in parallel (e.g., request handler has multiple instances to support potential multiple incoming goals from multiple wearable devices). Blocks that directly manipulate the virtual world are emphasized using dash-lined border. The simulated drone model works in conjunction with virtual world in Gazebo simulator.

The system is designed to have wearable devices swapped in and out for particular scenarios (e.g., one might involve a touch screen, another might involve a gesture device). The state publisher will remember the set of connected devices and provide, in real-time, necessary status information for the connected devices to know what is going on in the virtual world. When a device wants to make change in the virtual world, it will send its *goal* to the request handler. Depending on the goal, the request handler may combine the current drone state with the goal and request a plan from one of the planners through planner handler. Eventually, a plan (i.e., sequence of actions) will be sent to action processor.

The action processor knows the current drone state from drone controller, and, depending on the plan from request handler, it may make use of specialized component(s). The action processor is implemented using Actionlib[6], which provides a standardized interface for systematic management of the execution of actions, enabling monitoring and/or cancelling ongoing actions.

[4] http://www.ros.org
[5] hector_quadrotor: http://wiki.ros.org/hector_quadrotor
[6] http://wiki.ros.org/actionlib

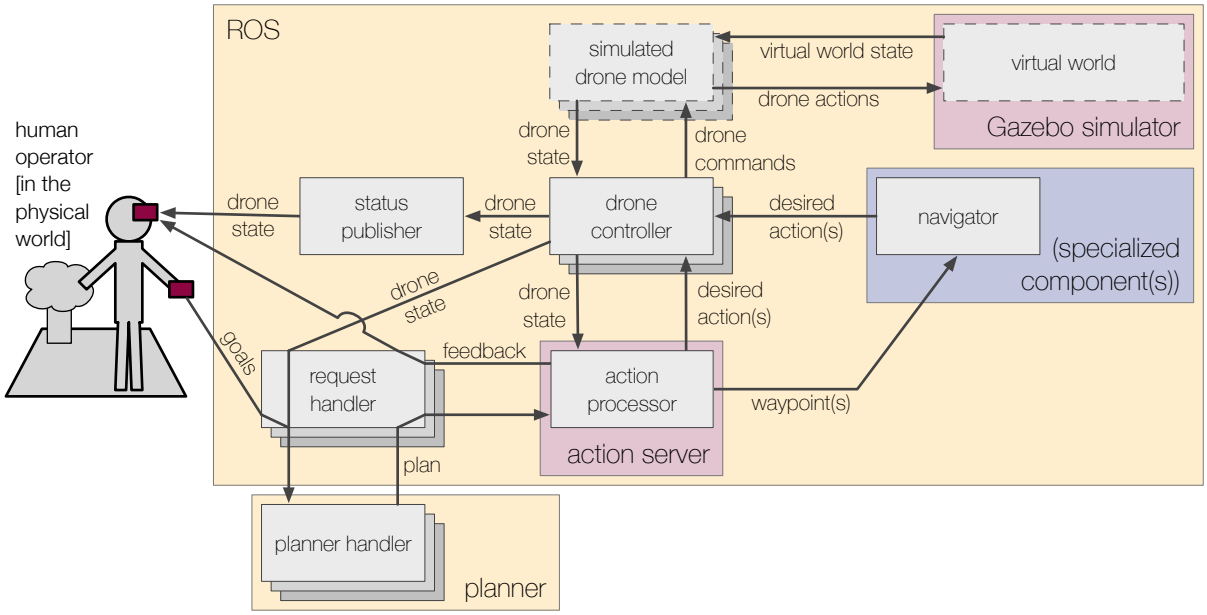

Figure 2. Overview of architecture for mixed reality simulation of drones. The ROS component contains a number of nodes (internal blocks). Stacked blocks represent multiple instances, each with its own state. Blocks with dashed lines border represent virtual entities. To walk through starting from the human operator: the operator enters goals, the planner develops a plan (series of actions), which is then fed to the action processor by the request handler. The action processor uses data about drone state to either push desired actions to the drone controller or send it to one or more specialized components (the present system has a navigator for managing moving drones). The drone controller sends commands to the simulated drone model, which uses the virtual world to enact the specified actions. Finally, information feedback to the user via the request handler. The status publisher provides real-time update of drones' status to the connected wearable devices.

Regardless of what components action processor may use, the desired actions will eventually be sent to drone controller. The drone controller takes care of directly controlling the virtual drones (e.g., flying, hovering). It works at a level higher than simulated drone model, which takes care of actual physics of the drones. The action processor will interpret results from the drone controller, and provide feedback through the request handler of that request if necessary.

While the architecture has been designed for simulating drones in mixed reality, the architecture is general enough to be adjusted to use on other kinds of unmanned systems. System designers would need to change our simulated drone model, drone controller, and navigator (or any specialized components) with their components to suit their projects.

A MIXED REALITY GAME WITH SIMULATED DRONES

We are developing a game that builds on the designed architecture and serves to create a stressful environment (Toups, Kerne, and Hamilton 2011) that requires players to pay attention to simulated drones while maintaining situation awareness (Endsley 1995; Wuertz et al. 2018) of the physical world. The game serves as a starting point to address the issues of team configurations, search and rescue methods, and device configurations. We do not expect this single game to serve to answer all questions, but it is a starting point from which other game and simulation designs can be developed and shows how the architecture is valuable.

The game design is an analog of search and rescue in a built environment. It makes use of existing buildings in the physical world and could be played in any environment where players could freely move and be tracked via GPS. Once implemented, we expect to use environments designed to simulate actual search and rescue. For example, Disaster City in College Station, Texas[7] would fit the purpose well.

Device Configuration

The game is played using a single wearable computer, which provides:

[7] https://teex.org/Pages/about-us/disaster-city.aspx

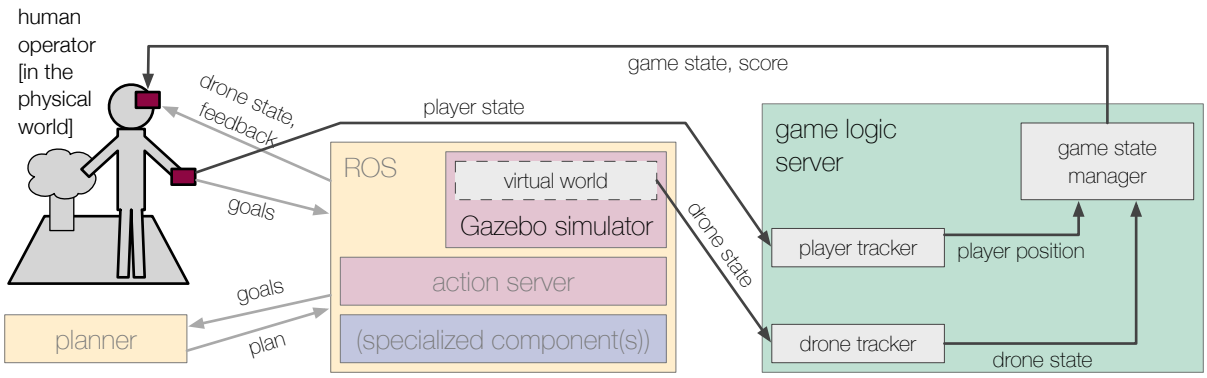

Figure 3. Overview of how the game logic connects to the architecture. Figure 2 is condensed in this figure to show game logic data flows.

- player input: one or more devices for the player to interact with the game;
- player feedback: one or more devices to inform the player of the game state;
- virtual reality simulation: tracking the state of drones via the architecture; and
- game logic: tracking the state of game entities and keeping score.

As part of addressing the issue of device configuration, the wearable can provide player input and player feedback through different composites of wearable devices. The following are device configurations we expect to evaluate, but are only a sample:

- a single touchscreen could serve to show a map: the player sets waypoints via touch and can observe drone status (Figure 4);
- a combination of a head-mounted display could show drone state and a handheld pointer could be used to direct drones in the physical environment; or
- a large, wrist-worn display could show game state while the player uses free-air gestures to provide instruction.

In our design, which presently addresses a single human player and one or more drones, a single wearable computer can serve to run the entire experience. This partially addresses the issue of team configurations (e.g., evaluating when one human works with multiple drones). To address multiple humans in a team, the game could be expanded and run on a wireless network of devices, distributed among players, likely with a single server to provide the virtual reality simulation and game logic.

Objective

The objective of the game is to find a hidden virtual object within one of the multiple structures of a physical built environment. Each structure exists physically, in whatever space the game is set, and has a virtual representation with a four-digit address. The physical structures may contain one of the following virtual elements: a clue, the hidden object, or nothing at all. The player needs to search each structure, either physically or with a drone to find out what it contains. Clues are a part of the address for the structure with the hidden object; clues may be hidden inside a structure (accessible only to the player) or may be hidden on top (accessible only to the drones). Once four unique clues are assembled, the player can use that information to identify the correct structure.

This design element begins to address search and rescue methods, with the player needing to consider trade-offs between performing activities themselves or having a drone perform the activity. The hidden object functions as an analog of in-danger persons or victims, and future games may incorporate more specific features around this concept (e.g., need for medical / psychological support, moving victims).

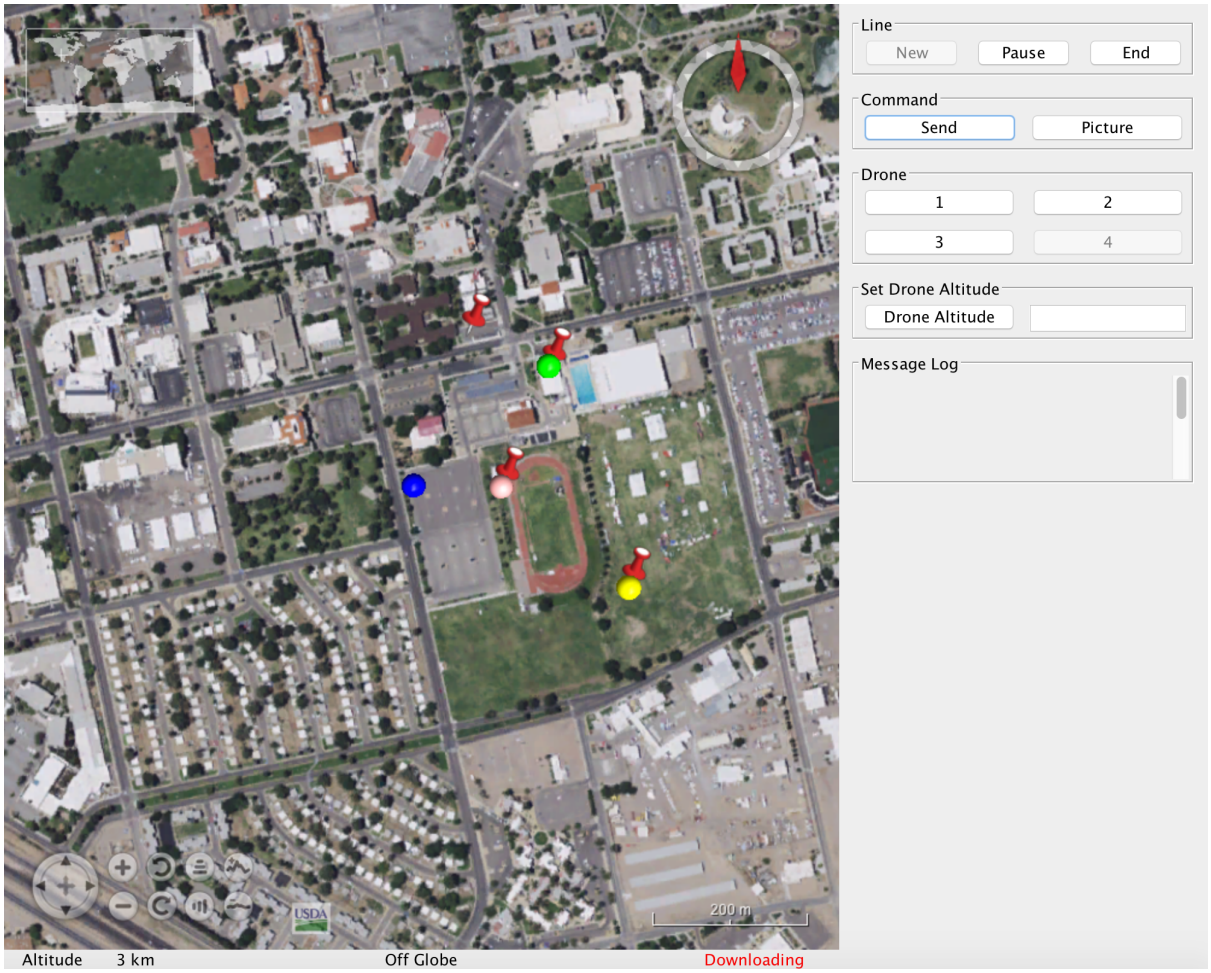

Figure 4. The map interface can be displayed on a wearable device to allow the user to set waypoints and check drone status.

Rules

There are two main constraints that limit player actions: time and drone battery. The game ends if time runs out, limiting the number of structures the player can visit. If a drone's battery runs out, it can no longer be used.

Because pausing to direct the drones will slow down the player, they are encouraged to attend to the wearable computer while moving in the physical environment. The drones also have a limited battery power, meaning that it is not possible to do everything via drone. This also drives a need to optimally spread out drones in the environment.

Because the game is mixed reality and the player is physically engaged in the game, there is no way to model player health or to balance for physical exhaustion. Consequently, the time and battery constraints are used to simulate some of these elements. Certain parts of terrain are dangerous either to the player or to the drones, and can detected remotely by the drones. If a player spends time in a dangerous area, time is deducted; likewise, if a drone spends time in a dangerous area, the drone loses battery faster.

Core Mechanics

To achieve the objective, the player may engage in core mechanics of moving in the physical environment or performing one of several drone actions, while avoiding dangerous areas. A key component of success, and a focus in developing game balance, is attention to how the player optimizes their own movement and the movement of the drones.

Player Mechanics

The player is free to move in the physical environment, to the limits of a specified play area. Because the game is timed, the player needs to focus on moving to the right structures with the help of intelligence provided by drones.

Figure 5. The physical prototype, a paper board game simulating the mixed reality game. A.: the human board with a bar for tracking amount of movement; B.: low-altitude drone board with detailed information; and C: high-altitude drone board with less detailed information.

At the same time, the player needs to identify and avoid virtual dangerous areas while navigating the physical environment to structures that contain clues or the hidden object. The player can search a structure if it is nearby, but this takes time. Ideally, the player should only search buildings that contain clues inside it or the hidden object, as determined by invoking drone actions.

Drone Mechanics

The player can fly the drone on top of the area to scan the map to find the location of the structures, their numbers, their entrance doors, and the most efficient route to get to each building door. Moreover, the drone can check if there is any clue on the top of a structure. The drone user interface is expressly not yet defined, as developing the interface and configuring devices is part of the research.

Similar to the player, there are dangerous areas to drones that deplete their batteries faster. This simulates, for example, needing to maneuver around trees.

The player can make choices about drone altitude. Different altitudes offer trade offs: they may avoid dangerous areas and provide a wider scope of information, but can scan in less detail.

Early Design Stage

We built a physical low-fidelity prototype for our game to evaluate and improve the game and its core mechanics (Rogers et al. 2011; Fullerton 2014). Such a prototypes are built inexpensively, to enable rapid redesign. In our case, as with many digital games, we prototype as a board game that will provide clear insights into how to build the mixed reality. As is the norm for this type of design work, we developed a number of prototypes and played them in the lab to develop the mixed reality game design described previously. In the remainder of this section, we describe the second major prototype we developed.

Our physical prototype is built on three boards, which represent the human's environment, the drone's low-altitude board, and the drone's high-altitude board (Figure 5: A, B, and C, respectively). All boards are the same size, a 6 × 6 grid that represent the same physical-world space. The boards each contain different sets of information, hidden by paper flaps:

- the human board consists of open space and building locations;
- the low-altitude drone board contains more detail (e.g., buildings, clues, dangerous for the drone and the player); and
- the high-altitude drone board contains low-detail information (e.g, building clues, dangerous areas for the drone only).

One token represents the human and one or more different-colored tokens represent drones.

At the beginning of the game, the human board and drone boards are completely covered. On each turn, the player can specify what the human does: either give a drone a destination or move themselves. If a drone has a destination, it moves as specified. Then, the information on the board is revealed at each location (e.g., that of the human and each drone).

Because the physical prototype needs to be turn-based to enable humans to manage it, the time and battery constraints are modeled by using the number of squares moved. Each of the human and drones has its own pool of movement points. Normally, moving one square costs one point, but dangerous areas (represented as black squares) cost four. Similarly, it costs a drone one point to move a square, two points to increase altitude, one point to decrease altitude, and two points to move through a dangerous area (red squares). The player can direct a drone by spending one movement point.

Revealing information on the board works as explained in the mixed reality game section. The game is won if the player reaches the specified building before their human movement pool is expended.

DISCUSSION

In this section, we address the trade-offs involved in using the architecture to address future search and rescue scenarios. We also discuss our plans for future work in this space.

Benefits of the Architecture

The present architecture enables the safe use of drones in a number of contexts, as well as enables developing replayable scenarios. Drones are challenging to work with and can be dangerous. Many studies have addressed the problem of using drones, such as privacy violation and security issues (Lidynia et al. 2017; Chang et al. 2017). Also, there are legal limits on where and how they may be flown (Barin et al. 2017), which can be at odds with work that needs to consider how they might be used autonomously. Using simulated drones sidesteps many of these issues, enabling a player to have a near-seamless experience of working with drones while also working in a physical environment.

One of the main benefits of using mixed reality through this architecture is the ability to present a contextual experience that use the physical world as a stand for the game world (Benford and Giannachi 2011). Unlike the complete artificial world of virtual reality, mixed reality combines virtual reality information with a physical reality experience. Through this approach, we do not need to simulate the environment, we simply use it. The physical environment affords and constrains action in the game through a combination of layout, size, climate, history and purpose (Sharma et al. 2017).

When training scenarios are re-used, participants are able to carry over knowledge from one scenario to another, which can be at odds with learning. The inclusion of virtual components to the simulation, that do not exist in the physical world, supports replayability. These components can be easily reconfigured, or even constructed procedurally (Togelius et al. 2011), creating different experiences with the same physical environment.

Limitations

One obvious limitation is that human players cannot directly interact with the virtual drones. While we expect many use cases to involve drones working in a space away from humans, this could reduce players' sense of immersion when the drones are working nearby.

An alternative design would create more immersion through the use of 3D imagery in an augmented reality environment. In such a setup, players would be able to see the drones projected on their views of the physical world. At the same time, we have concerns about such an approach, since part of the purpose of this work is to enable testing device configurations and an augmented reality setup necessarily requires augmented reality glasses as a device.

Future Work

In future, we will test the fully implemented game with users, primarily to address device configurations. In these controlled user studies, we will assemble a wearable computer into several possible configurations (e.g., those discussed previously) and have users play through the game. We will use the setup to gather performance data automatically, in which the gathered data will be used to evaluate the performance of the players and the different device configurations (Dolgov et al. 2017).

Another straightforward extension of the framework is to work with non-aerial unmanned systems, though the transition is non-trivial. Such unmanned systems require different navigation capabilities and are more challenging to simulate. We would expect to extend the specialized components (Figure 2) to account for these changes.

CONCLUSION

In this paper, we presented an architecture to test new combinations of human and robot teams in the context of urban search and rescue. While we present our own, initial game design, we expect the architecture to be useful to a range of researchers an practitioners, forming the basis for investigating and training within this unique, new domain. Our game design is just one of many possibilities built on this architecture, and we look forward to a variety of games in this space.

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WalkSafe: College Campus Safety App

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ABSTRACT

WalkSafe is a location-based app that notifies users of emergencies around them. The app is compared to The Pennsylvania State University's emergency notification system - PSUAlert, which provides time-based alerts. We identify weakness of the existing PSUAlert system and address them by introducing a location-based emergency notification system with the records of past incidents along with the type of emergency with respect to the user's location. We gathered user perception from 43 survey respondents that informed the design of the WalkSafe app. We use mixed-methods approach to evaluate WalkSafe with PSUAlert system as a baseline. We assess both systems with 22 participants by notifying them of the fake emergencies and asking them to use both systems to understand details regarding the emergency and its location. The pre- and post-surveys are evaluated using content analysis and paired t-test. Participant reported higher perceived convenience, perceived security, willingness to use, and willingness to share when using WalkSafe.

Keywords

Emergency alert; campus safety; real-time and location-based crime report.

INTRODUCTION

Schools and college campuses—where young people spend part or all of their day—are often assumed to be safe places (School and Campus Crime, 2013). Yet substantial increase in the number of mass shooting incidents on college campuses in the United States in recent years would suggest otherwise. In recent times, on April 16, 2007, Seung-Hui Cho shot and killed thirty-two students and faculty and wounded seventeen others on the campus of the Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia. This was the deadliest school shooting in United States history. Ten months later, on February 14, 2008, Steven Kazmierczak killed five and wounded eighteen in another mass shooting incident on the campus of Northern Illinois University. This was the second-deadliest university shooting in recent decades, and the fourth-deadliest in U.S. history (Kaminski et al., 2010).

Colleges and universities are required to keep records and report crime, particularly VAWA crimes, to the U.S. Department of Education as a result of the Jeanne Clery Act of 1990 (School and Campus Crime, 2018). In 2014, property crimes accounted for more than 50% of all campus crimes reported under the Clery Act. Burglary constituted 42% of crime, motor vehicle theft made up 9%, and arson 2%. Sexual offenses made up 32% (School and Campus Crime, 2018). Data collected by the Clery Act does not encompass all crime experienced by students at colleges and universities. The FBI separately collects reports from campus police as well as local and state law enforcement agencies through its Uniform Crime Reporting Program (UCR) (School and Campus Crime, 2018). Unlike the Clery data, UCR data indicate that violent and property crimes known to law enforcement have remained relatively constant for the past 10 years, with the exception of rape: rape known to law enforcement has increased significantly since 2005 (School and Campus Crime, 2018). Over that same time frame, college campuses have reported a rise in forcible sexual offenses that is 60% greater than the rise demonstrated by UCR data (School and Campus Crime, 2018).

Mass shootings along with violent crimes have led to an increase in perceived sense of fear for crimes. With increase in campus related crime, a lot of studies have been conducted to understand how perceived sense of fear can affect males and females on campus. Study of fear of crime has been gaining prominence since 1960s as shown by Skogan & Maxfield, 1981; Stanko, 1995; Stinchcombe et al., 1980. Research has consistently shown that some groups, especially women and the elderly, are more fearful of crime, despite lower levels of victimization than young males (Clemente & Kleiman, 1977; Dobbs et al., 2009; Ferraro, 1995, 1996;

Fetchenhauer & Buunk, 2005; Fisher & Sloan, 2003; Garofalo, 1979; Parker & Ray, 1990; Parker et al., 1993; Stafford & Galle, 1984; Stanko, 1995; Warr, 1984, 2000). One study showed that while women are significantly more fearful of crime prior to controlling for fear of rape, once fear of rape is considered, women's higher fear of other crimes seems to diminish such that there are either no sex differences in fear or men are more fearful than women (Dobbs et al., 2009). Researchers also identified several personal, contextual, and other factors associated with levels of fear of crime on campus (Kaminski et al., 2010).

With increase in crime and its perceived fear among the males and females of the college community, many campuses have expanded their emergency communication systems using multiple notification routes, such as text, e-mail, and phone alerts (Hamblen, 2008), though a survey of five hundred campuses using a particular emergency alert system found that only about 40 percent of students had registered for the service (Kaminski et al., 2010; Mark, 2008). Nevertheless, a critical question remains: Can technology be used to alleviate the perceived sense of fear for crimes on campus?

Use of mobile technology to notify and fight the campus crimes has increased in the passing years. Safe lines have been developed for students to address serious problems in their life like bullying to seek relief and counseling from destructive behaviors (Student Safeline, n.d.). Social media such as Twitter and Facebook (Shih et al., 2015) along with apps such as the Crisis Incident Chatter app (Shih et al., 2014a) and other local news apps (Carroll et al., 2015; Han et al., 2014; Shih et al., 2014b) have also been used to inform people of emergencies and incident happening around them.

The use of mobile/wearable technology, in sense of safety, different from aspect of campus crime has been explored in developing Automatic Fall Detection, or Automated Fall Detection for elderly (Campus Security, 2014). These systems feature sensors (multiple accelerometers and processors) that can detect between normal activity, and an actual fall and can be worn on waist depending on the waist (Automatic Fall Detection for Seniors, n.d.). Wearable technology has also been used in clothing (Mattmann et al., 2007) in the field of medicine for physical medicine and rehabilitation (Bonato, 2005) even for fitness as seen with the introduction of Jawbone, Fitbit, Nike Fuelband (Shaking up the wearables, 2014). It has been estimated that the global wearables market will grow at a compound annual rate of 35% over the next five years and hit 148 million units shipped in 2019 (Danova, 2015). Wearable smartwatch is introduced since 80's but it gained popularity in 2013 after Pebble, Samsung, Sony, Qualcomm and now Apple and Google introduced smartwatch to market. Keeping the past research in mind, we decided to survey 43 participants about their perception of safety. The survey and its result showed that there was definitely a room for improvement when it came to relaying type of crime information, its location, whether or not they should be informed about the crimes happening near their loved ones, etc. This requirement gathering helped in creating a campus safety app, WalkSafe, integrating Pebble smartwatch (a wearable smartwatch) that helps the college community by giving them locations of the campus crimes. The application (app), WalkSafe, is a new improved proactive version of the PSUAlert, Penn State University's email, call and text alert system in case of campus wide threat. WalkSafe, previously called Campus Alert, uses the user's GPS location to track the crimes that are reported on the campus and provide a geographical view of the incident with respect to the user's location. The incident also consists of the nature of the incident such as robbery, sexual assault, car accident, etc. along with the time and date of the incident when reported to the user. This gives user a compact yet pertinent information regarding their safety and gives them the power to prioritize their safety if need be. The app also keeps track of the previous incidents that have already been reported to the campus/local police and shows the incidents to the user on the map.

In this paper we strive to investigate the following research questions:

RQ: *In comparison with the PSU Alert system, will WalkSafe provide users a higher level of perceived sense of security?*

RQ: *In comparison with the PSU Alert system, will WalkSafe provide users a higher level of perceived convenience?*

RQ: *In comparison with the PSU Alert system, will WalkSafe provide users a higher level of willingness to use?*

RQ: *In comparison with the PSU Alert system, will WalkSafe provide users a higher level of willingness to share?*

This paper addresses the limitation of the PSUAlert and proposes WalkSafe as its alternative to make the campus more safe and harmless for its community. More specifically this paper provides the following contribution:

- We identify situations that lead PSUAlert to not perform up to the user standards of safety and we propose solutions with respect to these problems that is solved by our app:

- *Location based alert system:* We define a location-based incident alert system that gives user the proximity of the incident from his/her location along with incident's type, time and date.
- *List of previous incidents:* Our app gives a compact view of all the previous incidents around the user for a designated period of time. All the previous incidents list the incident type, time and date.

- We conducted usability testing with 22 users to compare PSUAlert and WalkSafe. The testing showed that WalkSafe is preferred by the participants more than PSUAlert for the information it conveyed.

Finally, we show the future work that can be done to make WalkSafe more reliable and safe. With the collaboration with local police, the app can be made applicable to any county, city and state and can serve to visitors who need to know the area so that they can judge for their security and safety. To the best of the our knowledge, no such campus safety app has been developed so far incorporating a wearable technology to safeguard the students, faculty, staff and the college community in general.

REQUIREMENTS GATHERING

We started out first by sending a digital survey in which 43 participants responded. The survey included questions such as participant demographics, their frequency in viewing statistics related to crime, their preference in being notified about crime, their preference for filtering crime related information, some features they would like to see in safety apps, etc. 17 said that they never viewed crime related statistics, 19 participants expressed to be notified of the crime/s immediately once it happened, 24 participants mentioned that they would like to filter the crime/s in their proximity and 15 participants said that they would like to customize the radius of the crime to their location. Based on these results, we developed the app WalkSafe. WalkSafe incorporated the insights from the survey results and to understand if the app met the safety needs of the college community, we user tested the app against PSUAlert-The Pennsylvania State University's emergency notification system.

THE WALKSAFE APP

The WalkSafe app is designed for the campus safety of the college community of The Pennsylvania State University. WalkSafe notifies the user of the emergencies/incidents happening around them based on the updates done to the University Police database. The past incidents are also reported based on the incidents previously reported to the University Police database. The current prototype of the app supports the incidents reported two days prior for the college community and visitors to check and access their safety. Wearable devices like Pebble smartwatches are taken into consideration when designing functions but it is secondary to the mobile app and interaction.

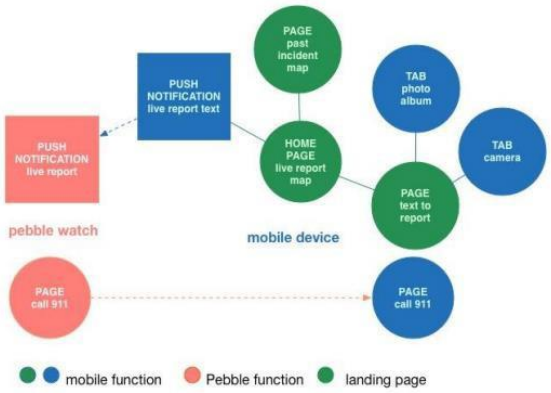

Figure 1. The application map of the app

The information architecture of the application is discussed below (see Figure 1). The information architecture refers to the organization of content and navigational flow of the application. An application map is presented to visualize the information architecture. As illustrated in the application map, the functions of the application are either Pebble-based or mobile-application based. When opening the application on a mobile device, users first enter a home page, which is a map view of current incidents. They will see their current location as a blue dot and reported local emergencies as red pinpoints. In addition, notifications will pop up if the user is close to an ongoing emergency. There are two landing pages that allow users to navigate from the home page: the past incident map and the text-to-report page. The past incident map indicates past incident that occurred nearby. On the text-to-report page, users report an incident to the emergency service via text. They can also take pictures or

access to their photo albums if they want attach pictures of an ongoing incident. When the application is closed, push-up notifications will be sent once the users are close to a live incident. If users have a Pebble watch, they will also receive notifications from the application. To report an emergency, users can push a combination of buttons and make a phone call to the emergency service.

The RQs, mentioned in the introduction, led to development of the information architecture of the app which in turn took shape of the app, WalkSafe. The purpose of the personas and storyboard is to provide a basis for the development of the app and its integration with wearable technology like Pebble smartwatch and its specific use case scenarios. The personas identified 4 main users of the app at The Pennsylvania State University: undergraduate student/s, graduate student/s, faculty and staff. Low-fidelity mock-ups are developed using paper prototypes. High-fidelity mockups are developed in Balsamiq (see Figure 2 and Figure 3). The working prototype is developed on iOS platform. The app is coded for iOS platform and is currently available on iOS.

Figure 2. Notification sent to Pebble and Cellphone main screen

Figure 3. High fidelity prototypes; Left: Landing page of app showing the emergency (red dot) with respect to user's position (blue dot); Right: Page showing past incidents (green dots)

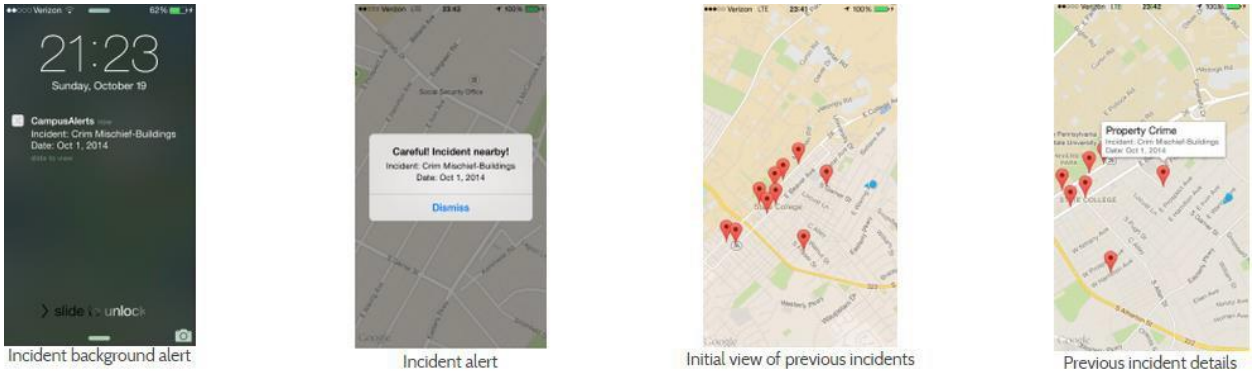

Figure 4. WalkSafe App: (a) Incident background alert, (b) Incident alert, (c) Initial View, (d) Previous incidents

When the WalkSafe app initially loads (see Figure 4c), the user's location is calculated. Once found, a map view is displayed which shows the user's location as a blue marker. Also plotted on the map are locally reported police incidents, denoted by red markers and plotted according to their own location data (Figure 4d). The user is able to interact with the map by zooming in and out, panning on the map, and selecting individual incidents. When the user moves location, the user's location marker is updated to reflect this change.

If a user taps on the screen where an incident marker is located, a text box pops up above the marker. This text box gives the user some details related to the incident, including the general category, the specific incident recorded, and the date in which it occurred. This is shown in Figure 4a.

As stated before, as a user moves their location information is updated. Every time their location information updates the distance between the user's location and all reported incidents is calculated. If this distance falls within the threshold for danger set in WalkSafe, the user is presented with an alert of the incident that the user is close to. Once a user dismisses this alert, they will not be alerted of it again (see Figure 4b).

In summary, we are trying to design an app for college community safety that can provide the necessary and pertinent information without compromising user's safety. WalkSafe strives to provide the location of the emergencies/incidents to the depending on user's location along with the type of the incident, its date and time. It also provides the details of the past incidents depending on the user's location so that user can prioritize their safety. The salient feature of the WalkSafe is that it gives the user all the relevant details about the incident with respect to their position on the map which makes it easier for the user to understand the danger surrounding them.

From the user study, we specifically strive to understand which system (PSUAlert or WalkSafe) do the college students, staff and faculty prefer based on their perceived sense of security, perceived sense of convenience, willingness to use and willingness to share the app.

USER STUDY

To better understand which system the college community prefers and how they will perceive both the systems in terms of security, convenience, willingness to use and willingness to, we designed and conducted a user study with 22 college members consisting of students, staff and faculty The Pennsylvania State University with approximately 45,000 students, and a total of 1,000 faculty and staff. All the participants were recruited through snowball sampling. The participants were 11 males and 11 females. The average age was 27 years ranging from 22 – 34 years.

The participants are first given a consent form to sign before the test is administered. The consent form includes the name of the investigators and the summary of the project. It also mentions that the participant is audio recorded for future reference but their identity will be kept private. The first section of the test is a pre-experiment survey. Following the survey is a controlled experiment. Then, a post-experiment survey is conducted. Last, the participants are interviewed. Post-surveys employees 7-point Likert scale questions (where 1= *Strongly disagree* and 7 = *Strongly agree*). Open-ended questions regarding their choices in the post-survey were asked in the interviews where the participants present their views about each system in terms of security, convenience, willingness to use and willingness to share both systems. The details of each test section of the study are discussed in the following paragraphs.

Pre-Survey

The pre-experiment survey asked the participants regarding their current phone brand, the operation system of their phone, and their prior knowledge with a smart watch. These questions are used as potential control variables.

Controlled Experiment

We conducted a within-subject experiment. To compare the usage of PSU Alert and our app, the participants are asked to walk along a route on campus using one system first and switch to another at the midpoint. The order of the two systems is randomized. The route starts from the HUB, the central building of the campus passing intersection of Pollock Road and the Pattee Mall, and ending at the endpoint at Information Sciences and Technology Building (IST). Note that in the PSU Alert system condition, fake The Pennsylvania State University Alert texts simulating real text messages are sent. For the designed application condition, test data obtained from the university police is used.

Post-Survey

At the end of the experiment, the participants fill in a post-survey. The post-survey consists of questions such as

probing the users to rate both systems according perceived sense of security, convenience, enjoyment, willingness to use, and willingness to share. In addition, demographics section are included at the end of questions (where 1= *Strongly disagree* and 7 = *Strongly agree*). The demographics survey included questions about their age, educational qualifications, gender, ethnicity and first language.

Interview

After the post-survey, a semi-structured interview is conducted. First, participants are asked to explain the reason behind their ratings for each dependent variable: perceived sense of security, perceived convenience and enjoyment toward both the PSU alert and the application. Afterwards, the researcher asks them to provide feedback regarding potential needs for customization function within the application. The last question focuses on gathering general feedback/recommendations towards the app. The interviews were audio-recorded and transcribed for analysis.

Measures

The interviews that were taken were transcribed and coded based on the metrics given by the stakeholders at the start of the project. These metrics formed the basis of the coding process and allowed the app to be rated with respect to its counterpart PSUAlert and realize its potential strengths and weakness. The four metrics that are used for coding the interviews are defined and discussed below:

Perceived sense of security: Perceived sense of security is defined as the attitude of the users towards the app in keeping them safe by providing timely and correct information when needed. This refers to how fast and correctly the user can recognize the emergency jeopardizing their safety and act accordingly to prioritize their safety.

Perceived sense of convenience: Perceived sense of convenience is defined as the ease with which the users can assimilate the information regarding the emergency such as the type of emergency like weather conditions, sexual assaults, accidents, etc. along with their date and time. This information pertains not only for the current emergency but also for the incidents that have happened in the past that user wants to grasp.

Willingness to use: Willingness to use the app refers to attitude of the users to use the app given that they feel secure using the app and also find the information regarding the threat/incident in the time of emergency as well as past incidents. This metric identifies the trust that the user puts in the app for delivering the right information so that they can prioritize their safety.

Willingness to share: Willingness to share describes the user's willingness to recommend the app to their friends and family while on campus for emergency purposes. This metric takes into account user's perceived safety and convenience using the app along with their willingness to use it.

RESULTS AND ANALYSIS

A paired sample T-test is performed to analyze the survey data to see if WalkSafe would lead to higher level of perceived sense of security, perceived convenience, willingness to use, and willingness to share than the PSUAlert system respectively.

Perceived sense of security: Participants reported that WalkSafe ($M = 5.5$, $SD = 1.3$) provides higher perceived sense of security than the PSU Alert system ($M = 4.7$, $SD = 1.64$; $t(8) = -2.1$, $p = < 0.05$).

> *"Because it applies to me and where I am as opposed to the PSU campus in general."* (P9)
>
> *"If there's something going on right now you want to know where it's at so you can know to avoid that area."* (P6)

The above statements by participants imply that incident location with respect to their own location played a major role in increasing the participant feeling more secure. The location of the danger on map near them showed them the exact location instead of taking for granted that users already know where the given location on campus is as is the case with PSUAlert.

Perceived sense of convenience: Participants perceived higher sense of convenience when using Alert ($M = 6.2$, $SD = 0.6$) than when using the PSU Alert system ($M = 4.8$, $SD = 1.6$; $t(8) = -3.5$, $p < 0.01$).

> *"It's probably more convenient because I will only be notified if the thing is closer to me"* (P9)
>
> *"With watch being just an added complimenting because you can see it more quickly than to remove phone from the pocket."* (P4)

Participants like the use of Pebble as they can feel the vibration of Pebble on their wrist that draws their attention to the emergency around them. They don't have to remove the cellphone from their pockets or purses as the notification about the incident is sent on the Pebble. The implication here might that not a lot of participants had used a smartwatch before though they had certainly heard about smartwatches.

Willingness to use: Participants reported that they were more willing to use WalkSafe (M = 6.3, SD = 0.8) than the PSU Alert system (M = 4.7, SD = 1.5; t(8) = -3.5, p < 0.01).

> *"It gives me a visual aspect as to what location is the alert from…."* (P2)
>
> *"I do feel that one [the app and watch] is a little bit more enjoyable [than the text alerts] even just because it does give more information as to what is going on."* (P8)
>
> *"Umm..I guess again I would go with the one on the watch just because it's pretty cool."* (P6)

WalkSafe gives a visual aspect of the incident whereas PSUAlert just mentions the location of the incident in text. Both the systems give similar information but utilize different means of communicating the information the users. Participants feel that WalkSafe is more interactive than PSUAlert because of the app's visual feature of showing location of incident/s and user.

Willingness to share: Participants reported higher level of willingness to share using WalkSafe (M = 6.33, SD = 0.7) than the PSU Alert system (M = 5.1, SD = 1.8; t(8) = -2.2, p < 0.05).

From the user study new features were added to the application and a mockup design was used for the second survey (see Figure 5). The features included in the improved version are filtered by crime, sharing the alert, setting up location range and adding multiple location.

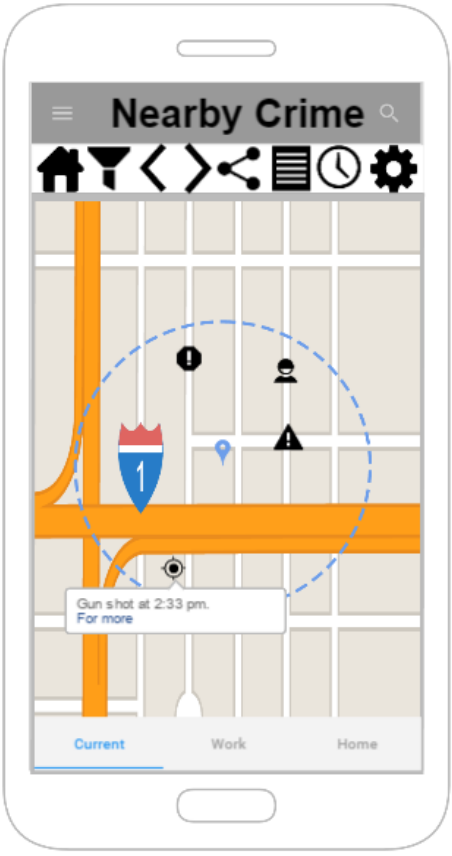

Figure 5 Improved design of WalkSafe app

A survey was conducted to evaluate the user perception of the improved design. There were 43 responses from different ethnographic. The survey was completed by 86% Asian with 51.2% male and 48.8% female. The survey questions included about their neighborhood safety their concern about neighborhood safety, application review and demographic questions. From the survey we learnt that less than 50% of people recorded that neighborhood is safety. However, on the other side highest percentage of people among all categories are concerned about their neighborhood safety. This shows the need of neighborhood safety application. This application has feature advanced feature to help users to learn how safety is their neighborhood. Almost no user has explored the safety places since only very limited doors available to reach out the resources. WalkSafe

makes this information handy and readily available. The survey helped to envision future roadmap for this application. Users came up with diversity of requirement as add on feature.

The survey broadly classified into three sections which focus on background of client, neighborhood safety and feedback on neighborhood safety applications. The questions under background section focus on people from diversity region. The research was interested in finding out how many percentage of people are aware of any neighborhood safety applications. It could be appropriate to state that only around 37% of the people are aware of such advanced technology applications. On the other side, more than 50% of the neighborhood is not safe to travel and live.

The participants reside in different country such as India, UK and USA. Over half said that they never get to know the safety of their neighborhood safety. Almost no one receives or make utilizes of any applications to learn safety of their neighborhood. So this depicts, the participants are not aware of any existing applications that facilitates such services. It could be either users' unawareness towards safety or the application limitation to attract enough number of audiences. Survey such as WalkSafe survey will help the participants learn about the application and how that would be very useful in our day today life.

Few questions focus on features that the participants are envisioning in any neighborhood safety applications. The list of questions begin with what type of filter will help participants to get most informative data. More than half of them preferred to have the search filter set to proximity near me. This will sort the results of crime activity that has happened closer to last known location. This filter helps any user to know how safe their current location is. Equally same percentage of participants opted to have another filter which sorts any crime activity which has happened near their loved ones. This option indicates, the participants are equally interested to know the safety of their loved ones as much their safety. Questions like this will take neighborhood safety applications to next level by knowing loved ones in family are safe as well. Sort by date and time option are the least preferred options among all other options. This option is more like informative to know the crime activity by date and time.

The survey included questions like how the user would like to get notified. All participants are very interested to get notified by some means. This shows how much all participants are very active participants for any practicing safety neighborhood applications. More than half of the participants likes to get notified as soon as any crime activity occurs irrespective of location. This will help to create awareness of known active criminal activity that has recently happened in any location. The second largest option preferred is criminal activity happening within defined range of region. The preferred option is have push notifications for every defined set of regular intervals.

Participants are very active in defining the features of applications that makes the application very active and engaged. Most of the users likes to know more information about any active criminal activity. Participants are interested to learn more about criminal activity, so they prefer to get any external reference such as news feeds, articles or quick feed that provides more detailed information about the crime. Any social media reference or related articles are very least preferred option. Most of the social media news feed are user controlled which deceives any information.

User has almost equal range of vote for all features that are listed to as upcoming features. Participants are very interested to have safety neighborhood application as crime-free route options as well. It is equally important to know take safe route as to know any active crime activity. This will not only help the users to learn crime activity but also to react to any crime activity. This feature will help users to find out safe zone and reach safely to any safe zone. User are also interested to learn how safety is any destination that the user has planned to journey. This is very important feature which prepares the user for any upcoming or active criminal activity. The options include display nearest safe zone along with distance from user last known activity. User suggest other features such as notify family members on safety, call feature to alert family on any active criminal activity and report any know incident. The last option may trigger false alarm which may lead to some serious consequences. If any such option has to be implement in any neighborhood safety applications, this has to be verified from different resources. On the other hand, waiting to confirm or validate any reported crime activity may take time which will delay pushing notifications to active users.

More than half of the participants agreed that safety neighborhood applications will definitely enhance personal safety. Almost all users also recommend such applications to their friends and family members. This will create awareness on locating safety neighborhood. All features and responses are very much aligned in involving family members and know safeties of beloved ones. Users' response include suggestion which allows application not only to notify neighborhood safety but also to help users to learn and navigate to safe zone in a safe route.

DISCUSSION

The overall results clearly show that the participants prefer WalkSafe in comparison to PSUAlert system. This may be due to Location-based system that is provided by Alert and the instant notification that is supported by Pebble smartwatch.

Perceived sense of security: One of the reasons participants felt more secure in using WalkSafe as compared to PSUAlert may be that it gave them the location of the incident with respect to their own location. Also, WalkSafe gave the information of the incident as and when it happened which helped them to access their safety in much better way. This information allowed the participants to realize the true magnitude of the incident and prioritize their safety. It also gave them an exhaustive list of all the incidents that happened in the nearby area that allowed them to judge the safety of the area.

Perceived sense of convenience: In terms of convenience, participants felt that having Pebble made a difference as they did not have to pull out their cellphones to check the notification. Since the Pebble showed them all the basic information regarding the incident on the watch itself, the participant need not remove his/her cellphone from the pocket to check the notification. Unlike PSUAlert where all the students, faculty and staff is notified of the incident when it takes places, the participants are notified of the system only if they are near the incidents. This helped them as the notification made them aware of the danger that is close to them as opposed to the incident that might not be related to them.

Willingness to use and Willingness to share: The reason the participants are more willing to share and use the app can be attributed to their feeling more secure and convenient in using the app. Another reason as to why participants are willing to share and use the app is because of the display feature of the app. Also, they found the app much more enjoyable in terms of the information that the app could give them as compared to PSUAlert system.

There are limitations to the testing design and experiment in general. First, the setting of our usability testing can be more realistic. To improve the naturalness of the setting, we can allow participants to use their own phone during the test. In addition, the content and frequency of the alerts can be more realistic by having access to real-life data such as these from the police department. In this study, we conducted surveys, interviews, and experiments partly due to the limitation of time. If feasible, it might be more appropriate to perform a diary study. In our study, we received mixed opinions on smartwatch. Therefore, researchers can gain more insight by looking into the user experience of smartwatch and the phone application separately.

Second, a more representative sample can help us increase the generalizability of our results. External validity of this study can also be higher if we recruit more participants from more diverse backgrounds.

Third, though we try to keep the interview questions consistent across all participants, there might still be bias coming from different wordings of the questions as well as different interviewers. By having a more clear instruction, we can reduce potential bias.

Last, a more detailed prototype might be helpful. It seems intuitive that by allowing users to interact with more functions, the more insights we can receive.

CONCLUSION AND FUTURE WORK

We showed in the study that the app, WalkSafe is preferred by the users because of the safety features it incorporates. The main features of the app namely: location-based interface, record of past incidents, type of emergency along with the WalkSafe's integration of Pebble smartwatch for the safety of the users led to users giving preference to WalkSafe over PSUAlert system. Preliminary results of this study are encouraging as the study shows the potential of using wearable technology for safety purposes.

There is still vast amount of work to be done to use wearable technology for safety purposes. Future work done in this field can look into how emergency number like 911 can be called directly from the wearable technology as opposed to calling it from cellphone when in emergency situation. The wearable technology like smartwatch can be hardwired to make a phone call to emergency services when a certain combination of the buttons are pressed on the smartwatch. Another thing can be looked into is adding the on/off notification systems for various incidents that the users can prioritize according to their requirements. This can eliminate the notifications from all the emergency incidents happening near-by them and will focus on the incidents that the user has turned on. The app can also be used as a standalone system. The app can be tied to the local police department of any town or city and this can act as an emergency notification system to the residents as well as the visitors of the place. Furthermore, the records of past incidents can also provide a glimpse to the visitor of the safety of the nearby places that can help them decide about their safety.

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Why IT systems for emergency response get rejected: examining responders' attitude to IT

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ABSTRACT

Emergency responders' attitude to IT is marked by resistance, aversity, and rejection. This attitude is specific to IT alone and does not extend to technology in general. Current research on the topic only presents partial, scattered, and unconnected accounts that do not provide a starting point on how to tackle the rejection. The available models for technology acceptance are also too general and do not take into account the specifics of the emergency response domain.

Through extensive user research combined with a grounded theory approach, this paper identifies twelve problem areas from which responders' negative attitude towards IT arises. By extending the technology acceptance models with this new knowledge, we provide system designers with an understanding of what to tackle and tune in their IT system designs so that a positive attitude among emergency responders can be achieved.

Keywords

Acceptance of ICT, Survey on existing approaches, Impact of IT, Grounded Theory

INTRODUCTION

Multiple studies[1] have reported that emergency responders' attitude to IT is one of resistance, if not outright rejection. A firefighter summarized the current situation as: "We have two proud centuries of tradition unhampered by progress"[2]. This attitude, however, cannot be dismissed as simple resistance to change. The same firefighter – just like many others in (BRIDGE 2011) – proudly told us how all processes and tools at his department had changed within his lifetime, with some of the changes even stemming from his own ideas. Among emergency responders, aversity to IT is only about IT, not about change or technology in general.

The attitude of responders to IT has been object of several research papers, but these have only provided partial glimpses, scattered and unconnected to each other. The research results, consisting mostly of observations and matter-of-fact evidence, have not been distilled into a clear set of core motives that drive the attitude. The present paper lifts these limitations:

1. It identifies the root causes and sheds light on the underlying issues of responders' attitude to IT.
2. It abstracts the evidence into a model of the multiple facets of this attitude.
3. It extends technology acceptance models in a way that can be directly used by system designers and project managers alike.

[1] To name just a few: Paul et al. 2008; Orthner et al. 2005; BRIDGE 2011; Adler et al. 2012; Ammenwerth et al. 2006b.
[2] Source: Personal interview with a Denver firefighter, May 2017.

STATE OF THE ART AND RESEARCH METHODOLOGY

Several technology acceptance models (Venkatesh et al. 2003; Dishaw et al. 2002; Ammenwerth et al. 2006b; Goodhue and Thompson 1995) link an individual's past experience with IT to their present attitude towards IT and to their future decision to use IT for a given task (see figure 1). While we do not dispute these models' validity, we note that none of the models consider the context, stress, and task overload that are typical of disaster and emergency response, even though stress is known to magnify negative feelings and attitudes (Seaward 2016).

Owing to their aim for general applicability, the technology acceptance models use very generic and abstract terms, which are difficult or impossible to relate with concrete aspects and concepts from the emergency response domain. As a result, it becomes impossible to know what aspects of IT give rise to which facets of the responders' attitude. This missing causality link leaves system designers powerless to either understand the problems or correct them.

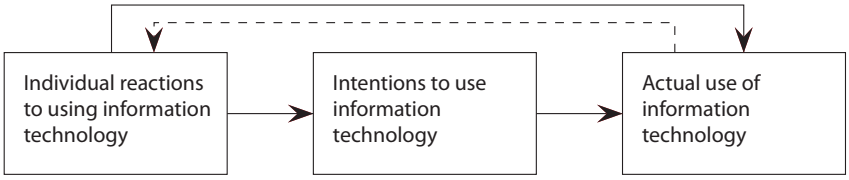

Figure 1. Commonalities of various technology acceptance models

As part of the DERMIS framework for emergency systems, (Turoff et al. 2004) name several concrete factors that impact the acceptance of IT among emergency responders. However, this is only done tangentially; DERMIS neither addresses, nor explains attitude to IT in emergency response front lines. The focus of the framework lies on *management* information systems for emergencies, a context where attitude to IT is traditionally positive (see section "Scope of the attitude to IT").

This paper is based on research carried out over four years in seven countries as part of the BRIDGE project[3], an EU-funded FP7 research whose goal is to develop technical and organizational solutions for inter-agency, cross-border crisis and emergency management. A combination of literature research, document analysis, and user-centered participatory design methods (Greenbaum 1991) were used to elicit and analyze the needs and problems of first responders with regard to ICT on the front lines. More than 300 hours of interviews, participant and non-participant observations, workshops, and other empiric research methods were carried out involving triagers, firefighters, paramedics, doctors, police, disaster relief workers, and incident commanders from Norway, UK, Netherlands, Ireland, Switzerland, Austria, and Germany[4]. At least two different methods of investigation were used for each question, as recommended by (Sanders 1992). An advisory board of responders accompanied the whole research in the role of a continuous focus group.

Due to the scarcity of pre-existing explanations and hypotheses for the responders' attitude to IT, a grounded theory approach (Glaser and Strauss 1967) was undertaken to group the findings and identify overarching patterns and issues. The coding and grouping of the gathered data identified twelve problem areas stemming from the introduction of IT. This is where the needs and practices of responders – especially in the front lines – clash with IT, giving rise to the reported aversity. The identified problem areas are discussed in detail in the next section.

SCOPE OF THE ATTITUDE TO IT

Technologists and decision makers commonly group Information Technology (IT) and Communication Technology (CT) under the same term: ICT[5]. First responders, however, see IT and CT as two very different things, for which different attitudes apply. While strongly resisting IT, responders use and trust CT in every facet of their work: radio on the front lines, phones, fax, and cellphones in higher levels of the response and where the infrastructure allows for it (Bhudhiraja 2015; Schmidt 2007).

[3] http://www.bridgeproject.eu/en

[4] In detail: THW Germany; Firefighters of Bonn (Germany), St. Gallen and Flums (Switzerland), Cork (Ireland), and Denver (US); Norwegian Air Ambulance and the Regional Centre for Emergency Medical Research and Development in Stavanger, Norway; Police representatives from Hertfordshire (UK) and Ghent (Belgium); the German Army at Ludwigshafen (Germany).

[5] For the remainder of this paper, we will use IT to refer to computers, software, middleware, storage, and input/output peripherals dedicated to information processing, and we will use CT to refer to radio, telephone, fax, voice, and other technologies whose primary goal is to enable people to communicate with each other. Technologies such as chat, VoIP, etc., fall under IT, because complex software stacks both play a crucial role and cannot be abstracted away, especially when failures occur. It is thus impossible to see the communication aspects of these technologies as separate from the underlying IT components.

Attitude towards IT strongly correlates with the position of a responder in the hierarchy and with the distance from the emergency scene (front- vs back-lines of response). Thus, the higher up the organizational hierarchy a responder is, and the farther away she is from front-line response, the higher the chances are that she uses and trusts IT systems in her daily work. Typical examples of IT at these levels include decision support systems, GIS databases, and other support systems. Responders at the higher levels of the hierarchy typically work in a well-established, predictable workflow, perform remote-command, managerial, or strategy roles, and use IT for disaster prevention tasks, strategy planning, and high-level or remote management (Bhudhiraja 2015). The nitty-gritty details and unpredictable situations on the ground turn here to simple statistics, record-keeping, or if-then decisions, which are all easily supported by IT. Consistent to this observation, (Paul et al. 2008) found out that EMS personnel have a negative and distrusting attitude towards IT, whereas for personnel from the emergency department at the hospital "...all the orders are on computers"[6]. As another example, (Orthner et al. 2005) report that hospital emergency departments commonly use computerized records, while first-line response agencies still use paper, voice, and fax.

Agent- and robot-based systems for gathering response-relevant data from the environment, from social networks, or other sources have been developed and deployed successfully, but hierarchy plays a role here as well. Citing (Sklar et al. 2014), "In any real-world deployment, a human will ultimately be responsible for the robot team's actions, typically a senior officer at tactical or strategic level"." Where UAVs and robot systems have been used successfully in the front lines, such as (Mohsin et al. 2016; Ramchurn et al. 2015), they function as an extension of the commander's senses, but they are not a tool that each front-line responder needs to grapple with.

SOURCES OF THE ATTITUDE TO IT

Current IT-based tools have a low cost-benefit ratio for first-line emergency response (Paul et al. 2008). Through extensive user and document research, we have identified the following crucial areas in which IT's drawbacks and cognitive costs give rise to the reported negative attitude.

Reliability

IT is not reliable enough for the needs of first responders, especially those in front-line emergency and disaster response. Even in less stressful environments, such as hospitals with a large and established IT infrastructure, physicians are reported to stop using IT and work on paper when they face many patients in a short time (Paul et al. 2008). The authors quote a physician as saying "...A situation like this is the time when the IT system gets overwhelmed". Firefighter commanders told us that they prefer to use whiteboards, flip-charts, and markers, because "they will not turn off as soon as power goes away, nor will they crash" (BRIDGE 2011). The availability of networking and IT infrastructure is another concern: "technology is good except when you are in the middle of the boondocks[7]" (Paul et al. 2008). IT for responders "must work. If I could rely on [the system], it would certainly be a relief" (Adler et al. 2012).

For agent-based systems, reliability means more than simply "not crashing". The agent's knowledge needs to be perceived as reliable too. Bellamy et al. 2017 report that "[agent-based systems] will be extraordinarily knowledgeable in very restricted domains — but this only exacerbates the problem of what happens when the user steps off the plateau of [the agent's] expertise [...] People are not accustomed to such discontinuities of competence."

Interoperability

Current IT-based tools are not easily interoperable with each other, nor can their parts be "mixed-and-matched" to repair a system or build a new one. There is often not even a common interoperability standard for IT-based emergency response tools. Federal countries, like Germany, the US, and Australia commonly have differing standards in neighboring states (Nocera and Garner 1999). Even when a country manages to choose a standard, its systems are typically not interoperable with the neighbor country. In comparison to IT, voice and paper have developed over thousands of years to be interoperable at a basic, subconscious level for humans. They can be used at any time, any place, and remain interoperable across borders or between different agencies. This is one of the keys to understanding why CT is so well-accepted: it simply extends the range of voice and paper over long distances, but does not restrict the message in any way. IT instead restricts the message contents, its formats, and the actions one can apply to that message.

[6]EMS personnel work on what can be seen as "the front lines" of an emergency call, while ED personnel work in a more controlled, less time-critical environment.

[7]Boondocks: a rural area (Merriam Webster 2017). Slang term referring to a place far from civilization.

Emergent behavior and improvisation

The ability to use a tool in an unforeseen role or context is essential for the emergency response domain. As a corollary, emergent behavior – behavior which was not designed on purpose – is expected from all the tools and systems[8]. IT systems for first-line emergency response typically do not support emergent behavior, they cannot be easily interfaced with each other, and they cannot be easily used to improvise. So far, IT has provided improvisation and emergent behavior only to the higher levels and the back-lines of emergency response. One could even argue that the best examples of this emergent behavior, such as Facebook's "I'm safe" notifications, the Ushahidi disaster maps, and the Twitter offers for "bed and breakfast for disaster victims"[9], arose from the public's IT tools, not from those of emergency responders.

Usability

Commercially available software is generally a hindrance in disaster response because of the limited functionality it offers (Paul et al. 2008). This is not a design fault as much as it is an inherent problem in the context. Even if software could support all the response situations and needs known up to the publication date, it still cannot adapt its behavior, data model, and functionality to match the needs of future, unknown disasters.

Worse than the limited functionality, commercial IT-based systems generally suffer from bad interface usability. This problem becomes critical in time-constrained and task-loaded situations, such as emergency response. Independently of how often they use computers in their daily work, both paramedics and emergency department personnel felt that "using current IT systems would constrain them in a disaster situation and they would prefer using paper to computers" (Paul et al. 2008).

In comparison to IT, where software interfaces are the norm, CT interfaces are often hardware-based. They have a long tradition and are based on well-known, long-lived standards and paradigms which incorporate usability lessons learned over decades. Software interfaces are, instead, much more varied and are based on comparatively short-lived paradigms[10]. Some of their lessons are not transferrable, whereas each new paradigm also introduces new kinds of usability problems.

Skill- and knowledge-based behavior

According to (Rasmussen 1983), human behavior can be skill-based (well-known, automatic, habitual, requiring no conscious thought), rule-based ("if X then do Y"), or knowledge-based (conscious mental processing, complex decisions for unfamiliar problems). The distinction between these three kinds of behavior is crucial for understanding responders' attitude to IT. Because every incident is different and unfamiliar, the responders' conscious mind is busy planning strategies and high-level actions. The responder's tools therefore *must* work at the skill- or rule-based levels of behavior. Unfortunately, current IT-based tools do not respect this:

1. They introduce changes into skill-based workflows, making them knowledge-driven. The responder's behavior becomes vulnerable to strong habit intrusion errors – performing the old, habitual workflow instead of the new one (Embrey 2003). Considerable training is then required to return these newly changed workflows to a skill-level behavior.
2. They often require the responders' explicit attention, e.g., to input data or to deal with a software problem. The behavior of responders then again becomes knowledge-driven.

In both cases, the drawback of knowledge-driven behavior is that it is very slow and highly error prone. In a situation where a mistake can cost a victim's or a responder's own life, it is easy to understand why responders are reluctant to accept IT, especially when it is mandated externally, and the more so when IT is not fully under the responder's control.

[8] All of the definitions of "emergent behavior" revolve around the idea that emergent behavior arises only when the system is put to use. Such behavior cannot be predicted at system design time and is not merely the sum of the individual behaviors of each single component of the system.

[9] When a disaster happens, people notify each other on Facebook that they are safe, mark on Google maps/Ushahidi places where help or resources are needed, and offer each other shelter on Twitter. All these behaviors were emergent; none of them was foreseen during the design of those social networks.

[10] As an example, the basic keypad design on the telephone has not changed in the last 70 years (Deininger 1960), whereas the Push-To-Talk interaction for radios has existed for the better part of a century. In comparison, at least five software interface paradigms, each with their own incompatible variations, have come and gone in the last 30 years of IT's life.

Impact on workflows and responsibilities

Like any complex system, an organization's formal rules – the ones the organization purports to follow – are always in a degraded state. They are never detailed enough, or, alternatively, they are so detailed that they contradict each other to a deadlock. It is only thanks to people's improvisation – their informal tasks – that the organization can work[11].

Introducing and adapting IT in an organization requires a fine alignment of the system to both the formal and the informal tasks (Ammenwerth et al. 2006a; Ammenwerth et al. 2006b), but this is oftentimes neglected. (Ritter et al. 2014) report that many medical systems are never used because they either introduce practices that conflict with other aspects of the user's job, or they require changes that affect other people's responsibilities. The same can be said about IT systems for emergency response: they often reshuffle tasks, workflows, and responsibilities in a way that does not match the organization's reality, or in a way that hinders some response steps to the benefit of others.

Oftentimes an organization has certain formal rules that are in reality never followed. IT systems cause such rules to be highlighted, because as soon as the rules are enforced by the system, it becomes clear how dysfunctional they are (Ammenwerth et al. 2006a). The organization then hurries to change, fix, or repeal these rules. At this point, the IT system becomes a hindrance and may get cast aside, because it continues to enforce the old, dysfunctional rule set. As an antidote to this problem, system designers should always very carefully analyze both the formal and the informal context in response organisations.

Some rescue-related processes require a certain preparation time (e.g., driving supplies to the incident area). Because other (slow) processes are carried out in parallel during this preparation time, there is rarely a large waiting gap and the workflow *seems* relatively smooth. When IT speeds up one of the processes, it risks disrupting the choreography of the response as a whole. (Büscher et al. 2016) report that in the Haiti earthquake, the agencies' search and rescue workflow was badly disrupted when the victims "made the process quicker" by using mobile phones to call for help, instead of waiting to be found.

The price of structured data

When writing things down on paper, the first responder uses it as an extension of her memory. The data is free-form, maybe structured in a way that makes sense to the responder, but this structure is developed on the spot, depends on the order in which events are witnessed, and is unique to the responder. Interoperability and compatibility with other responders is ensured by virtue of the data being expressed in a human language, most often in the responders' mother tongue. Interoperability and compatibility within the same profession is also supported by the practitioners' shared vocabulary.

In comparison, most IT approaches so far offer interfaces that support only structured data entry. These interfaces are not perceived as an extension to memory, but as an explicit data entry task. Citing (Paul et al. 2008): "EMS personnel find it difficult to use hand-held technology that constrains free-form data entry. [Whereas] CT enables the communication of unstructured information in the form of natural language, IT forces [responders] to convert [their] verbal communications into the schema of underlying databases". The authors also report that "EMS personnel do not carry computers on ambulances or helicopters; even when installed they will be used for communication, not for information". In our observations and user research we also noticed responders using a smartphone to send photos or recordings of the scene (i.e., communicate unstructured information). In essence, they were using IT to perform a CT task.

The adoption of IT for its primary purpose, information processing, is higher in remote command rooms, but paper has a stronghold here as well. As there is currently no seamless information flow between CT and IT, data coming through CT have to be entered into IT systems by a human. When users can't extract structured information from unstructured communication, or when they are overloaded with information, they revert to paper and verbal communication and simply drop IT (Paul et al. 2008).

Information-pull paradigm

Many work processes in disaster response are built around information that is saved directly on the world. To name a few examples: triagers mark victims visibly with a color to distinguish them, firefighters put knots on their lifelines to know which way the exit is, medics write important notes on the victims' face or body, and firefighter search troupes leave marks on doors to signify whether somebody is still inside (see figure 2). This information is

[11] Organizations are complex socio-technical systems and have the characteristics typical of this class of systems. One of the characteristics of such systems is that they are always degraded (Cook 1998).

pushed automatically from the world into the senses of other responders, just in time, as soon as they come to the place where they need this knowledge. To continue our examples: Paramedics see the triage color as soon as they come near the victim, firefighters can feel the knots whenever they follow the rope as a guide, and other medics can read the notes on a victim's face as soon as they start treating the victim. Current IT tools, instead, rarely push information to the responders who need it (Paul et al. 2008). The information available through such tools must be actively requested – pulled – by responders.

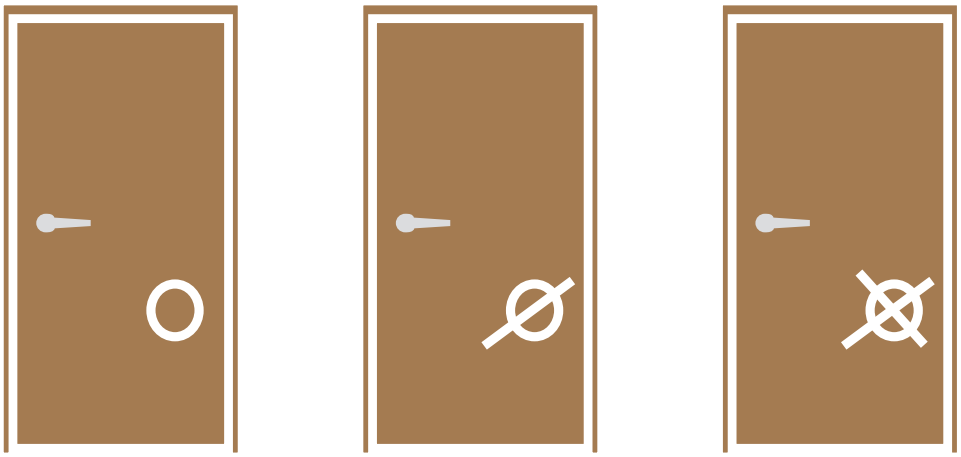

Figure 2. Search troupe chalk marks and their meaning.

Displacement of authority

Before the widespread use of CT, when there was no direct communication between involved parties, authority was correlated to hierarchy, e.g., only commanders could request additional resources or trigger certain response steps. CT allowed authority to flow downwards to the front-line responders, because they had the best view of the situation[12]. Now, with IT's automated workflows, required data fields, and automated decisions, (some) authority is again removed from front-line responders and relegated to the system. However, because the system's decisions arise deterministically from its software, the *real* decision authority lies not with the responders, not even with the system, but with the IT company who wrote the software. Authority is thus not only displaced geographically away from the front lines, but it is also displaced back in time, to when the design of the IT system was finalized.

Overturning of the key concepts of "truth" and "right"

The ability to log every action, decision, movement, and measurement, which is inherent in IT systems, opens the way to recording, reconstructing, and evaluating a responder's actions (Jentsch et al. 2013). However, the "truth" that is reconstructed from the logs will be incomplete and different from what actually happened, because there are no ways to record the conflicting informations, perceptions, experience, and thoughts that caused a responder to take a certain action or decision[13]. Under this new, "reconstructed" truth, actions that were right in the triager's frame of reference may suddenly appear wrong, leading to unjust blame and punishment. To complicate matters even further, this problem, which is introduced by IT, cannot be solved by IT alone. All possible solutions[14] involve re-educating organizations and societies to not seek blame. Excellent and concrete guidance on the matter can be found in (Dekker 2013).

Loss of flexibility

Traditional emergency response tools and workflows allow almost any element to be redefined, replaced, or left out on the spot. No triage tags? Use colored clothespins or spray paint on people's faces. No fax? Send someone to dispatch a message. Emergency responders are, in a sense, "hackers" and "programmers" of the response effort. They know how to "reprogram" and redefine response activities at will and on the fly. The introduction of IT

[12]Source: Personal interview with a Denver firefighter, May 2017. See also (Turoff et al. 2004).

[13]The responder typically cannot complete or correct this picture from memory, because her actions, being at the skill level, were automated and subconscious.

[14]Anonymizing data before evaluation, refraining from evaluating a responder's actions.

systems reduces this flexibility despite the designers' best intentions, because the IT system – especially its software – cannot be left out or replaced on the fly by the responders themselves. Flexibility is further diminished in another way as well. All current IT interaction paradigms hardcode what they expect from the user[15], making it impossible to redefine the system's actions without completely reprogramming the software.

Subjective perception

The acceptance of any tool or technology is influenced by the subjective perception of benefit: A person can't use or accept what she doesn't see as beneficial (Paul et al. 2008). On the other hand, people also can't see the benefits of something until they use it and get some positive experiences with it. Because all responders start their work at the front lines, with a CT and paper approach, and because most of them do not rise high enough in the hierarchy to a level where IT tools are widely used, they end up in a vicious circle. These responders never get a positive experience with IT at work, they get enough bad experiences with IT in real life or from hearsay, so they prejudice IT already before its introduction.

EXTENDING THE TECHNOLOGY ACCEPTANCE MODELS

In the discussion on state of the art, we pointed out that current technology acceptance models do not consider the particulars of the emergency response domain, or, alternatively, they are so general that the particulars of this domain are lost in the abstraction. Due to their generic terms, current technology acceptance models also do not give system designers any concrete starting point or problem that can be directly tackled to improve the design of systems for emergency response. Both of these shortcomings can be solved with the knowledge provided in the previous section. Thus, the problem areas and sources of attitude to IT represent concrete points for system designers to tackle. Furthermore, knowledge of these sources allows for extending technology acceptance models as in figure 3, preserving their qualities while at the same time grounding them to the emergency response domain.

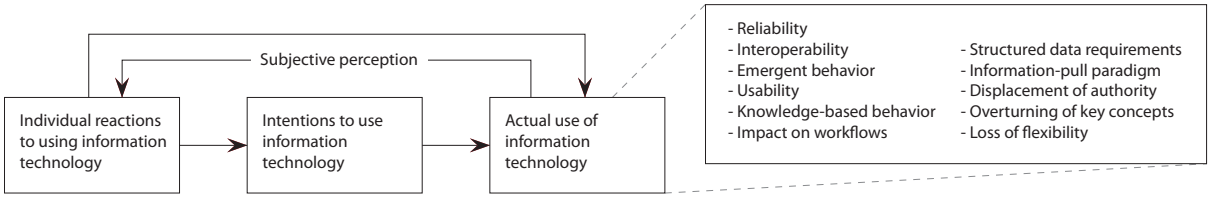

Figure 3. Extension of technology acceptance models for the emergency response domain

The revised model is based on the proposition that actual use of IT raises concerns in each of the discussed problem areas. These concerns then become the basis for (negative) individual reactions to IT, but cannot be balanced by positive use cases and reactions, because the hierarchy characteristics of IT in emergency response cause such positive examples to be present only in the higher and remote-command hierarchy levels. Subjective perception thus remains negative and in turn feeds back onto the responders' individual attitude towards IT, reinforcing the aversity.

CONCLUSION AND OUTLOOK

This paper presented the results of a detailed study which aimed at identifying the root causes of responders' negative attitude to IT in emergency response. Through extensive user research combined with a grounded theory approach, the issues expressed by responders were categorized into twelve problem areas from which the negative attitude towards IT arises. The paper thus solves the limitations of current research into the topic. It raises the state of the knowledge from reports and observations to a more general concept model that both explains the attitude and provides actionable points to improve it. Unlike current, generic IT acceptance models, the model we present is rooted in the emergency response domain and speaks the same language.

That said, this paper is only the beginning of a deeper investigation into the issue of acceptance of IT in emergency response front lines. Several questions remain open for future work:

- Are there other key concepts determining acceptance?

[15] Hardcoding is best clarified by an example. Consider the task of showing where response resources are located. In the implicit interaction paradigm, the system might be programmed to recognize drawings on a whiteboard and create a map automatically. In the explicit interaction paradigm, somebody would have to drag and drop icons on the screen. Now, imagine that instead of the whiteboard or screen, responders use Playmobil® figurines on a table. Every responder would immediately understand the new representation, but neither the implicit nor the explicit interaction paradigms would know what to do with it.

- Are the presented concepts and problem areas disjoint or do they depend on each other to some degree?
- Given that the research was carried out in the EU, how does the model apply to emergency response in other countries?
- What are some best practices to tackle each of the problem areas presented in the model?

ACKNOWLEDGEMENTS

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A Conceptual Framework for Civil-Military Interaction in Peace Support Operations

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ABSTRACT

In complex emergencies, civil and military organizations often find themselves being partners in an international effort aimed at peace keeping, humanitarian relief, and development support. Civil and military partners need to exchange information and to cooperate as required. This assumes effective and efficient Civil-Military Interaction (CMI). However, CMI research literature shows that, in practice, this is far from a reality. In particular, our research indicates that deficiencies in knowledge processes and knowledge management within international civil and military organizations contribute to the causes of ineffective and inefficient CMI. Our research aims to investigate the feasibility of developing technical solutions exploiting knowledge engineering, to support fieldworkers in overcoming these CMI problems. As a first step, this paper introduces a Conceptual Framework (CF) that captures reference models of the CMI domain. The CF has been developed to analyze CMI problems and underlying KM deficiencies. It is being illustrated, explored and validated using real-world case studies.

Keywords

Civil-Military Interaction (CMI), domain modeling, process model, knowledge management, case study.

INTRODUCTION

In the post-Cold War era, military forces are increasingly being deployed for Peace Support Operations (PSOs), defined as 'a military and civil operation by an international coalition, initiated by the UN and aimed to build durable peace in the aftermath of a conflict' (UN, 1992; Fortna, 2004). Recent and ongoing examples include the operations in Afghanistan and Mali. PSOs are becoming increasingly ambitious and more civil in nature, by including stabilization, reconstruction, peace building, and conflict prevention. As a result, when conducting a PSO, military forces often need to interact with a wide range of civil organizations, including government departments, Intergovernmental Organizations (IOs) such as UN and Red Cross, International Non-Governmental Organizations (INGOs), and various local actors (Frerks, 2016). PSOs are often being conducted in the context of a complex emergency, characterized by a combination of an international conflict, large-scale displacement of people, and fragile or failing economic, political and social institutions (Weiss & Collins, 2000). Our research focuses on Civil-Military Interaction (CMI) between international PSO actors at the field level in the context of a complex emergency, with CMI defined as 'the interaction, at the required level, between military and civil actors' (NATO, 2002; De Coning & Friis, 2011).

Effective CMI is in the interest of both civil and military actors, which is widely understood and acknowledged on both sides (Lucius & Rietjens, 2016). IOs and INGOs need a safe environment for their activities and may request specific technical support from the military. The military may use IOs and INGOs as a source of vital information about local actors. Both sides need CMI to avoid interference between military operations and civil activities. However, CMI in PSOs is often far from effective, being hampered by a host of factors, ranging from technical through organizational to cultural (Ooms & Van den Heuvel, 2012). We adopt the term 'CMI inhibitors' for these factors. CMI inhibitors are persistent and have been studied extensively. However, technical solutions to support field workers to overcome them are still mostly lacking. Our initial research indicates that various CMI inhibitors are related to knowledge process deficiencies in civil and military organizations, which in turn may be caused by deficiencies in Knowledge Management (KM). Our research aims to investigate the feasibility of developing technical support for field workers involved in CMI. These technical solutions should alleviate CMI inhibitors and related KM deficiencies, using knowledge engineering. To this end, CMI inhibitors will be analyzed and diagnosed, to investigate causal relations with KM deficiencies.

As a first step in this research, a Conceptual Framework (CF) for the CMI domain has been developed. The CF consists of a set of structural and behavioral reference models and includes the modeling of working processes and underlying knowledge processes, which are shown to be interlinked. The CF provides a framework for a structured analysis of KM-related CMI inhibitors in the working processes of military and civil field workers. This CF is currently being validated and used in case studies to investigate what goes wrong in their knowledge processes, resulting in ineffective and inefficient CMI at field level.

This paper presents the CF, its design and rationale, the underlying theory, and the development of its reference models. In the next section the relation between CMI and knowledge processes is discussed, which includes KM theory as required. The third section provides an overview of the CF design, for which an Enterprise Architecture (EA) approach has been taken. This is followed by an overview of the reference models, including examples.

BASIC KNOWLEDGE PROCESSES, AND RELATED KM THEORY

The Concept of Knowledge and Related Concepts

As KM is a relative young discipline, definitions of its basic concepts have not yet matured. Hence, at the outset of our research we have adopted the following definition of knowledge, based on (Schreiber *et al.*, 2000; Alavi & Leidner, 2001; King, 2005): 'Knowledge is what people enables to attach meaning to data and in that way generate information. Knowledge can be applied in multiple situations and over a longer period. When residing inside the human brain, knowledge consists of two components: explicit knowledge, that is or can be codified, and tacit knowledge, consisting of experience, skills and attitude. Knowledge outside the human brain is explicit knowledge[1].' This definition defines knowledge in terms of its relation to data and information. These are distinct, yet closely interrelated concepts, correlating with a hierarchical view on knowledge (Alavi & Leidner, 2001). Data may be transformed into information, and information into knowledge[2]. These interrelated concepts together with their transformation processes are depicted in Figure 1.

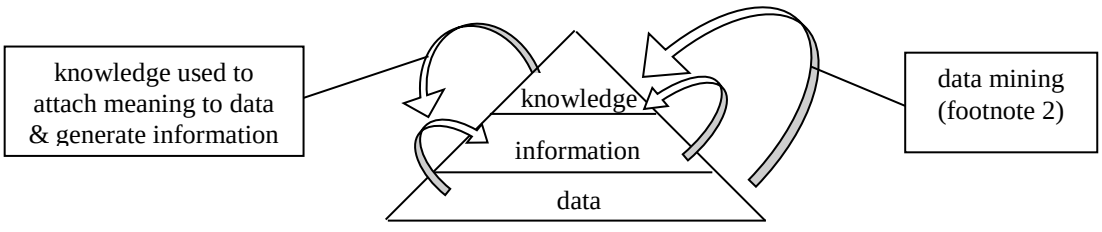


Figure 1. Interrelated Concepts of Data, Information and Knowledge, with Transformation Processes

[1] Some KM scholars, e.g. (Weggeman, 1997; Alavi & Leidner, 2001) are regarding all knowledge residing outside the human brain as information. We don't take this stance, as reflected in the adopted definition.

[2] Data may also be transformed directly into knowledge, using a transformation process known as data mining.

Knowledge Management and Basic Knowledge Processes

Based on various definitions in the KM literature (*inter alia* Weggeman, 1997; Van der Spek & Spijkervet, 1998; Schreiber *et al*., 2000; King, 2005), we define KM as follows: 'KM is aimed at supporting and improving the performance of basic knowledge processes within an organization, with the purpose of getting the right knowledge to the right people in the right form at the right time'. This definition of KM implies that knowledge process deficiencies could be caused by KM deficiencies. Unfortunately, as with the concept of knowledge, knowledge processes appear to be ambiguously defined and labelled in the KM literature. However, most KM scholars agree on a set of four basic knowledge processes, as applied in our research: knowledge creation, codification, transfer, and application[3]. Table 1 provides a short description of each, including synonyms as found in the KM literature.

Table 1. Basic Knowledge Processes

Process	Synonyms	Description
knowledge creation	development; acquisition; generation	Defined as 'to find effective ways to translate ongoing experience into knowledge' (Dixon, 2000:17). May be output of research & development, fusion, adaptation, and knowledge networking (Davenport & Prusak, 1998)
knowledge codification	consolidation; mapping; store & retrieve	Applies to explicit knowledge if stored & retrieved (Alavi & Leidner, 2001). Mapping, i.e. pointing to knowledge locations including people, aims at consolidation of tacit knowledge (Davenport & Prusak, 1998)
knowledge transfer	distribution; sharing; combining; transmission; exchange	Aimed at 'leveraging common knowledge by transferring […] across time and space' (Dixon, 2000:17). Transfer mechanisms depend on type of knowledge (Davenport & Prusak, 1998; Weggeman, 1997)
knowledge application	use; absorption; combination	Combination is application when applying knowledge in multi-disciplinary teams (Van der Spek & Spijkervet, 1998). Applying knowledge leverages its potential for action (Schreiber *et al.*, 2000)

The workings of these basic knowledge processes can be illustrated with a CMI scenario at field level, as depicted in Figure 2. It shows the basic CMI dyad of two field workers with their parent organizations, participating in a PSO: a liaison officer (LO) from the Headquarters of the First German-Netherlands Army Corps (1GNC HQ), interacting with a field worker from the UN World Food Program (WFP), an IO.

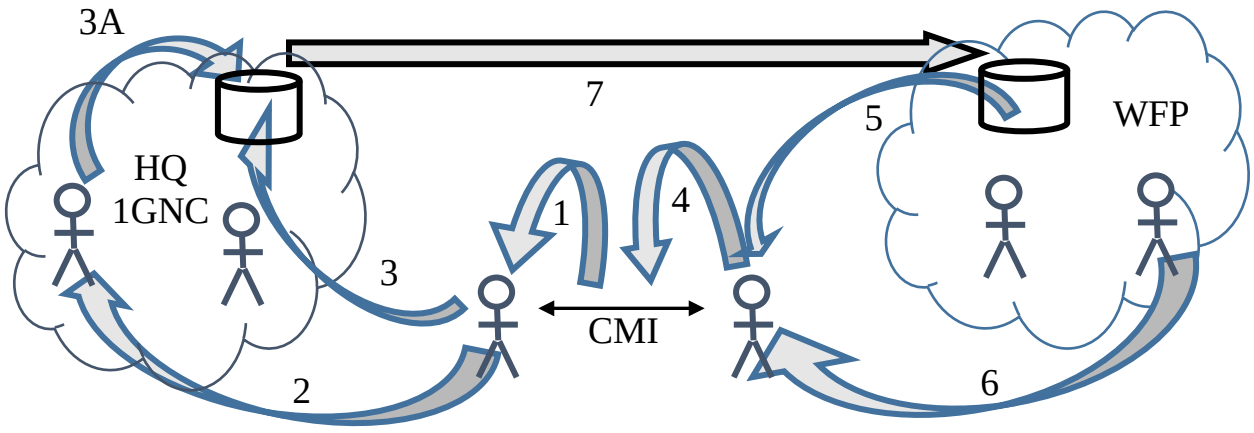


Figure 2. Interaction between military (1GNC) and civilian (WFP) organizations, with knowledge processes

[3] One notable exception is the set of basic knowledge processes as defined by Nonaka & Takeuchi (1995): socialization, externalization, combination, and internalization. These constitute the building blocks of their 'theory of organizational knowledge creation'. It can be shown that their process set maps onto the set of Table 1, indicating that both sets are comprehensive and complementary (PhD research of first author, yet unpublished).

The numbered arrows in Figure 2 are the basic knowledge processes in CMI. The direction of the arrows is specific to this example scenario and not generic to all CMI. In Textbox 1 these basic knowledge processes are described using the example of the interaction between 1GNC and WFP.

1GNC HQ has been deployed for a PSO in a complex emergency. WFP is already active in the same area. The HQ has despatched LOs to get in contact with IOs and INGOs. One LO is interacting with a fieldworker from WFP. As a result of this interaction, the LO might create knowledge required by 1GNC HQ (1), e.g. an update on the attitude of the local population towards foreign military forces. This knowledge is either memorized or jotted down. However, to be useful for the HQ, he should transfer this knowledge to HQ staff personnel (2) and/or codify it for storage in an HQ database (3). The latter process might require staff support for analysis and formatting (3A). On the civil side, the WFP field worker might apply her personal knowledge in the interaction with the LO (4). If she lacks knowledge, e.g. about the capabilities and intentions of this military force, and wants to make use of the codified knowledge in the WFP organization, she could retrieve it from a database (5). If this knowledge is not codified but available as personal knowledge of one of her co-workers, e.g. someone who has cooperated with 1GNC in the joint assessment process, she should be able to identify this co-worker (using the results of knowledge mapping) and share this knowledge using a transfer mechanism (6). Finally, the knowledge required by the WFP organization and available at 1GNC HQ (e.g. security information about the area around a planned food distribution location) could be transferred by 1GNC HQ to WFP, using an interorganizational knowledge transfer process (7).

Textbox 1. Description of Basic Knowledge Processes in CMI Scenario

CONCEPTUAL FRAMEWORK DESIGN

Based on various definitions and suggestions about the purpose of a CF in the research literature (Shields & Rangarjan, 2013; Brains *et al.*, 2011; Alberts *et al.*, 2001), we define the CF of the CMI domain (CMI CF) as follows: 'a CMI CF consists of a set of reference models specifying the structural and behavioral aspects of the CMI domain, including its working processes and underlying knowledge processes, and how these processes are interlinked.' The purpose of the CMI CF is to support problem analysis and diagnosis of CMI inhibitors and KM deficiencies, and their causal relations. The CMI CF design is based on literature research, interviews of some 25 subject matter experts, and exploratory field research. We witnessed various large-scale civil-military exercises, both on the civil and the military side; we interviewed field workers from the military, IOs and INGOs during those exercises; and we interviewed subject matter experts at INGOs, at NATO Centers of Excellence and at the Netherlands' Ministries of Defence and Foreign Affairs. The CMI CF is currently being refined and validated in case studies. The CMI CF serves as the 'theoretical proposition' for the design of these case studies (Yin, 2014).

Enterprise Architecture Approach

The term Enterprise Architecture has been defined in various ways (Enterprise Architecture Research Forum, 2013; The Open Group, 2006; Gartner, 2018). Enterprise Architecture is widely used by governments, military and civil organizations to ensure coherence between business processes and the supporting Information Technology (IT) (such as information services, applications, infrastructure), commonly referred to as 'business-IT alignment'. Most Enterprise Architecture definitions mention 'change' in relation to its purpose. Our research involves investigating the feasibility of developing knowledge engineering-based support, i.e. technical change, to support CMI processes and KM, i.e. organizational change. This implies that the purpose of Enterprise Architecture, defined as 'business-IT alignment in the face of technological and organizational change', supports the purpose of our research. Hence, CMI CF design has taken an Enterprise Architecture approach.

Architecture description concepts

The international standard ISO/IEC/IEEE 42010 defines the concepts to be used for architecture description (International Organization for Standardization, 2011). This standard includes a meta-model of these concepts and their relations. Figure 3 depicts the part of this meta-model that is relevant for our CMI CF design. It should be noted that the concept 'Model Kinds' in this meta-model is defined in the standard as 'conventions for a type of modeling, e.g. class diagram, data flow diagram, etc.' This implies that Model Kinds are expressed as models of Architecture Description Languages (ADLs) such as the Universal Modeling Language (UML) (OMG, 2017) and Business Process Model and Notation (BPMN) (OMG, 2011).

The CMI CF can now be described in terms of the architecture concepts of standard ISO/IEC/IEEE 42010 as follows: 'The CMI domain is the System together with its Environment, of which the CMI CF is the Architecture Description, consisting of Architecture Viewpoints, Views and (symbolic) Models, created and formulated using an Architecture Framework and Architecture Description Languages.'

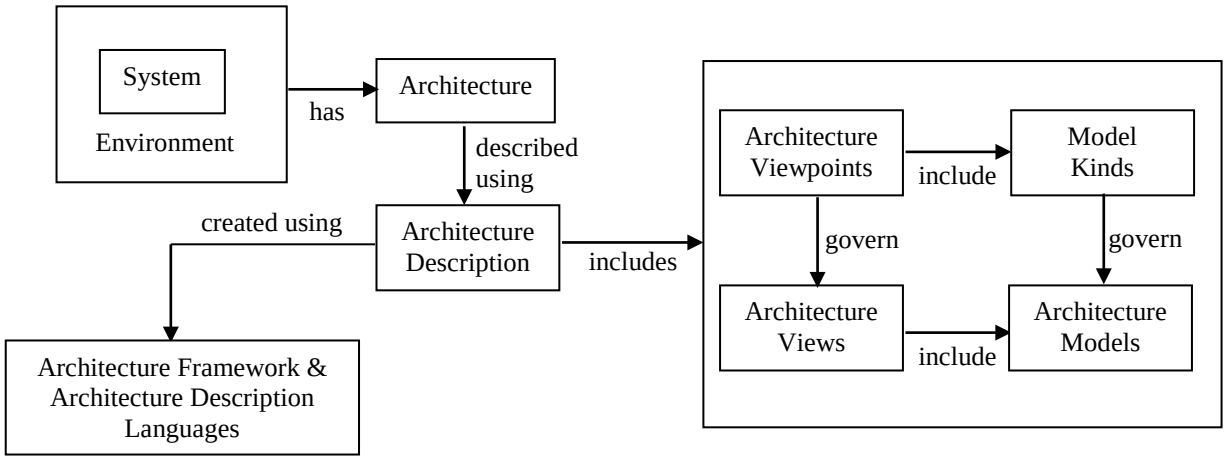


Figure 3. Meta-model of architecture concepts used for CMI CF design, after ISO/IEC/IEEE 42010

When designing the CMI CF structure, choices have been made for each of these architecture concepts, as summarized in Table 2.

Table 2. Concepts of CMI CF Structure

Viewpoint	View	ADL	Model	Model Kind
Operational Viewpoint	Domain View (structure)	UML	CMI Domain concepts model	Class diagram
		UML	CMI Actor model	Class diagram
	Interaction View (behavior)	BPMN	CMI Working process model	Collaboration diagram
		n.a.	CMI Knowledge process model	n.a.
Applications Viewpoint	PM		TBD	
Infrastructure Viewpoint	PM		TBD	

Domain modeling should include both the structural (i.e. static) aspects and the behavioral (i.e. dynamic) aspects of the domain (Dietz, 2006; Fowler, 2004). For this reason, two Architecture Views have been specified for the Operational Viewpoint: the Domain View, covering the structural aspects, and the Interaction View, covering the behavioral aspects of the CMI domain. For both views, a suitable ADL and Model Kind are to be chosen, and which Models are to be developed, using this ADL and Model Kind. In earlier research we specified CMI domain modeling requirements and evaluated a selection of ADLs against these requirements. The results of this evaluation have been used for the CMI CF design, however a discussion of this evaluation is beyond the scope of this paper.

Structural domain aspects comprise the domain concepts and their relations. The class diagram of UML is a long-established modeling standard for this purpose and is widely used. Hence, UML has been chosen as the ADL and its class diagram as the Model Kind for the Domain View. Two Models have been defined for the Domain View: the CMI Domain concepts model, and the CMI Actor model. Behavioral domain aspects comprise the processes its actors are involved in. BPMN 2.0 (OMG, 2011) is a widely used modeling language offering an intuitive presentation, making it readily understandable by practitioners. Hence, BPMN has been

chosen as the ADL and its collaboration diagram as the Model Kind for the Interaction View. Again, two models have been defined for the Interaction View: the CMI Working process model and the CMI Knowledge process model. However, as BPMN does not support knowledge process modeling, modeling notation from the KM literature has been used, which is not standardized. Therefore, we propose additional symbology.

REFERENCE MODELS

CMI Domain concepts model

The CMI Domain concepts model has been developed as an UML class diagram, which is depicted in Figure 4. In this model, the main concepts of the CMI domain are modeled as UML classes. To reduce complexity, the subclasses of the class CMI Actor are described in a separate model: the CMI Actor model. According to UML convention, references to UML classes in this paper are in initial capitals.

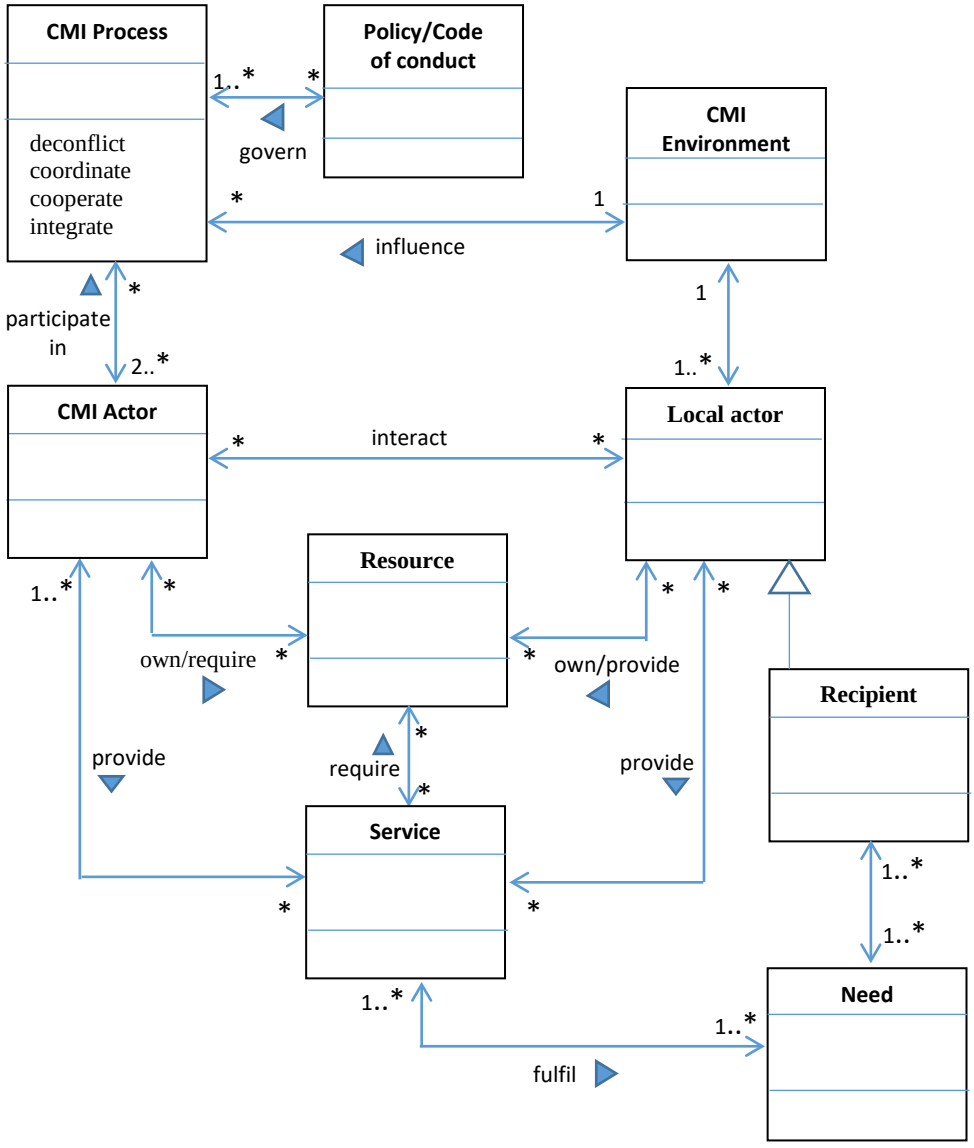


Figure 4. UML class diagram of CMI Domain concepts model

The central concept of the CMI domain is the CMI Process. Its purpose is to realize the level of interaction (De Coning & Friis, 2011) chosen by its participants, i.e. to de-conflict, coordinate, cooperate, or integrate. These are modeled as operations of the class. A CMI Actor may be an organization involved in CMI or an individual from that organization. The CMI Environment is defined as a region affected by a complex emergency, including its

Local actors. Local actors may include: the local population; Civil Society Organizations (CSOs), including local NGOs and Community-Based Organizations (CBOs); commercial organizations; the local government; and the security sector. The CMI Environment, i.e. the features of the region, the complex emergency and the Local actors all influence the CMI Process. Local actors may act in different roles: either as Recipients of the Services being provided by CMI Actors, or as actors involved in the provision of those Services. Local actors acting in the latter role may be implementing partners of CMI Actors, e.g. CSOs assisting in needs assessment or food distribution.

CMI Working process model

The CMI Working process model consists of eleven BPMN collaboration diagrams, which together are modeling all CMI-related activities in a PSO. Table 3 provides an overview of the Working process model composition. Two main processes are distinguished: PSO preparation and PSO execution. Both main processes are further specified as sets of sub-processes (hence the BPMN-term 'parent process' in Table 3). In PSO preparation, the two sub-processes are: Generic preparations and Deployment preparations.

Once deployed for a PSO, CMI Actors may be involved in three types of operations: Peace Enforcement and limited Humanitarian Relief (PE/(HR)); Peace Support and Humanitarian Relief (PS/HR); or Peace Support and Development Support (PS/DS). Each type of operation has been modeled as a sub-process of the PSO execution process. These process types may occur in any order and may be different in adjacent regions.

Transitions between these (sub-)processes can be sequential or conditional. A sequential transition occurs between the main processes PSO preparation and PSO execution, and between the sub-processes Generic preparations and Deployment preparations. Conditional transitions occur between the sub-processes modeling the types of operation of a PSO. The conditions for transition are determined by two parameters: the security situation and the humanitarian situation. Assessment of both parameters is included as an activity in each sub-process diagram.

Table 3. Composition of CMI Working process model

parent process	sub-process	called process
PSO preparation	Generic preparations	not applicable
	Deployment preparations	
PSO execution	Peace Enforcement & limited Humanitarian Relief (PE/(HR))	- Military securing operations - CMI patterns: X: Operational de-confliction Y: Military protection Z: Military assistance
	Peace Support & Humanitarian Relief (PS/HR)	
	Peace Support & Development Support (PS/DS)	

CMI activities occur during each of the three types of operations of the PSO. These have been modeled in BPMN as called processes, which are invoked by the active sub-process. We have modeled CMI activities in four called processes: Military securing operations, which may be running continuously, and three CMI patterns which may be invoked when required: CMI pattern X: Operational de-confliction; CMI pattern Y: Military protection; and CMI pattern Z: Military assistance. For brevity, only CMI Pattern Y is described in more detail here. Figure 5 illustrates the described transitions and relations between the eleven processes, sub-processes and called processes of the CMI Working process model. Called processes are running in parallel with the calling sub-process, hence the term 'relation' applies, rather than 'transition'.

In the models of sub-processes and called processes, the creation, exchange and use of information and knowledge has been indicated. As BPMN does not include notation for the modeling of basic knowledge processes such as knowledge creation, use, and transfer, the BPMN notation for information (message) exchange (i.e. dashed arrows) and data flow (i.e. dotted arrows) has been used for this purpose. Database icons are used in the collaboration diagrams as a metaphor for the aggregate of all explicit and tacit knowledge which is (potentially) available within a CMI Actor organization about the following three knowledge domains:

A - knowledge about other CMI Actors;
B - lessons learned and best practices from previous PSO exercises and operations;
C - knowledge about the CMI Environment, incl. Local actors and the complex emergency.

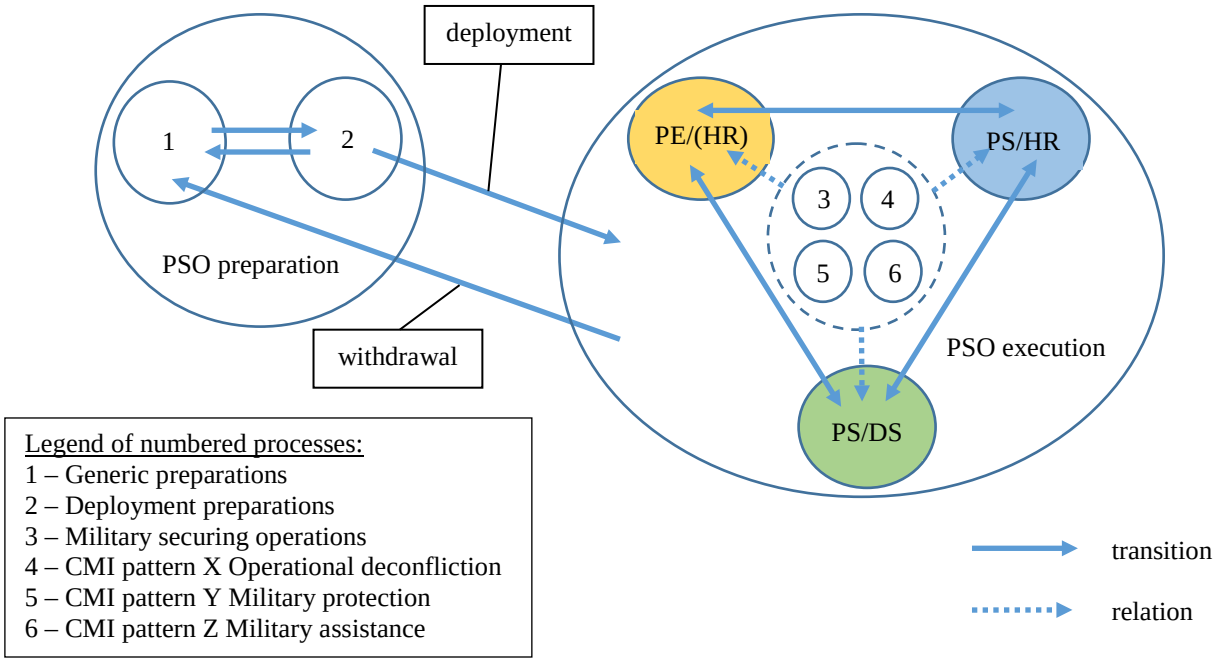


Figure 5. Transitions and relations between processes in CMI Working process model

CMI Pattern Y – Military protection

CMI pattern Y is one of the three CMI patterns which are modeled as called processes in the CMI Working process model. Its BPMN collaboration diagram is shown in Figure 6. Military protection can be requested by a civil CMI Actor and conducted by the military in close coordination with the civil CMI Actor(s) being protected. The protection may take various forms, such as: escorting a humanitarian convoy; guarding a humanitarian storage facility; or patrolling in a refugee camp. Military protection may be requested and conducted during any of the three sub-processes of the PSO execution process: PE/(HR), PS/HR or PS/DS. CMI pattern Y has been modeled as a collaboration diagram with two pools: the military and civil CMI Actors (IOs/INGOs). Using fictitious actors, Textbox 2 provides an example of the process. The process model is described next.

WFP is coordinating the provision and distribution of food in the 1GNC sector. Along a remote section of an access road, WFP is often experiencing the looting of food transports by armed groups, forcing the trucks of local NGOs to stop and handover the food. WFP submits a request to 1GNC HQ to provide protection for the trucks by armed military personnel on each truck. This request is assessed by the 1GNC operations section. It is concluded that such protection cannot be sustained for more than a few days. Alternative solutions are being discussed with WFP. It is proposed to form daily food convoys, which will be escorted with armed personnel carriers. One INGO objects against this solution, since they fear that, by being escorted by the military, they would appear as taking sides. However, 1GNC staff explains that this is the only feasible solution, and in the end they agree.

Textbox 2. Fictitious example of CMI pattern Y – Military protection

This process is triggered by a request for military protection from a civil CMI Actor, which is followed by a call activity in the military process, as modeled in each of the sub-process models of the PSO execution process model. Hence, the start situation for the military is that a request for military protection has been received, modeled as a catching message start event. The corresponding start situation for the IO/INGO is that it is waiting for a response, which is modeled as a conditional start event. The military first performs an assessment about whether the requested protection is required, i.e. whether the threat as perceived by the requesting IO/INGO

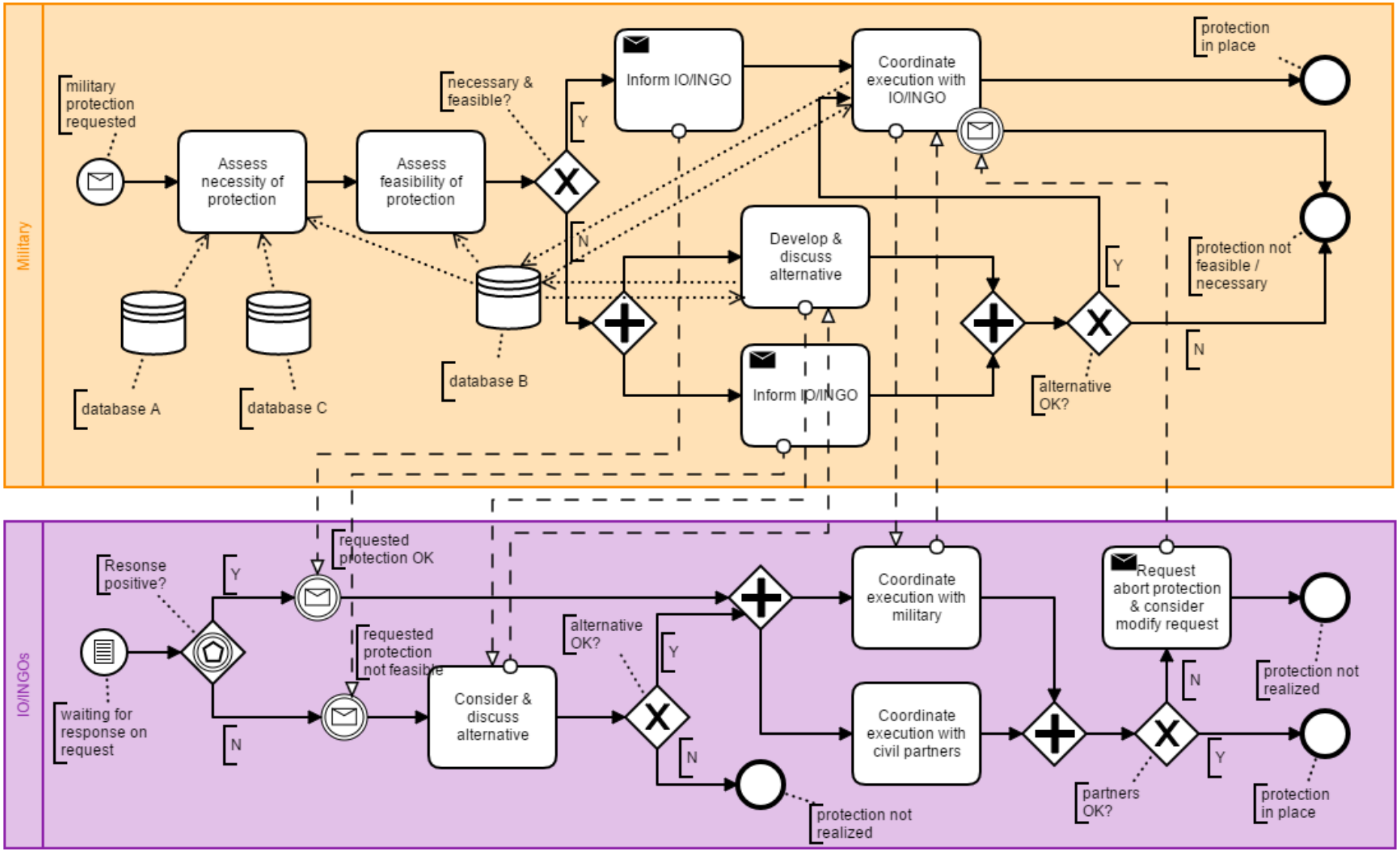


Figure 6. Collaboration diagram of CMI pattern Y – Military protection

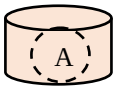
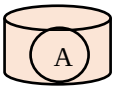
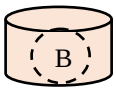
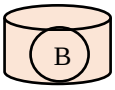
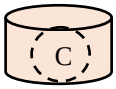
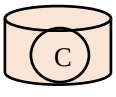
corresponds with the military threat assessment for this situation. This is modeled as a task which makes use of the information and knowledge about opposing forces, e.g. their capabilities and recent activities (database C), and about the IO/INGO, e.g. its method of working and the experiences the military has with collaboration with this IO/INGO (databases A and B, respectively). Based on the outcome of this assessment, the military assesses next whether it is feasible to provide the required protection, based on availability of the required military assets. The outcome of both assessments answers the question whether the requested protection is necessary and feasible, which is modeled as an exclusive gateway, followed by (in both cases) a send task. If the request for protection is granted, then the military proceeds with its execution, in coordination with the requesting IO/INGO. If the provision of protection is deemed not feasible or not required at the requested level, then the military informs the IO/INGO accordingly. In parallel, the military develops one or more alternatives, such as scaled down protection and/or a modified way of working by the IO/INGO. It makes use of lessons learned and best practices obtained from similar situations in the past (database B), and discusses alternatives with the IO/INGO. This is modeled as a splitting parallel gateway followed by two tasks conducted in parallel. If both parties agree on an alternative, then the military proceeds with its execution, in coordination with the IO/INGO. If no agreement is reached, then the process terminates. This is modeled as an exclusive gateway after the merging parallel gateway.

The IO/INGO reacts to the two possible outcomes of its request, modeled as an event-based gateway. In case of a positive reply, or an agreed alternative, it proceeds with coordinating with the military on how the protection is to be executed. The request for protection may have been submitted on behalf of other INGOs which the requesting IO/INGO is coordinating or cooperating with (e.g. an IO acting as UNOCHA sector coordinator). In this case the IO/INGO coordinates the execution of protection with these INGOs as well, which is modeled as a parallel gateway. Since different INGOs may have different attitudes towards operating together with the military, some may object against the way military protection is being executed. If these differences cannot be resolved and hamper the execution of protection, then the IO/INGO requests the military to abort its protection activities, and considers submitting a modified request for protection.

CMI Knowledge process model

The CMI Knowledge process model represents the knowledge processes in CMI Actor organizations that underpin their working processes. The CMI Working process model serves to identify those CMI inhibitors that may be caused by deficiencies in knowledge processes. The CMI Knowledge process model identifies the knowledge process deficiencies that may be the cause of CMI inhibitors. In this way, both process models complement each other. Research literature on KM and Organizational Learning has been studied to identify knowledge process models which could serve our research. Unfortunately, to the best of our knowledge, a standard notation for knowledge process model diagrams does not yet exist. For this reason, we propose a set of symbols to indicate both the knowledge domain and the type of knowledge: explicit or tacit, as depicted in Table 4. The proposed knowledge domains A, B, and C are similar to those used in the BPMN collaboration diagrams. The symbols represent all tacit and explicit knowledge collectively held by a CMI Actor organization, rather than just (explicit, codified) knowledge stored in a database.

Table 4. Knowledge notation in CMI Knowledge process model

knowledge domain	tacit knowledge	explicit knowledge
A: Knowledge about CMI Actors		
B: Best practices and lessons learned		
C: Knowledge about CMI Environment		

Knowledge process models from the KM and Organizational Learning research literature have been customized to model the various knowledge processes in the CMI domain, which together constitute the CMI Knowledge process model of the CMI CF. The following example shows how the knowledge process model 'Knowledge creation in teams', as proposed in (Dixon, 2000), has been adapted to serve as knowledge process model 'Knowledge creation at CMI field level'. Process steps have been added, labels have been changed to reflect domain-specific aspects, and the proposed knowledge notation from Table 4 has been added. Figure 7 shows the original process model from (Dixon, 2000), Figure 8 shows the end result, as customized for the CMI domain. It should be noted that Nancy Dixon (2000) coined the term 'Common knowledge' for organizational knowledge, i.e. tacit and explicit knowledge collectively held within an organization.

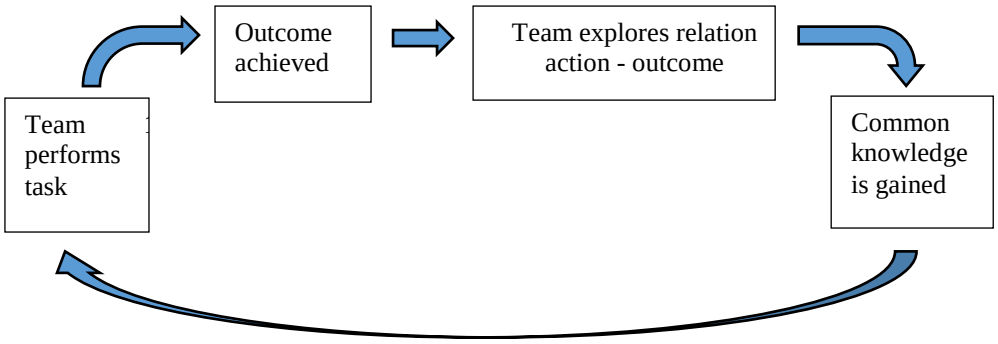


Figure 7. Knowledge process model 'Knowledge creation in teams', after (Dixon, 2000)

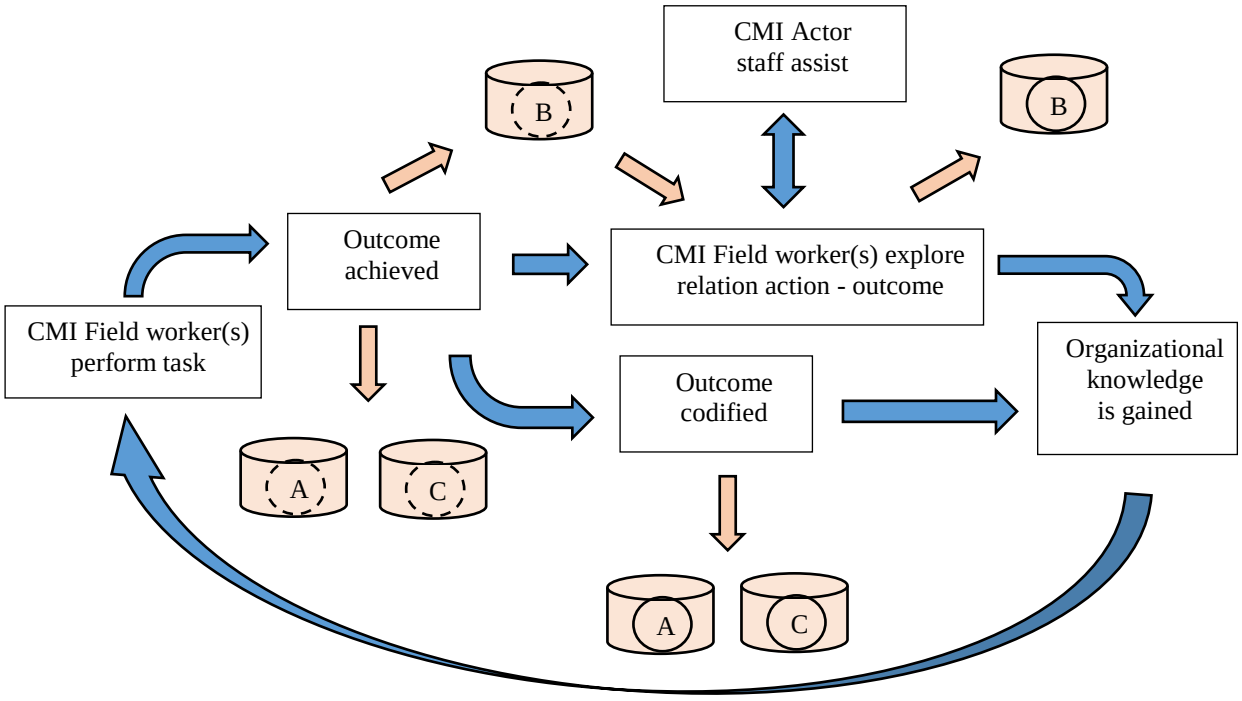


Figure 8. Knowledge process model 'Knowledge creation at CMI field level'

Comparing the knowledge process model depicted in Figure 7 with the working and knowledge practices in the CMI domain, the following remarks can be made. When applied to the working processes at field level in the CMI domain, the knowledge process model 'Knowledge creation in teams' applies primarily to the creation of knowledge about domain B, i.e. the lessons learned and best practices obtained from the interaction in a CMI working process. Some knowledge about domain A, i.e. about other CMI Actors involved in the interaction, might be created as well, e.g. knowledge about their methods of work or capacities. However, creating this knowledge probably does not require the evaluation process depicted in Figure 7. The same is probably true for

knowledge about domain C, i.e. knowledge about the CMI environment, e.g. an update on the condition of an access road or the attitude of a local leader. Knowledge about domain A and C could be codified and transferred within the CMI Actor organization without delay. CMI Field workers, e.g. LOs of a military HQ, might often be operating individually in the field, and rely on staff support from their parent organization to identify and evaluate the lessons learned and best practices obtained from their experiences in the field. For this reason, a notional staff actor has been added to the knowledge process model.

Knowledge created in the context of CMI field working processes is initially tacit knowledge, residing in the CMI Field worker's head. Although sharing of tacit knowledge is possible, transfer of this knowledge within the CMI Actor organization is facilitated by transforming this tacit knowledge into explicit knowledge (codification). This step is implicit in the model of Figure 7, and has been indicated using the knowledge notation as proposed in Table 4.

Taking these remarks into account and using the notation as in Table 4, the generic knowledge process model 'Knowledge creation in teams' as shown in Figure 7 can be translated into the specific knowledge process model 'Knowledge creation at CMI field level', as shown in Figure 8. Blue arrows indicate the process workflow and pink arrows the creation of knowledge products. It should be noted that probably not all knowledge created at CMI field level can or will be codified. If not codified, this knowledge is to be transferred within the CMI Actor organization using transfer mechanisms for tacit knowledge. Some knowledge created at field level can get lost, being neither codified nor transferred.

CONCLUSIONS AND FURTHER RESEARCH

This paper introduces and explores a conceptual framework (CF) for civil-military interaction (CMI) in complex emergencies. Basic knowledge processes and knowledge management theory are outlined and illustrated using a fictitious but realistic example of interaction between a military and an intergovernmental organization. The architectural approach in designing the CF is described. The reference models that comprise the CF and represent CMI structure and behavior are formalized, with CMI domain concepts modelled in UML and collaboration diagrams modelled in BPMN.

The key contribution of this paper is to conceptualize CMI processes around knowledge management theory. Its main limitation is that the CF has not yet been fully validated. The next step in this line of research is to validate the CF; this is now in progress exploiting a combination of case studies, interviews and data collection. A validated CF is required for further empirical research into KM-related problems in CMI at field level, aimed at answering the question 'why is the right knowledge not available at the right time for the field worker who needs it?' The ultimate research goal is to use the validated CF to select and implement knowledge engineering technologies that could support the knowledge and working processes, i.e. the actual practices, of CMI actors.

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The Hidden Crisis : Developing Smart Big Data pipelines to address Grand Challenges of Bridge Infrastructure health in the United States

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ABSTRACT

The American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure gave bridges a C+ (mediocre) grade in 2017. Approximately, 1 in 5 rural bridges are in critical condition, which presents serious challenges to public safety and economic growth. Fortunately, during a series of workshops on this topic organized by the authors, it has become clear that Big Data could provide a timely solution to these critical problems. In this work in progress paper we describe a conceptual framework for developing SMart big data pipelines for Aging Rural bridge Transportation Infrastructure (SMARTI). Our framework and associated research questions are organized around four focus areas:

- Next-Generation Health Monitoring: Sensors; Unmanned Aerial Vehicle/System (UAV/UAS); wireless networks
- Data Management: Data security and quality; intellectual property; standards and shared best practices; curation
- Decision Support Systems: Analysis and modeling; data analytics; decision making; visualization,
- Socio-Technological Impact: Policy; societal, economic and environmental impact; disaster and crisis management.

Keywords

Bridge Structural Health, Next-Generation Health Monitoring, Data Management, Decision Support Systems, Socio-Technical Impact.

INTRODUCTION

Out of 138 economies worldwide, the US ranks 11th when it comes to infrastructure competitiveness, according to the World Economic Forum's Global Competitiveness Index. America's infrastructure, particularly, its 50-100+ year-old bridges are in poor health and constitute a **hidden crisis** not being discussed publicly. This is illustrated by the Interstate 35W bridge collapse in Minneapolis on Aug. 1, 2007. According to news reports,

during that Wednesday evening's rush hour, the bridge spanning the Mississippi River suddenly gave way, killing 13 people and injuring 145. An article in Govtech.com concluded that "for 17 years leading up to the collapse, reports cited structural problems with the bridge, and the federal government rated it as 'structurally deficient' — a rating given to approximately 75,000 other U.S. bridges in 2007. Transportation experts across the public and private sectors agree that the U.S. infrastructure is in peril, a sentiment that's supported with startling statistics from a 2011 study called Failure to Act, by the American Society of Civil Engineers (ASCE). The American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure gave bridges a C+ (mediocre) grade in 2017. The number of structurally deficient bridges, (those needing significant attention or replacement) exceeds 57,000, is slightly over 9% of the 614,000 bridges that are part of the Federal Highway Administration's National Bridge Inventory (NBI) (ASCE 2017). Bridges included in the NBI are structures over a depression/obstruction whose opening along the roadway centerline is greater than 20 feet that carry a public road, which is classified as any road open to public travel because it is under public jurisdiction and maintained by a public authority (USDOT 1996). Furthermore, the US Department of Transportation estimates it could cost as much as $1 trillion just to bring the current Interstate and highways system in the US up to date.

While it is recognized that the number of structurally deficient bridges has dropped from 12% since 2007, ASCEs Report Card includes Midwest states of Iowa, Missouri, Nebraska, Oklahoma and South Dakota in its "bottom five" states having the highest number of structurally deficient bridges or the "bottom five" based on percentage of total inventory. This constraint ignores many "off-system" bridges that are shorter than 20 feet and/or support roads that do not strictly conform to the definition of being "public." Many such structures exist in the Midwest and are very important links in the transportation infrastructure "chain," especially in association with agribusiness. Another important transportation sector with deep ties to the Midwest and strong influence on its economy are the railroads. Railroads have existed in the Midwest since the mid-19th century and, as they expanded, placement of bridges and trestles naturally increased. ASCE identifies 100,000 in service rail bridges, with many in use for decades.

NBI data shows that approximately 1 in 5 rural roadway bridges in Nebraska are structurally deficient. Similar challenges exist for our aging rail infrastructure. The reality that both state and private industry have shrinking budgets for bridge inspection and repair exacerbates these problems. Fortunately, during a series of workshops on this topic run by the authors it became clear that Big Data could provide a timely solution to these critical problems. Our past workshops, surveys and other events have generated tremendous interest in using Big Data for efficiencies related to rural bridge transportation infrastructure. These efforts have led to partnerships between bridge owners, maintainers and researchers at the forefront of Big Data, machine and deep learning, data governance, and civil engineering domains for structural health monitoring. This community has identified four focus areas (next generation health monitoring; data management; decision making; and socio-technical impact) to address the grand challenges for bridge health assessment using Big Data technologies as listed on the left hand side of Figure 1.

Our research work in each focus area collectively form the interconnected components of a SMart Big Data pipeline for Aging Rural bridge Transportation Infrastructure (SMARTI). Important, data-driven, research questions for each focus area have been identified by the Research Team and industry partners and are summarized under Project Deliverables along with assigned responsibilities. Aging, rural bridges will be selected in consultation with State Department of Transportation and railroad owners to serve as testbeds for delivering data products that facilitate decision-making and ultimately, economically, reliably improve bridge life and safety. Datasets will be prioritized to address challenges faced by private, local, state, and federal bridge owners. The proposed project will build upon past successes from the Research Team's BD Spokes Planning Grant activities related to building partnerships, hosting workshops and hackathons, cataloging bridge health datasets across sectors, building schemas, and enabling broad access to the

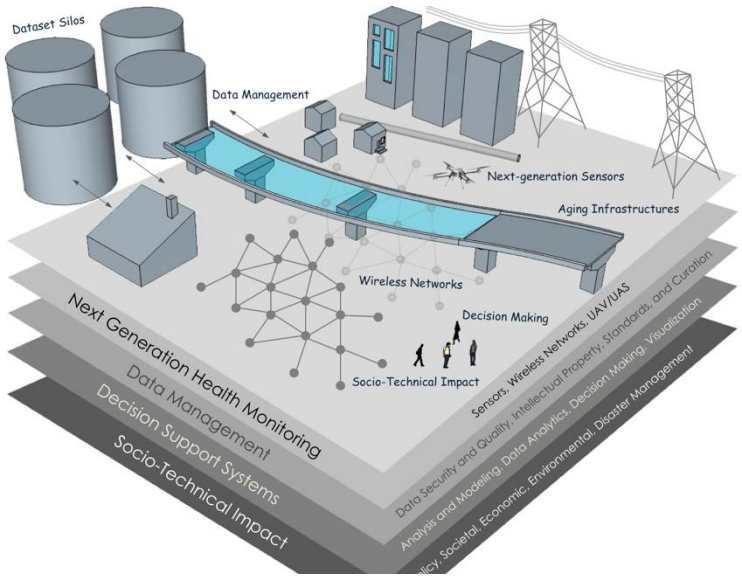

Figure 1: Interconnected layers and elements of the SMart Big Data pipeline for Aging Rural Bridge Transportation Infrastructure (SMARTI)

bridge inspection datasets using a combination of access control and anonymization techniques (Domingo-Ferrer et. al 2016) deemed acceptable by data owners.

SMARTI FRAMEWORK AND FOCUS AREAS FOR FURTHER RESEARCH

Bridges in rural areas often do not warrant the costs associated with continuous monitoring solutions or state-of-the-art planning solutions for proactive maintenance of their health. Nebraska has the 7th highest percentage of structurally deficient rural bridges in the US. With 60% of those bridges constructed between the 1930s and 1960s, the aging infrastructure must receive periodic inspections to assess potential deficiencies (Nebraska Legislature, 2014). Other states having many rural bridges, such as Midwest states, are in similar situations. While inspection and management/maintenance processes may differ for the railroad industry, a similar situation exists solely based on the age of many key assets within that transportation sector. These situations provide timely and necessary opportunities for bringing to bear efficiencies of Big Data and next-generation monitoring technologies.

Big Data solutions are integral components for effective bridge health monitoring not solely because the data is "large", "diverse", and "fast" but also because analytics may identify hidden, important relationships between datasets that have traditionally been housed in different silos. For example, data collected from multiple bridges could provide additional, significant and previously unknown information associated with the effects of "systems-of-systems" decisions on their health (e.g., construction contractors, techniques and materials used to construct a group of bridges). Ambient or differential temperatures collected from various structures are examples of data that can be used in population health analysis, which may help better define drivers of excessive bridge stresses and deformations and long-term effects of their cycles over time. The effects of technology advancements on measuring, monitoring, and examining bridge health also offer myriad opportunities for impactful Big Data solutions. For example, video and pictures are becoming easier to collect during manual visual inspection, but the effective integration of this information into the data "stream" has not been fully utilized.

FOCUS AREA 1: NEXT-GEN HEALTH MONITORING

SMARTI is heavily dependent on mined and collected data. In the bridge industry, a common term associated with data collection is health monitoring. When rural bridges are those whose "health needs monitoring," approaches currently used to assess their health vary widely and often almost exclusively rely on qualitative and subjective data provided through human (manual and visual) inspections. The Federal Highway Administration's (FHWAs) Bridge Inspector's Reference Manual (USDOT, 2012) mandates that roadway bridges in the NBI have an inspection every two years. However, many of the rural bridges may not have any data due to inspection policies (bridges shorter than 20 feet not included in the inspections) or due to lack of resources/skilled engineers. ASCE notes that the number of structurally deficient bridges consist 33% of the total bridge deck area in the country. These statistics indicate a demand for research that considers innovative, next-generation monitoring technologies which can offer necessary, inexpensive insights via contact or non-contact data collection and intelligent, computationally based decision-making. Our goal is to integrate durable, low-cost sensing systems with Big Data pipelines that will automate the health monitoring process to provide advanced warning of deficiencies that could be a concern, including cracks, spalling, corrosion, material degradation, substructure deterioration, and extreme demands imposed by natural or man-made events such as tornados, hurricanes, earthquakes, high-wind events, fire, scour, vandalism, impact, and blast. We envision the bridge being the sensor and would become smart information "nodes" in the transportation network that continually provide health information to owners and suggest reliable mitigation schemes. Such an approach would require durable, low-cost sensing to be performed with on-site fusion techniques to bring down the number of sensors and bandwidth requirements.

FOCUS AREA 2: DATA MANAGEMENT

This focus area focuses on long-term usefulness and quality of important, collected and shared data while preserving security and privacy expectations. As sensing technologies with different modalities (data feeds, pictures, videos, audio files) proliferate, the resulting data deluge experienced by bridge inspectors and decision makers is a real challenge. The authors have observed during workshops and collaboration meetings with stakeholders that data deluge and resulting interpretation and misinterpretation have emerged as some of the most significant impediments to sharing within and between public and private sectors. To improve data usage and sharing, data management is essential. Improvements in data security and portability are essential for long-term preservation and trust in any smart and connected infrastructure data pipeline. Data discovery and reuse are additional challenges that usually follow smart infrastructure sensing.

FOCUS AREA 3: DECISION SUPPORT SYSTEMS

One of the key components associated with developing, improving, and commoditizing SMARTI is the creation and integration of confident decision support systems (DSSs). These would consist of physical and statistical model development efforts that can create and enhance the big data pipeline by:

- providing accurate, relevant snapshots of current and future health of a bridge or a system of bridges;
- covering nontraditional, aspects associated with rural bridge systems, e.g. socio-technical implications;
- utilizing Big Data decision-making tools and technologies to make SMARTI "smarter;" and
- efficiently and accurately visualizing current and future condition of all bridges at various time scales.

DSSs have long been shown to help various industries become safer and more efficient (Wang, Gang, et al 2016). Unfortunately, there is often reluctance for their adoption in many industries and the bridge industry is no different. We recently classified common barriers to DSS adoption in the bridge industry: fear of losing control by relying on decision support systems; data security concerns; data "deluge" concerns; fear of technology and the need to acquire new skills; and concerns about impact on the workforce (Gandhi et al., 2017). We also observed in small collaborative sessions with industry partners, that few advanced analytics tools are available to assist public and private owners with the management of bridge health. Even when traditional sensor information (e.g. material strains, deformations) is collected, data-driven decision support and risk assessment process are largely rudimentary or non-existent. Many recent efforts focus on improving past visual inspection methodologies (Washer et al., 2014), improved component degradation models and robotic inspection devices that work alongside bridge inspectors (Szary and Roda, 2014). Machine/deep learning techniques that indicate deterioration of bridge health coupled with intuitive data visualization techniques and tools are needed to provide an optimal user experience through data exploration and interaction.

FOCUS AREA 4: SOCIO-TECHNOLOGICAL IMPACT:

Bridges are essential to the functioning of the transportation infrastructure. Bridge closures, maintenance or load restrictions have a significant impact on the local regions that they serve, especially in agricultural/rural areas with limited alternatives. Team partnerships with a large university transportation center, the Nebraska Transportation Center (NTC), and the regional Mid-America Transportation Center (MATC), along with the EU Horizon 2020 Smart Mature Resilience project will help us integrate Big Data enabled decision support systems into cases for socio-technical impact determination. This focus area will investigate institutional challenges in the transition to a focus from just building bridge infrastructure to a mindset of continuously monitoring the health of our infrastructure and how this transition contributes to building resilient rural communities that can deal with disasters. This investigation should include governance strategies for developing flexible, resilient, and sustainable systems, technologies, processes and methods for addressing the impacts associated with maintaining the health of critical infrastructure such as bridges to transition to a focus from just building infrastructure to a mindset of continuously monitoring the health of our infrastructure.

CONCLUDING REMARKS

America is facing an infrastructure crisis in general; however, aging bridges and their "health" is in dire condition. In our research described briefly in this work in progress paper, we explain our SMart Big Data pipeline for Aging Rural bridge Transportation Infrastructure (SMARTI). Our primary objective with this framework is to provide the foundation for a platform to share bridge health data across stakeholders. It integrates expertise from computer science and engineering disciplines to pave the way for bringing Big Data opportunities to bridge health assessment with particular emphasis in rural areas. We believe that our effort will bring together stakeholders to leverage a common data set and technologies for bridge health monitoring and risk mitigation.

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Challenges of Modeling Community-Driven Disaster Operations Management in Disaster Recurrent Areas: The Example of Portsmouth, Virginia

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ABSTRACT

Although one of the dominant paradigms in managing disaster operations is that of modeling decisions around the activities of humanitarian organizations, recent literature has highlighted the importance of managing disaster operations from the perspective of the affected community. Modeling community-driven disaster operations has a unique set of challenges, however, several of which are highlighted in this research effort. These include engaging the community and coordinating amongst multiple decision makers, defining a clear community objective, and planning with long decision horizons. Using the urban area of Portsmouth, Virginia as a case study, this work in progress paper demonstrates a decision support system-based approach which addresses these critical elements of community-driven disaster operations management.

Keywords

Community-Driven Disaster Operations, Disaster Management, Community Engagement, Recurrent Disasters, Resilience.

INTRODUCTION

Although the importance of managing disaster response and preparedness cannot be understated, managing disaster operations is a challenging process. First of all, technical disaster operations activities must be carried out in complex environments that are characterized by both uncertainty and urgency (Bealt & Mansouri, 2018; Chacko et al., 2016). Secondly, there is the challenge of coordinating a network of diverse and geographically separated stakeholders (Comfort, 2007; Balcik, et al., 2010; Dubey & Altay, 2018). Additionally, these diverse stakeholders may have different, and possibly conflicting, goals, some of which will be dependent on their roles in the process (Balcik, et al., 2010; Chacko, 2015). Given this complexity, it is critical for researchers to continue developing decision support systems that can lead to more timely and effective decision making.

Since much of the literature surrounding the management of disaster operations is generally motivated by planning for a specific disaster event (Overstreet et al., 2011; Chacko, Zobel, and Rees, 2014; Chacko et al., 2016), discussions on goals have typically focused on the immediate needs associated with a current emergency. While there recently has been a shift towards alleviating human suffering (See Holguin-Veras et al., 2013), much of the focus of such work still deals with managing the 'disaster at hand,' with an emphasis on humanitarian and disaster-relief organizations (Bealt & Mansouri, 2018). As a result, it misses out on the opportunity to also consider information about long-term community stability and viability in a disaster-prone area (Habsburg-Lothringen, 2015; Bealt & Mansouri, 2018).

The literature on community-driven disaster operations, i.e. disaster efforts motivated by the needs and capacities of the affected community, is limited and is only now emerging (Bealt & Mansouri, 2018). To our knowledge, only Bealt & Mansouri (2018) and Chacko et al. (2016) explicitly emphasize the importance of community-driven disaster operations. Bealt & Mansouri (2018) focus on using local collaborative networks to support disaster operations while Chacko et al. (2016) focus on modeling mitigation and long-term recovery for communities. This current study, in turn, focuses on discussing the unique challenges that arise when modeling community-driven disaster operations management. Thus, the main purpose of this paper is to explicate some of these challenges and to discuss how they can be addressed, using the urban area of Portsmouth, Virginia as a specific case study. We begin our discussion by providing a brief survey of the literature on community engagement in disaster operations, and introduce objectives for community viability over longer-term decision horizons. We then present the case study and discuss the possible implementation of the proposed modeling approach in that context.

SURVEY OF RELATED LITERATURE

The first official US assessments of disasters occurred around 1964 and led, in part, to a conceptual shift from an engineering/structural perspective of disasters to one *more inclusive of data about the human and social dimensions.* This also included a shift from vulnerability models, which emphasized risk reduction, to models that were more active in placing responsibility of actions/decisions on people, rather than models that simply reacted to nature (Cutter et al., 2008). This shift emphasized the placement of the affected community at the forefront of disaster operations, emphasizing the community's goals - community stability and viability over the long-term (Pearce, 2003; NRC, 2006). This emphasis results in a few unique challenges, however, including the definition of clear community objectives, long decision horizons, and engagement and effective coordination with other stakeholders (Chacko, 2015). In the following sections, we'll review the literature to explicate these challenges.

Community Engagement & Coordination

One of the dominant paradigms in managing disaster operations is that of modeling decisions around the activities of humanitarian organizations (Chacko, 2015; Bealt & Mansouri, 2018). This emphasis begs the question, however, of whether the needs of the affected communities are truly addressed in such situations (Saab, Maitland, & Tapia, 2008; Bealt & Mansouri, 2018). In order to broaden the effectiveness of disaster operations, it is necessary to consider and directly engage with the affected community (Sheppard et al., 2013; Bealt & Mansouri, 2018), including stakeholders such as the local government, etc. In fact, Birkmann (2008) argues that community engagement when managing disaster operations makes the community more resilient. This raises a unique challenge: in what areas should the community specifically be engaged? Pearce (2003) & NRC (2006) suggest that engaging the affected community on their values and goals is an important area. In addition, it can be important to engage the community in ascribing levels of importance to various disaster operations activities (NRC, 2006).

A critical challenge that arises from community engagement is how to coordinate relevant disaster operations actors to work towards the goals of the affected community. Though much of the coordination in disaster operations is driven by the bureaucratic model (National Response Framework (NRF)), such a paradigm has critical limitations, specifically that 'it is not likely to accommodate the multi-dimensional crisis situation found in large-scale disasters' (Majchrzak, Jarvenpaa, & Hollingshead, 2007, p. 159). Critically, Bealt and Mansouri (2018) highlight from their study that effective coordination occurs when information sharing is facilitated by the affected community. This is because the local community has local knowledge - a better understanding of local needs, the local context, and available local resources (Bealt & Mansouri, 2018). This fits well into the context of the broader literature on coordination amongst inter-dependent actors, which asserts that effective coordination occurs through shared goals (Gittell, 2006; Bealt & Mansouri, 2018), information sharing (Comfort et al., 2004; Gittell, 2006; Dubey, Altay, & Blome, 2017; Balcik et al., 2010; Bealt & Mansouri, 2018), and mutual respect (Gittell, 2006; Dubey, Altay, & Blome, 2017).

If such coordination among actors is facilitated by the affected community, then it is important to consider how the community clearly defines their goals and values and how they can appropriately share them internally.

Defining a Clear Community Objective

Defining and quantifying appropriate outcomes from the viewpoint of those who are impacted is critical to disaster operations management since the affected community has a very personal stake in such outcomes (Miskel, 2008; Holguin-Veras et al.'s, 2013). Moreover, including the community in the process of defining the

objectives of those operations is also critical for gaining their acceptance, since they often will not want to follow, much less embrace, the process otherwise (Berke et al., 1993; Pearce, 2003). It is also important, however, to consider the community's objectives within the larger context of regional impacts, in order to avoid solutions that may be locally optimal but globally inappropriate. The question therefore arises, if the community is included in defining such objectives, then what kind of framework should be used to do so?

If the defined objective(s) are consistent with the community's values (in the broadest sense), then we might expect them to focus on the community's stability and viability over the long-term. This is both naturally consistent and consistent with findings from applied research (see Habsburg-Lothringen, 2015). With such an emphasis on long-term stability and community viability, there is a subsequent need to widen the focus to include broader system linkages that are external to the disaster event. If this is the case, then a sustainability framework becomes appropriate, in which possible community objectives such as Economic Development, Quality of Life Concerns, and Ecological issues are all considered in tandem (NRC, 2006; Smith and Wenger, 2007).

Within this broader context, it is important to define clear objectives not only to recover from disasters and to build back from disaster impacts in accordance with community values, but also to bounce back *quickly*. In other words, time plays a critical role when defining community objectives because the longer a community is under duress the more it suffers (see Holguin-Veras et al.'s (2013) seminal work on objectives for humanitarian relief work). In order to determine the extent to which the objectives have been achieved they must be quantified, so that the relative extent of the loss suffered, and the speed of the recovery process, can be assessed. As a result, the concept of resilience becomes an important aspect of the discussion.

Resilience is a useful measure for focusing on a system's coping and recovery capacity, for the purpose of reducing the amount of loss that an entity suffers over time, in response to the impacts of a disaster event (Zobel and Khansa, 2012; 2014). To measure such resilience with respect to the various defined objectives of a community, we adopt the approach of calculating the area under a time series loss curve as a percentage of the total area Q^* available if no loss occurs (Bruneau et al., 2003; Zobel, 2011): $R = \left(\int_{t_0}^{t_1} q(t)dt\right)/Q^*$, so that $R \in [0,1]$, where $q(t)$ is the time curve of the community functionality being measured, and t_0 and t_1 are the beginning and end points, respectively, over which the measurement is taken. Because the quantity Q^* depends on specifying a decision horizon over which this functionality should be considered, taking a long-term view implies that we must also adopt a long decision horizon.

Long Decision Horizons

Much of the current disaster operations management literature underplays the recurrent nature of many hazards and focuses instead on the impacts of a single hazard within a relatively short time period (Salmerón and Apte, 2010; Kappes et al., 2012; Chacko, Zobel, & Rees, 2014, Chacko et al., 2016). Particularly when taking a longer-term view, however, it is very important to consider such recurrence in order to emphasize reducing repetitive disaster damages (e.g. rebuilding in flood plains) (Godschalk & Salvesan, 2004; Salmerón and Apte, 2010). This argument is often echoed in a real-world context and by disaster management professionals (City of Portsmouth, 2010; Mitchell et al., 2013). In particular, a long decision horizon adds a new challenge - the need to manage disaster operations (including both the data and decision making) from the perspective of multiple hazards. This is because over a longer time frame various different disasters and their epiphenomena (cascading effects of primary disasters resulting in secondary disasters) may affect a given community in different ways that need to be captured (Basher, 2006; Kappes et al., 2012; Zhang, Li, & Liu, 2012; Chacko, Zobel, & Rees, 2014, Chacko et al., 2016). By addressing disasters within a longer time window, inter-temporal factors may be included in the analysis across multiple events (Mileti, 1999; Psaraftis et al., 1986; Van de Walle and Turoff, 2008). As an example of this, Mitchell et al. (2013), in their applied research of flooding in the tidewater region of Virginia, recommend a suitable decision horizon of 20 to 30 years.

MANAGING COMMUNITY-DRIVEN DISASTER OPERATION CHALLENGES

Given this context of long-term disaster operations management to support community viability in the face of possibly recurrent disasters, we propose a two-step decision making methodology within the context of a decision support system environment.

Step 1: Engaging with the Community & Identifying Appropriate Goals

The first step in our methodology explicitly acknowledges community involvement in specifying appropriate long-term goals. This initial step requires the community to determine three sets of inputs to be included in the

analysis to follow: (1) the resilience based *measures* that the community can use to assess the achievement of their goals (2) the list of possible candidate projects/activities that could be implemented to achieve their goals; and (3) the list of policies that reflect the community's various and sometimes competing long-term goals. In addition, the relative importance of each of the policies being considered, along with any additional policies that the community wants to include in its analysis, and the community's "posture" (see below) in enacting these policies.

The *measures* that reflect the community's long-term critical goals will be maximized or minimized as objective functions in a mathematical optimization problem that will be run under a variety of different possible scenarios. Stated conversely, if the community does *not* include a measure in its objective specification, the community should not care if that measure is paid no attention in the analysis that ensues. The candidate disaster operation projects may range from the small to the large. For example, a community may contemplate a project to place curbing along a river or a canal; to build an earthen berm, or a low concrete wall. There might be a variation of the previous project that provides a high concrete wall. A further project might suggest buying back (i.e., moving out) houses and property in the floodplain, in particular those structures that repeatedly are "hit" over and over by successive disasters. Another project of a different ilk might involve the relocation of a disaster supply depot.

The community's "posture" in enacting the most relevant policies represents an *a priori* indication of whether it wants these policies to be "set in stone" over the whole 20-year (say) study horizon, or whether they can be altered given the latest set of conditions and events. For example, a community may decide in advance that it is committed to prioritizing the ecological sustainability," no matter *what*; regardless of the disaster circumstances that ensue, i.e., the populace may say that they refuse to further damage the environment in response. Or, a community may insist it will be equitable in its treatment of its citizenry regardless of what the disaster brings; hence, every socio-economic group will receive equal support in response to damage regardless of political power, influence, etc. Conversely, the community may decide to remain committed to its objective measures and thus, whenever a disaster occurs, to choose (mathematically) the policy that best fulfills the objective function values as expressed by the community.

Step 2: Modeling

In the methodology's second step, a discrete-event simulation model is invoked to generate a large number of independent *disaster sequences* that, in turn, get presented to a planning model for analysis of what to do following the occurrence of each consecutive disaster. A resource allocation model is then run immediately *after each disaster event* to determine how best to proceed, given what has just transpired and what is *expected* to transpire in the future. The model and plan are then adapted based on these results so that an "optimal" path is followed until the next disaster occurs. The state of affairs at the end of the sequence (i.e., the end of the study horizon) is then examined, and the results are stored for each community measure of interest. This is repeated for each disaster sequence. Finally, the mean, median, mode, spread, etc. across all independent sequences are calculated. The results can be presented to the community for feedback and for reconsideration, or validation, of the specified set of measures and of the community's current "posture." Because the quality of the results depends on the quality of the collected data, it is very important to include explicit consideration of the associated uncertainties, including sensitivity analyses within the individual optimizations, in order to properly compare the effectiveness of the different policies over time. Only by examining the results of such multiple replications across a long study horizon can a community properly ensure that it has examined the best set of disaster operation decisions across the policies it cares about.

Case Study: Portsmouth, Virginia

Portsmouth, VA, provides a good example of a community that has been the source of recurrent disasters, particularly flooding, over the past 100 years (City of Portsmouth, 2010; Mitchell et al., 2013). A Google map rendering of Portsmouth with a FEMA risk-of-flooding overlay is shown in Figure 1; red shading in that figure indicates high-flooding risk areas, whereas pink shading represents regions of moderate flood risk.

To enhance this example, we divide the Portsmouth community into four homogenous regions based on median income and location, as shown in Figure 2. The unique characteristics of these regions provide some interesting notes: Region 1 is characterized by being in the floodplain; regions 2, 3, and 4 are *not.* Also, note that region 2 does not abut water (although flooding may occur there); hence it makes no sense to mitigate there with sea walls. Finally, we identify region 4 (along the waterfront) as the business district.

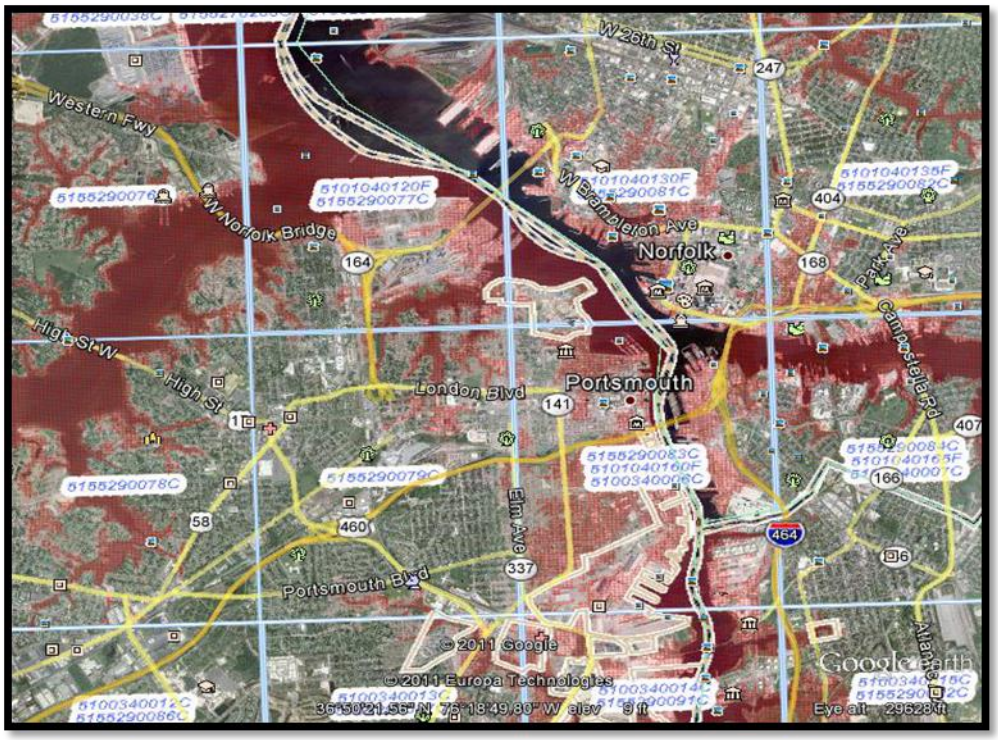
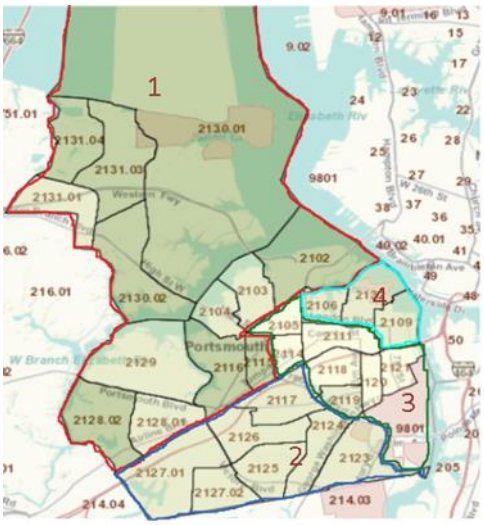


Figure 1. Google Map Image of Portsmouth, VA (USA) with a Flood Hazard Overlay

Source: Google Earth, Version 7; Flooding Risk Overlay provided by FEMA's "Stay Dry," Version 3.



Region	Description
1	Wealthy; in floodplain
2	Middle median income
3	Lowest median income
4	Business district

Figure 2. The Four Defined Portsmouth, VA, Regions

Source: U.S. Census Bureau, 2006-2010 American Community Survey

Proposed Solutions to Community-Driven Disaster Operation Challenges

To analyze the disasters to be faced by Portsmouth, we may generate the inter-arrival times and severity of storm damage from data collected from Mitchell et al. (2013), reflecting Portsmouth's history of storm damage. To further demonstrate the capability to model different types of disasters, we may classify Portsmouth storms into two different *types*. The first storm type consists of tropical storms, Nor'easters, and category 1 and 2 hurricanes, whereas the second consists of category 3 and higher hurricanes. Based on historical storm data for the past 100 years, we may then fit triangular distributions for both severity and inter-arrival times for each type

of storm, with different parameters representing the most likely, the smallest, and the largest values occurring.

Because the sequences of disasters discussed above will be drawn from distributions based on historical data and/or expert opinions of both severity intensities and inter-arrival times, plots of the impact of the events on the community's chosen objectives over time do not necessarily follow closed-form expressions. However, if we assume (essentially) instantaneous disaster effects and linear recoveries from them (or that nonlinear recoveries may be approximated by piecewise linear functions), we may generate curves q(t), as in Figure 3, to represent changes in these measures over time. Using Chacko et al., (2016), we may then calculate resilience as a function of the piecewise area under q(t). This piecewise-linear approximation of the response is particularly appropriate because of the long time frames being considered, however, it is not strictly necessary for calculating the area beneath the response curve since there are a variety of numerical integration methods that could be used for this purpose if a different approach were adopted.

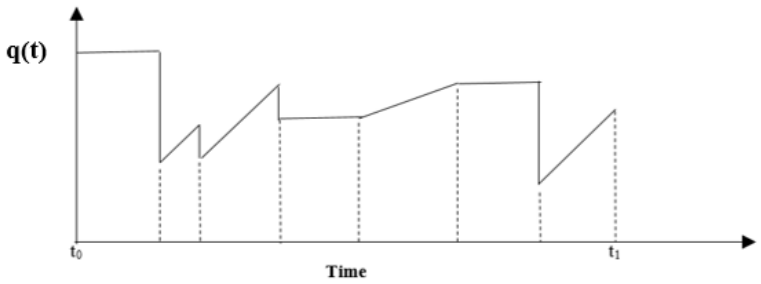


Figure 3. Computational approach for calculating resilience.

The methodology is implemented via a basic resource-allocation mathematical model, where both long-term mitigation and long-term recovery projects are mathematically drawn from among a pool of possible disaster operation projects. These projects are categorized either under long-term mitigation projects or long-term recovery projects, and they are allocated resources in order to meet the community's goals and objectives while implementing community-specified, significant policies. The form of the model may generally be written as

Pursue Objective(s)		*(1a)*
subject to:	*physical constraints*	*(1b)*
	long-term mitigation project constraints	*(1c)*
	long-term recovery project constraints	*(1d)*
	policy constraints	*(1e)*
	non-negativity constraints, etc.	*(1f)*

The objective in this model is to maximize the community's chosen objectives, or community values, including such options as *equity among social classes; preferential treatment for the elderly; preferential treatment for businesses; measures reflecting safety*, etc., through investment of limited resources into mitigation and recovery decision options. These various values may be considered singly, as a group of independent objectives detailed lexicographically, or in the form of a weighted combination (with weighting specified by the stakeholders), that combines to a single objective. The function *q(t)* then represents the extent to which the objective or objectives are being achieved at each time *t*, relative to a given target value of 100% achievement. This may be calculated by using either proxy variables or direct measurements, depending on the nature of the objective under consideration. The resource limitations are primarily financial and construction-related, and are functions of both time and region, but any additional resource constraint that obtains in a particular scenario can and should be included.

Taking such an approach can allow the community to assess the range of possible outcomes it is likely to see over the planning horizon for each policy it considers, both through the quantitative results of the analysis and through visualizing the long-term trajectory of the community with respect to their chosen objectives. The community thus may choose the policy that most effectively accommodates its long-term wishes. Alternatively, however, the community may instead determine that none of its proposed measures, policies, and project

combinations provides a satisfactory solution, given the disasters it expects to face. It is critical that communities be able to make this assessment before, rather than after, facing a sequence of disasters. In such cases, new/different projects, resources, etc., must be considered with the model being re-run and re-assessed.

CONCLUSIONS

This research highlights the challenges of modeling community-driven disaster operations management, specifically the challenges of: engaging the community and coordinating amongst multiple decision makers, defining a clear community objective, and planning with long decision horizons. Using the urban area of Portsmouth, Virginia, this research demonstrated, as a work in progress, a decision support system approach which addresses critical elements of community-driven disaster operations management. The proposed approach provides data informing answers to multiple, general questions, from which the community then must engage in open, informed discussion, considering interactively-determined tradeoffs, before it specifies its recommended course of action for mitigating against and responding to upcoming disasters.

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Turning data into action: supporting humanitarian field workers with open data

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ABSTRACT

In the aftermath of disasters, information is of the essence for humanitarian decision makers in the field. Their concrete information needs is highly context-influenced and often they find themselves unable to access the right information at the right time. We propose a novel ICT-based approach to address these information needs more accurately. First, we select a group of in-field decision makers and collect their concrete information needs in the disaster aftermath. We then review to what extent existing data and tools can already address these needs. We conclude that existing solutions fall short in meeting important information needs of the selected group. We describe the design of an information system prototype to address these gaps more accurately. We combine data of the International Aid Transparency Initiative and the Humanitarian Data Exchange to form the data-backend of our system. We describe our implementation approach and evaluation plan.

Keywords

Humanitarian disaster response, decision-making support, information needs, information systems

INTRODUCTION

Even with general consensus that information management is a key element in disaster response (e.g. Van de Walle et al., 2009; Van de Walle et al., 2015; Knox Clarke et al., 2016) the issue of unmet information requirements in the disaster aftermath persists. Field-based humanitarian decision makers today still have a daunting task to fulfill when they have to draw conclusions out of the myriad data from field assessments, reports, phone calls, emails, social media and mobile services available to them.

The rise of new humanitarian and development technologies such as HDX and IATI, offer more data access for humanitarians than ever before. The challenge in utilizing these lies in shifting from simple data gathering to extracting meaningful information (Van den Homberg et al., 2014). It becomes evident that intelligent, context-aware tools are needed that infer the situation of the decision maker, can opaquely analyze various data in the background and present meaningful, actionable information to the user.

Therefore, the ways in which decision makers are equipped with data, has to receive stronger research focus. In the pressing and demanding circumstances in which humanitarian decision makers operate, they cannot be expected to browse through filters, functions and data that do not relate to their particular context.

Objective

In this work in progress we therefore examine the feasibility of a novel ICT-based approach, a prototypically implemented software that builds on existing data sources to address particular information needs of humanitarian decision makers in the field. We argue that, using our presented system, both, generic information needs (e.g. on

the developing response situation) as well as specific information needs (e.g. localized priorities) can be better met. Throughout or research process, we collect the technical and organizational challenges (e.g. data quality, data literacy, data governance, privacy, ethics) in developing, adopting and evaluating such a system and combine our findings in *lessons learnt*.

To keep our development and evaluation approach feasible, we deliberately choose a narrow research focus. We collect concrete information needs from a small group of humanitarian decision makers who have been active in a specific geographic area during a specific humanitarian response. This group represents our target group for whom the system will be prototypically developed. The group will evaluate the system, allowing us to measure its capability to address the groups' information needs.

We aim to demonstrate that data from state-of-the-art humanitarian and development initiatives, can satisfy some of the identified information needs. And thus, a higher incentive is offered to humanitarians to actively collect, process and share data through jointly creating a common operational picture.

RELATED WORK

Gralla et al., in their 2015 report, summarize humanitarian field managers' information needs and common decision problems. They collected concrete information needs for different phases of disaster response and categorized identified decisions into broader categories. Their findings are particularly valuable for the requirements definition of humanitarian decision support systems (Gralla et al., 2015). This work was further verified and examined in the wake of the 2013 Typhoon Yolanda that struck the Philippines (Comes et al., 2015).

One study that aims to address humanitarian information challenges practically was conducted by Calderon et al. They implemented a collaborative system that can be utilized as an information hub for humanitarian workers (Calderon et al., 2014). The hub pooled information from various sources and offered it as a 'single-stop'-shop for addressing information needs in disasters. We propose a different approach in the way, context is understood by the system. Calderon et al. expect continuous user inputs into their system to understand the user's context - a requirement that might add to users' information overload and demand mental capacity and time that might not be available for in-field decision makers. We will focus on automatic context-detection by the system itself.

In their fundamental work on the conceptualization of information systems for emergencies Turoff et al. outlined principles for the development of these kind of systems (Turoff et al., 2004). The here developed prototype, with its deliberately limited case, will especially follow the premises on Information Focus as well as Information Validity and Timeliness.

From the report of Hall et al. on the 2015 Nepal earthquake response, two main indications for improved humanitarian information support can be drawn which will inform our prototype requirement analysis: decision makers should be informed on the relief activities that pertain to them in order to support their sensemaking and situational awareness and they should be able to report their information needs proactively.

We will further draw from the findings of Comes et al. on their design principles, challenges and characteristics of humanitarian information systems, with a specific focus on logistics, supply chain management and situational awareness (Comes et al., 2016).

These findings clearly uncover practical in-field challenges in humanitarian information work. Humanitarian workers need stronger evidence and therefore more tailored, reliable information to base their decisions. In the following we outline our proposed approach to address this pressing problematic.

METHODOLOGY

Based on the above described current state of research, in the following we outline our approach to design a novel information system that is suited to address a very specific set of humanitarian workers' information needs. We use a specific methodology comprised of several steps: First, we narrow our focus to a specific geographic area: Gorkha District, Nepal, building on previous research (e.g. Baharmand et al., 2016). Second, we select a small group of humanitarian decision makers as our concrete target group in this district and collect specific information needs from that group. Third, we review available data and systems that can be utilized in meeting some of those information needs. By comparing the information needs and the available data and systems, we can observe discrepancies between *what needs to be known* and *how it can be answered*. Fourth, this uncovers concrete information gaps and informs our development plan for a novel prototypically implemented software that addresses these gaps and aims to transform the already available data into actionable information. Fifth, we describe an evaluation plan that will measure the impact, adoption and perceived usefulness of the prototype.

Selection of Case

The 2015 Gorkha earthquake in Nepal killed almost 9.000 people (Guha-Sapir et al., 2015). Remarkably, considering the recent history of earthquakes and flooding in Nepal, the country is not ranked under the global disaster hotspots: it ranks 107. in the World Risk Index and 43. in the INFORM Index (INFORM, 2018; Krich et al., 2017). Droughts, flooding and landslides add to Nepal's risk profile and cause continuous humanitarian involvements. This provides a large pool of actors familiar with the Nepalese context who have fresh memories of what information needs are crucial to fulfill in disaster response which can guide our system requirement analysis. Prior work of the authors involved the collaboration with humanitarian organizations in Nepal. Those existing relations provide an environment of trust and ease the interview and data collection process. Based on these relations, a small group of humanitarian decision makers will be selected as the target group.

Determining Information Needs

We will conduct semi-structured interviews with the selected target group. The identified information needs, decisions and their categorization by Gralla et al. (2015) constitute our baseline. Based on those, we investigate what concrete decision problems and information needs the interviewees frequently face and what information they require to be able to make the best possible decision. We focus on information needs that occur in the first days, weeks and months in the disaster aftermath and that recur frequently, rather than arise only occasionally.

Review of State-of-the-Art Data and Systems

Relevant data will be collected from different sources including common humanitarian platforms, Nepalese authorities, online data stores from NGOs etc. The data sets are reviewed based on their capability to address decision makers' information needs. Analogue, existing systems that can be accessed and used by decision makers to meet information needs are assessed.

Implementation Plan

The determined information needs and the reviewed data and systems uncover what gaps exist, i.e. what needs are still unmet. The observed discrepancies will argue for a more tailored ICT-based solution. Based on these observations, we define software requirements and create a development plan. The development will take place over several weeks with certain milestones. At each milestone, the new version will be tested by the selected target group, who gives feedback and thereby informs the next phase of development. An open source development approach will be used to facilitate the involvement of the target group in a flexible manner (Currion et al., 2009).

Evaluation Plan

Aside from the technical feasibility, i.e. the possibilities to connect and integrate various data sources and information platforms, this study will also examine the socio-technical challenges involved in designing, building and integrating such a software for humanitarian operations in the field. In order to capture these lessons learned, as well as to assess the overall impact of the developed platform, an impact evaluation approach is used. This approach will not only examine the overall impact as a single indicator, but rather serve as a guideline for capturing and categorizing the observations made during the development and implementation process in accordance with case-study research (Yin, 1994).

PRELIMINARY RESULTS

This chapter summarizes the preliminary results of this work in progress. We first outline our findings regarding concrete information needs of decision makers. Then, we present the results of our data and systems' review. Consequently, we outline our implementation process so far and describe the planned evaluation.

Identified Information Needs

A first step to develop a system to support in-field humanitarian operations using the data available in the various platforms, is to understand their information needs. These information needs will inform the majority of the functional requirements of the platform. In order to become a feasible and workable set of functional requirements, we examine these information needs in the scope of our case study. This will not only ensure am internally consistent and compatible set of requirements but also that these requirements, and the resulting prototype can be evaluated in a practical context. Within this scope we determine the information needs in several steps. Initially we examine existing literature and case studies related to the context of the case study to get an understanding of the actors and their (high-level) information needs. Following this desk research we verify these requirements with the results from previous field research. As a last step we further operationalize the information needs into requirements through interactive workshops in the field.

The research conducted by Baharmand et al. in 2015, focuses on the same geographical region as our research (Baharmand et al., 2015). In their work the authors examined the challenges in information management at the local level. Specifically they highlight the possibilities to improve the role of the communities and local actors by

enabling better access to information available in the humanitarian community. In this research a similar approach is chosen: working from the decisions made in the field towards the information needs to support these decisions in several steps. This approach was also recently used in a field study conducted as part of the COMRADES project. In one of the project deliverables, "Socio-Technical Requirements" (Comes et al., 2017), decisions and related information needs of the community in the Gorkha district were examined.

From this desk research, identified information needs include:

- Situational awareness: Through the research the need for a '3W-like' overview (who is doing what where) is often mentioned. Being aware of what organizations are operating in a specific area, what their actions and projects are and their contact information.
- Needs assessment: Furthermore, the research shows the need for an integrated, detailed overview of the needs across different sectors (assessment information). While this information does exist, it is scattered across different systems and sources. This makes it challenging to provide a single integrated, localized overview.
- Operational circumstances: Finally, the need for a localized status on the operational circumstances are mentioned. This overview includes the available resources in the region that could be utilized, but also the logistical options to deliver aid and mobilize the resources (resource and logistics mapping).

In the upcoming research these information needs will be further explored, discussed and operationalized through interactive workshops following the examples of the previous studies highlighted above. However, these initial findings already give an insight in the possible requirements for a system addressing the localized in-field information needs. These initial findings enable us to already to examine how existing data sources match with these information needs, and the technical possibilities to transform this data into a usable format and information overview relevant to the local actors.

Reviewed Data and Systems

In this section we present our findings on existing data and systems that are relevant in addressing in-field decision makers' information needs.

Reviewed Data

Various data sources exist that can be utilized to meet in-field humanitarian decision makers' information needs. In the following we present the sources we selected and explain why they should be integrated in the data-backend of a more tailored humanitarian information system.

International Aid Transparency Initiative (IATI): We select IATI data because it contains information on what humanitarian and development organizations are active in what sectors and regions in Nepal. It is useful for humanitarian decision makers because of its 3W nature and because it can inform on possible organizational partnerships in the response (e.g. joint efforts, shared resources and facilities). IATI's technical XML standardization eases its processing through information systems. The IATI Data Use Strategy for 2017-2019 specifically mentions the importance of further use cases of IATI data, besides donor reporting, to make the international development and humanitarian sector more transparent and accountable (International Aid Transparency Initiative, 2017). Our integration of IATI data constitutes such an additional use case.

Humanitarian Exchange Language (HXL): In comparison to IATI's high political buy-in and complex technical standardization characteristics, the Humanitarian Exchange Language (HXL) is a rather bottom-up initiative that stems from perceived in-field deficiencies in humanitarian coordination, communication and collaboration (Warner et al., 2016). HXL data contains operational information on humanitarian responses: how many people are affected in what region? what do they need? what is the status of the infrastructure? HXL data therefore is an important resource in the effort to create an elaborate picture of the response situation.

Humanitarian Data Exchange (HDX): The Humanitarian Data Exchange stores data in different formats from different humanitarian hotspots worldwide. United Nation bodies, national authorities and NGOs upload baseline data (e.g. demographics, economic and geographic data) and operational data (e.g. number of affected people, assessed needs, infrastructure damage) into the platform. Currently, it stores 316 datasets on Nepal, which makes it a valuable resource for creating an humanitarian overview of the country.

Demographics: Official statistics on Nepal (e.g. census data) are provided by Nepalese government authorities mostly in PDF. NGOs including NepalInData, OpenKnowledgeNepal, Code4Nepal and others, manually transfer and publish these data in easier to access formats like CSV. These official data can be utilized to understand local contexts, dynamics and coping capacities in Nepal.

Logistics: The humanitarian logistics cluster stores baseline logistics information on the Nepalese road network,

ports, aviation, railways, waterways, storage facilities, transportation services, telecommunications, government contacts etc. The data is highly valuable in the planning of logistics of humanitarian response operations.

Indices: Data from the global risk indices INFORM and World Risk Index hold information on the vulnerability and exposure of countries' populations. The data can be utilized to inform disaster response strategies and prioritize actions.

Financial Tracking Service (FTS): The United Nations Office for the Coordination of Humanitarian Affairs operates the humanitarian Financial Tracking Service. Similar to IATI, it is useful to track financial and in-kind flows from donors to implementing organizations with short descriptions about the purpose of each flow. FTS data thereby helps to understand who is doing what in the response. However, the level of granularity is often not high enough to extract information that is directly actionable and meaningful for in-field decision makers.

We conclude, various data that can be used to address in-field disaster decision makers' information needs exist in different formats, stemming from diverse sources. Each dataset provides individual aspects that can partly answer decision makers questions during disaster response. It is however the combination and integration of all of these datasets that promises the greatest information support. In this work in progress we will therefore implement a data unification process into the proposed software prototype. The unified data model will facilitate the intelligent selection of the right data, at the right time, in the right context.

Reviewed Systems

To understand the current state of information systems that can support humanitarian decision makers in the selected case, we reviewed systems that are applied in at least one of the following fields: IATI, HDX, HXL, disaster decision support and data portals dealing with Nepal. We use the term 'system' synonymous for different kinds of software: websites, portals, platforms, information systems, desktop applications, web services, mobile apps, software libraries and data stores. Our findings are summarized in table 1.

Table 1. Summary of reviewed Systems

System	URL	Functionality	Type of Data (if identifiable)
Humanitarian Data Exchange	https://data.humdata.org/group/npl	The Humanitarian Data Exchange allows organizations to upload, manage and use humanitarian data. It currently stores 316 datasets on Nepal, incl. baseline data (e.g. demographics, borders) and operational data (e.g. number of affected people by earthquakes, number of destroyed houses). The data can be searched, ordered and filtered by different criteria e.g. publishing organization, data format and data content type. The platform includes a micro-site with data on the 2015 earthquakes (https://data.humdata.org/group/nepal-earthquake).	CSV, XLS, HXL, JSON, spatial data
Nepalese Aid Management Platform	http://amis.mof.gov.np/portal/	The Aid Management Platform of the Nepalese Ministry of Finance makes information on development projects in Nepal publicly accessible. The Platform has a sub-component (http://earthquake.mof.gov.np/portal/) which holds only the information on development projects related to the 2015 earthquakes and makes these publicly available in the same way. Decision makers can get an overview of development actors involved in the 2015 earthquake response and the sectors in which those actors were working.	Official development data
Nepalese Disaster Risk Portal	http://drrportal.gov.np/	The Disaster Risk Portal of the Government of Nepal provides public access to various disaster related information on Nepal. It includes updates on recent incidents (e.g. earthquakes, floods, fires), maps, relief efforts and more. It is a very good resource for decision makers to acquire official disaster related information on Nepal.	Official disaster statistics
SinhupalCheck	https://sindhupalcheck.developmentcheck.org	SindhupalCheck is a platform that collects citizen feedback on post-disaster aid effectiveness. Citizens' opinions on the aid delivered to them is granularly collected and openly published.	Crowdsourced citizen data
NepalMap	https://www.nepalmap.org	NepalMap (by Code4Nepal) is an openly accessible frontend dashboard that allows queries on different Nepalese districts and displays baseline data, e.g. demographics, education, social & human development, based on the queried sub-national districts.	Demographics, education, human & social development
NepalInData	https://nepalindata.com/data/	NepalInData manually copied data from official PDF reports of Nepalese authorities and created an openly accessible query and visualization form for the data. Decision makers can use the tool to retrieve baseline data on various sectors incl. foreign aid, infrastructure, social & human development.	Demographics/Census, MDGs, agricultural, human & social development, economic
IATI portals	https://www.openaid.nl/	Organization tailored dashboard frontend that openly display finance data of IATI reported development activities to the general public. Decision makers can learn what activities were conducted in Nepal, what organizations have been active and in what sectors.	IATI

IATI Studio	https://www.iatistudio.com/	IATI Studio includes a dashboard frontend for all IATI data referenced in the IATI registry, it allows the creation of custom charts based on user selected IATI criteria, the publishing of IATI data and also allows the creation of custom generated micro-sites aimed to ease the work with IATI for non-technical users. Decision makers can use the dashboard and custom chart features to get an overview of financial flows within development projects to particular countries.	IATI
D-Portal	http://d-portal.org/	D-Portal is a dashboard frontend for all IATI data referenced in the IATI registry. Decision makers can review what development organizations were active in Nepal (in some cases on a sub-national level) and within what sectors they have been active..	IATI
NepalMonitor	https://www.nepalmonitor.org/	NepalMonitor is an Ushahidi-based, crowdsourced, geographic information platform. Everyone with access to the platform can submit reports on incidents they witnessed or were directly affected by. Decision makers can get a real time overview of citizen reports and thereby inform themselves about the perceived situations on the ground.	Crowdsourced geographic data

A major concern with the reviewed systems is that they try to answer many questions for a broad and diverse target group. They hold many data sets dealing with very different aspects. They provide filtering methods but only on user input and are not intelligently context-aware for specific user situations. The amount of possible questions users get answers to is not helpful to reduce the demand to mental capacity. And the amount of information and data available needs to be assessed by decision makers, in order to know what data is helpful and what is not. This adds to the information overload which should actually be reduced by decision support systems. Our approach therefore is to prototype a more tailored system, in other words: deliberately limit the scope and use case of the system, i.e. its data and functions. Remarkably, many of the reviewed systems provide web services like APIs to allow other software to connect to them. In our development approach we can therefore integrate those connections.

Implementation

Building on the state of research and reviewed data and systems, we have identified that humanitarian in-field decision makers need more tailored information system support to address their information needs during disasters. In the following we outline our prototypically development approach for such a novel system.

Our prototype contains a data-backend, programming logic and two example frontend clients. The data-backend is a PostgreSQL database that stores IATI, HDX and HXL data. The programming logic is a Python web service (API) that connects the data-backend with the front-end clients. The two clients are a JavaScript based website and an Android application. Figure 1 outlines the architecture of the prototype. Via the client, the user sends a request to the API. He can type in a set of keywords (figure 2), submit the request and the prototype backend receives the keywords. In a separate process, the backend has already collected IATI, HXL and HDX data and stored it into its database (evidence base). Corresponding to the received keywords, the prototype queries its evidence base: For example, if the user queries “injured”, the prototype will select all HXL data on injured persons and returns it to the client.

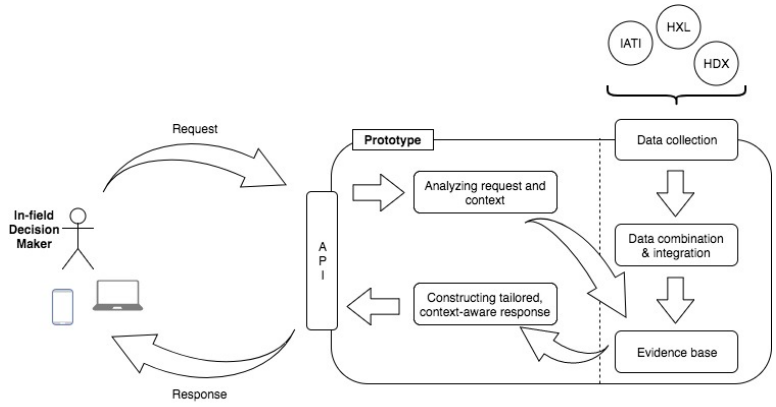

Figure 1. Overview of proposed Prototype

The Python programming logic is developed around the identified information needs of the target group. It accepts user requests in the form of search terms (e.g. "injured", "phones", "near me") and responds with information that it selects from the data-backend. We chose to start with an API because it allows working with data flexibly and is applicable for a variety of use cases: Web platforms, desktop applications, mobile apps, can all communicate with the same API. We chose Python as implementation language for the API because IATI, HDX and HXL have

software libraries in Python that allow us to easily integrate them in our work. Also, Python is widely-applied in data science and often used in IATI software projects.

Table 2 shows example API calls and their results. For example, the first row shows a query that asks for information on what shelter items have been distributed in the Gorkha district.

Table 2. Example API Requests and Responses

API request	API response (JSON)	Description
http://x.x.x.x:8000/shelter/?district=Gorkha&format=json	{"id":75,"district":"Gorkha","blankets":69096,"cgi":14473,"clothes":0,"kitchenSets":12549,"tarpaulin":82768,"tents":7161}	The response lists the numbers of shelter items that were distributed in the district given in the API request.
http://x.x.x.x:8000/hxl/?district=Gorkha&format=json	{"id":154,"district":"Gorkha","population":271061,"peopleInjured":952,"femalesInjured":0,"malesInjured":0,"peopleDead":0,"femalesDead":230,"malesDead":213,"housesDamaged":13917,"housesDestroyed":44610}	The response lists the numbers of fatalities, injured persons, damaged and destroyed houses within the district given in the API request.
http://x.x.x.x:8000/combined/?district=Gorkha&format=json	{"id":154,"district":"Gorkha","blankets":69096,"cgi":14473,"clothes":0,"kitchenSets":12549,"tarpaulin":82768,"tents":7161,"population":271061,"peopleInjured":952,"femalesInjured":0,"malesInjured":0,"peopleDead":0,"femalesDead":230,"malesDead":213,"housesamaged":13917,"housesDestroyed":44610}	The response combines the results from the first and the second API request above.

Figure 2 show how the Android client makes use of the prototype's API. The client uses search terms that allow users to e.g. rank Nepalese districts by the number of injured people (far left screen), display phone contact information of development organizations active in the response (mid screen) and display operational information of the response depending on the location of the user (far right screen). The prototype queries the IATI, HXL and HDX data stores regularly to provide the latest available data updates. In the direct disaster aftermath, having accurate real-time data is almost impossible. The prototypes' data accuracy depends on the frequency of updates on the HDX and IATI data stores. It is planned that a timestamp of the latest data update is presented to give the user an understanding of how recent the data is.

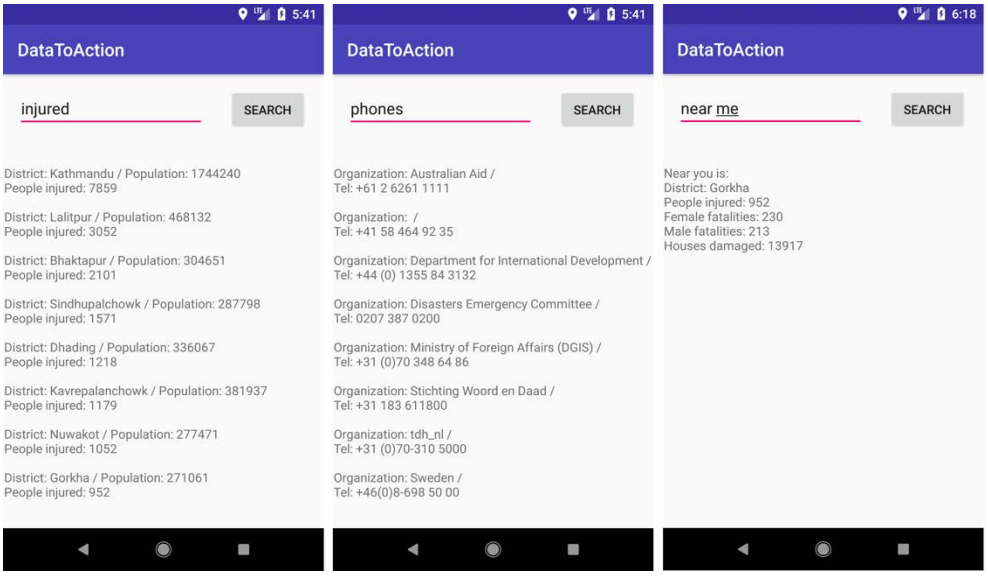

Figure 2. Android Client showing API Results

Evaluation

The development of the prototype is currently ongoing, therefore no evaluation results are presented here. Instead

we outline our envisaged approach to evaluate the system in its future states.

Evaluation methods for information systems is an established field and many different methods exist. Impact evaluation methods aim to measure the change that has occurred between a baseline measurement and the resulting changes in indicators following the implementation of a system (Rawlings and Rubio, 2005). Other methods have a more predictive nature and aim to assess the impact prior to an intervention (Roche, 1999). Specifically looking at information systems, impact can be determined using two main criteria according to Hamilton and Chervany (1981). Firstly, the impact has to be considered with respect to the efforts and investments needed to develop and operate the system: the system efficiency. Secondly, this should be contrasted with the changes in the organizational effectiveness at both the individual users and the overall organization's effectiveness: the system effectiveness. These aspects of information system evaluation have been applied to the humanitarian context in previous research, specifically on services and platforms offered by digital humanitarians (Meesters, 2013). We adapt these various categories to assess the impact of our system as well, as illustrated in figure 3.

	System-efficiency (development)			System-effectiveness (adoption)		
	Level	*Objective*	*Measurement*	*Level*	*Objective*	*Measurement examples*
0	*Systems*	Tech. compliance Design quality Governance	Data accessibility UI, compatibility, robust Privacy, quality assurance			
1	*Resource consumption*	Resources Function design Participation	Development efforts Requirements specification Adoption and involvement	*Information & support*	Info. quality Presentation Info. quantity	Accuracy, relevance, reliability Graphical, accessibility Access to data, more sources
2	*Capability*	Available capacity Job satisfaction	Productivity, response time Performance of users	*Process & user performance*	Automation Decision making Performance	Task automation, data use Understanding, confidence Usefulness, added value
3	*Investments*	Support Investments	Training, documentation Hardware / software costs	*Organizational performance*	Financial Beneficiaries Network	Higher contribution Regulation, transparency Reputation, advocacy

Figure 3. Levels, objectives & measurements for evaluating a management information system (Hamilton and Chervany, 1981)

Data for these different criteria will be collected throughout the project, following the paradigm of 'Action Research' (Brydon-Miller et al., 2003). As 'a reflective process of progressive problem solving' (Stringer, 2013), we will use the development of a prototype to address the challenge of satisficing the information needs of in-field decisions makers as input for our evaluation. The open and flexible development procedure allows us to evaluate new versions successively as the prototype evolves over time. Representatives from our target groups can give feedback during the development phases and thereby influence the requirements for the next iteration. Throughout the iterative development process, using the criteria listed above, we will examine the impact of our development efforts and document our findings.

CONCLUSION

This paper represents a work in progress. However, our preliminary results are summarized in the following.

We see huge demand for addressing information needs of in-field decision makers in disaster response. Requirements for the composition of these information are diverse and context-influenced: who needs what information at what time in what format and quality? We narrow our focus to study the information needs of a small decision maker group and assess how existing solutions perform in meeting their information needs. We reviewed data sets and systems that can be utilized to meet those information requirements. Our preliminary results show that a wide variety of data and systems on the Nepalese context exists. They range from raw census data to sophisticated online information systems. Of course, data is of little use in raw format and needs to be processed and presented in a meaningful, actionable way. Many systems observed are performing well at answering a multitude of questions. However, being presented with options and information not needed at a certain time for a certain decision is adding to information overload and increases demand to mental capacities of in-field humanitarians.

We observe a trend of humanitarian data being collected and transferred upwards to inform headquarters and donors. On the operational level in the field, information needs are still often unmet and more fine-grained: e.g. road statuses and contact information are needed. In this work in progress we develop and evaluate a new information system prototype that uses existing data sources to address these localized information needs better. We conclude that a well-designed information support system needs to be tailored to the user and his situation. It opaquely processes data and analyses the situation in the background. And as a result, it intelligently presents

information that is actionable for the user. Future developments of the prototype will also look into how concrete information needs of disaster-affected communities, in addition to humanitarian decision makers, can be better addressed (Comes et al., 2017).

ACKNOWLEDGEMENTS

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Determining flooded areas using crowd sensing data and weather radar precipitation: a case study in Brazil

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ABSTRACT

Crowd sensing data (also known as crowdsourcing) are of great significance to support flood risk management. With the growing volume of available data in the past few years, researchers have used in situ sensor data to filter and prioritize volunteers' information. Nevertheless, stationary, in situ sensors are only capable of monitoring a limited region, and this could hamper proper decision-making. This study investigates the use of weather radar precipitation to support the processing of crowd sensing data with the goal of improving situation awareness in a disaster and early warnings (e.g., floods). Results from a case study carried out in the city of São Paulo, Brazil, demonstrate that weather radar data are able to validate flooded areas identified from clusters of crowd sensing data. In this manner, crowd sensing and weather radar data together can not only help engage citizens, but also generate high-quality data at finer spatial and temporal resolutions to improve the decision-making related to weather-related disaster events.

Keywords

Crowd sensing data, Weather radar precipitation, Kernel density estimation, Flood management, Collaborative platforms.

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INTRODUCTION

Catastrophic impacts caused by floods around the world have called for the adoption and preparation of measures, which could increase the resilience of vulnerable communities. This is even more important since the occurrence of disaster tends to grow in the next few years due to climate changes. In this manner, flood management requires a proper understanding of flooded areas that are important and fundamental not only to take response actions and conduct relief tasks, but also to trace vulnerable locations and thus training and preparing communities in case of an event. An important component of flood management is the implementation and improvement of flood forecasting and warning systems. Regional and national institutions have been deploying several data collection systems for supporting flood management; these include rainfall gauges, hydrological stations, humidity sensors, and weather data. Among them, a weather radar is a remote sensing-based equipment that measures the volume of rainfall analyzing the backscattered energy of a microwave pulse emitted to the atmosphere (Dixon and Wiener 1993). These are particularly valuable for monitoring the rainfall over an entire area instead of a single point like done by rainfall gauges.

In parallel, the power of crowds in estimating current situation at affected areas and in supporting data analysis for disaster management has been demonstrated in several research works (Horita, Degrossi, et al. 2013; Klonner et al. 2016; Granell and Ostermann 2016). These data comprise a collection of volunteered data produced by individuals and informal institutions, i.e., by ordinary citizens using appropriate tools to gather and disseminate their views and knowledge on the web (Goodchild 2007). For example, Wang et al. (2016) conducted a social media analysis from spatial, temporal, and content perspectives for wildfire hazards. In the particular case of floods, Kusumo et al. (2017) examined volunteered information for planning evacuation shelters in case of floods and Horita, Albuquerque, Degrossi, et al. (2015) presented a decision support system that integrates volunteered information and sensor data for flood management.

Although volunteered information has shown its potential to support flood risk management, it also increases the amount of available and useful data, which can lead to information being overlooked or even misused by decision-makers. Both practice and academia have been developing geospatial approaches to process such data; among them, impressive results were achieved when processing volunteered information using data provided by stationary sensors (e.g., hydrological stations, or rainfall gauges) (Albuquerque et al. 2016; Assis, Albuquerque, et al. 2016). At the same time that these approaches open further opportunities, they also raise new challenges, which the main are twofold: 1) if a sensor fails, or is broken, data processing is not reliable and sound; and 2) stationary sensors are able to monitor a limited region, in which it is located. Here, weather radar data show up as an interesting alternative, because they are able to provide measurements of environmental variables (e.g., rainfall) over an entire area instead of a single point through scans.

On the basis of these challenges, this ongoing work investigates weather radar systems as alternative data sources that could support crowd sensing data assessment and improve decision-making in disaster management (e.g., floods). For doing so, data were collected in the period from December 2017 to January 2018 with weather radar systems and a crowd sensing platform, which in turn were employed in a case study conducted in the city of São Paulo, Brazil for identifying flooded areas. This is a relevant case study mainly because the city has high population density (i.e., 12 million inhabitants, or 20.4 million for the whole metropolitan region) and a recurrent problem with flooding, which have incurred financial losses close to US$ 80 million in 2008 (i.e., 42% of Brazilian losses with disasters). Moreover, in contrast to existing works focused on analyzing the use of crowdsourcing data to determine or monitor weather conditions (Demirbas et al. 2010; Chatfield and Brajawidagda 2014; Muller et al. 2015), this work is the first study in the literature centered on utilizing rainfall data provided by weather radar systems to assess crowd sensing data.

This work is structured as follows. Section “Background” introduces the theoretical background of this study. Section “Research Method” outlines the used research method, while Section “Case Study” details the case study conducted for empirically analyzing the method. Section “Results” presents the preliminary results. Eventually, Section “Discussions and Conclusions” summarizes the findings and also describes future lines of work.

BACKGROUND

Crowdsourcing for flood management

The emergence of Web 2.0 and evolution of mobile devices have become the basis for the emergence of a new paradigm, where users in general (i.e., citizens) become established as producers of data and information (Niko et al. 2011). Interestingly, all these generated data and information in many cases, are more detailed and of a higher quality than those provided by official organizations (Goodchild 2007). In this context, Heipke (2010) proposed the

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term "crowdsourcing" for this phenomenon, which involves content production being carried out by a third party that is assigned to intelligence and knowledge. It is based on the experience of volunteers, who are independent in the way they use their free time and are located in remote and diverse areas.

In a similar context, but more closely linked to geographical issues, Goodchild (2007) coined the term Volunteered Geographic Information (VGI) to name this phenomenon which was defined as a collection of digital spatial data produced by individuals and non-formal institutions, i.e., by ordinary citizens using appropriate tools to gather and disseminate their views and geographical knowledge on the web. As a result, these volunteered data have a high potential to expand and qualify the amount of information available about the events and experiences of the community members to perform their activities (Coleman et al. 2009). This volunteered information is classified into the following types (Albuquerque et al. 2016): 1) Social media, i.e., information shared using social media platforms (e.g., Twitter); 2) Collaborative mapping, i.e., spatial information generated by volunteers using mapping platforms (e.g., OpenStreetMap); and 3) Crowd sensing, e.g., applications and platforms (e.g., Ushahidi) focused on gathering pre-determined information about a phenomenon (e.g., water level of river).

Different from social media platforms in which information is shared for general purposes and its meaning is only obtained through machine learning techniques, collaborative mapping and crowd sensing platforms demand an active involvement of users to provide structured information. Since these new platforms provide a great volume of useful data, they should be pre-processed before reaching decision-makers. Several filtering and data processing approaches thus have been developed to overcome this issue; for example, analyzing the geographic relations between official stationary sensors and volunteered information (Albuquerque et al. 2016; Assis, Albuquerque, et al. 2016). However, these approaches often are spatially limited to the location of sensors, i.e., a rainfall gauge provides the precipitation information for its location, it is not able to provide data from a rain occurring 5 km far from it. In this manner, weather radar systems are a relevant and important alternative that can be employed to improve situation awareness, which may also improve the quality and use of information generated by volunteers.

Weather radar system for flood management

The weather radar (RAdio Detection And Ranging) is a remote sensing based equipment that measures the rainfall backscattered energy of an emitted microwave pulse to the atmosphere. Different from rain gauges, the weather radar is able to estimates rain over an entire area through scans instead of a single point. The energy measured by the radar is called radar reflectivity factor (Z). To obtain the quantitative rainfall rate (R) in mmh^{-1} a Z-R relationship is applied. Thereby, it is possible to make a real-time rainfall evaluation over urban areas, and provide support for flood warning and management.

Since it is a great source of information for disaster (and flood) management, these weather radar systems have been employed in both practice and research. Within these works, Borga et al. (2014) used rainfall maps using weather radar and rain gauge data for reports of debris flows and flash floods and showed that rain-gauges networks are generally not dense enough to monitor precipitating systems with high temporal and spatial variability. Furthermore, Yang et al. (2004) utilized weather radar measurements to apply a coupled distributed hydrological model for flood forecasting and control. Another application of weather radar for flood monitoring can be seen on Flash Project (Gourley et al. 2017) that uses weather radar data to estimate water balance to improve the techniques of flash flood monitoring and prediction. Likewise, Ehret et al. (2008) described an approach that combines rainfall observations provided by weather radar systems and rainfall gauges for flood forecasting.

There is also an emerging line of works that are focused on combing the crowdsourcing data with remote sensing data for supporting flood management; for instance, Rosser et al. (2017) presented a method that combines data from different data sources (i.e., remote sensing, social media, and topographic maps) with the aim of estimating flood inundation extent. However, existing studies are still very few and further research works are required in order to provide a better understanding of how remote sensing could be employed with crowdsourcing data.

RESEARCH METHOD

Overview

The objective of this paper is to investigate the use of weather radar systems as an alternative source of information to support crowd sensing data processing. This is particularly important because current and existing approaches have used stationary sensor data, which are able to provide data only from a limited region. In contrast, weather radar systems are capable to provide rainfall information over an entire area. Therefore, this work addresses the following research question: *how can weather radar data validate flooded areas identified by crowd sensing data?*

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In order to address the proposed question, we propose a method that comprises three components: 1) weather radar data processing, 2) crowd sensing data processing, and 3) data analysis. Figure 1 depicts the method with its components.

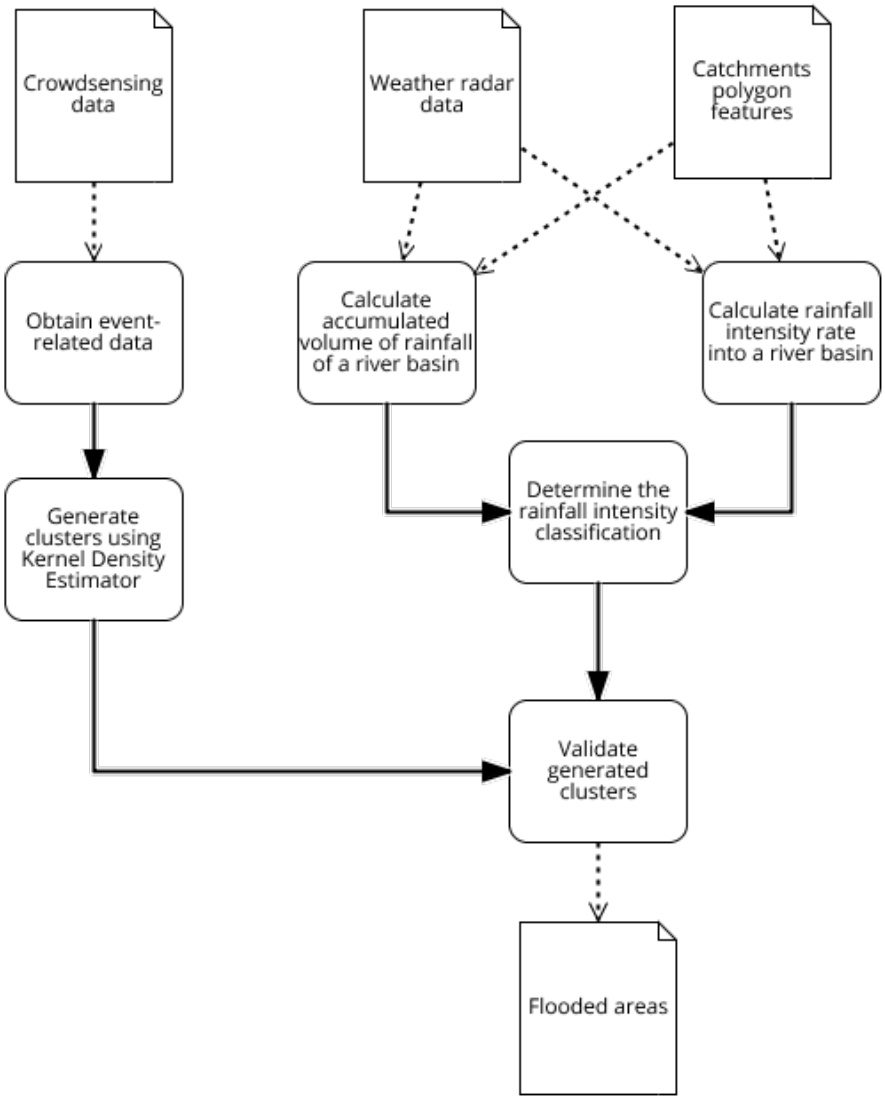

Figure 1. Research method

Weather radar data processing

The weather radar data processing gathers the rainfall data from the weather radar system to calculate the rainfall intensity rate and the accumulated volume of rainfall in a river basin. The rainfall was considered over the area of the river basins, since it is the area in which the precipitation collects and drains into one outlet. Therefore a flood event can happen in a region where there was no rainfall, but is downstream of an area where there was intense precipitation. The observation field of weather radar systems used on this study has a spatial resolution of 100 meters with a time step of 5-minutes per measurements, while the rainfall estimation is calculated using Calheiros and Zawadzki (1987)'s method. This method is based on a probability adjustment between the reflectivity factor and rainfall gauges.

With the rainfall estimation, the intensity and accumulated volume of precipitation within each river basin are calculated in a 5-minutes time span. The volume of precipitation within the river basin was calculated by the spatial mean volume of rainfall inside the basin, considering the largest value, between the last hour and the antecedent hour prior to a flood report (0 to 60 minutes, and 60.01 to 120 minutes prior to an event). Two hours were considered

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since the concentration time of the river basins were close to two hours. The concentration time of a river basin can be defined as the time needed for the water to flow from the most remote point in a river basin to its outlet.

The rainfall intensity was calculated using the maximum instantaneous intensity of the mean spatial value for the river basin in the last hour. Therefore, based on the determined volume and intensity of the precipitation within the river basin, a classification of severity of rainfall was developed: This classification comprises four main classes: "0" indicates that there was no rainfall over the location; "1" indicates a weak precipitation with volume that ranges from 1 to 5 mm and intensity of 1 to 10 mmh^{-1}; "2" represents a moderate rainfall with volume from 5 to 10 mm and intensity of 10 to 20 mmh^{-1}; and lastly "3" indicates heavy precipitation with volumes and intensity higher than 10 mm and 20 mmh^{-1}, respectively. Similar categorization is suggested by Stull(2000)

Crowd sensing data processing

In parallel to weather radar data processing, the crowd sensing data processing aims at collecting and processing data provided by a collaborative platform. Having gathered raw data, it focuses on extracting only those data that are related to the disaster event of interest (e.g., floods). Since collaborative platforms, in particular, those focused on crowd sensing data are able to provide more structured data, disaster events often turn to be categories at the platform; therefore, the filtering process selects the data associated only with the category of interest (floods).

Once the event-related data is obtained, a cluster analysis is conducted to identify spatial patterns of the crowd sensing information and thus to create a map with flooded areas. The cluster analysis was based on Kernel Density Estimation (KDE) that "is a non-parametric method using local information defined by windows (also called kernels) to estimate densities of specified features at given locations" (Shi 2010). It is an important and widespread method for mapping spatial patterns of point events.

KDE requires one input for execution, the bandwidth, i.e., the distance threshold between elements to create a kernel. Two other parameters were supplemented to generate the clusters: a) number of cluster elements, i.e., the minimum number of data elements that can be combined to create a cluster and b) the lag time, i.e., the interval of time between data elements and the cluster creation. This was primordial because all the parameters are important and aim to maintain the quality of data; for example, identifying a real-time flooded area using a group of elements from the last 30 minutes may provide more accurate results than another one using data from the last 240 minutes. Based on this, the configuration settings of KDE have been selected based on testing experiments that examined bandwidths of: 100, 150 and 200 meters; the number of elements needed to create a cluster: 3, 4, and 5; and lag time of 15, 30, 45, and 60 minutes. Due to the limit of words however the description of these such experiments are beyond the scope of this work. The best configuration setting resulting from the comparison tests performed was with: a bandwidth of 200 meters; over three elements to create a cluster; and, a lag time of 30 minutes.

Data analysis

When a cluster is identified, it is validated through a geospatial data analysis with the precipitation severity classification. The steps of analysis are manifold. It first determines the geometric center (centroid) of the cluster in terms of its longitude and latitude. Then, these coordinates are used to identify the precipitation severity classification that was determined by the weather radar data processing. As mentioned before, a class can assume the following categories: 0 (no rain), 1 (weak rain), 2 (moderate rain), and 3 (heavy rain).

Classified clusters are then filtered and only those clusters at rainy areas (i.e., those classified in categories 1, 2, and 3) measured by the weather radar system remain. As a result, these represent the validated flooded areas identified by the volunteered information.

CASE STUDY

Study area

São Paulo city has more than 12 million inhabitants, an area of 1.5 million km², and a population density of 7,400 inhabitants per km^2. Located in Southeast Brazil (Figure 2), it is the country´s largest city (with 5.9% of its population) and the core of São Paulo Metropolitan Region (SPMR). Which, in turn, is the fifth largest megacity in the world, with around 21.3 million people in 2016 (United Nations 2016). SPMR is Brazil's main economic center, with important industrial, commercial and financial complexes. SPMR contributed with 17.63% of Brazilian's GDP and 54.48% of São Paulo's State GDP, in 2015 (Empresa Paulista de Planejamento Metropolitano (Emplasa) 2018).

Brazil passed through a fast urbanization process, going from an urban population of 36% in 1950 to 86% in 2015. The same occurred with the SPMR, which went from less than 2 to more 20 million inhabitants, from 1940 to

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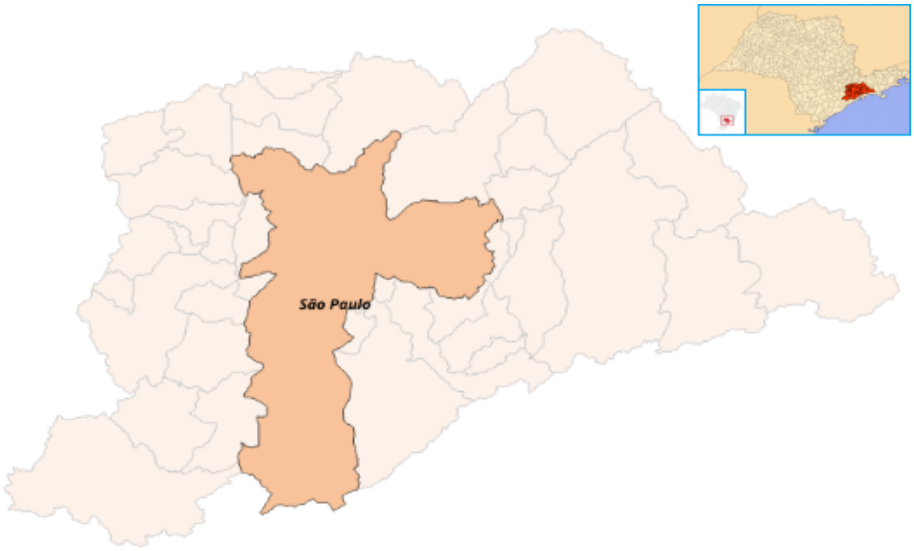

Figure 2. Study area: São Paulo city, Metropolitan Region and State in Brazil

2017 (Silva Dias et al. 2013). The fast urbanization was not accompanied by adequate planning and infrastructure implementation, establishing several vulnerabilities.

São Paulo is a region with heavy rainfall episodes. Large amounts of rainfall occur, due to the South Atlantic convergence zone (SACZ), in the rainfall season (from October until March), as well as heavy rainfall episodes that occur during the dry season, due to cold fronts from southern Chile and Argentina (M. S. Teixeira and Satyamurty 2011). There has been a significant positive trend on daily rainfall extremes in São Paulo city from 1933 to 2010, probably associated to the effects of climate variability and change, as well as urban growth effects, as from heat island and pollution (Silva Dias et al. 2013).

Therefore, these severe weather events associated with environmental and urban vulnerabilities cause frequent losses and disruptions due to flooding. Floods affect citizens, public and private services and activities. Floods in São Paulo city in 2008 alone reflected in losses of up to R$248.55 million to the city, and up to R$564.17 million to the country (Haddad and E. Teixeira 2015). Thus São Paulo city was defined as the study area for its complexity, population size (crowdsource data), and its flooding issues and impacts.

Data

In the period from December 2017 to January 2018, heavy rain damaged several regions of the city of São Paulo in Brazil and most of them have led to impacts to the community routines. Precipitation volumes of these months were significant (i.e., 141mm in December and 161mm in January), although they did no reach high historical records (i.e., 193mm in December and 218mm in January, from 1995). In December 2017, the highest amounts of precipitation were obtained in "Penha" gauge station with 200.9mm (this overwhelmed the historical volume for the month), “Vila Mariana” gauge with 190.0mm, and "Itaquera" gauge with 181.1mm. While, in January, the gauge in the city center (“ Praça da Sé ” gauge) and again ‘Itaquera ” gauge reached the highest amounts of rainfall volume with 185.6mm and 166.4mm, respectively.

Furthermore, 66 flooded locations were issued by the São Paulo Emergency Management Center (CGE, in Portuguese)[1]. Since 1999 when it was created, this center monitors meteorological conditions and issues weather forecasts and warnings of flood events in the city. A team conducts the monitoring task in continuous shifts of 24/7 using satellite imagery, forecasting models, and hydro-meteorological data from stationary stations. This team comprises operators from interdisciplinary backgrounds, i.e., meteorologists, engineers, technicians, and journalists. Members of the County Traffic Engineering Company (CET, in Portuguese), Civil Defense, and Fire Department support activities of CGE by providing updated and reliable information about current occurrences of events in the city.

Rainfall data provided by two weather radar in the city of São Paulo were used in this work. These are X-band Weather Radar Systems that generate spatially distributed horizontal data, on the temporal evolution of precipitation

[1] http://www.cgesp.org

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around a determined area, which can have a radius coverage of up to 60 km (in our case, 21.6 km) and with a time lag between scans of 5 minutes. Through analyzing data from the period of December 2017 to January 2018, two events of heavy rain were determined and later adopted as main case studies. Table 1 shows the regions where the highest values of the accumulated amount of precipitation were observed by the weather radar systems within the indicated day (i.e., January 16, 2018 and January 21, 2018).

Table 1. Accumulated volume of rainfall in São Paulo, Brazil.

Date	Region	Accumulated volume of rainfall (mm)
2018/01/16	Campo Limpo	21,5
2018/01/21	São Miguel	63,4

Together, these two events reached values close to 19.47% of the historical maximum precipitation of January (i.e., 218mm), which also provided concrete evidence of the passage of intense meteorological systems over the city of São Paulo. Therefore, we gathered rainfall data provided by the weather radars system in a 5-minutes resolution for the studied period; these data are generated as a NetCDF file[2] that associates metadata to spatial positions.

The crowd sensing data used in this study were shared by citizens utilizing a mobile app. When creating a report through the app, a user first indicates the type associated with the report (e.g., hazard), then its subtype (e.g., flood or fog). Geospatial location of the report is automatically gathered using the GPS of the smartphone. It is also possible to include a photo or a comment. In the period of study, 735 geo-referenced reports in the area of São Paulo were obtained from this platform. These reports consist of a set of data: type, subtype, date in milliseconds, a unique ID, information about the user, and the coordinates of the report. Metadata is shared in a JSON format. Table 2 outlines the crowd sensing dataset separated among the existing subtypes

Table 2. Crowd sensing dataset per subtype.

	Subtype			
Date	Flood	Weather	Fog	Hail
2018/01/16	230 (46.09%)	6 (8.45%)	14 (15.55%)	21 (28.00%)
2018/01/21	269 (53.90%)	65 (91.54%)	76 (84.44%)	54 (72.00%)
	499	71	90	75

The majority of data is related to reports that indicate flooded areas - 499 reports (close to 67.89%). While, reports of Fog represent the second subtype with - 90 reports (12.24% of all data), which is followed by remaining subtypes: Hail (10.20%) and Weather (9.67%).

RESULTS

A high concentration of crowd sensing data could be identified at the city center and southwest region of São Paulo on January 16^{th}, 2018, while the condition on January 21^{st}, 2018, was restricted only at the central region of the city. Figures 3 and 4 display the condition on these two cases studied; with crowd sensing data as green points, weather radar systems locations as red triangles, the area covered by these systems as circles, and the geographical area of São Paulo delimited.

After employing the research method in the case study, it was identified a total of 97 clusters associated with flooded areas. Interestingly, 4.12% of these clusters were attributed to the "no rain" severity class, while the others were assigned to "heavy rain" class and "moderate rain", 54.64% and 41.24%, respectively. Table 3 shows the distribution of the clusters according to the rain severity classification.

The clusters attributed to the rain severity classification "0" were removed and only the remaining ones were adopted as validated clusters of rainfall response. Since the aim of this paper was to investigate the use of weather radars system precipitation to support the processing of crowd sensing data and to improve information quality and situation awareness in a disaster. We compared the location of generated clusters with historical hot spots of flooded areas reported by CGE; the main idea here is that cluster polygons are expected to be located in known areas of

[2]NetCDF (Network Common Data Form) is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data.

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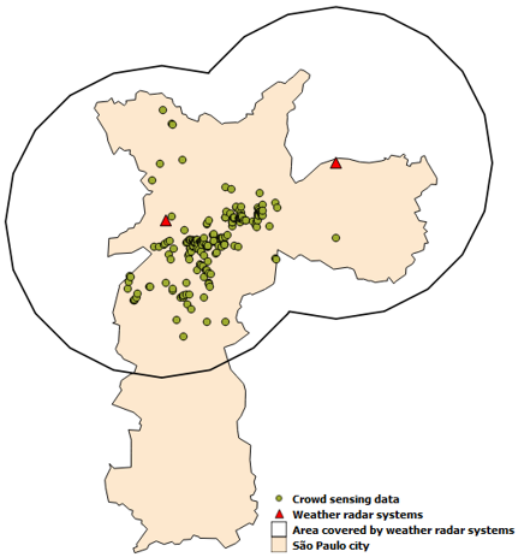

Figure 3. Crowd sensing data on January 16^{th}, 2018.

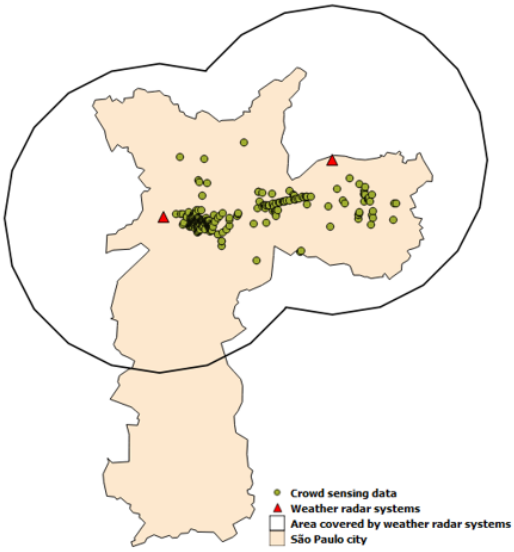

Figure 4. Crowd sensing data on January 21^{st}, 2018.

flooding (i.e., historical data of flood events). This historical data covered a period from January 2007 to December 2017, which consists of 9,667 reports of flooded areas in the city of São Paulo, i.e., almost 1,000 of events per year. Areas with frequent events can be verified at the city center, close to the Municipal Market; further areas can also be verified alongside Tietê Expressway and Pinheiros Expressway. Other verified locations with a high concentration of reports are close to Ibirapuera Park, Mario Pimenta Park, and São Paulo Golf Club. These areas concentrated over 60% of reports published by CGE on its website. Figure 5 displays the validated clusters as red polygons, weather radars locations as red triangles, and historical data of reported flooded areas by CGE as a heat map.

An analysis of the results presented in Figure 5 show that most of the validated cluster polygons - i.e., flooded areas - were located at regions with a high concentration of historical flooded areas, from CGE in both case studies. Furthermore, it is worthwhile to mention that none of the clusters were located in areas with no previous reports from CGE. This provides evidence that the research method is able to identify valuable flooded areas from volunteered data and weather radars system data.

DISCUSSIONS AND CONCLUSIONS

This ongoing work presented a research method that could be employed to support crowd sensing data processing and thus improve decision-making in disaster management (e.g., by identifying flooded areas). Through analyzing information provided by a crowd sensing platform, the method first generates spatial clusters, which are later analyzed and validated using weather radars system data. From December 2017 to January 2018, a case study has been carried out in the city of São Paulo, Brazil using rainfall data provided by two weather radars located in the city, as well as information shared by volunteers utilizing a crowd sensing platform. Study findings indeed indicated that rainfall data provided by weather radars system are able to validate flooded areas, which were identified by volunteered information. Furthermore, the research method utilized a clustering approach to determine those flooded areas that thus may support more informative decisions in flood management. To the best of our knowledge, this is the first research work that uses weather radar data to process crowdsourcing data.

Results obtained in this research provided preliminary evidence, which shows that rainfall data provided by weather radars system are of great value for validating volunteered information. The results were promising in exploring

Table 3. Distribution of clusters according to the rain severity classification.

Time (min)	Rain Intensity Class				Total
	0	1	2	3	
30	4 (4.12%)	0 (0%)	40 (41.24%)	53 (54.64%)	97

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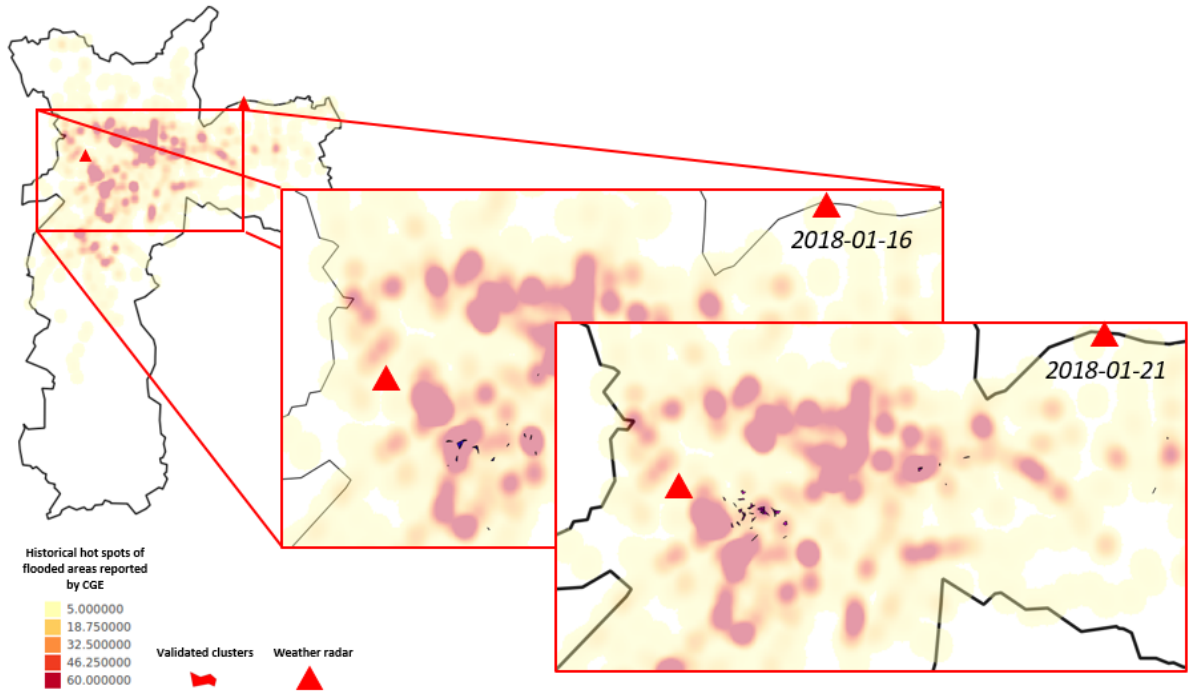

Figure 5. Validated clusters of flooded areas. Validated clusters are displayed as red polygons, weather radars locations as red triangles, and historical flooded areas reported by CGE as heat map.

the potential of the crowd sensing data, by validating and ensuring its quality based on precipitation data from weather radars in the drainage basin. The results showed compatible with historical records from CGE. Public organizations that monitor flooding areas usually have limited capability of reach and resources to be in all places needed, especially when a crisis situation strike. As for example, CGE monitors the entire São Paulo city (i.e. with limited personnel or hydrological gauge stations to cover a large area). Therefore using population input from crowdsourcing data associated with a spatial precipitation information (from weather radars) to ensure data quality can greatly enlarge the reach and coverage of real-time information. These preliminary results as the future works here proposed, can provide significant gains in disaster management, flood and situation awareness, forecasting and empowerment of citizens in relation to disaster (flooding) risks.

Hence, this can be employed as an additional step in existing research works that are focused on data processing; for example, in the approach proposed by Assis, Behnck, et al. (2016), which employed data provided by rainfall gauge stations to prioritize on-topic social media messages. In order to improve the rigorous of spatial analysis (Mohaymany et al. 2013), there is also a need to employ other clustering approaches like Moran's I or DBSCAN, or even understand in which cases those approaches are more suitable (García-Palomares et al. 2015).

Although it is possible to move towards the effective identification of flood clusters, an additional stage in the analysis should be also considered. This includes incorporating environmental characteristics, such as the physical parameters related to flood vulnerability as in research conducted by Rimba et al. (2017). In this sense, an overlap considering the physical processes involved with flooding, as well as the precipitation from the weather radars system, can provide a greater understanding to better identify and map, in an area, the likelihood of flooding. A better understanding of decision-making requirements should be also covered when filtering and analyzing the usefulness of these flooded clusters (Horita, Albuquerque, and Marchezini 2018). In this manner, the framework proposed by Horita, Albuquerque, Marchezini, and Mendiondo (2017) could be combined with the method introduced in this work and thus describe how decision-making tasks might be impacted by processed crowd sensing data.

More case studies should be conducted to improve the generalization of the overall work, as well as to gather new insights for improving the research method. This includes performing new studies adopting different empirical settings; for example, using weather radar data for validating volunteered information in the situation of landslides. Furthermore, KDE settings could diverse in three perspectives: spatial, temporal, and minimal number of elements. Different combinations of these perspectives should be also investigated to obtain more accurate clustering results; for example, by determining a smaller area (150m), a longer period (120min), and a greater number of minimal elements (five elements). Furthermore, other collaborative platforms (e.g., Ushahidi) and social media platforms (e.g., Twitter, Flickr, and Instagram) should be investigated.

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Finally, future work lines should also employ this volunteered data as alternative data for flood modelling, forecasting and warning through precipitation-streamflow artificial intelligence (neural networks, etc) or hydrological models, using radar rainfall and hydrological gauges as inputs; for example, by using the water balance models developed by Gourley et al. (2017). This approach thus has a great potential to improve monitoring because it considers the soil's characteristics and orography. Therefore, we believe a model that integrates precipitation data (from radars, satellites, gauge stations), together with the characteristics of the river basins (shape, time of concentration, land use, soil's characteristics, slope, hydraulic features, etc) and crowd sensing data can improve the way we monitor, forecast and warn flooding areas and flooding risks, providing better tools for citizens, as well as public and private entities to be aware, collaborate and prevent the impacts of flooding.

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Measuring Innovations in Crisis Management

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ABSTRACT

Crisis management (CM) organizations regularly face the challenge to assess the potential impact of a change in their socio-technical setup. No matter if a new software, a new tool, a simple workflow or a broader organizational structure become available, CM organizations need to estimate the potential added value under a high degree of uncertainty. In general, the more reliable information about the new solution is available, the more informed the decisions are. One promising way in assessing the potential impact of new CM solutions can be found through its application in an as realistic as possible and an as secure as necessary setup. However, such artificial scenarios like simulation exercises hold the risk of measuring the performance of the solution itself rather than its contribution to the CM operation. In this paper we review the state of the art in measuring crisis management performance, discuss the results in the context of performance measurement in general and present a performance measurement approach supporting a structured assessment of innovative CM solutions applied within collaborative demonstration project.

Keywords

Performance measurement, crisis management, innovation.

INTRODUCTION

During CM operations even minor decisions can directly have a major impact on human lives. In consequence, CM organizations rely on proven and well known infrastructures, procedures and tools which are applied to run the operations. These circumstances lead to a relatively high tendency of reluctance towards any kind of change in the way how CM operations are planned, executed and evaluated. Decision makers in CM need to be very careful and require clear evidence before introducing new ways of how their operations are designed, planned and executed.

The probably most comprehensible way to reach decision-making reliability is the combination of external reputation (e.g. through well documented references of other organizations) with internal evaluations (e.g. through actual applications and testing of new solutions). Combining both elements, the internal and external perspectives, decision makers are able to get relevant data supporting certain decisions as well as to establish trust within the organizations towards the successful implementation of a new solution. Hence, CM organizations get in a better position to justify their decisions on appropriate data (evidence) as well as to ensure the required backing within the organization in order to support organizational change (organizational trust).

However, what if there are no appropriate external reputations CM organizations can refer to, for example because of different value systems between the commercial and humanitarian sector? When thinking of "innovation" in its original meaning ("Innovare" as "to change into something new") there probably should even be no clear reputations. This of course does not mean that the new solution is not allowed to have any experience at all. Even the contrary, CM organizations often experience companies pitching solutions which have quite acknowledged expertise but they can still be innovative for the CM domain. If we think about technological innovations, e.g. RFID chips to track and monitor relief goods or mobile applications as communication means, there is still the uncertainty whether one piece of technology being successful in one context has the same performance in another application domain (Coletti et al. 2017). One reason for the potential mismatch is not only that there are different application requirements but mainly that even a small technological change takes place in a broader socio-technical context which has to be elaborated first (Orlikowski 1993, Toyama 2004).

The internal reliability of a new solution, i.e. the provision of appropriate data proving the potential impact of the innovation, remains as an alternative to identify the innovation degree and measure potential impact. There are many elaborated and standardized approaches to measure attributes of specific artefacts like the sensitive analysis of a simulation run, the technological readiness level (TLR) of a software or the perceived usability of a tool. It can be questioned how such measures satisfy the need of CM organizations to make informed decisions about investments in changes of legacy infrastructures, procedures or tools. Thus, the research question of this paper is how the potential impact of a solution can be measured for the specific application domain of CM. Are there any generic performance measurement approaches available and if not, how could such approaches be designed in order to systematically identify and analyze relevant data?

In this paper we firstly present the results of a literature review on general performance measurement in crisis management. This step is necessary in order to first clarify whether and how CM performance and effectiveness can be measured. Based on these findings we discuss how objective- and process-oriented performance measurement in general can be identified in order to systemize and interrelate relevant metrics. Finally, we present a use case of an adjustable performance measurement architecture being deployed in an ongoing CM demonstration project.

LITERATURE REVIEW

Our literature analysis of publications dealing with performance measurement in crisis management within Scopus, the largest abstract and citation database for peer-reviewed literature[1], results in more than 500 hits. In order to gather an as broad as possible picture the following generic search string was applied: („performance measurement" OR effectiveness) AND („crisis management" OR „disaster relief"). Comparing the number of relevant sources per year, it becomes obvious that there is an ongoing increase of results starting in the early 2000s with a peak in 2006, which is two years after the major south East Asian tsunami disaster. Since then, publications have increased even more with a maximum of more than 50 sources in 2013 (see Figure 1).

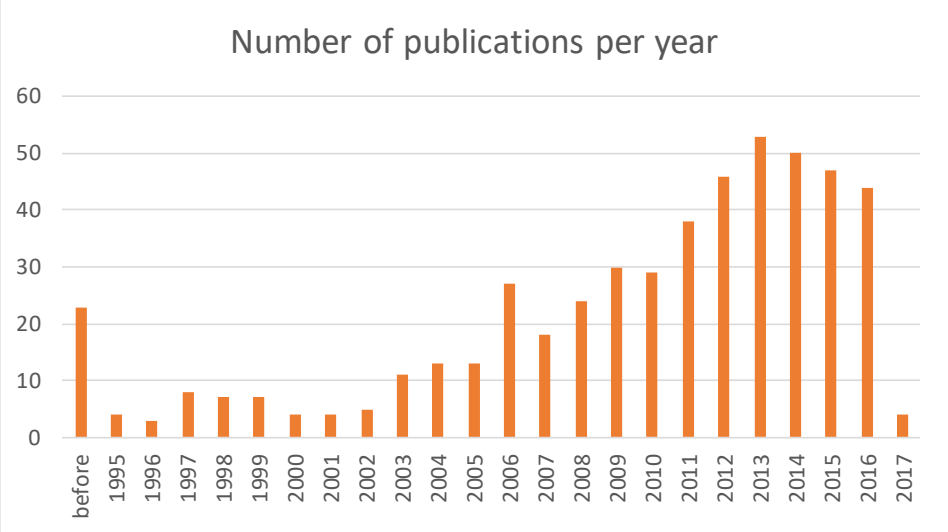

Figure 1: Number of publications per year

[1] https://www.elsevier.com/solutions/scopus

The found results stem from a wide variety of research areas, including Social Sciences, Business and Management, Engineering and Computer Science among the top ones (see Figure 2).

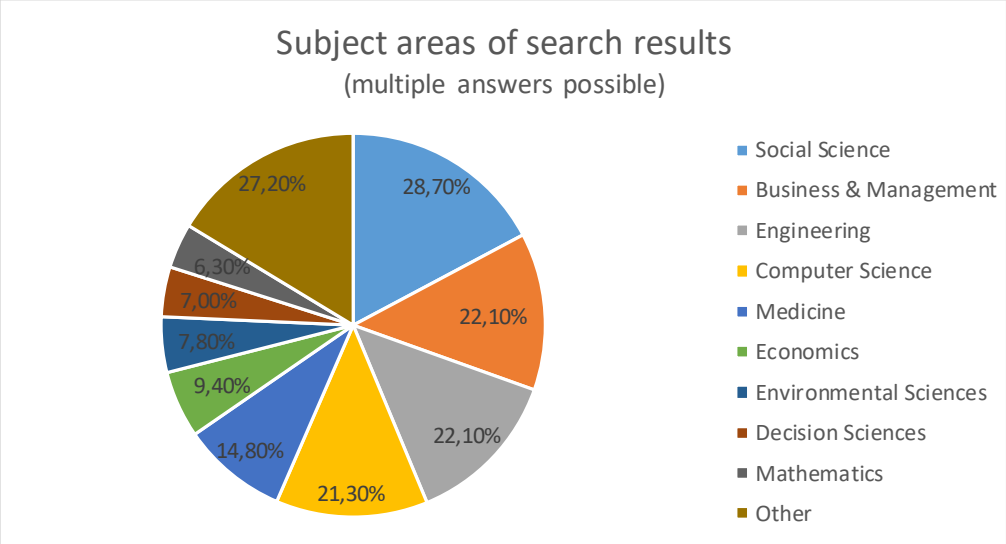

Figure 2: Subject areas of search results

However, when reviewing the first sources, it becomes apparent, that especially by including “effectiveness” in the search term, the search delivers many results which only measure the effectiveness of e.g. a model or an algorithm that has been developed. The actual CM performance and effectiveness is, in most cases, considered as an underlying assumption being directly related to the model or algorithm effectiveness. However, neglecting the measurement of operational applicability (relevance) significantly limits the conclusions regarding the potential impact of the investigated artifact. Having excluded the term “effectiveness”, the search only leads to 14 results. The excluded sources are not necessarily concerned with the performance measurement of crisis management itself but rather try to provide a solution to a problem and aim at measuring the effectiveness of this specific solution – with a missing relation to the potential impact on CM effectiveness. Nonetheless, they are of interest, as even when giving statements about the effectiveness of one single model, algorithm etc. certain methods for doing so have to be developed or applied.

Considering only sources which deal with trial-related performance measurement by extending the search term, i.e. adding “AND experiment OR trial” to it, leads to a significantly less amount of sources. Only 34 out of the over 500 publication satisfy the refined search term. While the yearly amount of publications shows similar behavior as the first search, the results of the refined search mostly stem from more technical research areas such as computer science or engineering (see Figure 3).

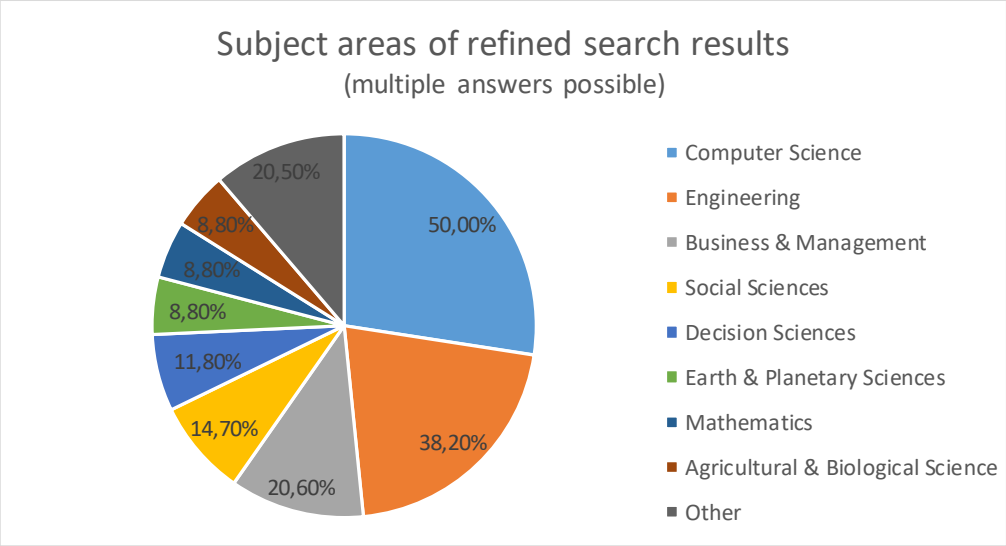

Figure 3: Subject areas of refined search results

Reflecting the overall results, it can be concluded that the area of performance measurement is highly multi-disciplinary. In order to showcase the huge range of the identified approaches, rooted both in positivistic and interpretivist domains, an exemplary selection will be reviewed in the following sub-paragraph.

Insights from the literature review

Schulz and Heigh (2009) present a logistics performance measurement approach on the case of a Development Indicator Tool which has been developed with the International Federation of Red Cross and Red Crescent Societies (IFRC). The project was initiated by the Logistics and Resource Mobilization Department (LRMD) of the IFRC that defined a logistics strategy which required concrete scores of response levels to be achieved when delivering relief supplies. In order to achieve this aim, a descriptive approach is utilized, starting from explicating the strategic change which has been initiated by the LRMD and targets the establishment of regional instead of central supply chains through the formation of regional logistics units (RLUs). Schulz and Heigh (2009) conclude that the design and implementation process for performance measurement systems must be kept simple and requires ongoing improvement and development by the RLUs. Thereby it is essential to involve tool users and administrators besides developers at early stage to achieve an acceptance towards its introduction and make all stakeholders getting familiar with it. Co-creation and mutual understanding of the involved parties is perceived as a key success factor. In this context, support from organizations' management is of particular importance. Furthermore, the key action behind performance measurement is seen in analyzing the needs for development, which is revealed by the actions' impact on defined target scores. In case of the LRMD the system for instance is supposed to become an efficient web-based application to replace data interchange via email. Driven by simplicity, the case at LRMD is moreover supposed to foster the emergence of research contributions that provide conceptual and practical insights of system development and improvement in the context of humanitarian logistics.

Rongier et al. (2013) developed a method that supports decision making in real-time during response and further at its implementation to demonstrate how performance indicators support crisis response management and the collaboration of stakeholders. The authors present a four-step procedure for CM PMS, applied in a case study at the French Red Cross. For that purpose, a web-based prototype of the PMS was developed and tested in practice. Therefore, the tools requirements and characteristics are further listed, and its pages and database illustrated before a conclusion is drawn. The identified KPIs are structured along the dimensions *efficiency*, *relevance*, *expectations*, *satisfaction*, *agility*, and *impact*. Due to the focus on a PMS dashboard the actual measurements were identified in the literature and covered for example logistical areas like response times defined as "cycle times" (p. 1098) or response quantities (p. 1100). The actual PMS was presented for the first time in Rongier et al. (2010), which was also identified by our literature search. The underlying research methodology involved the same practitioner organization as the (2013) paper, however it was related to a specific earthquake scenario.

Owen et al. (2016) investigate the challenges faced by representatives on the strategic level of emergency management and to elaborate on their relevance for tactical front-line operations and political compliance. The

analyzed data is retrieved from a former study on emergency management and the method includes both surveys and interviews with representatives from 36 Australian organizations of the respective branch. In contrary to Rongier et al. (2013) the authors conclude "that before we can propose any revision of measures to assess emergency management performance, we need to understand the interaction between underlying values base and the tensions inherent in carrying out emergency management work." (p. 186).

The work conducted by Wang (2012) is intended to provide guidance for organizational performance (OP) during crisis through the design and development of a measurement framework that supports organizations in linking their OP with their strategies, technical systems and crisis management objectives. This is motivated by the identified need to derive improvement measures mitigating future incidents. In order to draw linkages across the organizations' performance, strategy, objectives and technical systems, multi-dimensional frameworks are needed. Following a literature analysis Wang (2012) compiled a set of performance indicators in the areas *information dissemination, involvement of top management in CM tasks, cooperation with stakeholders, financial measures, stakeholders' confidence in the sustainability of an organization, documentation, and time for making specified improvements* (p. 679). The author acknowledges the limitation of the generalizability of the framework due to the diversity of CM organizations and recommends further investigations of "(…) operational variables for a specific business context for empirical validation purposes" (p. 684).

One major conclusion of the sources is that the performance measurement of disaster relief operations is a difficult task requiring context-specific adjustments due to various challenges which can be classified in four categories (Abrahamsson et al. 2010):

1. *Evaluation based on value judgement:* Any evaluation needs to be based on certain values, i.e. in order to be capable of assessing how successful an operation has been there need to be values which define what is supposed to be successful. At least implicitly, these values, which can also be understood or formulated as objectives of an operation, will always be based on subjective opinion and personal beliefs.
2. *Complexity of crisis situations:* The high complexity of crisis situations significantly affects the way, a relief operation can be analyzed, understood and evaluated. High dependencies and complicated relationships between actors as well as causal ones lead to great difficulties when trying to understand what happened as well as why it happened.
3. *Questionable validity of information:* When evaluating an operation, this evaluation has to be based on information about how the course of events during the operation. Often such information is gained by conducting interviews etc. and rarely based on e.g. ongoing data collection. Consequently, there is always the question how reliable humans are as a source of information and therefore how valid the information is on which an evaluation is based upon (in terms of generalizability of specific results).
4. *Limiting operation conditions:* Every disaster relief operation can have negative effects or outcomes, which simply could not have been prevented, independently of how successful the operation has been. Any immediate and unavoidable casualties caused by the crisis should not be included into the evaluation of an operation. For example, the number of injured people is not relevant for the evaluation while the time until they receive help is. Overall, it can be difficult to distinguish between the evaluation of the operation's performance itself and the analysis of what might have happened under different circumstances.

In general, these challenges make it difficult if not impossible to establish a generic performance measurement approach for crisis management in general, and in the context of measuring CM innovation in particular. What CM effectiveness is depends on many variables like the observed time frame, the type of CM entity, its organizational level or the specific crisis situation. Hence, the results of the literature analysis suggest that dedicated iterative and systematic procedures are necessary in order to develop appropriate performance measurement approaches being able to give insights of specific solutions on the CM performance. Owen et al. (2016) also concludes that before suggesting measures to assess crisis management, it is necessary to understand the complex and often intertwined challenges and relationships of crisis management and its actors. Only after making sense of the interaction between the underlying value base and the events and actions of an operation, methods to measure and evaluate the performance of it can be developed (Owen et al. 2016).

Overall, the literature analysis show that the high variety in scenarios, tasks, stakeholders etc. related to disasters, results in a lack of generic performance indicators - especially when evaluating and measuring CM innovations. The results of the identified papers can be very useful for the development of specific performance measurement project as the documented results might be fitting to the high variety of potential cases (e.g. an open set of performance indicators for the area of humanitarian logistics can be utilized for specific cases, see

Widera and Hellingrath 2011). However, it appears to be necessary to develop a structured approach supporting the case-based identification of:

- Specific CM objectives and values (e.g. evacuation of an area or the setup and maintenance of an internally displaced persons camp)
- Clear systematization of the relief operation (e.g. responsibilities or specific processes and workflows)
- Appropriate research methods covering both quantitative and qualitative data gathering and analysis techniques (e.g. sensitivity analysis of simulation results in combination with focus groups of potential simulation applicants in CM organizations)
- Differentiation of the investigated objects (e.g. controllable vs. uncontrollable variables or operation specific phenomena vs. solution-specific perspective).

In the next paragraph we briefly introduce different considerations and existing approaches in the area of performance measurement in order to be used for the measurement of CM innovations.

PERFORMANCE MEASUREMENT

Following the literature review above, the identification of innovative and value adding solutions in CM can only be achieved through a context-dependent and specific measurement, analysis and adjustment of its exemplary application in a secure environment such as trials, serious games or exercises. For a supporting performance measurement approach there are several guidelines and elaborated concepts to be considered. As discussed above, each indicator might have a weighted importance for the overall CM performance of a single organization or a dedicated scenario, and that is the reason why the identification of key performance indicators (KPIs) might be useful. A systematization and categorization of potential KPIs prevents an isolated view and possible misinterpretation. However, because of the different actors involved in CM operations, different processes with specific objectives and relations need to be considered for the identification of relevant KPIs for an application.

The findings from the literature review described above offer a huge source of potentially appropriate indicators. They can be considered as an open set of CM KPIs. However, in order to ensure the relevance of the KPIs in particular CM applications, a specific set of KPIs needs to be developed for each application (or application context). Paramenter (2010) differentiates between result (e.g. number of evacuated persons) and performance indicators (e.g. time needed to evacuate) as well as key result indicators and KPIs. KPIs can be defined as business-oriented relevant and numeric information and represent a set of measures focusing on those aspects of organizational performance that are most critical for the current and future success of the organization (Paramenter 2010). Thus, the indicators can be related to different elements (like objectives or processes) and weighted by targeting specific goals (Reichmann 1990).

Thus, it might be concluded that each performance measurement application is specific and hardly transferable. However, there are some general aspects to be considered for the specific identification of KPIs. Schulz and High (2009) provided an overview of KPI requirements, which is presented in the following table.

Requirement	Short Description
Validity	Address the real performance drivers.
Relevance	Reveal decision relevant information.
Cardinality	Cover a wide range of key issues under consideration.
Completeness	Use additional metrics if not all relevant issues can be covered by only one.
Comparability	Allow intra- and inter-organizational comparisons as well as comparisons over time.
Compatibility	Input data for calculating the metrics should be available from the existing systems.
Cost and benefit	Development and continuous measuring costs have to be contrasted with the resulting benefits.

Table 1: KPI Requirements (Schulz and High 2009)

In addition, the following two points should be added: (1) manageability (Keller and Hellingrath 2007) and (2) adaptability (Preißler 2008). By considering the *manageability* of possible KPIs, more than just the reasonable

economic relationship between costs and benefits of measuring the KPI itself will be ensured. This is especially important when reflecting the today's technical opportunities to store huge amounts of data requiring advanced data analysis approaches, which are probably not covered in CM organizations as they are covering main core competencies. *Adaptable* KPIs enable a necessary flexibility, which can be caused by changing structures and processes. Thus, organizations using the selected KPIs do not have to invest in time consuming redefinitions of metrics.

As a final notice on requirements of KPIs, they should be constructed in a way that an assignment of measurement points to specific process steps is allowed. As VDI 4400 (2002) points out, existing data collection tools are able to document relevant processes by the identification of events in form of quantity and time data as each KPI should to be quantifiable. The following figure illustrates how measurement points can be assigned to processes within in an example of a distribution process model.

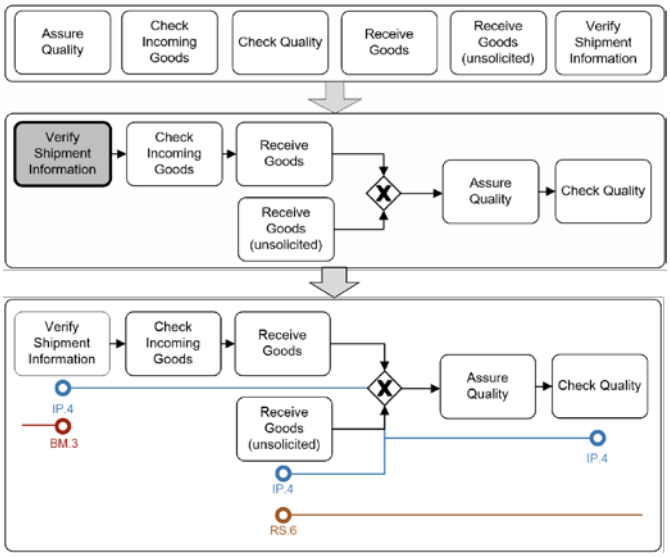

Figure 4: Assignment of KPIs in a humanitarian organization (Widera and Hellingrath 2016)

The figure depicts an exemplary representation of how warehousing tasks can be structured along a process using the BPMN standard. This logical structure visualizes an ideal flow of the sequence, e.g. the shipment information should be verified (grey box marking the starting event) before the delivery gets accepted. To each of such clearly defined processes specific measurement points can be assigned. Setting specific measurement points, concrete stages in process sequences are predefined in order to evaluate the performance executed within the tasks. The IP.4 KPIs represents the "Mean quality inspection costs per incoming goods item" and is an important performance driver in humanitarian logistics. Such a process orientation puts the organization in a position to analyze several tasks they have to deal with. The identified open set of KPIs can be found in Widera and Hellingrath (2011, pp. 1335-1336).

In the last years a large amount of different performance measurement concepts have been provided within the scientific community. Keller and Hellingrath (2007) presented an overview of existing frameworks only for the area of logistics and supply chain management. The overview is illustrated in the table below:

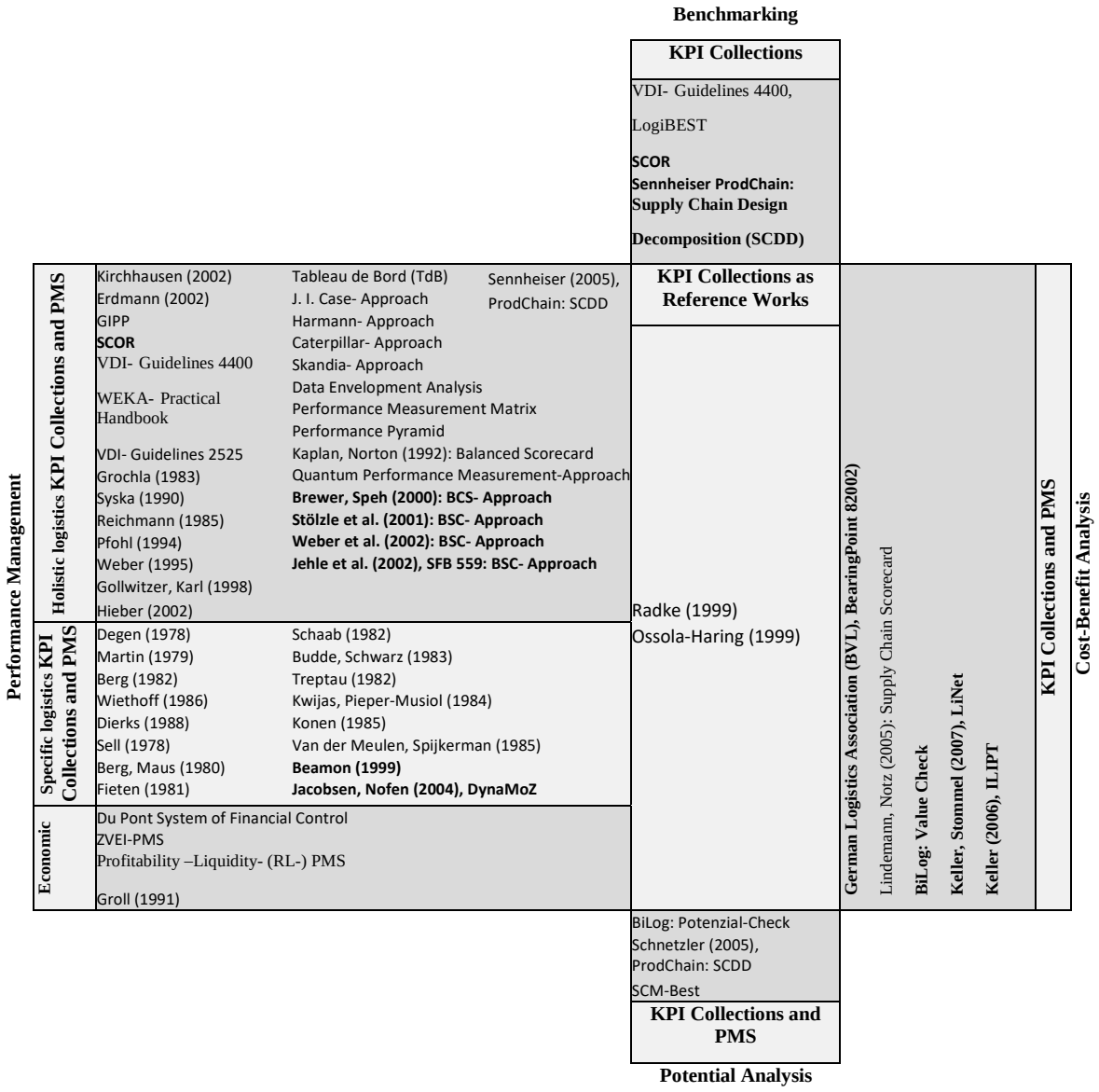

Table 2: Performance Measurement Concepts (Keller and Hellingrath 2007)

The overview of the performance measurement systems (PMS) listed in the table above is systemized by an orientation on the field of application. The following classifications were used: benchmarking, cost-benefit analysis, potential analysis as well as performance measurement divided into economic, specific logistics and holistic logistics PMS. Each inter-organizational PMS is listed in bold type.

It can be stated, that commercial enterprises are able to fall back on a wide range of established and proved PMS. They offer several advantages and disadvantages in order to fulfill organization-specific and inter-organizational requirements for performance measurement. Keller and Hellingrath (2007) conclude, that a general comparability of these different PMS is nearly impossible as each KPI contains differences in terms of classification, notation, definitions, calculations and applications. They propose to develop a holistic approach for performance measurement, which can be classified between the PMS investigated. The existing PMS and the developed framework cannot be discussed in detail in this work, but out to be deepened in further literature (Keller and Hellingrath 2007, Keller 2009). For the area of CM performance measurement approaches these findings suggest that there might be a good reason and a realistic chance to design and develop a generic PMS focusing on the identification of innovations in a secure (i.e. non-operational) context. For this purpose we present a use case of a demonstration project covering the area of innovations in crisis management. The main idea of the project is to develop a trial-oriented environment being able to identify major innovations in CM.

USE CASE: TRIAL-ORIENTED PERFORMANCE MEASUREMENT

In this chapter we present the performance measurement developed in the project "Driving Innovation in Crisis Management for European Resilience" (DRIVER+, www.driver-project.eu). The demonstration project addresses the challenge for CM organizations to assess and integrate new solutions, while coping with a rapidly changing infrastructure, evolving risks across cultural, administrative and national boundaries and engage with populations to enhance their resilience. The aim is to develop a Pan-European test-bed supporting the evaluation of CM solutions in realistic but secure environments in the face of their true benefits and for their overall suitability, before being adopted by CM practitioners. For this purpose a dedicated methodology was developed, which cannot be discussed in detail in this paper. The DRIVER+ methodology provides a structured approach of a CM innovation test-bed supporting the involved stakeholders to identify, design, plan execute and analyze relevant trials.

A key element of this methodology is the performance measurement architecture. The architecture is structured along performance measurement dimensions of DRIVER+ trials. It allows an explicit relation to tasks, processes and organization- or mission-specific targets. Because of the functional complexity of specific measurement "objects", the first step is to categorize them according to the DRIVER+ logic. The following figure illustrates the architecture of the DRIVER+ performance measurement dimensions.

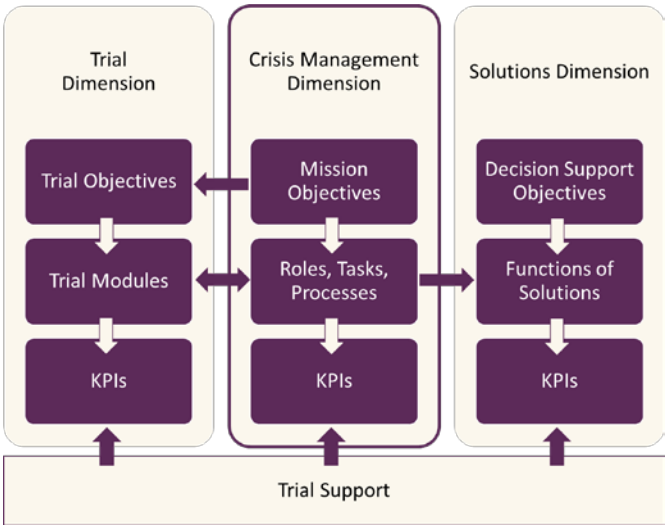

Figure 5: Performance Measurement Dimensions in DRIVER+ Experiments

The three dimensions include the trial dimension, the solution dimension and – as the core DRIVER+ dimension – the CM dimension. All three performance measurement dimensions are served by an overall performance measurement trial support, where all potentially relevant guidelines, recommendations, and trial data is collected, stored and processed (e.g. the actual KPI definition guidelines, generic KPIs, domain-specific KPIs or data storage policies).

(1) The *trial dimension* covers the perspective of the trial owner (i.e. the organization hosting a DRIVER+ trial) and measures all relevant data related to the predefined trial objectives. One example in case of a trial in the context of spontaneous volunteer management could be the question how many voluntary participants can be motivated to join a trial in order to fill sandbags needed to build a dike (KPI could be: "*participating volunteers/required volunteers"* or "*participating volunteer profile/representative volunteer profiles*"). The trial objectives are defined by the trial owner, but the main source are the CM practitioner needs and, hence, the objectives of the missions being "simulated" in a trial. In order to "operationalize" the trial objectives, trial modules are derived (e.g. communication and coordination of volunteers taking part in the trial). Within this module, the trial owner is able to define which processes are required to fulfil the objectives and assign specific weighting. This step contains an estimation of the effectiveness of each processes (with relation to the trial objectives). Once this task is done, the trial owner can apply the performance measurement guidelines to deduce specific and relevant KPIs.

(2) The CM dimension is, however, the *key performance measurement* area. In the context of one upcoming trial on the a chemical spill one exemplary KPI can be derived from the major objectives targeting the evacuation of affected population (e.g. "*number of evacuated persons/number of persons to be evacuated"*).The identification of CM objectives, described as mission objectives, is the foremost

place to indicate whether a change of a process, the application of a new technology or a training module has an impact on the CM performance. Besides, the CM objectives need to be understood as the determining element of experiment objectives and the decision support objectives. Due to the different relief situations, stakeholders and time horizons the measurement objects vary in terms of specific roles, tasks, and processes. The question if a particular performance is effective or not can only be evaluated once the involved actors including their responsibilities and practices are defined. These definitions have to be used to identify and configure the appropriate KPIs.

(3) Finally yet importantly, the solutions dimension must be measured in order to learn whether a particular piece of technology or a new process has the potential to drive innovation in CM. In the presented example it could be a solution supporting evacuation tasks through the interaction with citizens; here one objective or solution function could be to identify the location of evacuees through the application of drones (one related KPI could be *"time to locate evacuees with a drone/time to locate evacuees without a drone"*). The solutions objectives have always a relation to ease or support one particular task, decision problem or a process, even if this is only defined as a new standard operational procedure. Hence, the decision support objectives build the first starting point for evaluating the performance of a particular solution. These objectives need to be derived or at least have a direct relation to the CM objectives, in terms of a practical impact. The identified objectives can be used to extract specific solution functions which in turn can be used to derive appropriate KPIs. One important aspect here is, that the KPIs need to have a relation to the CM KPIs. To give an example, a high usability of a software might be absolutely irrelevant if the software itself has no contribution to the relevant CM performance (which does not mean, usability should not have to be measured, but its CM impact is key for the overall evaluation).

Having the three dimensions and its interrelations in mind, a clear and structured way allows to identify relevant KPIs being able to assess the *real impact of new solutions in CM*. This process is supported with generic rules of performance measurement approaches (as discussed above), procedural guidelines and recommendations. Evaluation examples can be found e.g. in Detzer et al. (2016), Havlik et al. (2016), van den Berg et al. (2016), Dubost et al. (2017).

Looking back at the initial problem on the lack of generic performance measurement approaches and the combination of the desire to support the identification of innovation for CM organizations focusing on the questions *how to measure and analyze* can be described as the main conclusion from both the literature review and our practical findings. Starting from a multi-dimensional framework (see Wang 2012) like the three-dimensional DRIVER+ approach, a structured and significant analysis of potential innovation impacts can be enabled in a relevant (practitioner-driven) and rigor manner. The suggested way is to follow predefined guidelines and steps identifying specific CM objectives and values (see also Schulz and Heigh 2009 and Owen et al. 2016), an as clear as possible systematization of the CM operation (see Rongier et al. 2013), the application of mixed-research approaches covering both quantitative and qualitative data gathering and analysis techniques (see Coletti et al. 2017) and a clear differentiation of the investigated objects (e.g. Wiel et al. 2010).

SUMMARY AND OUTLOOK

We have presented and discussed the state of the art on general performance measurement in crisis management based on a literature review. The findings show that the high variety in scenarios, tasks, stakeholders and interdependencies related to disasters, results in a lack of generic performance measurement approaches in the literature. In order to develop an appropriate measurement approach to evaluate CM innovations existing works in the area of performance measurement research were discussed. We presented a way how objective- and process-oriented performance measurement can be identified and developed in order to systemize and interrelate relevant metrics. Finally, we introduced a use case of an adjustable performance measurement architecture being deployed in an ongoing CM demonstration project DRIVER+.

The current state of the projects allows the conclusion of the applicability of the presented approach. It is especially the practitioners who are giving positive feedback when applying the performance measurement approach. Due to having a clear structure between and within the dimensions there definition of KPIs and the sense making of the gathered data allows the creation of (internal) evidence of the trialed solutions is eased significantly. Sophisticated data analysis approaches of certain artefacts (like flight or machine learning algorithms) become much more useful because of a dedicated relation to the specific KPIs of involved stakeholders.

However, the presented results reflect the conceptualization of the performance measurement approach and only first results of the development of the first trial taking place in June 2018. We have incorporated some results of preparatory trials (exemplary objectives and KPIs introduced in the last chapters), but in order to provide an

elaborated reflection on the application results it is necessary to incorporate further trials with other stakeholders and also to compare the gathered qualitative and quantitative data of the trial itself.

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Ontology-based Representation of Crisis Management Procedures for Climate Events

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ABSTRACT

One of the most critical challenges faced by authorities during the management of a climate-related crisis is the overwhelming flow of heterogeneous information coming from humans and deployed sensors (e.g. cameras, temperature measurements, etc.), which has to be processed in order to filter meaningful items and provide crisis decision support. Towards addressing this challenge, ontologies can provide a semantically unified representation of the domain, along with superior capabilities in querying and information retrieval. Nevertheless, the recently proposed ontologies only cover subsets of the relevant concepts. This paper proposes a more "all-around" lightweight ontology for climate crisis management, which greatly facilitates decision support and merges several pertinent aspects: representation of a crisis, climate parameters that may cause climate crises, sensor analysis, crisis incidents and related impacts, first responder unit allocations. The ontology could constitute the backbone of the decision support systems for crisis management.

Keywords

Crisis management, ontology, semantic integration, decision support, description logics.

INTRODUCTION

The effective management of a climate-related crisis (e.g. flood, earthquake, forest fire, etc.) entails serious challenges for the authorities, the efficient handling of which is a key aspect for public security. One of the most critical challenges is the overwhelming flow of incoming information from artificial and human sensors (Babitski et al., 2011). The former type of sensors includes e.g. video footage from static cameras, water level and temperature measurements from deployed devices, while the latter type mostly includes social media posts, a rapidly increasing means for conveying information as a crisis incident unravels (Reuter & Kaufhold, 2017). All this vastly heterogeneous information has to be processed by the authorities and the numerous organizations involved in a crisis, in order to filter any meaningful items that could facilitate crisis management.

Towards addressing this challenge, recent trends in Crisis Information Management Systems (CIMS) turn to the use of *ontologies* for facilitating decision support during a crisis (Liu et al., 2013). Ontologies serve as the foundation for providing a semantically unified representation of concepts and relationships that is shareable by different users and is processable by machines (Grimm et al., 2011). Furthermore, ontologies are often associated with state-of-the-art logical reasoning services, which provide superior capabilities in querying and information retrieval, as opposed to standard SQL-based applications (Babitski et al., 2011). Finally, since nowadays a non-trivial subset of the knowledge and data useful to support a decision is available (in heterogeneous formats) in the Web, a further advantage of using an ontology-based representation is that it facilitates the integration of structured knowledge and data available on the Web (Rospocher & Serafini, 2012). This trait is also very useful with regards to information streams coming from social media.

The need to address the interoperability challenge in crisis management has led to the development of a diverse variety of relevant ontologies that provide interoperability in specific scenarios. A thorough overview of recent existing approaches is given in (Liu et al., 2013). However, although crisis management pertains several aspects (climate conditions, unit assignments, incidents and impacts, etc.), and, despite the variety in modelling approaches, the drawback with the proposed ontologies is that they cover only specific aspects relevant to their use case. Consequently, the resulting ontology-based systems have a narrow practical focus and provide only limited decision support to the authorities.

In this context, this paper proposes a lightweight ontology for climate crisis management, which adopts features from the most prominent existing models, but is more "all-around" and complete, merging all pertinent aspects of crisis management: representation of a crisis (along with climate parameters that may cause climate crises), sensor analysis, crisis incidents and related impacts, first responder unit allocations. The ontology constitutes the backbone of the decision support system developed in the context of the beAWARE EU-funded project[1] focusing on crisis management of climate events.

The rest of the paper is structured as follows: The next section presents existing prominent ontologies for crisis management, and discusses the comparative advantages of our proposed ontology. Next, an overview of the project's user requirements is given, mapping the latter to ontology functional requirements. The ontology is presented in full detail in the next section, followed by a respective evaluation. The paper is concluded with final remarks and directions for future research.

RELATED WORK

The advent of semantic technologies (Hendler, 2009) has led to the widespread adoption of ontology-based approaches in numerous domains, including crisis management, amongst others. Several relevant ontologies have been proposed in literature, e.g. *SOFERS* (Liu et al., 2014), *ISyCri* (Truptil et al., 2008), and the approaches by Lauras et al. (2015), Mescherin et al. (2013), and Zavarella et al. (2014). A recent thorough review of the state of the art in crisis management ontologies is given in (Liu et al., 2013).

Besides the above, two of the most prominent approaches in crisis management and response are *MOAC* (Limbu, 2012) and *SoKNOS* (Babitski et al., 2011). MOAC (Management of a Crisis Vocabulary), is a lightweight vocabulary that provides terms for linking crisis information from three different sources: (a) traditional humanitarian agencies, (b) volunteer and technical committees, (c) disaster affected communities. The vocabulary has been developed based on contributions from various key stakeholders, like the Inter Agency Standing Committee (IASC)[2], the Global Shelter Cluster[3], and the Ushahidi platform[4], who were also involved

[1] http://beaware-project.eu/

[2] https://interagencystandingcommittee.org/iasc/

[3] https://www.sheltercluster.org/

[4] https://www.ushahidi.com/

in assessing MOAC's usability, functionality, and structure.

SoKNOS, on the other hand, is a set of ontologies ensuring that newly created information, as well as integrated sensor information, is semantically characterized, supporting the goal of a shared and semantically unambiguous information basis across organizations managing crisis incidents. The central SoKNOS ontology is a core domain ontology defining the basic vocabulary of the emergency management domain. Additional dedicated ontologies are used for representing resources and damages, and deployment regulations defining the relations between resources and damages. Furthermore, for the definition of system components, ontologies of user interfaces and interactions as well as geo sensors have been developed. Based on the aforementioned ontologies, additional specialized application ontologies can be defined for each application used in the disaster scenario. As indicated by the authors, all ontologies in SoKNOS have been developed in close cooperation with domain experts, such as fire brigade officers.

Finally, another highly relevant approach, albeit rather outdated, is the *BACAREX* ontology (de la Asunción et al., 2005), which is part of the SIADEX framework for facilitating the design of plans for fighting forest fires. More specifically, BACAREX is a heavyweight ontology of planning objects and activities related to the forest fighting plan in the Andalusian regional government. For every object stored, the ontology records both operational (e.g. geographic coordinates of the object) and informational metadata (i.e. information that may be needed by the technical staff during a forest fire incident, e.g. the radio channel of the responder responsible for a specific forest sector).

Overall, the ontologies reported above share the drawback of covering only a subset of the notions involved in climate-related crisis management (climate conditions, unit assignments, incidents and impacts). Contrary to these existing approaches, our proposed ontology consists of modules for representing *all* aspects pertinent to crisis management. Nevertheless, and as described in more detail in the next section, our proposed model adopts concepts from some of the existing ontologies as well, predominantly from MOAC and SoKNOS.

USER REQUIREMENTS AND ONTOLOGY COMPETENCY QUESTIONS

The basis for the creation of a climate-related crisis management ontology are the needs and requirements of the domain experts. The user requirements were extracted by domain experts in the context of an EU project, which aims at developing a framework providing various services before, during, and after the occurrence of natural disasters. A common methodology has been used to define the use cases and requirements of the system, starting with the identification of the status of available tools through an existing situation analysis, in order to clarify the current digital landscape concerning emergency service requirements. The requirements of the pilot cases at hand were studied by identifying and interviewing stakeholders concerned with integrated risk management (municipalities, regional/local civil protection agencies, etc.), focusing on their needs and the current gaps both in the situational awareness and command and control aspect of the disaster response.

Table 1. Subset of the user requirements.

UR#	Requirement name	Requirement description
UR_107	Localize video, audio and images	Provide authorities with the ability to localize videos, audio and images sent by citizens from their mobile phones.
UR_108	Localize task status	Provide authorities with the ability to localize first responders' reports regarding the status of their assigned tasks.
UR_109	Localize tweets	Provide authorities with the ability to localize Twitter messages concerning a crisis event.
UR_110	Localize calls	Provide authorities with the ability to localize phone calls to an emergency number concerning a crisis event.
UR_111	Detect elements at risk from video	Provide authorities with the ability to detect and count elements at risk (e.g. cars and people) from video and images sent from mobile phones and social media.
UR_120	Map of rescue teams and task evaluation	Display to authorities the location in time of first responder teams and provide the ability to evaluate in real time the execution of the assigned tasks with a global visualization of the activities performed.

First, a common structure and a related terminology were established; as a consequence, a general emergency

situation is subdivided in scenarios, use cases and requirements. In detail, an *operational scenario* is defined as the environmental and ecological context of the natural disaster and its impact on the elements at risk and stakeholder assets. Furthermore, a *use case* is defined as a conceptual description of intended or expected utilization of the system to prepare for, respond to, or act upon the occurrence of the scenario or various aspects therein. This use case is defined and specified from an operational user's point-of-view. Finally, *user requirements* describe expectations, requests, and guidelines for functionalities, capabilities, and features of the system that would facilitate successful completion of the use cases. In the following, the list of requirements extracted from all the use case descriptions was clarified and shared among the domain experts (i.e. rescue teams, water management authorities). Table 1 contains an indicative subset of the user requirements, which the ontology can currently respond to; the full list of user requirements can be found in beAWARE deliverable D2.1 (Norbiato et al., 2017). These user requirements are catalogued as [*UR_xzz*], where *x* is the identifier of the scenario in which the requirement originated, and *zz* is the serial number of the requirement.

The user requirements are mapped to the ontology's *Competency Questions* (*CQs*). A competency question is a natural language sentence that expresses a pattern for a type of question people expect an ontology to answer (Uschold & Gruninger, 1996). The answerability of CQs hence becomes a functional requirement of the ontology. Based on the list of user requirements above, the ontology is able to respond to several CQs, such as providing the location of a specific media item (e.g. a tweet, video, image etc.), or indicate the number and type of vulnerable objects detected from videos.

THE PROPOSED ONTOLOGY

As already discussed previously, the proposed ontology semantically represents three key aspects of climate management: (a) climate-related natural disasters and associated climate conditions, (b) analyses of data coming from human and artificial sensors, (c) unit assignments and mission status. This section delves deeper into the respective representations.

Ontology Language

The ontology language deployed for developing the proposed ontology is *OWL 2* (*Web Ontology Language*), a declarative knowledge representation language for formally describing a domain of interest, representing ontologies with formally defined meaning and semantics (W3C, 2012). OWL 2 is a W3C recommendation based on the solid mathematical background of *Description Logics* (Baader, 2003), and, thus, it currently constitutes the most popular ontology language.

For representing a given domain via OWL 2, one has to come up with a set of core terms, and to agree on their meaning as well as on their interrelations. The vocabulary (terminology), together with the interrelationships, constitutes the main context of an OWL 2 document. OWL 2 offers the following modelling building blocks:

- *Classes* provide an abstraction mechanism for grouping objects with similar characteristics, and denote the set of objects comprised by a concept. There may be diverse criteria for grouping objects/individuals and one individual may simultaneously belong to several classes. Classes can also form a hierarchy of more generic (superclasses) and more specific (subclasses) notions.
- *Individuals* of an OWL class (also referred to as class instances) are the objects belonging to this class.
- *Properties*, which are further categorized into: (a) *Object properties* that describe single individuals, class memberships, and how classes and individuals can relate to each other based on their instances; (b) *Data properties* that describe single individuals by asserting specific data values, either from pre-defined data types (e.g. string, integer, boolean, etc.) or within a data range expression defined by the user; (c) *Annotation properties* that give additional description to the domain being modelled, without having any effect on the logical aspects of the ontology.

Representing Natural Disasters

The representation of climate-related natural disasters in the proposed ontology is illustrated in Figure 1. Class "*Natural Disaster Type*" represents the various types of disasters, e.g. floods, forest fires, storms or earthquakes etc. Disasters may lead to other disasters (via property "*leads to*"); for instance, a heat wave may lead to forest fires, or storms may lead to floods. Each type of disaster is characterized by certain climate parameters, represented via class "*Parameter*"; for example, solar radiation and temperature are two parameters that characterize a heat wave. The scheme for representing environmental and meteorological conditions is based to some extent on the *PESCaDO* ontologies (Rospocher & Serafini, 2012), and, more specifically, we adopted a number of related properties from classes *EnvironmentalData* and *EnvironmentalNode*.

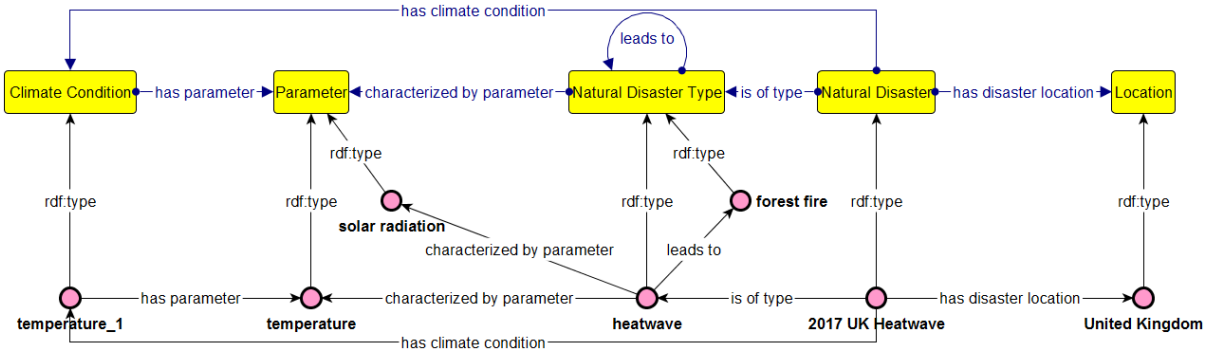

Figure 1: Representation of climate-related natural disasters in the proposed ontology.

Moreover, the actual manifestation of a natural disaster is represented via class "*Natural Disaster*", an instance of which has specific climate conditions with specific values. The figure displays a sample temperature measurement, which was recorded during the 2017 UK heatwave[5] (17-22 June). Note that in Figure 1 and in the following two figures, data properties are omitted for reasons of brevity.

Representing Analyzed Data

Besides the representation of climate-related natural disasters and pertinent notions, the proposed ontology also encompasses information relevant to the analysis of input data coming from the various sensors of the framework. This information is fed to the ontology from the various analysis components; the core constructs in the ontology are illustrated in Figure 2.

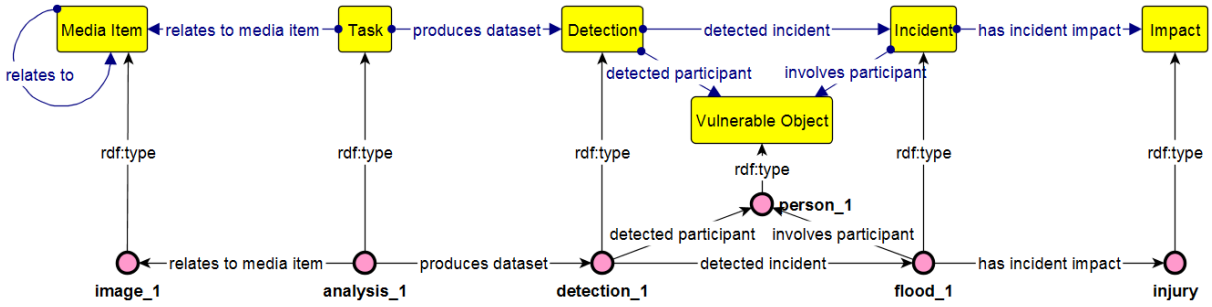

Figure 2: Representation of analyzed data in the proposed ontology.

Class "*Media Item*" represents an item of analyzed data, which is related to some analysis task (via class "*Task*"). Media items can be pieces of text, images, videos, or even social media posts, all of them submitted during the occurrence of a climate crisis. The analysis of the respective items (text analysis, image analysis or video analysis) produces a "*Detection*" dataset containing all relevant information (e.g., an object detection task may produce a dataset of detected incidents, objects, and confidence scores). The figure also demonstrates an example of a video analysis instance, where a potentially injured person is detected in the flood.

Note that the ontology already contains a complete typology of vulnerable objects (e.g. assets, stakeholders, infrastructure, buildings etc.), impacts and incidents, as well as various other properties (e.g. severity levels, confidence scores, detection timestamps etc.), that are not displayed in Figure 2 for reasons of brevity. Part of this scheme for representing disaster impacts is inspired by *MOAC* (Limbu, 2012), mainly classes *AffectedPopulation*, *CollapsedStructure*, *CompromisedBridge*, *Deaths*, *InfrastructureDamage* and properties *affectedby* and *impact*. Moreover, for categorizing damages and resources we were based on *SoKNOS* (Babitski et al., 2011), and, more specifically on the SoKNOS approach for representing damages and their association to resources (Babitski et al., 2009).

Representing Unit Assignments

The third component of the proposed ontology is responsible for semantically representing response unit assignments. The adopted representation is based on the approach proposed by the *OASIS* project (Couturier & Wilkinson, 2005), mainly the part for representing mission assignments to units and associating missions to

[5] http://www.bbc.com/news/uk-40353118

incidents taking place during the climate crisis.

Figure 3 displays the respective concepts in the proposed ontology. First responders (class "*Responder*") are assigned one or more missions (class "*Mission*"), which in turn relate to incidents that involve participating entities (class "*Vulnerable Object*"). A mission is also characterized by start and end time, status and mission priority; these properties are omitted from the figure but reside in the ontology.

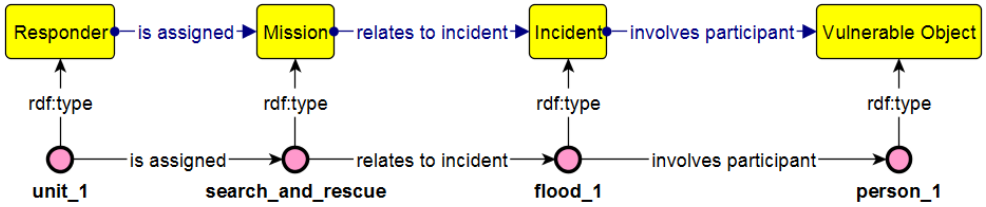

Figure 3: Representation of mission assignments to first responder units in the proposed ontology.

Finally, Figure 3 also displays a specific unit, which has been assigned the rescue mission of the injured person trapped in the flood (see Figure 2).

ONTOLOGY EVALUATION

This section presents an evaluation of the ontology, as far as *quality* and *structure* are concerned.

Evaluating the Consistency and Quality

For evaluating the consistency and overall quality of the ontology we used *OOPS!* (*OntOlogy Pitfall Scanner*), an online tool for detecting the most common pitfalls[6] in ontologies (Poveda-Villalón et al., 2014). After analyzing the ontology, OOPS! provides an indicator for each pitfall detected, according to their possible negative consequences, and suggests modifications in order to improve the ontology quality. The system detects (a) *critical pitfalls* affecting the ontology's consistency, which are crucial to be corrected; (b) *important pitfalls*, which are not equally critical, but are considered as important to be corrected; (c) *minor pitfalls*, which do not cause any critical problems, but correcting them will improve the quality of the ontology. Table 2 presents the pitfalls detected by OOPS! while evaluating our ontology, along with a brief description of their meaning and the number of cases for which they were specified.

Table 2. Ontology pitfalls detected by OOPS!.

No	Pitfall description	Results
1	*Missing annotations* (*Minor*): Ontology terms lack annotation properties that would improve the ontology understanding and usability from a user point of view.	76 cases
2	*Missing disjointness* (*Important*): The ontology lacks disjoint axioms between classes or between properties that should be defined as disjoint.	Applies to whole ontology
3	*Inverse relationships not explicitly declared* (*Minor*): This pitfall appears when any relationship (except for symmetric properties) does not have an inverse relationship defined within the ontology.	19 cases
4	*Symmetric or transitive object properties* (*Suggestion*): The domain and range axioms are equal for each of the following object properties. Could they be symmetric or transitive? "*leadsTo*", "*relatesTo*".	2 cases

Regarding pitfall #1, OOPS! detected 76 cases where annotations and descriptions were missing. To overcome this pitfall and to improve the ontology's expressiveness, we assigned human readable annotations to every defined concept in the ontology, with the adoption of properties `rdfs:label` and `rdfs:comment`.

Concerning pitfall #2, the tool warned on the absence of disjoint axioms. Specifying that classes are disjoint enables a system to validate the ontology more efficiently. We fixed this shortcoming by introducing disjointness between subclasses of the "*Task*" and "*Vulnerable Object*" classes.

[6] A catalogue of common pitfalls is given at http://oops.linkeddata.es/catalogue.jsp

Pitfall #3 issued a warning on the absence of pairs of inverse properties for all of the object properties in the ontology (19 cases in total). The pitfall was resolved by introducing the corresponding pairs of inverse properties into the ontology, in order to improve its completeness.

Pitfall #4 consisted of a suggestion about two specific object properties (see Figure 1 and Figure 2, respectively). In order to resolve this issue, we made the former property symmetric and the latter transitive.

Evaluating the Structure

For evaluating the structure, we relied on *OntoMetrics*[7], an online framework that validates ontologies based on established metrics. Table 3 presents the results derived from the analysis by OntoMetrics. *Base Metrics* comprise of simple metrics, like the counting of classes, axioms, objects etc.; these metrics show the quantity of ontology elements. *Schema metrics*, on the other hand, address the design of the ontology; metrics in this category indicate the richness, width, depth, and inheritance of an ontology schema design.

Starting with the base metrics, the total count of classes and properties indicates that the proposed ontology is rather a lightweight model, which could be easily adopted by various applications, contrary to heavier "monolithic" ontologies that pose significant challenges in integration. Furthermore, *DL expressivity* refers to the Description Logics variant the ontology belongs to (see also section "*Ontology Language*"). $SI^{(D)}$ indicates a simple ontology (universal restrictions, limited existential quantification) with inverse, transitive, and datatype properties.

Table 3. Ontology metrics produced by the OntoMetrics tool.

Base Metrics	Class count	38
	Object property count	37
	Data property count	22
	SubClassOf axioms count	21
	Disjoint classes axioms count	2
	Inverse object properties axioms count	18
	Transitive object property axioms count	2
	Symmetric object property axioms count	1
	DL expressivity	$SI^{(D)}$
Schema Metrics	Attribute richness	0.578947
	Inheritance richness	0.657895
	Relationship richness	0.609375
	Axiom/class ratio	10.184211
	Class/relation ratio	0.59375

Regarding schema metrics, the measurements in the table are adopted from (Gangemi et al., 2005) and (Tartir et al., 2010). *Attribute richness* is defined as the average number of attributes per class and can indicate both the quality of ontology design and the amount of information pertaining to instance data. The more attributes that are defined the more knowledge the ontology conveys. *Inheritance richness* is defined as the average number of subclasses per class and is a good indicator of how well knowledge is grouped into different categories and subcategories in the ontology. This measure can distinguish a horizontal ontology (where classes have a large number of direct subclasses) from a vertical ontology (where classes have a small number of direct subclasses). The respective value in the table indicates that the proposed ontology is somewhere in between; this is reasonable, since the ontology covers many aspects (breadth) while thoroughly modelling some of them (depth). *Relationship richness* refers to the ratio of the number of non-inheritance relationships (i.e. object properties, equivalent classes, disjoint classes) divided by the total number of inheritance (i.e. subclass relations) and non-inheritance relationships defined in the ontology. This metric reflects the diversity of the types of relations in the ontology. Finally, *axiom/class ratio* and *class/relation ratio* describe the ratio between axioms-classes and

[7] https://ontometrics.informatik.uni-rostock.de

classes-relations, respectively, and are indications of the ontology's transparency.

Compliance with User Requirements

As discussed in section "*User Requirements and Ontology Competency Questions*", user requirements are mapped to CQs that the ontology is expected to answer. Following the methodology proposed in (Zemmouchi-Ghomari & Ghomari, 2013), we translated the CQs into SPARQL queries (Harris & Prud'hommeaux, 2013) and evaluated the retrieved results. Table 4 includes an indicative set of CQs, along with their SPARQL translation and an evaluation of the retrieved result sets.

Table 4. Indicative CQs and SPARQL translation.

Competency Question	SPARQL query	Correct?

What is the location of each media item?	`SELECT ?item ?location WHERE {`
	`  ?item rdf:type :MediaItem .`
	`  ?location rdf:type :Location .`
	`  ?item :hasMediaLocation ?location .`
	`}`
		Yes

What is the location and mission status of each rescue team?	`SELECT ?team ?location ?status WHERE {`
	`  ?team rdf:type :Responder .`
	`  ?location rdf:type :Location .`
	`  ?mission rdf:type :Mission .`
	`  ?team :hasResponderLocation ?location .`
	`  ?team :isAssignedMission ?mission .`
	`  ?mission :hasMissionStatus ?status .`
	`}`
		Yes

Which affected vulnerable objects were detected in a specific video?	`SELECT ?object WHERE {`
	`  ?object rdf:type :VulnerableObject .`
	`  ?dataset rdf:type :Dataset .`
	`  ?task rdf:type :Task .`
	`  ?dataset :detectedParticipant ?object .`
	`  ?task :producesDataset ?dataset .`
	`  ?task :relatesToMediaItem :video_1 .`
	`}`
		Yes

What is the impact and affected vulnerable objects of a specific incident?	`SELECT ?incident ?impact ?object WHERE {`
	`  ?incident rdf:type :Incident .`
	`  ?impact rdf:type :Impact .`
	`  ?object rdf:type :VulnerableObject .`
	`  ?incident :hasIncidentImpact ?impact .`
	`  ?incident :involvesParticipant ?object .`
	`}`
		Yes

The set of CQs currently includes 29 queries translated into SPARQL, all of which have been evaluated positively. Nevertheless, as the project progresses, the ontology will naturally further expand, resulting in additional CQs being added to the original set of queries.

Publicly Available Version of the Ontology

A publicly available version of the ontology will shortly be released on the project's website, along with the respective project deliverable which is due June 2018, containing the ontology documentation and sample instantiations of the notions discussed.

CONCLUSIONS AND FUTURE WORK

This paper argued that existing ontologies for climate-related crisis management only cover subsets of the pertinent concepts, and proposed a lightweight ontology for semantically integrating all the relevant notions:

representation of a crisis, along with associated climate parameters, sensor analysis, crisis incidents and impacts, and first responder unit allocations. The paper also presented how the proposed ontology satisfies the requirements of the end users and discussed on the validation of the ontology. The ontology is already being deployed in the context of an EU-funded project, and can potentially serve as the underlying knowledge base for any crisis management system, providing authorities with superior decision support capabilities.

Regarding directions for future work, and besides iterative refinements to the model that will take place as the project progresses, further research will focus on the reasoning techniques, which will be applied on top of the ontology, in order to facilitate decision support. Our first aim is to provide mechanisms for generating automated warnings (including reports) based on the current situation and respective context stored in the knowledge base. Another imminent step is to have the end-users evaluate the ontology-based decision support and the recommendations provided by it. This assessment will take place in a few months' time, when the first pilot deployments will be evaluated in the field, and our findings will then be publicly released.

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Sentinel-1 Based Near-Real Time Flood Mapping Service

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ABSTRACT

Globally floods are categorized as one of most devastating natural disasters and annually causing a major loss to human lives and economy. For rapid damage assessment and planning relief activities a large scale spatio-temporal overview is required to assist local authorities. This paper aims to provide an overview of a Sentinel-1 based near-real time flood mapping/monitoring service; which is implemented as an operational service under the framework of I-REACT (Improving Resilience to Emergencies through Advanced Cyber Technologies) project.

Keywords

Sentinel-1, EODC, Flood mapping service, SAR, Azure Service Bus.

INTRODUCTION

In recent years, the volume of data acquired by Earth observation (EO) satellites has been growing exponentially. Apart from the increasing number of satellites orbiting the Earth, the contribution of improved spatiotemporal resolution to the data volume is also significant. Therefore, in this age of big EO data, the domain of data driven applications is also quickly expanding (Chi et al. 2016). Key to any operational application are scalable and highly efficient data management and processing systems.

The advantage of using synthetic aperture radar (SAR) data instead of optical imagery is due to its weather independent data acquisition capability (Ulaby et al. 2014). At the time of flooding (especially caused by heavy rains) weather is mostly overcast and acquisition of cloud free optical data is a challenging task. For search and rescue operations it is very important for first responders to get the big picture of the spatial extent of the flooded areas (Martinis et al. 2009). This is a key information for the first responder to organize relief activities.

In this paper we present an overview of a near-real time computation of flood delineation map from Sentinel-1 data. The Earth Observation Data Center (EODC[1]) platform offers an environment for EO data processing and includes

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[1]https://www.eodc.eu

a Petabyte-scale EO data archive, a high performance computing infrastructure and virtual machines for remote data handling and visualization (Naeimi et al. 2016). Here we discuss the system infrastructure and integration of different components of SAR processing chain.

I-REACT project–concept and big picture

The I-REACT project has a multi-tier architecture which is called I-REACTOR. Based on the presentation, application process and data management tasks I-REACTOR's functions are logically separated into different loosely coupled modules that can be easily modified without affecting the other modules. However, in case of S-1 flood mapping service the point of contact to I-REACTOR is IDI (I-REACT Data Interface), where final products are pushed onto the front-end for further data harmonization, processing and visualization. Figure 1 shows the different components of I-REACTOR and their internal associations and dependencies.

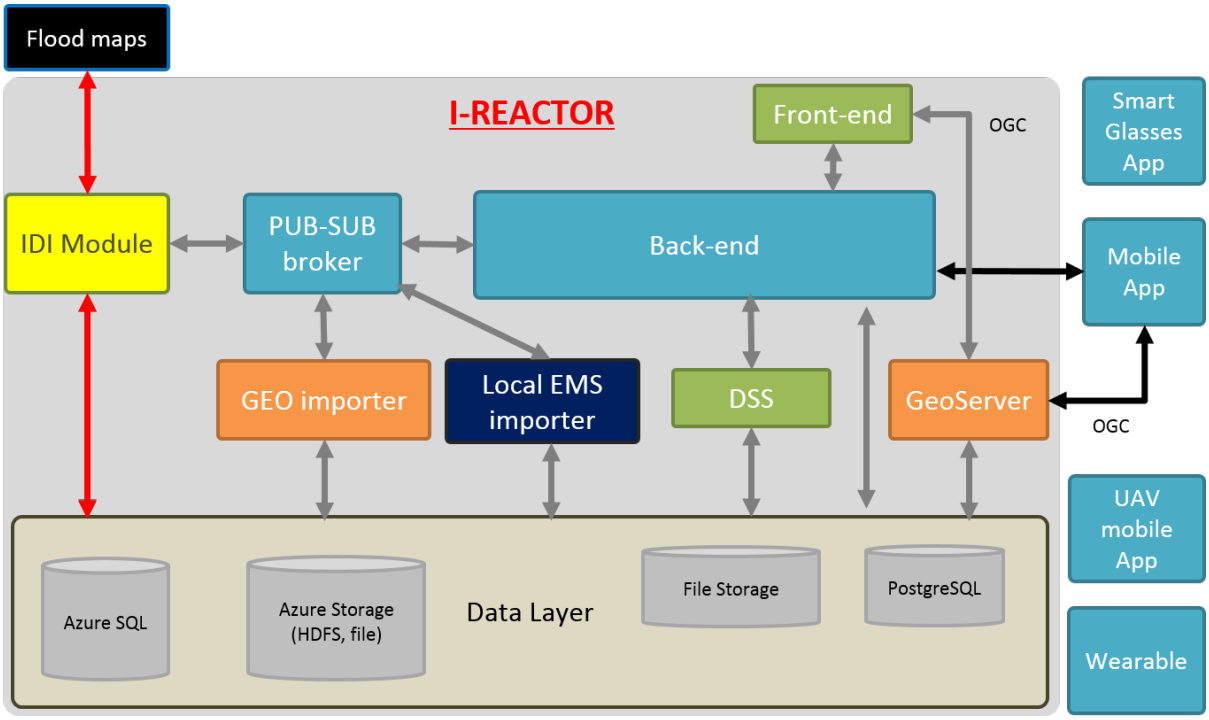

Figure 1. An overview of I-REACTOR framework.

TU WIEN SAR TOOLBOX AND PRODUCTS

SAR Geophysical Retrieval Toolbox (SGRT)

The SAR Geophysical Retrieval Toolbox (SGRT) is a software package developed by the Vienna University of Technology (TU Wien) for extracting geophysical parameters from Synthetic Aperture Radars (SARs) data. The version 2.0 of the SGRT, written in Python programming language, is an adaptation to Sentinel-1 (S1) of the earlier SGRT 1.0 developed for ENVISAT Advanced Synthetic Aperture Radar (ASAR) data, incorporating optimizations intended for handling the considerably higher spatial resolution and resulting explosion in data volumes foreseen of Sentinel-1 relative to ENVISAT ASAR (Naeimi et al. 2016). SGRT consists of four types of processing chains where different number of workflows are defined under each type, namely:

- *Pre-processing:* calibration, radiometric correction, georeferencing and terrain correction, resampling and tiling, quality control
- *Analytics:* time series analysis to extract model parameters
- *Production:* generates level-2 and higher-level products from preprocessed data using model parameters.
- *Near-Real-Time (NRT):* this component is designed to integrate different workflows and SGRT functionalities in a fully automatic processing chain for product generation.

Furthermore, SGRT is equipped with several image and signal processing components. Some of the SGRT modules are used in external utilities and plug-ins. e.g. the Python based Time Series Analyzer is an in-house tool, developed and integrated with the open source QGIS software to visualize Sentinel-1 time series. SGRT is under continuous development and with every new release, new functionalities and workflows are introduced.

Supporting products and modules

In order to develop an operational service a reliable quality control mechanism is essential to minimize the artifacts in the final product. In mountainous areas, topographic noise is very common which is due to steep slopes and shadow effect caused by the SAR side looking acquisition geometry. In order to remove topographic errors, the HAND (height above the nearest drainage) index (Nobre et al. 2011) was used. Figure 2 shows an example of flood map before and after applying the Hand Index mask.

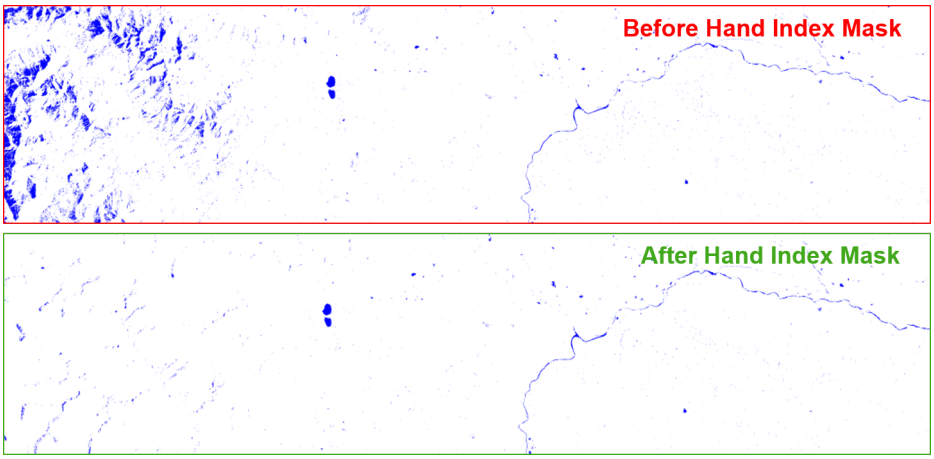

Figure 2. Application of Hand Index mask to remove the topographic noise.

Border noise in S1 A/B and ENVISAT ASAR is quite consistent which is a major source of error in time series analysis. In order to handle this error source an independent border noise removal module (Ali et al. 2018) was developed and integrated into the SGRT. Figure 3 shows an example for S1 border noise removal mask (border noise removal mask shown in magenta colour).

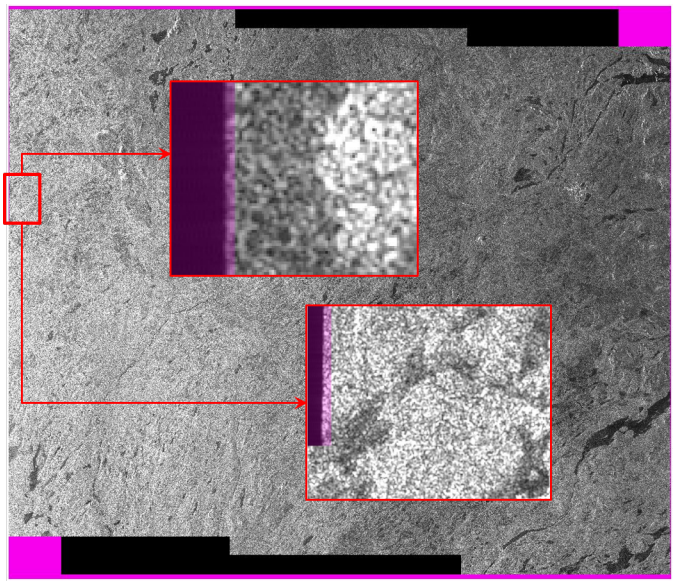

Figure 3. An example S1 border noise removal mask.

TEST SITES AND DATASET

Test sites in Europe

Currently the flood mapping service is mainly being tested in different countries in Europe. Study sites include United Kingdom, Malta and pre-defined regions of interest (red polygons) in Italy, Spain and Finland as shown in Figure 4.

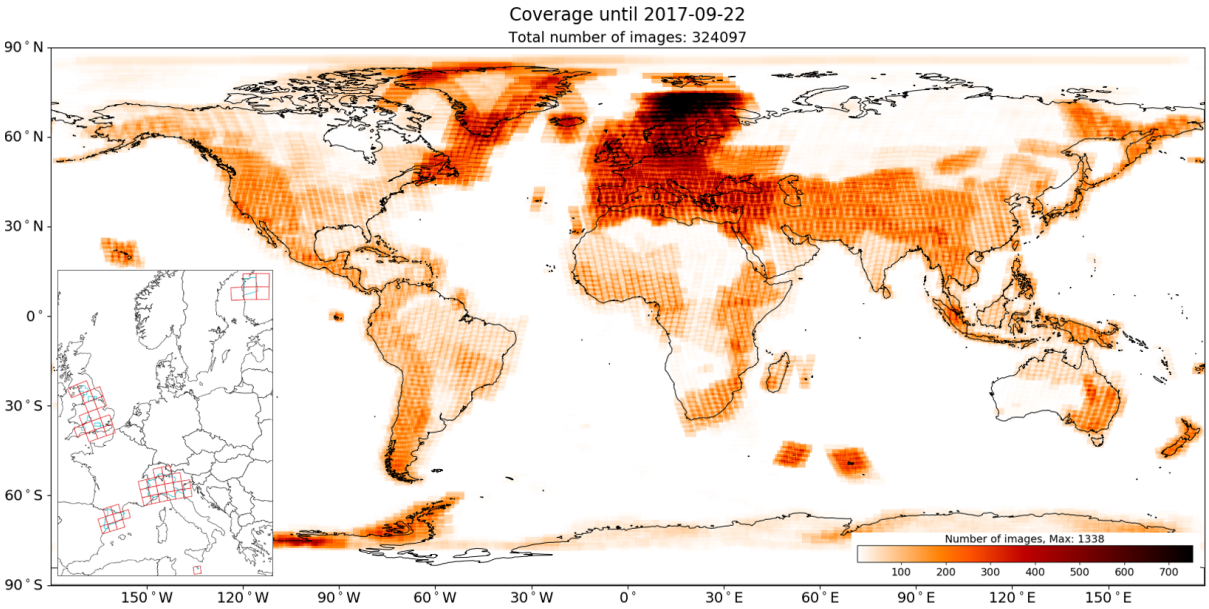

Figure 4. Primary regions of interest (inset, red tiles) for I-REACT flood mapping service, and Sentinel-1 Interferometric Wide Swath (GRD product) coverage map.

Data acquisition and management

The data acquired by the Sentinel-1 satellites is downlinked to the collaborative ground segment from where via ESA network it is being distributed to other sources like Scientific Hub[2] and ESA Server ZAMG (Zentralanstalt für Meteorologie und Geodynamik). From ZAMG, data is pushed to the national mirror and then to the EODC (Earth Observation Data Centre) data storage. The S1 data at the EODC warehouse are currently available approximately 2.5 hours after the initial signal processing by ESA (level-1 product) and 6.25 hours after the acquisition.

The S-1 level-1 data are archived on fast discs storage and backed up using a robotic tape library on a regular basis. In order to manage the raw and processed S1 data files a dedicated meta-database (EOMDB: Earth Observation Meta-DataBase) has been established, which allows tracking of data availability and processing status (see Figure 4).

METHODOLOGY: REAL-TIME FLOOD MONITORING / MAPPING SERVICE DESIGN

The Sentinel-1 based flood mapping and monitoring service is an external module which has been developed and maintained by TU Wien for I-REACT project, which can be triggered upon request via Azure Service Bus[3]–a cloud messaging service between applications and services.

Infrastructure and service logic implementation scheme

Within the framework of I-REACT project, the Sentinel-1(S-1) data processing chain for flood mapping service is implemented within a virtual machine hosted by the Earth Observation Data Centre (EODC). The processing chain and dataflow includes following steps as illustrated in Figure 5

- *Flood mapping processor:* The flood mapping algorithm is developed by TUWien and implemented within a virtual machine at the Science Integration and development Platform (SIDP) hosted by EODC. The

[2] https://scihub.copernicus.eu/
[3] https://azure.microsoft.com/en-us/services/service-bus/

processing chain includes pre-processing of the SAR data, data quality controls, flood mapping, and necessary post-processing steps. The SIDP is connect to the Vienna Scientific Cluster with more than 2000 computing nodes which might be used for heavy processing tasks that need parallel processing. The final products are flood and flood frequency maps.

- *Service on request and triggering mechanism:* this service is established to provide rapid post disaster flooding status and inundation extent maps, which can be used for post-disaster management and relief activities. In this service the user/customer will contact TU Wien through I-REACT coordination (e.g. via Azure Service Bus) to trigger the flood mapping/monitoring service. The requested product will be delivered to the IDI. The flood mapping/monitoring service is fully automatic and can be triggered over a defined location with the message received via Azure Service Bus.

- *Watchdog:* after getting the triggering message–with a bounding box of an area of interest and monitoring period (start and end date)–via Azure Service Bus, the program will automatically connect to the EOMDB and get the available raw files. Then the processing chain will be activated for available files. If there is/are no file(s) then a watchdog will be activated and and it will update EOMDB after every two hours and look for new files for the area of interest. Every time when it will find new file(s) a new independent processing chain instance will be launched. This process will continue until the image acquisition date is less than or equal to the end date defined in the message.

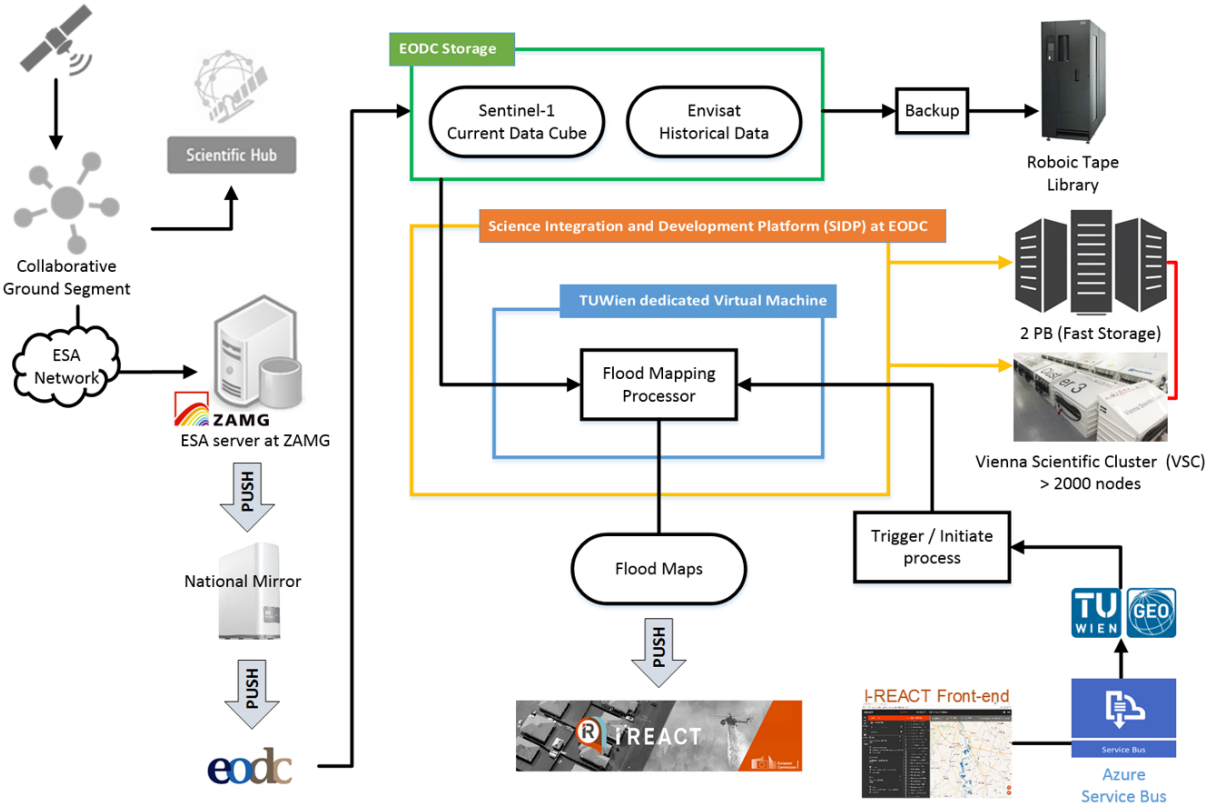

Figure 5. An overview of infrastructure and service logic for near-real time flood mapping/monitoring.

RESULTS AND PROTOTYPE

The stability of the processing chain and the implemented service logic was tested by triggering the service for three different requests simultaneously. The processing chain ran successfully and processed 21 Sentinel-1 scenes. The final product of 2.5 GB was uploaded to the IDI database. Due to the limited number of cores on the test machine, the processing chain ran for more than 24 hours. In case of multiple requests the processing time can be minimized by increasing the computing power.

Sentinel-1 based flood and flood frequency maps were produced for all five test site. Figure 6 shows an example of Sentinel-1 based flood frequency product for a test site in Italy (Emilia–Romagna).

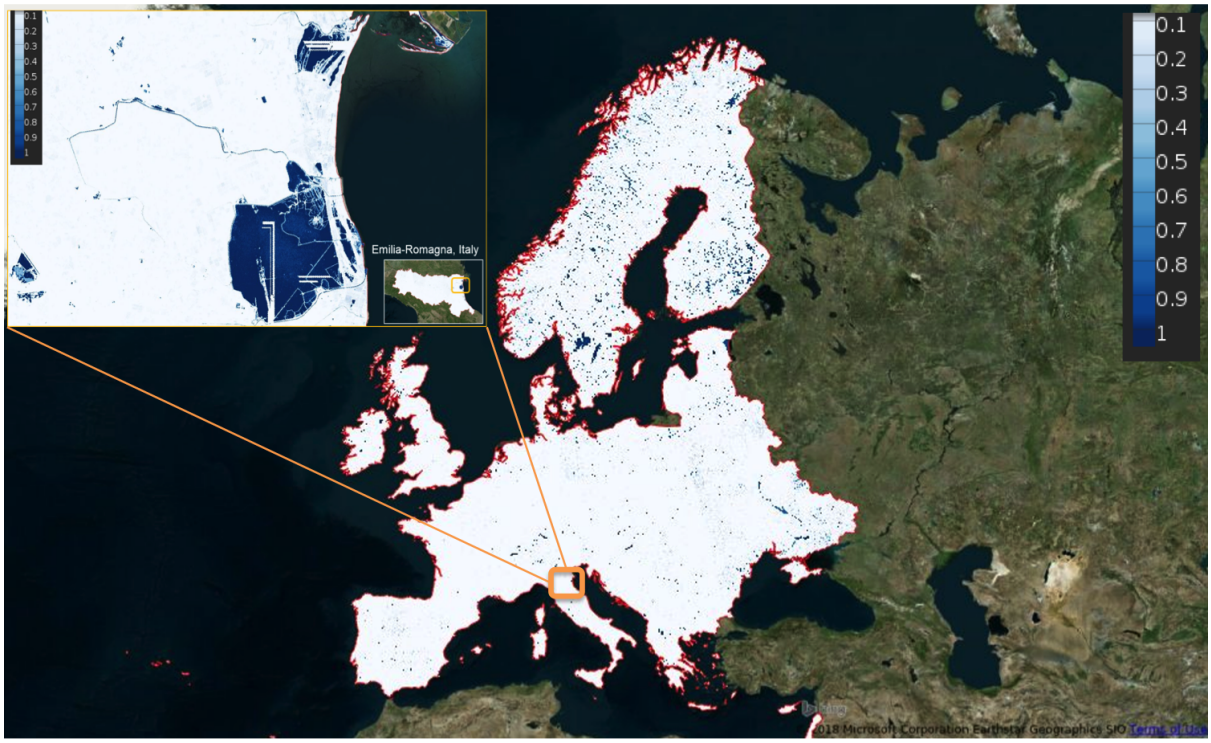

Figure 6. An example of multi-temporal flood frequency layer for Europe.

In addition to the final product–flood or flood frequency maps–that will be delivered to the IDI, different Sentinel-1 based intermediate products will also be produced. The intermediate products includes pre-processed data and various biophysical and statistical parameters as well. In order to query the data/product a pre-defined set of minimum required metadata is also pushed to the IDI.

After data harmonization step flood maps become available for visualization on the front-end (I-REACT main web-page) of the I-REACTOR. Figure 7 shows the display of the flood frequency product on the front-end of the I-REACT emergency service management website.

CONCLUSION

In this short paper we have demonstrated a framework and feasibility of setting up an operational flood mapping and monitoring service by exploiting a big-data infrastructure and high performance computing facility. This service will be operational under the framework of I-REACT project, and new development in terms of algorithm improvement and performance enhancement will be integrated into the SGRT.

ACKNOWLEDGMENT

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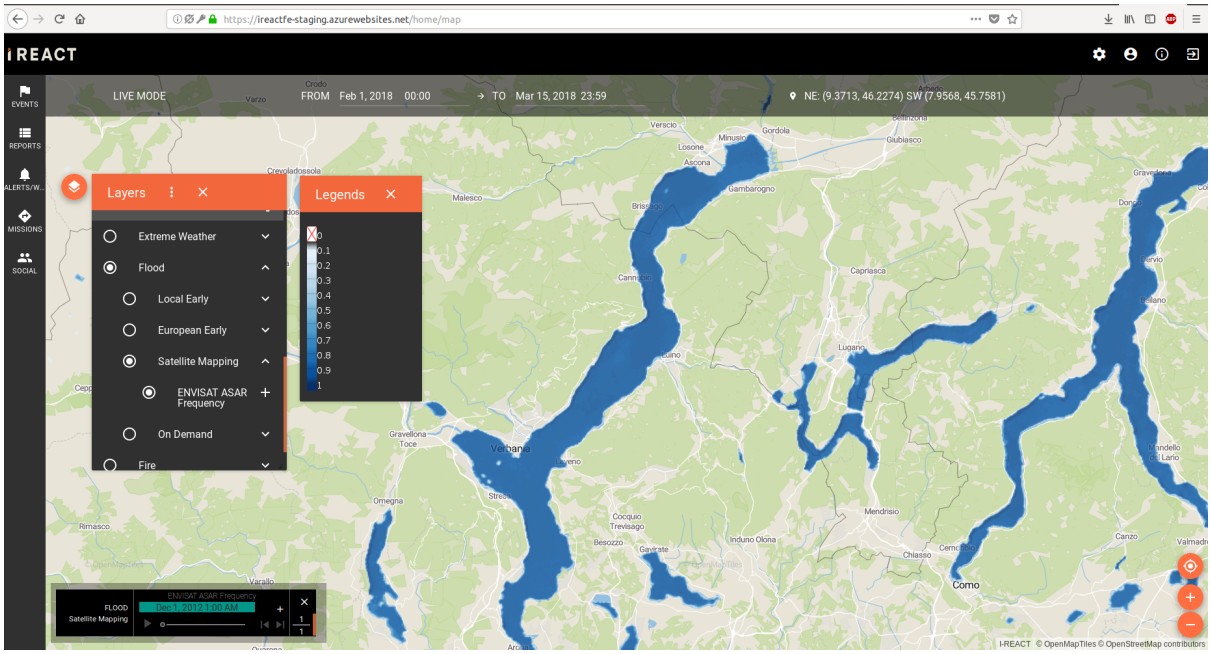

Figure 7. Front-end of the I-REACT emergency service management system where the water frequency product (in blue colour) is over-laid to the base map. Water frequency with spatial resolution of 75 meters is calculated by using Envisat ASAR data cubes covering 10-years time spam (2002–2012).

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PERCEIVE: Precipitation Data Characterization by means on Frequent Spatio-Temporal Sequences

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ABSTRACT

Nowadays large amounts of climatology data, including daily precipitation data, are collected by means of sensors located in different locations of the world. The data driven analysis of these large data sets by means of scalable machine learning and data mining techniques allows extracting interesting knowledge from data, inferring interesting patterns and correlations among sets of spatio-temporal events and characterizing them. In this paper, we describe the PERCEIVE framework. PERCEIVE is a data-driven framework based on frequent spatio-temporal sequences and aims at extracting frequent correlations among spatio-temporal precipitation events. It is implemented by using R and Apache Spark, for scalability reasons, and provides also a visualization module that can be used to intuitively show the extracted patterns. A preliminary set of experiments show the efficiency and the effectiveness of PERCEIVE.

Keywords

Spatio-temporal sequence mining, Data characterization

INTRODUCTION

Association rules and frequent sequences are well-known descriptive pattern-based techniques (Tan et al. 2005; Flach 2012) that have been used in many application contexts to describe and model the main characteristics of the analyzed data (e.g., market basket data (Agrawal and Srikant 1994), census data (Appice et al. 2003), medical data (Xiao and Chiusano 2014), biological data (Pan et al. 2003; Hasan et al. 2012)). However, to the best of our knowledge, those two typical data mining techniques have never been used to characterize climatology data and in particular spatio-temporal sequences of precipitation events. Many complex and precise meteorological models have been proposed to predict precipitations and forecast precipitation and fire events. Also, data mining approaches have been proposed to address the prediction/forecast problem (e.g. (Cheng and Wang 2008)). However, our goal is different. Specifically, we are interested in inferring the correlations among precipitation events to describe the analyzed events and understand whether, based on the analyzed data, some common patterns and trends can be discovered. To address this goal we propose a framework, called PERCEIVE, based on Frequent Spatio-Temporal Sequences (FSTSs). Frequent Spatio-Temporal Sequences are patterns representing correlations among set of events. For instance, the sequence $\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}(0) \rightarrow \{(pos_2, heavy\ rain)\}(2)$ represents the following sequence of events: heavy rain in pos_1 and snowstorm in pos_2 at the same time, followed by a heavy rain event in pos_2 two days after the occurrence of the first two events. These human-readable patterns can provide interesting insights to domain experts. Specifically, the extracted set of spatio-temporal sequences can be used to characterize precipitation events and can also be considered during the definition of new climate or meteorological models.

Since the amount of collected data is potentially big, PERCEIVE is based on Apache Spark big data framework, coupled with R, to extract Frequent Spatio-Temporal Sequences. Moreover, PERCEIVE displays also the extracted

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patterns on maps to facilitate domain expert analyses. Specifically, the domain expert can analyze one single pattern (FSTS) at a time or groups of similar patterns (FSTSs) to inspect the main spatio-temporal correlations between sets of precipitation events highlighted by PERCEIVE. PERCEIVE automatically extracts FSTSs from the precipitation data without the human intervention, i.e., it is completely data driven during the knowledge extraction step. The domain expert is involved only in the last phase to inspect the extracted spatio-temporal sequential patterns. Even if we used PERCEIVE to characterize precipitation events, the proposed framework is general and can be applied to analyze any type of spatio-temporal events.

An initial campaign of experiments, performed on real data about precipitation events in the USA, confirms that PERCEIVE is efficient and effective in extracting interesting knowledge.

The paper is organized as follows. The frequent spatio-temporal sequence mining problem, and the related main concepts, are introduced. Then, the PERCEIVE framework and its main components are described. Finally, the results of a preliminary campaign of experiments are reported in the experimental section, while the last section draws conclusions and presents future work.

FREQUENT SPATIO-TEMPORAL SEQUENCES

In the following, we report the basic definitions related to the frequent spatio-temporal sequence mining problem and we formally define the addressed mining problem.

We initially introduce the concept of spatial event, which correlates an event type with the location in which it occurs. Then, we define the temporal database concept and we describe how it can be used to store for each spatial event also the information about when each spatial event occurred.

A spatial event is a pair (position, type of event) storing the information about an event type (e.g., heavy rain, snowstorm) and the georeferenced position in which it occurs (e.g., a heavy rain event located in (Lat=42.361145, Long=-71.057083)).

Definition 1 (Spatial event) *Let $P = \{p_1, \ldots, p_n\}$ be a set of positions, where each position p_i is a pair (latitude, longitude). Let $ET = \{et_1, \ldots, et_m\}$ be a set of event types.*

A spatial event se_i is a pair (p_i, et_i), where $p_i \in P, et_i \in ET$.

For instance, the spatial event $se = (p_1, heavy\ rain)$ represents the occurrence of a heavy rain event located in p_1, where $p_1 = (Lat. = 42.361145, Long. = -71.057083)$.

In the frequent sequence mining problem, a set of (spatial) events is referred to as a transaction. For instance, the set $\{(p_5, heavy\ rain), (p_1, snowstorm), (p_4, light\ rain)\}$ is a transaction composed of 3 spatial events.

Definition 2 (Transaction of spatial events) *Let $SE = \{se_1, \ldots, se_l\}$ be a set of spatial events.*

A spatial transaction $tr = \{se_1, \ldots, se_k\}$ is defined as a non-empty set of spatial events $se_i \in SE$, i.e., $tr \subseteq SE$.

A temporal database is used to store the temporal information associated with the records stored in it. In our context, we are interested in storing the timestamps of the sets of spatial events we are analyzing. Specifically, a temporal database storing spatial events is defined as a set of pairs *(timestamp, transaction of spatial events)*. Each pair is called record and stores the set of spatial events occurred at time *timestamp*. In our context, we suppose that the domain of the timestamp attribute is a finite sequence of discrete values associated with the period under analysis (e.g., the sequence of dates in the period under analysis). Without loss of generality, we assume that the interval between two consecutive timestamps is a fixed constant (e.g., the interval between two consecutive timestamps is equal to one day if we are storing daily events).

Definition 3 (Temporal database of spatial events) *Let $T = \{t_1, \ldots, t_k\}$ be a finite sequence of discrete timestamps, such that $t_{j+1} = t_j + \Delta t$, where Δt is the fixed step/interval between two consecutive timestamps.*

A temporal database $TD = \{r_1, \ldots, r_n\}$ is defined as a set of records $r_i = (t_i, tr_i)$, where $t_i \in T$, $tr_i \subseteq SE$ and $t_i \neq t_j, \forall i \neq j$. The i-th record r_i contains the set of spatial events tr_i occurred at time t_i.

Table 1. Running example temporal database storing spatial events. For the sake of clarity, in each spatial event we report the "alias" of the position instead of its (Lat., Long.) coordinates.

Timestamp	*Set of spatial events*
04/01/2016	$\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}$
04/02/2016	$\{(pos_1, snowstorm), (pos_4, light\ rain), (pos_5, heavy\ rain)\}$
04/03/2016	$\{(pos_1, heavy\ rain), (pos_2, heavy\ rain), (pos_3, snowstorm), (pos_6, light\ rain)\}$
04/04/2016	$\{(pos_5, heavy\ rain)\}$
04/05/2016	$\{(pos_2, heavy\ rain), (pos_3, light\ rain)\}$
04/06/2016	$\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}$
04/07/2016	$\{(pos_1, heavy\ rain), (pos_2, heavy\ rain), (pos_3, snowstorm), (pos_6, light\ rain)\}$
04/08/2016	$\{(pos_2, heavy\ rain)\}$
04/09/2016	$\{(pos_1, heavy\ rain)\}$

Note that, according to Definition 3, each timestamp appears at most one time in the temporal database and the record associated with it contains all the spatial events occurred in that specific timestamp (i.e., we cannot have events occurred at the same time in different records).

Table 1 reports a running example temporal database $TD_{example}$ storing the information about daily sets of spatial events (i.e., Δt is set to 1 day and each timestamp in T is a date). The first record of $TD_{example}$ means that a heavy rain event and a snowstorm event occurred in positions pos_1 and pos_3 on April 1, 2016, respectively. Note that a different number of events can occur in each timestamp (e.g., two events occurred on April 1, 2016 while three events occurred in April 2, 2016) and the same event type can be associated with many positions at the same time (e.g., heavy rain occurred in position pos_1 and pos_2 on April 3, 2016).

In our context, we are interested in identifying frequent sequences of sets of spatial events. Specifically, a sequence s is an ordered list of transactions of spatial events $\{tr_1, \ldots, tr_q\}$. Each transaction tr_i in a sequence s is also characterized by the time distance/interval from the first transaction of events tr_1 in s. For instance, the sequence $s_1 = \{(pos_1, heavy\ rain), (pos_3, snowstorm)\}(0) \rightarrow \{(pos_2, heavy\ rain)\}(2)$ represents the following sequence of events: heavy rain in pos_1 and snowstorm in pos_3 at the same time, followed by a heavy rain event in pos_2 two days after the occurrence of the first two events. The sequence s_1 occurs three times in the running example database (see Table 1). The first occurrence of s_1 is associated with the 1st and 3rd record of the running example, the second occurrence is associated with the 3rd and 5th record, while the third occurrence is supported by the 6th and 8th record. Hence, the frequency of s_1 in the running example database is three.

Definition 4 (Sequence of spatial events) *A sequence of spatial events s is defined as $tr_1(\delta t_1) \rightarrow tr_2(\delta t_2) \rightarrow \ldots \rightarrow tr_q(\delta t_q)$, where tr_i is a transaction of spatial events and δt_i is the time distance/interval of those events from the first event(s) of the sequence (i.e., the events in tr_1).*

Note that each sequence represents a set of spatial events and the relative distance/interval between them instead of the information about the absolute time when the sequence of events occurred. The main motivation of this definition is that we are not interested in identifying one single occurrence of a set of events. Instead, we are interested in learning patterns which occur periodically and characterize the relative temporal distance between spatial events. This type of patterns could be useful to develop a system for future event prediction, even if this is not the main goal of this paper.

The support of a sequence represents the frequency of the sequence in the temporal database, i.e., the number of times the sequence occurs in the temporal database. This measure is used to estimate the "statistical relevance" of the sequence. Specifically, the higher the support value, the higher the probability that the extracted sequence models a real characteristic of the analyzed data.

Definition 5 (Support of a sequence of spatial events) *The absolute support (sup) of an arbitrary sequence s in the temporal database TD is defined as the number of occurrences of s in TD.*

For instance, the support of the sequence $\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}(0) \rightarrow \{(pos_2, heavy\ rain)\}(2)$ in the running database is three because it occurs in the combinations of records {1st, 3rd}, {3rd, 5th}, and {6th, 8th} (see Table 1), while the support of the sequence $\{(pos_2, heavy\ rain)\}(0) \rightarrow \{(pos_5, heavy\ rain)\}(1) \rightarrow$

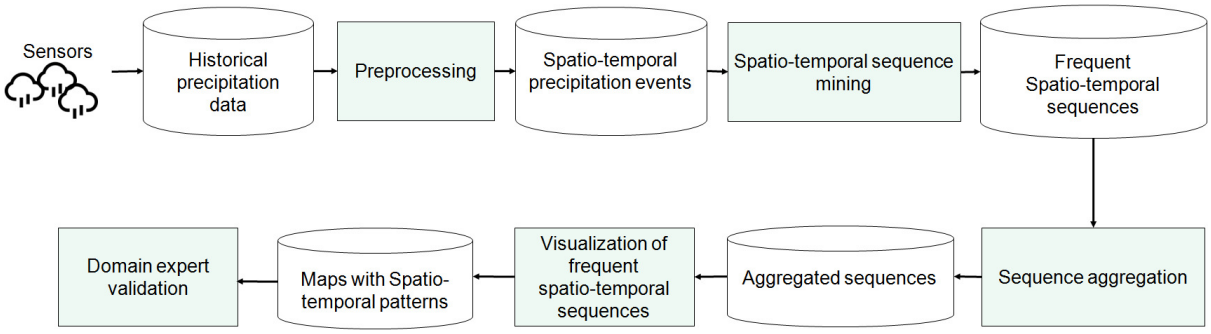

Figure 1. Architecture of the PERCEIVE **framework**

$\{(pos_2, heavy\ rain), (pos_3, light\ rain)\}(2)$ is one, because only the triplet of records $\{3rd, 4th, 5th\}$ of the running example database matches/supports that sequence.

Another measure of interest is the confidence measure, which is usually used to assess the ability of the sequence to predict future events. The confidence of a sequence s represents the conditional probability of having the last set of events (transaction of events) of s given the first $q-1$ sets of events of s (i.e., it estimates the probability of occurrence of the last set of events given the occurrence of the antecedent events). For this reason, in the following we will use the term "antecedent" to refer to the first $q-1$ sets of events of s and "consequent" to refer to the last sets of events of s (i.e., tr_q).

Definition 6 (Confidence of a sequence of spatial events) *The confidence ($conf$) of a sequence $s = tr_1(\delta t_1) \rightarrow tr_2(\delta t_2) \rightarrow \ldots \rightarrow tr_q(\delta t_q)$ is defined as*

$$\frac{sup\Big(tr_1(\delta t_1) \rightarrow tr_2(\delta t_2) \rightarrow \ldots \rightarrow tr_q(\delta t_q)\Big)}{sup\Big(tr_1(\delta t_1) \rightarrow tr_2(\delta t_2) \rightarrow \ldots \rightarrow tr_{q-1}(\delta t_{q-1})\Big)}$$

For instance, $conf\Big(\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}(0) \rightarrow \{(pos_2, heavy\ rain)\}(2)\Big)$ is 0.75 (i.e., 75%) because $\{(pos_1, heavy\ rain), (pos_3, snowstorm)\}$ occurs four times in the running example database but only in three cases the spatial event $\{(pos_2, heavy\ rain)\}$ occurs two days after the first two events.

Frequent spatio-temporal sequence mining problem. Given a temporal database of spatial events, a minimum support threshold $minsup$, and a minimum confidence threshold $minconf$, the frequent spatio-temporal sequence mining problem consists in extracting all the spatio-temporal sequences with a support value greater than or equal to $minsup$ and a confidence value greater than or equal to $minconf$. These sequences are referred as "Frequent Spatio-Temporal Sequences (FSTSs)" in the following. This set of mined sequences can be used to model/characterize the analyzed events.

FRAMEWORK

This section describes the Sequence-based Precipitation Data Characterization and Visualization (PERCEIVE) framework we designed to analyze the spatio-temporal correlation among precipitations. In this paper, we focus our analysis only on precipitations. However, the proposed framework can be effectively used to characterize and visualize also other types of spatial events (e.g. fires, traffic jams).

The architecture of PERCEIVE is reported in Figure 1 and its main building blocks are described in the following.

Data Preprocessing. Initially, PERCEIVE collects and preprocesses the data about the precipitations in order to obtain data consistent with the spatio-temporal data format defined in Definition 3. Specifically, the data about the precipitations are collected by means of several sensors located on the areas under observation. Each sensor collects a set of readings that must be collected and merged with the readings of the other sensors. Moreover, the readings are continuous values. Since we are interested in analyzing sequences of spatial events, we must map these values to events. We perform this operation by applying a threshold called $minprec$. Specifically, for each pair (sensor,

date) we analyze the daily precipitation, in tenths of mm per day. If the daily precipitation associated with a pair (sensor, date) is greater than or equal to $minprec$, we decide that a "relevant" precipitation event happened and hence a "spatio-temporal" event occurred in (sensor, date). We decided to use PERCEIVE to perform a daily-based analysis. Hence, the preprocessing step generates one record for each date of the period under analysis and the set of spatial-events ("relevant" precipitations) occurring in each date. However, a different time granularity can be set.

The data preprocessing step has been implemented by using an SQL Server database to store and query the data and a program written in R.

Spatio-Temporal Sequence Mining. After the input data collection and preprocessing step, PERCEIVE mines the frequent spatio-temporal sequences characterized by a support and confidence greater than or equal to the user defined thresholds $minsup$ and $minconf$, respectively. Moreover, PERCEIVE prunes the sequences containing events for which the distance is less than $mindistance$ km because they are usually considered irrelevant or trivial correlations in the precipitation analysis domain. We set $mindistance$ to 50 km in all our experiments. The mined sequences characterize, by means of human-readable sequences, the correlations among the precipitations of the areas under analysis. This automatic data-driven approach allows extracting/inferring knowledge from the input data without the intervention of domain experts. The extracted sequences can be manually analyzed to understand what the correlations about precipitation events are and how they move from one area to another.

Several algorithms can be used to mine frequent sequences (e.g. (Zaki 2001; Zaki 2000; Wang and Han 2004)). However, a specific solution is needed to mine spatio-temporal sequences. Similarly to the solution exploited by Bruno and Garza in (Bruno and Garza 2010) to mine temporal sequences, we use a windowing transformation and a frequent itemset mining algorithm to extract frequent spatio-temporal sequences. The windowing transformation creates a set of "macro" records, each one representing the events occurred in a specific date and the events occurred in the w following dates. As described in (Bruno and Garza 2010), an itemset mining algorithm can then be applied on the transformed data to efficiently mine frequent temporal sequences. Since our input data are spatial events, the output of this process is a set of frequent spatio-temporal sequences. To implement a scalable solution, PERCEIVE exploits the Apache Spark (Zaharia et al. 2010) implementation of the FP-growth itemset mining algorithm (Han et al. 2000) coupled with a windowing function written in Java.

Sequence Aggregation. To provide a better characterization of the correlations among precipitation events, PERCEIVE applies two aggregation (clustering) procedures on the mined frequent sequences with the aim of (i) grouping sequences characterized by the same consequent (i.e. sequences for which the last spatio-temporal event is the same) and (ii) grouping sequences characterized by the same consequent and similar antecedents (i.e., FSTSs with at least $minoverlap$% spatio-temporal events in common in their antecedent and exactly the same consequent) to reduce the redundancy related to similar sequences. Aggregation step (i) allows obtaining a global view of the different preconditions of events that are correlated with precipitation events in a specific position of interest. For instance, suppose that only the following two sequences are characterize by position pos_5 as consequent:
$s_1 = \{(pos_1, precipitation)\}(0) \rightarrow \{(pos_5, precipitation)\}(1)$
$s_2 = \{(pos_3, precipitation)\}(0) \rightarrow \{(pos_5, precipitation)\}(1)$

Aggregation step (i) groups them together proving the global information that, based on the rules inferred from the data, the precipitations in position pos_5 happens frequently when the day before a precipitation occurred in position pos_1 or pos_3.

Aggregation step (ii) is used to merge rules characterized by the same consequent and similar antecedents. It allows achieving two goals: redundancy removal (each set of similar sequences is merged in one group and hence domain experts analyze one group instead of many singular sequences) and spatio-temporal trend confirmation, supported by slightly different sequences.

This component has been implemented in R (R Core Team 2018).

Sequence Visualization. To facilitate the exploration of the knowledge represented by FSTSs, the mined sequences are visualized on a map. The visualization component allows domain experts to analyze the direction of the spatio-temporal correlations and the time intervals between the precipitation events represented by the extracted sequences. PERCEIVE can visualize either one single sequence or one "group" of aggregated sequences at a time.

Also, the visualization part has been implemented by using the R software.

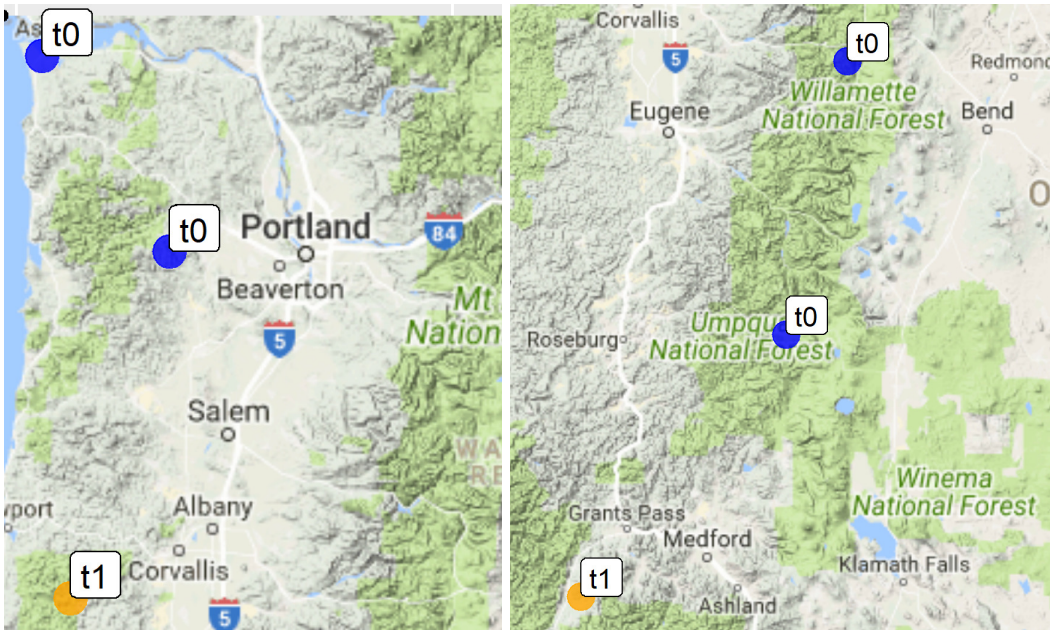

Figure 2. Oregon precipitations: Examples of mined FSTSs

PRELIMINARY EXPERIMENTAL EVALUATION

We performed a set of experiments by using the real GHCN-Daily dataset (Menne, Durre, Korzeniewski, et al. n.d.). Specifically, we focused our analyses on the precipitation information available in the downloaded data to assess the quality and the quantity of the frequent spatio-temporal sequences (FSTSs) extracted by using PERCEIVE. We have performed an initial qualitative analysis of the extracted FSTSs, supported also by the visualization component. Then, quantitative analyses have been performed to understand the characteristics of the mined FSTSs in terms of support and confidence.

Dataset. We used the precipitation data related to the Oregon country to perform our experiments. The used data (Menne, Durre, Korzeniewski, et al. n.d.), which are provided by the NOAA National Climatic Data Center, were collected by means of 1652 sensors located in Oregon. The data set contains the historical daily precipitation information for each sensor. We considered the precipitation data from 2014 to 2016. A detailed description of the collected data is reported in (Menne, Durre, Vose, et al. 2012).

Qualitative analysis and data visualization

We performed an initial set of experiments by considering the precipitations of year 2016. We set $minprec$ to 300 tenths of mm per day (i.e., a daily precipitation event is considered only if the measured daily precipitation is greater than 300 tenths of mm), $minsup$ to 5% (i.e., only the sequences that occurred at least in 5% of analyzed data is mined), and $minconf$ to 75%.

PERCEIVE has automatically mined a set of FSTSs representing interesting frequent correlations among sets of precipitation events in different areas of Oregon. Specifically, 2,417 FSTSs have been automatically extracted. Figure 2 reports two representative examples of the mined FSTSs on a geographical map. The blue points are related to the antecedent items/events while the orange one represents the consequent one (i.e., the last event of the sequence). Both FSTSs are characterized by a confidence equal to 100%. It means that, according to the analyzed historical data, if precipitations are happening in the blue points after one day a precipitation will happen in the location associated with the orange point. The graphical representation FSTSs allows to easily analyze the mined sequences and hence the represented correlations among spatio-temporal events.

Since some FSTSs are similar, to easy the manually inspection the mined FSTSs by means of the domain expert, the last component of PERCEIVE group together similar FSTSs to provide a more compact information to the end user. For instance, in this case, by using the first aggregation step, which aggregates FSTSs characterized by the same consequent, 32 aggregations/groups are generated, which are two orders of magnitude less than the number of mined FSTSs, and 113 groups are obtained by applying approach (ii), which generates groups of FSTSs that are

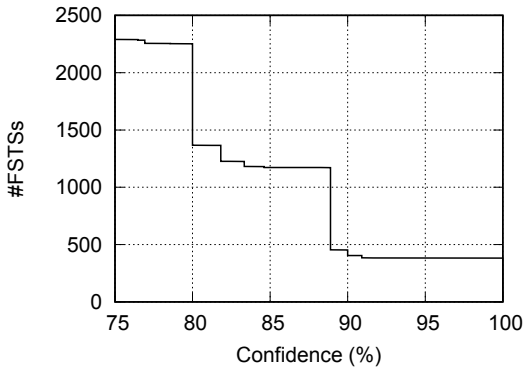

Figure 3. Distribution of the number of FSTSs with respect to their confidence value

characterized by the same consequent and similar antecedents. This means that 113 "trends" are identified (one for each group identified by the second aggregation procedure). The domain expert can analyze one group at a time instead of one single FSTS at a time reducing the time needed to inspect the mined sequences. Moreover, the presence of groups of similar FSTSs, emitted by the second aggregation procedure, can be considered as a reinforcement of the strength of single FSTSs (i.e., the higher the number of FSTSs in a group, the higher the probability that the represented "trend/correlation" among the involved spatio-temporal events is relevant).

We performed a similar set of experiments by considering the precipitations occurred in 2014 and 2015, respectively. Many of the mined FSTSs are similar to the ones mined by considering year 2016. Hence, the correlations among precipitation events seem to be, on the average, independent of the considered year. They are probably related to the geological characteristics of the areas under analysis and the impact that they have on the wind direction and the cloud movement. One of the most interesting features of PERCEIVE is that all the correlations between precipitations among different areas have been mined automatically without the intervention of domain experts, who however are extremely useful to inspect and validate the mined patterns.

Quantitative analysis

In the previous section we already reported some quantitative information about the number of mined FSTSs. In this section we analyze the distribution of the number of mined FSTSs with respect to their confidence value, to understand if the mined sequences can potentially be used for predictive purposes. Figure 3 reports the cumulative number of mined FSTSs with respect to their confidence value. Specifically, each point (confidence, cumulative number of FSTSs) of the reported curve corresponds to the number of FSTSs with a confidence value greater than or equal to confidence.

The achieved results confirm that many of the mined FSTSs are characterized by a high confidence value and specifically 382 of them have a confidence equal to 100%. Hence, a large part of the mined FSTSs are characterized by a potential high prediction quality. Then, they have been aggregated in 114 groups of similar FSTSs, which means that in 2016, in the Oregon State, 114 different sets of FSTSs having confidence equal to 100% have been found. In order to confirm the affordability of the system, other tests for other years (2014 and 2015) have been performed, showing similar results as in 2016.

CONCLUSIONS

In this paper we proposed PERCEIVE. To the best of our knowledge, PERCEIVE is the first data-driven framework that characterizes spatio-temporal precipitation events by using frequent spatio-temporal sequences. The preliminary performed experiments show the ability of PERCEIVE to automatically mine recurrent spatio-temporal patterns. Further experiments, which will involve also domain experts for the validation step, will be performed by considering different countries and other types of spatio-temporal events. The potential correlation with the geographical characteristics of the considered areas will also be investigated. The exploitation of the extracted FSTSs for the precipitation prediction problem will be investigated and a prediction algorithm based on FSTSs will be designed as well. Finally, an improvement of the visualization module will be performed, in order to better distinguish event typologies and magnitudes.

ACKNOWLEDGMENT

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Calibrating Ensemble Forecasts to Produce More Reliable Probabilistic Extreme Weather Forecasts

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ABSTRACT

Accurate predictions of severe weather events are extremely important for society, economy, and environment. Due to the fact that weather forecasts are inherently uncertain, it is required to give information about forecast uncertainty to all users providing weather forecasts in probabilistic terms utilizing ensemble forecasts. Since ensemble forecasts tend to be under dispersive and biased, they need to be calibrated with statistical methods. This paper presents a method for the calibration of temperature forecasts using Gaussian regression, and the calibration of wind gust forecasts with a box-cox t-distribution method. Statistical calibration was made for the operational European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble prediction system (ENS) forecasts for lead times from 3 to 360 hours. The verification results showed that calibration improved both temperature and wind gust ensemble forecasts. The probabilistic temperature forecasts were better after calibration over whole lead time scale, but the probabilistic wind gust forecasts up to 240 hours.

Keywords

Weather forecasts, probabilistic forecasting, statistical calibration, high impact weather events.

INTRODUCTION

Due to climate change, extreme weather events are expected to become more frequent, more extreme and longer lasting. Greater evaporation will lead to increased water vapor in the atmosphere, producing more intense precipitation. This, together with rapid snow melting, increases the likelihood of floods. Also, higher temperatures will increase the frequency of wildfires and heat waves as well as other natural disasters.

Current systems for risk management are still limited in their effectiveness. Despite technological progresses and the availability of large amounts of data, there is no platform that integrates and analyses in real time all the useful data to manage emergencies for improving prediction and management of extreme climate and weather events. At the moment, there are several on-going EU projects (http://www.i-react.eu/, http://beaware-project.eu/ and http://anywhere-h2020.eu/) that are aiming to solve this problem. All these project have the similar objective to establish a multi-hazard platform to integrate emergency management data coming from multiple sources, including that provided by citizens. This way, the necessary information from different sources can be produced faster for citizens and civil protection agencies to enhance prevention and reacting against natural disasters.

One objective of the I-REACT project, is to improve European level high-impact weather event detection. Finnish Meteorological Institute (FMI) is responsible for developing and providing the forecasted occurrence risk maps for the system. These risk maps provide information in terms of probabilities based on relevant thresholds of precipitation amount, wind speed, and temperature phenomena that can have serious societal impact. FMI's focus in the project is in the medium-range weather forecasts which consist the lead times from few hours to two weeks.

Nowadays, Numerical Weather Prediction (NWP) models are the main tool to provide weather forecast guidance to stakeholders. Different NWP models support weather forecasting from daily to weekly forecast scales and also from monthly to seasonal scales (e.g. Molteni et.al. 1996; Willet et.al. 2009). The initial state for NWP models is made using data-assimilation. In data-assimilation process atmospheric physical variables represented by weather observations are combined with short range forecasts fields of previous forecast cycle to make the best estimate for atmospheric state. NWP models can simulate most large scale physical processes in the atmosphere but some

processes are totally excluded or inadequately modelled. The initial analysis has also errors and together with modelling errors the forecast will also be erroneous. Due to the fact that the atmosphere is a chaotic system, the error is typically small in short forecast ranges and it will increase towards longer forecast ranges. Therefore, rather than integrating a single forecast from a supposedly best guess of the initial state, it has been shown that a better approach would be to provide multiple separate forecasts with slightly different initial conditions, or different formulations of a forecast model (Palmer, 2000). This approach is called ensemble prediction and is used to estimate the forecast uncertainty. The probabilistic output of ensemble forecast system is a useful tool for end-users to base the decisions on, e.g. the impacts of hazardous extreme weather events.

In the ideal situation, the ensemble spread would equal the true probability distribution of forecast uncertainty. In reality, medium-range ensemble forecasts suffer from local forecast biases and also in most cases from too high forecast confidence compared to measured forecast uncertainty. Due to this, post-processing for ensemble forecast output is necessary to guarantee optimal forecast reliability and accuracy. In this process statistical post-processing methods are applied to the raw model output. Most of the recently used statistical methods share a general approach of correcting the current forecast by using past forecast errors, as has been done for deterministic forecasts in the so-called Model Output Statistics (MOS) procedure introduced originally by Glahn and Lowry (1972). This process makes use of information from prior forecasts and observations to produce probabilistic forecasts or to improve their reliability. The method providing the best outcome is dependent on the weather variable being forecasted. The calibration has been shown to be useful at a variety of forecast time scales including the lead times from few hours (e.g. Lugt, 2013) to two weeks (e.g. Wilks, 2009). Different statistical methods and approaches have also been widely used (Hansen and Emanuel. 2003, Rosgaard et. al. 2016, Wilks 2015).

This paper describes the calibration of European Centre for Medium-Range Weather Forecast (ECMWF) ensemble prediction system (ENS) forecasts. The calibration methods that were used are Gaussian distribution for temperature and Box-Cox t-distribution for wind gust forecasts. These calibration methods are currently in use of The Grand Limited Area Model Ensemble Prediction System, GLAMEPS. The GALMEPS model (Iversen et.al. 2011) and calibration of the model are developed by the HIRLAM-C consortium which consists of several European meteorological institutes. Compared to global models (like ECMWF), limited area models are able to produce finer spatial resolution output because computational resources are focused on a specific area instead of covering the whole globe. Therefore, these models can usually produce better forecasts, but the forecast length of limited area models is only two or three days which is much less compared to global models which provide forecasts up to 10-15 days ahead. In this study, our goal was to investigate whether the calibration methods that are used for calibration of GLAMEPS model, could be applied also for longer range ECMWF ENS forecasts in European domain.

In the I-REACT project, we utilize both the short term GLAMEPS forecasts and the longer term ECMWF ENS forecasts to provide reliable probabilistic forecasts for high-impact weather monitoring. Provided early warning products estimate the probability of occurrence of heavy rainfall, strong wind gusts, and extreme high/low temperatures, and are routinely produced across Europe. The forecast probability of the occurrence of different severe weather events is defined based on specific pre-defined thresholds which can be modified based on the end-users needs. In addition, the calibrated ensemble forecasts are provided as an input for weather dependent impact variables such as fire weather index and heat wave forecast.

FORECAST AND OBSERVATION DATA

The ECMWF operational ensemble forecast system (ENS) consists of 51 members computed twice a day at 0000UTC and 1200UTC. Temporal resolution of the forecasts is 3 hours for lead times up to 144 hours, and 6 hours for lead times from 150 to 360 hours. The ECMWF model covers the entire globe but for this study we only used the European domain. Forecasts were extracted on a 0.2° grid from 32.60°N to 73.40°N and from 26.00°W to 42.40°E (Figure 1). For calibration coefficient calculation, 2 meter temperature and 10 meter wind gust forecasts were interpolated to the observation station points.

Temperature and wind gust observations were gathered from European SYNOP (surface synoptic observations) stations. A plot of these station locations that where operationally available for calibration is provided in Figure 1. Also, the information of the station elevation was gathered for the calibration model definition.

Figure 1: Forecasting domain and station locations (dots) for the calibration and verification of ECMWF ensemble forecasts.

METHODS

Good (and useful) ensemble forecasts should produce no mean errors (bias); otherwise, the probabilities will be biased as well. The ensemble forecasts should also have the ability to span the full climatological range otherwise the probabilities will either over- or under-forecast the risks of anomalous or extreme weather events. This can be validated by comparing the spread-skill relationship, which should be positively correlated on average in well-calibrated ensemble forecasts. The calibration method that is most suitable for specific variable is mostly dependent on the error distribution that forecasts tend to have.

Calibration Methods

For 2 meter temperature, a Gaussian regression (e.g. Gneiting et.al. 2005) was used with the following parameters:

$$mean = a + b * ensemble_mean + c * model_elevation$$
$$stdev = exp(d + e * log(ensemble_std) + f * log(max(1,model_elevation))),$$

where *ensemble_mean* denotes the mean value and *ensemble_std* the standard deviation of the 51 ensemble members; the variable *model_elevation* indicates the average elevation (meters above the mean sea level) of each grid point in the ECMWF model.

The regression coefficients *a, b, c, d, e,* and *f* were estimated by using point observations and forecasts for the last 30 days and are updated once a week. Separate values were calculated for each lead time and for each forecast cycle independently. The coefficients were determined to be common for the entire region to obtain a large enough training data set. Another benefit of using common calibration coefficients for the entire domain was that forecast maps do not produce inconsistencies between different calibration areas.

For 10 meter wind gust, a box-cox t-distribution (Rigby and Stasinopoulos, 2006) was used with the following parameters:

*mu = a + b * ensemble_mean + c * model_elevation*
*sigma = exp(d + e * log(ensemble_std) + f * log(max(1,model_elevation)))*
*nu = g + h * ensemble_mean*
tau = exp(i),

where *mu* denotes the median of the distribution, *sigma* the variance, *nu* the skewness, and *tau* the kurtosis.

The above-mentioned model distribution was created for each grid point, and converted back to ensemble members by extracting evenly spaced quantiles from the distribution. The rank of the each member was maintained by reordering the members to same order as they have in the raw ensemble. The conserving of the members' order is essential if the ensemble forecasts are used as input for indexes that utilize more than one variable.

Verification Metrics

The reliability characteristics (bias and dispersion) of the probabilistic forecasts were defined with rank histograms (e.g. Wilks, 2006). The rank histogram illustrates in which bin of the ensemble forecast the observation falls. The rank histogram shows how well the ensemble spread of the forecast represents the true variability of the observations. In an ensemble with perfect spread, each member represents an equally likely scenario and the form of rank histogram is flat. A U-shaped form of the rank histogram indicates that the ensemble spread is too small and many observations fall outside the extremes of the ensemble. If a U-shaped rank histogram is asymmetric, the ensemble contains bias.

The Brier Skill Score (BSS) was used to diagnose the quality of the probabilistic forecasts predicting higher temperature and wind gusts. The Brier Score (Brier, 1950) measures the magnitude of the probabilistic forecasts errors computed over the verification sample. The Brier Score (BS) is calculated with the following formula:

$$\mathrm{BS} = \frac{1}{n}\sum_{i=1}^{n}(y_\mathrm{i} - o_\mathrm{i})^2.$$

The value of the probability forecast, y_i, is between 0 and 1 and the value of observation, o_i, is either 0 (no occurrence) or 1 (occurrence). The Brier Score ranges between 0 and 1 and the perfect score is 0.

The Brier Skill Score (e.g. Wilks, 2006) measures the relative skill of the probabilistic forecast over the sample climatology (reference forecast). The Brier Skill Score is calculated with following formula:

$$\mathrm{BSS} = 1 - \frac{BS}{BS_ref}.$$

The Brier Skill Score ranges between -∞ and 1. When the BSS results in positive values, the model is more accurate than the reference. A value of 0 indicates no skill over the reference model, while negative values indicate that the reference model is more accurate.

RESULTS

Figures 2 and 3 show the rank histograms for temperature and gust forecasts with shorter (upper) and longer (lower) lead times. As can be seen from Figure 2, the temperature forecasts tend to be underdispersive and negatively biased before calibration (red bars). Underdispersion is especially a problem in the beginning of medium-range forecasts which can be seen when comparing the amount of outliers of the upper and lower histograms. After calibration, the histogram (orange bars) is almost flat which indicates that calibration can improve the ensemble forecasts. The same kind of feature can be seen from the wind gust forecasts (Figure 3). However, contrary to the temperature forecasts, the wind gust forecasts exhibit positive bias.

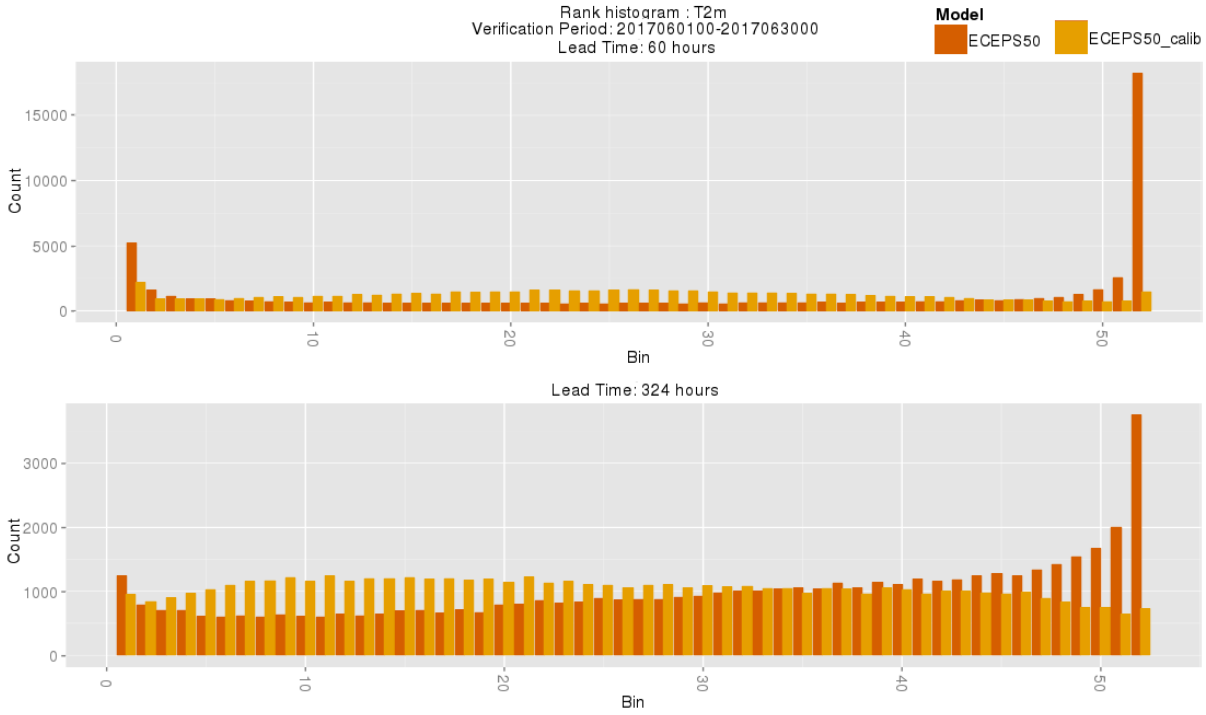

Figure 2: Rank histograms illustrating the under dispersion and negative (cold) bias of raw temperature forecasts with lead times of 60 (upper) and 324 hours (lower). (ECEPS50 = ECMWF-ENS)

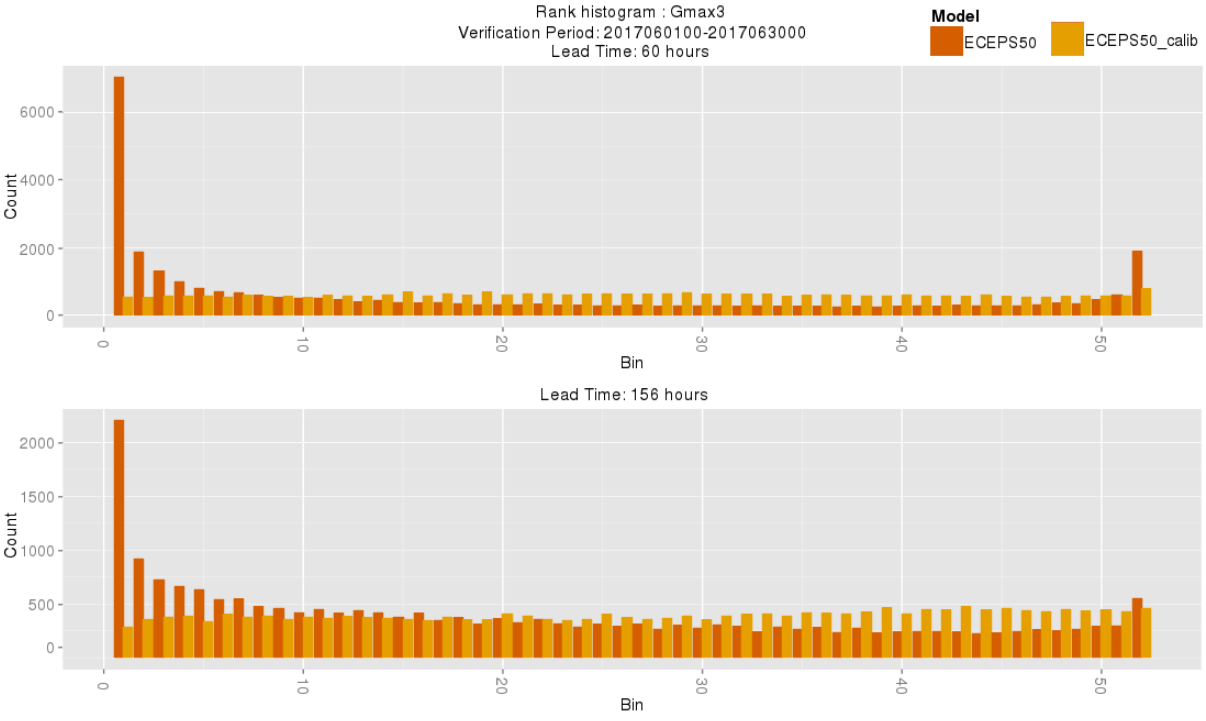

Figure 3: Rank histograms illustrating the under dispersion and positive bias of raw wind gust forecasts with lead times of 60 (upper) and 156 hours (lower). (ECEPS50 = ECMWF-ENS)

In Figure 4, the BSS for probabilistic temperature forecasts with a threshold temperature of 25℃ is shown.The verification results are plotted only for lead times when the forecast time is 12 UTC and the daily temperature is usually the highest. The sample climatology of the verification period is used as a reference model when calculating the BSS. Figure 4 shows that the BSS is better in the calibrated forecasts for all lead times. This result proves that our calibration model is capable to improve ensemble forecasts also in the higher part of temperature

distribution.

The BSS for probabilistic wind gust forecasts with a threshold of 15 m/s are shown in Figure 5. The verification results indicate that wind gust forecasts can be improved with calibration, especially with lead times of up to 240 hours. However, for lead times above 240 hours the raw and calibrated forecasts are generally equally good.

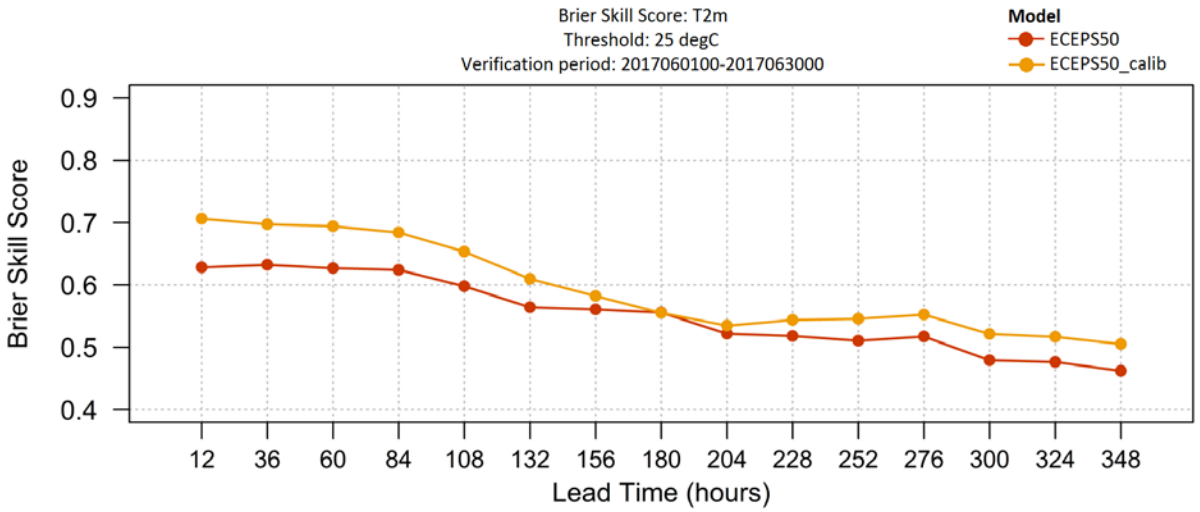

Figure 4: The Brier Skill Score for the probabilistic temperature forecasts (threshold 25°C)

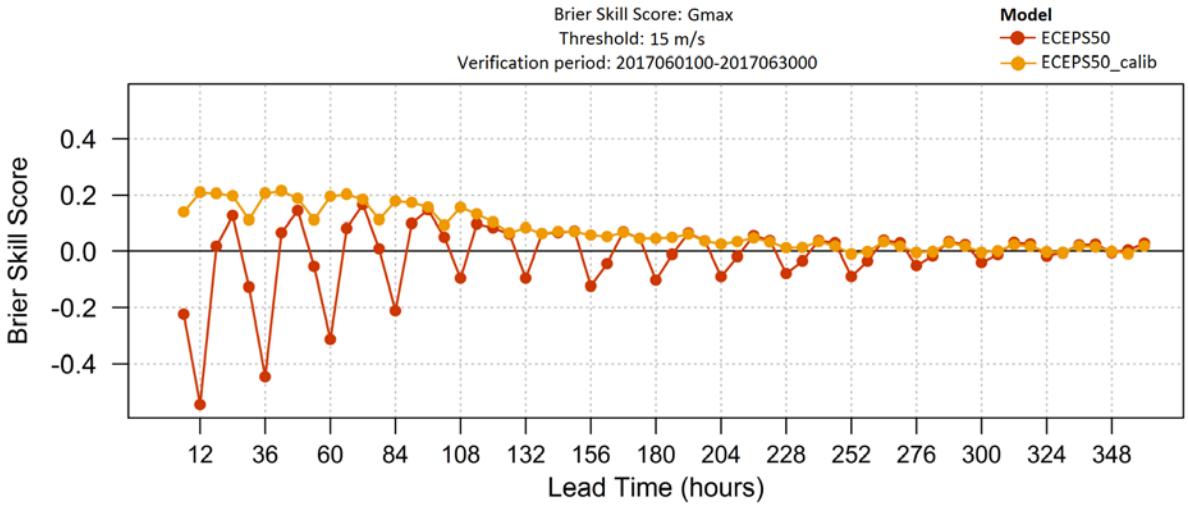

Figure 5: The Brier skill score for probabilistic wind gust forecasts (threshold 15 m/s)

Figures 6 and 7 illustrate the probabilistic weather forecasts for high temperature and strong gust respectively. Forecasts are based on the calibrated ECMWF ENS forecasts. The threshold for probabilistic temperature forecast is 37°C, and for probabilistic gust forecast 17 m/s.

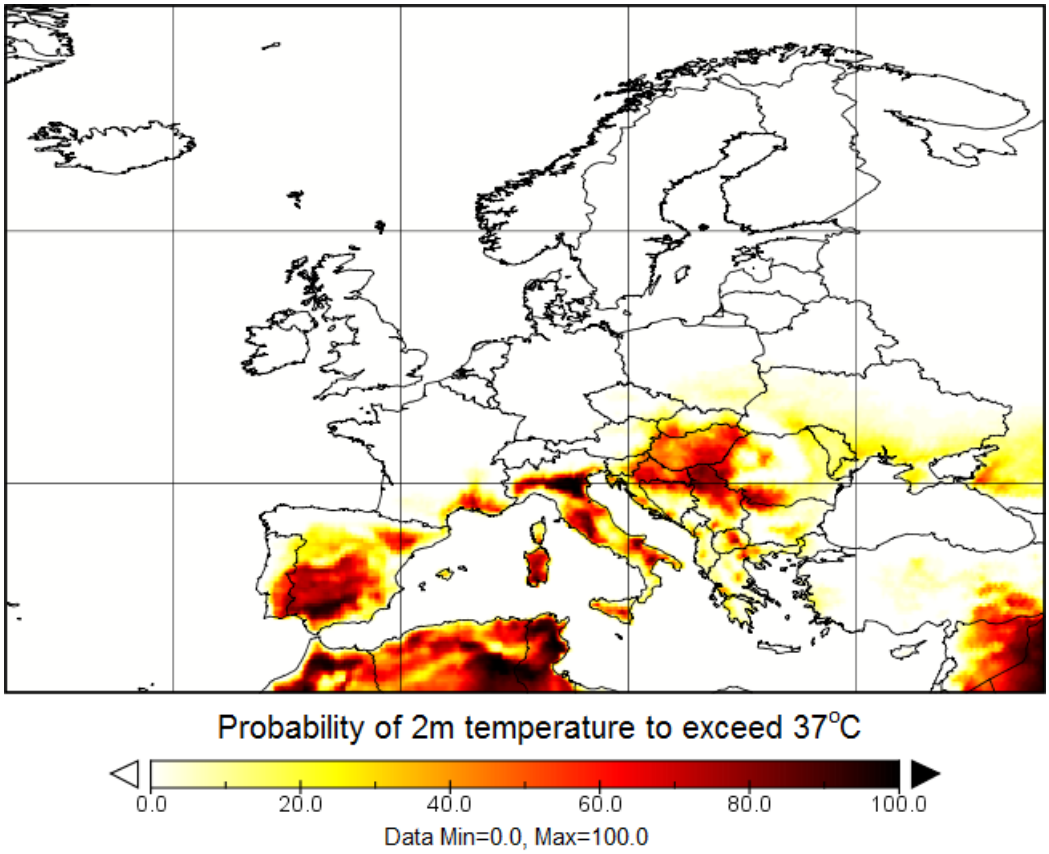

Figure 6: Probabilistic forecast for extreme high temperature, forecast valid time 4th August 2017, 15 UTC

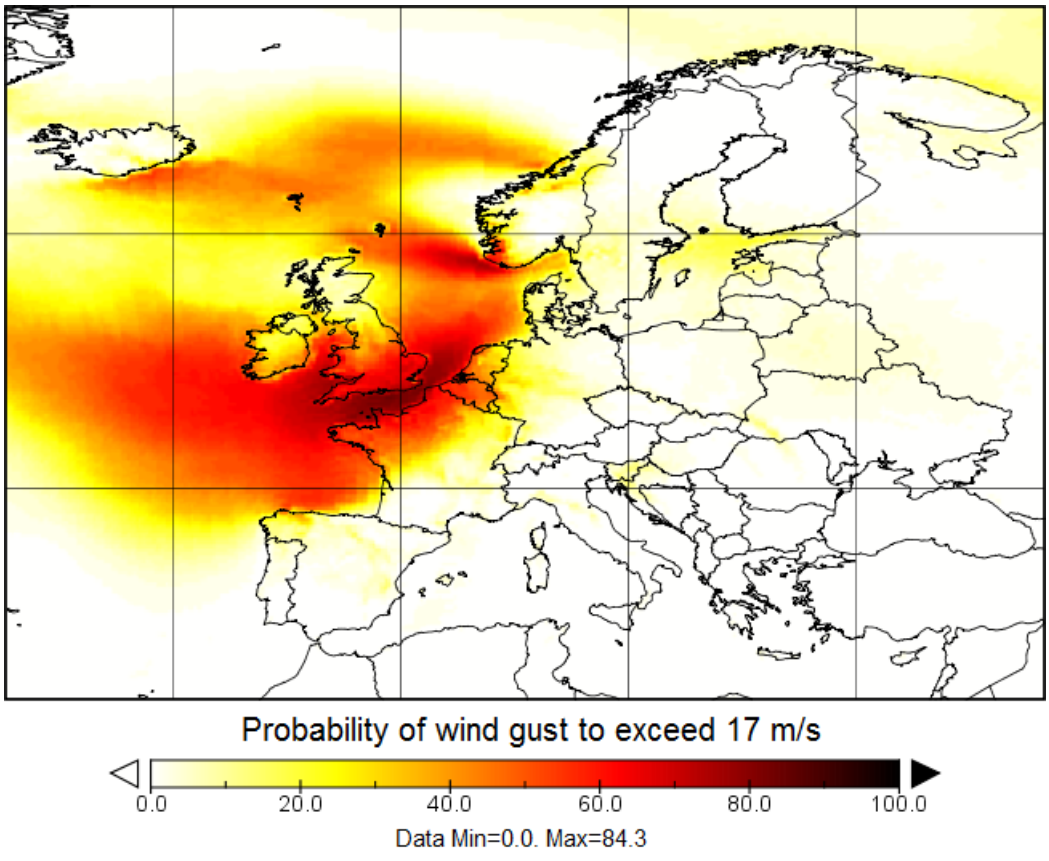

Figure 7: Probabilistic forecast for high wind gusts, forecast valid time 21st October 2017 12 UTC

CONCLUSION

In this paper we examined the effect of calibration for ECMWF ENS temperature and wind gust forecasts. The Gaussian distribution was used for temperature and a box-cox t-distribution for wind forecasts. The calibration was tested as an operational part of forecast post-processing. Therefore, calibration coefficients were calculated by using the past 30 day's forecast and observations pairs instead of huge amount of historical data which would be more time consuming. The calibration coefficient were updated once a week, and separate coefficients were estimated for each lead time independently.

The quality of these calibrated forecasts, compared to raw forecasts, was estimated using rank histogram and Brier Skill Score (BSS). The verification results showed that tested calibration methods improved the overall ensemble forecasts (whole range of values) and also the probabilistic forecast based on some higher threshold. The probabilistic temperature forecasts were better after calibration over whole lead time scale, but the probabilistic wind gust forecasts just up to 240 hours. This result is in line with the previous studies (e.g. Hagedorn, 2008) which have shown that with longer lead times the historical training period should be longer than 30 days. This seemed to be more common for variables whose distribution of the forecast error does not follow the normal distribution.

The purpose of these developed weather forecast products is to provide information of the upcoming extreme weather events early enough, so that necessary preparedness and mitigation actions can be made by the authorized experts. When providing calibrated ensemble forecasts instead of raw ones, we can provide more accurate probabilistic weather forecasts to the end users.

Since the verification results of calibration were promising for both temperature and wind forecasts, next steps would definitely be to test the calibration of the other parameters. The method that will be investigated for precipitation is the zero-adjusted gamma distribution that has been tested for GLAMEPS model.

ACKNOWLEDGMENTS

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Online clustering and classification for real-time event detection in Twitter

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ABSTRACT

Event detection from social media is a challenging task due to the volume, the velocity and the variety of user-generated data requiring real-time processing. Despite recent works on this subject, a generalized and scalable approach that could be applied across languages and topics has not been consolidated, yet. In this paper, we propose a methodology for real-time event detection from Twitter data that allows users to select a topic of interest by defining a simple set of keywords and a matching rule. We implement the proposed methodology and evaluate it with real data to detect different types of events.

Keywords

Event detection, Social Media, Clustering, Machine Learning, Twitter

INTRODUCTION

There is an unprecedented number of personal mobile devices (smartphones, tablets) that can offer high-end capabilities in terms of computational power, connectivity, and real-time collection of geolocalized data including multimedia contents such as audio, images, videos. Such technological innovations are significantly expanding the sensing power of communication networks, giving momentum to a massively distributed and user-driven data collection process known as "crowdsensing". According to the International Telecommunication Union (Sanou 2013) there are more than 6.8 billions mobile phone subscriptions in the world. This translates in almost one mobile phone subscription per person, and this figure is globally rising each year. People equipped with mobile devices act as a mass of multimedia sensors, which generate a significant amount of real-time data, especially via social media platforms such as Facebook, YouTube, Flickr, and Twitter. The use of on-line social media platforms, coupled with the ubiquity of mobile devices capable of providing geolocated multimedia contents, offers the opportunity to exploit the generated data in order to detect in real-time the occurrence of an event. This capability can be very useful, especially when unexpected events such as natural hazards or terroristic attacks occur. Such events require prompt detection in order to activate response procedures. Also, tracking other kinds of events such as recurrent daily phenomena or planned gatherings can provide insights that can be exploited in commercial domains such as targeted advertisement. Twitter is the most studied social network in the emergency domain (Simon et al. 2015), probably due to the ease of sending and extracting information and to its open data policy. Twitter is categorized as a micro-blogging service, which is a form of communication that allows users to send brief text messages (formerly up to 140 characters, recently updated to 280), also known as Tweets, or media such as photographs or audio clips. By default, user posts are public, and they can be automatically retrieved using Twitter's Application Program Interfaces (API), which can be freely used under the limitations specified in the terms of service (*Twitter REST APIs* 2018). As shown in (Vieweg et al. 2010), Twitter is also used to give situational information during emergency events: during the Boston Bombing in 2013 it has been estimated that 27,800,000 Tweets have been written about that event. Furthermore, the information provided by Twitter can become viral (i.e., spread rapidly and on a vast scale across the Web) very easily thanks to Retweets, which are generated when a user re-posts (forwards) a message from another user. For all the aforementioned characteristics, we select Twitter as the social media platform to investigate.

However, including data from social media in emergency management processes poses several challenges, including the availability of location, the truthfulness and accuracy of the shared information, as well as the big volume, velocity, and variety of data. In this paper we propose a methodology aimed to detect in real-time events from

an online social media network, and that can run on commodity hardware. The proposed methodology exploits machine learning algorithms such as clustering and classification and it is general with respect to the event type to be detected. Our methodology allows the end-user to define a set of relevant keywords and a matching criteria for each event of interest.

In the remainder of this paper we initially discuss related works and then we present our methodology. Next, we detail the implementation of the proposed methodology and show the results achieved with real Twitter data. Finally, we outline conclusions and future works.

RELATED WORKS

During the last decade, a number of studies have been done on event detection from social media data. Those who were most successful are volumetric approaches based on pre-selected keywords, like the one implemented in SensePlace (Maceachren et al. 2011), TEDAS (R. Li et al. 2012) and Twitcident (Abel et al. 2012), which enrich the emergency information using text semantics. However, these approaches use a predefined set of keywords to gather the initial data, hence they can detect only the event type for which they are designed for. Similar approaches are presented in (Marcus et al. 2011; Hila Becker 2011) where a Tweets' similarity metric based on a reference taxonomy is used. Another kind of approach is based on the Tweets' position, i.e. (Chen and Roy 2009) where a spatio-temporal analysis has been used to cluster Flickr photos, but this method is not designed to work with real-time data. Another method is the Topic Detection and Tracking (TDT), which had a lot of contributions in the past years such as (Yang et al. 1998; Allan et al. 1998). However, TDT works best with big documents and not with short messages like Tweets. Our work uses some ideas from the previous categories but it is different from all of them because it is based on a pipeline that involves: an online-clustering algorithm that uses a text similarity metric to group similar Tweets, a subsequent classifier to detect if an event happened, a scoring mechanism to rank the clusters containing the event, and a matching module to determine whether the event is among the user's interests. Such pipeline is generic and completely agnostic with respect to the event topic. Moreover, our approach can easily run on commodity hardware.

EVENT DETECTION METHODOLOGY

The concept of event has multiple definitions: it can be "a thing that happens or takes place, especially one of importance", or "a planned public or social occasion", or "each of several particular contests making up a sports competition", etc. We use the definition provided within the Information Retrieval (IR) community and reported in (Allan 2002): "an event is a flow of remarkable volume of temporally ordered messages" and we add to that a further constrain, i.e., that the ordered messages have to belong to the same topic.

In order to detect an event, we discretized the time in slots of size T, and denote by M the associated set of messages, each of which we assume to be composed by a multiset of words. We assume to have access to a given source, which produces a real-time stream of short text messages that we gather and process in a specific pipeline aimed to detect the occurrence of events matching with user-defined topics.

First, we apply to each message common pre-processing functions in order to remove not relevant contents. Next, we run an online clustering algorithm that groups similar messages together into a set of clusters C, where each cluster c_j is represented by its centroid r_j. At the end of each slot, we analyze C with a binary classifier in order to detect whether it contains an event or not. For the scope of this paper we assume that each slot contains at most one event, but the methodology can be easily extended to multiple events per slot. If the classifier detects an event, we assign a score to each cluster c_j and we select the highest in rank to identify the cluster that contains the event. Finally, we compare its content with a set of user-defined topics in order to decide whether the event (cluster) matches or not.

In the following subsections we detail each of the aforementioned steps of our methodology, which are represented in Fig. 1.

Text preprocessing

First, we apply common text pre-processing functions such as tokenization, stopwords and URL removal. Next, we apply a methodology to reduce inflectional forms and sometimes derivationally related forms of a word to a common base form. For this goal we can use either stemming or lemmatization. Stemming usually refers to a crude heuristic process that cuts the ends of words, and often includes the removal of derivational affixes. Lemmatization uses a vocabulary and morphological analysis of words, aiming to return the base dictionary form of a word, which is known as the *lemma*. A *stemmer* is normally faster but less accurate than a *lemmatizer*. The selection among such methods does not affect the validity of our methodology, and it can be made according to a trade-off between computational speed and accuracy depending on the application needs and on the cost of computational resources. An in-depth analysis of the pros and cons of such methods is outside the scope of this work.

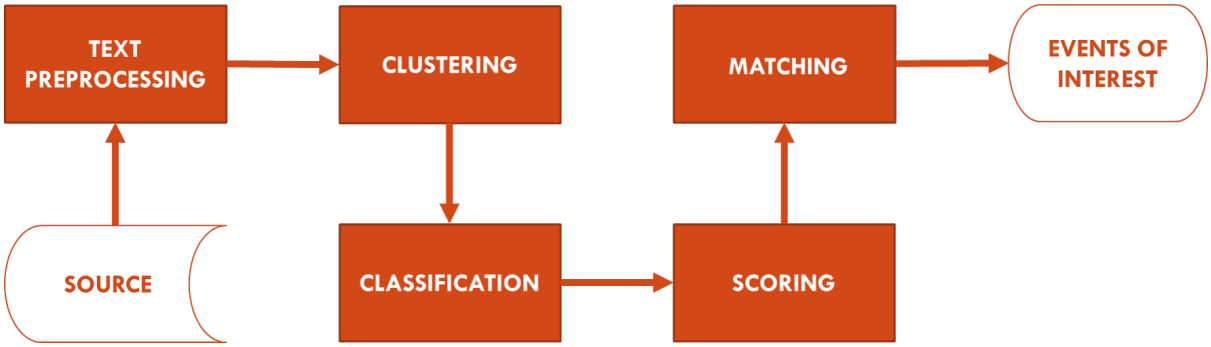


Figure 1. Block diagram of the proposed methodology

Clustering Algorithm

Some online (i.e. without initial knowledge) algorithms have been proposed in literature, e.g., (Liberty et al. 2014; Choromanska and Monteleoni 2011). However, the majority of them are based on k-means (Na et al. 2010), meaning that the maximum number of clusters have to be known a-priori. This assumption does not hold in our case because the number of clusters is assumed to be equal to the number of topics, which is unknown and can be very large. Other online algorithms, such as (Allan 2002; K. Li et al. 2011), can work with arbitrary number of clusters but they foresee heavy maintenance operations on clusters, e.g. merging, which prevent their real-time use in case of high throughput data such as the scenario we are considering. For the aforementioned reasons, we design a lightweight online and incremental (i.e. able to process real-time data) clustering algorithm that is structured in two phases: *attach* and *age*. The *attach* phase runs continuously with the objective to cluster incoming messages, while the *age* phase is executed every T, i.e., at the end of each time slot, with the aim to remove old and not relevant clusters. In the following paragraphs we detail such two phases.

The attach phase We represent messages M as well as clusters centroids R using the Bag Of Words (BOW)(Huang 2008) approach. We define a message $m_i = \{w_k, tf(w_k, m_i), \forall w_k \in m_i\}$, where $tf(w_k, m_i)$ is the Term Frequency (Huang 2008) of word w_k in the message m_i. We represent cluster centroids R in a similar way but with the Document Frequency $df(w_k, c_j)$ (Huang 2008) instead of the Term Frequency, i.e., $r_j = \{w_k, df(w_k, c_j) : \forall w_k \in m_i, \forall m_i \in c_j\}$, where:

$$df(w_k, c_j) = |\{m \in c_j : w_k \in m\}|$$

The clusters C are formed according to a similarity metric between a message m_i and a cluster c_j, i.e., $sim(m_i, c_j)$(Eq. 1), which sums all document frequencies of words that are both included in the message m_i and in the centroid r_j. Additionally, document frequencies of words in the centroid that are prefix of at least one word in the message m_j are added to $sim(m_i, c_j)$. In case multiple prefixes are found, we aggregate the longest matching one. If $sim(m_i, c_j)$ is below a certain threshold Th_s, m_i forms a new cluster, otherwise it is attached to the cluster having the highest sim. Ties are solved by randomly selecting the destination cluster.

$$sim(m_i, c_j) = \sum_{w_k \in m_i} df(w_k, c_j) \tag{1}$$

After a message m_i is attached to a cluster c_j, its centroid r_j is updated. In order to reduce the number of words in the centroids, we aggregate the document frequencies of words that are prefix of other ones, keeping the shortest word.

The age phase At the end of each temporal slot, the clusters are analyzed in order to understand if there is an event. Our goal is to have one event for each cluster and vice-versa (one cluster for each event) but it can happen that messages belonging to one event are split across more than one cluster. The age phase aims to avoid clusters growing too large and generic, thus attracting many topics, and to prevent the proliferation of very small clusters that represent topics no longer active. To tackle the first problem we remove the clusters older than a certain number Th_{a1} of slots, while to address the second one we remove the clusters which did not receive messages in the last Th_{a2} slots. When a cluster is removed, all its messages are deleted.

Classification

At the end of each time slot we have a set of clusters C and we want to remove the entire group if it does not contain any event. We achieve this goal by training a binary classifier and considering different set of features that can be grouped into four categories:

- Textual features: text metrics calculated using the words belonging to the set of centroids R, namely the Term-Frequency Inverse-Document-Frequency ($TFIDF$), which is computed according to its standard definition, normalized and averaged, considering each centroid r_j as a document and each word w_k as a term. The normalization is done with respect to the max tf and max idf.
- Temporal features: the Age of the cluster set $Age(C)$, which contains the cluster ages in terms of number of slots since their creation, and the cluster last updates $LU(C)$, which represents the most recent message attach time of all clusters.
- Dimensional features: they include the number of clusters $|C|$, the number of words of their centroids $size(R)$, how many new messages were attached to each cluster in the slot t ($\Delta_{c_j} = |c_j(t)| - |c_j(t-1)|$) over the initial cluster size $|c_j(t-1)|$ and over the total number of messages $|M|$ in the slot .
- Twitter specific features: for each cluster we count the number of followers (FR) and followees (FE) of the users that generated the messages included in the cluster.

We report in Table 1 the summary of the feature sets used.

Table 1. Feature sets used in the classification phase.

Textual	Dimensional
$TFIDF = \{\sum_{w_k \in r_j} tfidf(w_k, r_j, R) \forall r_j \in R\}$ $norm(TFIDF)$ $\mu(TFIDF)$	$\|C\|$ $Size(R) = \{\|r_j\|, \forall r_j \in R\}$ $\Delta_C = \{\Delta_{c_j}, \forall c_j \in C\}$ $\Delta_{\%new} = \{\Delta_{c_j}/\|M\|, \forall c_j \in C\}$ $\Delta_{\%new_c} = \{\Delta_{c_j}/\|c_j\|, \forall c_j \in C\}$
Temporal	**Twitter**
$Age(C)$ $LU(C)$	$FE = \{\|followee_{c_j}\|, \forall c_j \in C\}$ $FR = \{\|followers_{c_j}\|, \forall c_j \in C\}$

To train the binary classifier, we actually use as features the minimum, maximum, mean and variance of all the aforementioned features sets.

Scoring

If the binary classifier detects the presence of one event in the cluster set C, we rank the clusters in order to find the one that contains the event. Assuming that an event generates event-specific messages, i.e., messages containing a set of specific words in relation with the event topic, we have to spot the most specific cluster. In order to do so, we use the average tfidf of the words in each cluster. Also, assuming that the occurrence of an event corresponds to an increase in the volume of event-specific messages, we have to find a cluster that has substantially grown in the last slot, without favoring clusters of a specific size. For this purpose we use the percentage of new elements over the total number of messages in the temporal windows $|M|$ and the *0.5 double normalization* of the percentage of new elements being added to the cluster c_j over the cluster size $|c_j|$.

The formula of the cluster score $score(C_j)$ is reported in Equation 2. We select the cluster with the highest score as the cluster that represents the event.

$$score(C_j) = \frac{\sum_{w_k \in c_j} tfidf(w_k, c_j, c)}{|c_j|} * \frac{\Delta_{c_j}}{|M|} * \left(0.5 + 0.5 * \frac{\Delta_{c_j}}{|c_j|}\right) \tag{2}$$

Matching

Because all previous steps are agnostic with respect to the event topic to be detected, a further one is required in order to understand if the identified event is within the user-defined topics. We assume that the system lets users to define a set of words for each topic of interest, and a set of corresponding rules that are tested in the matching phase. For example, if at least one word in the user-defined set is found in the cluster centroid (not null intersection), or else, if all words of a user-defined set are included in the centroid (inclusion), then the cluster is selected. Any rule can be defined using simple algebra of sets. Note that all user-defined words must be either stemmed or lemmatized (depending on the technique used) in order to be comparable with the centroids. This approach keeps the methodology general to any kind of topic.

IMPLEMENTATION AND RESULTS

We implement the methodology using many technologies and frameworks, as shown in Fig. 2. We use a streamer to process real-time Twitter messages, implementing it in Python using Twython[1]. We temporally store Tweets in a MongoDB database[2]. The text processing phase is implemented using the Natural Language Toolkit (NLTK)(Xue 2010) while the clustering algorithm is implemented using Cython[3], which increase by 5 times the performance with respect to pure Python implementations. For the classification phase we manually label some cluster sets with the help of a Python script, then we analyze the data (to study feature correlation and to compare the performance of several machine learning classifiers) using Weka[4]. We implement the final classification algorithm, the Scoring and the Filter blocks in Python.

The Python distribution used in our work is Anaconda[5] 4.1.1 which includes, scipy[6], numpy[7], scikit-learn[8] and pandas[9].

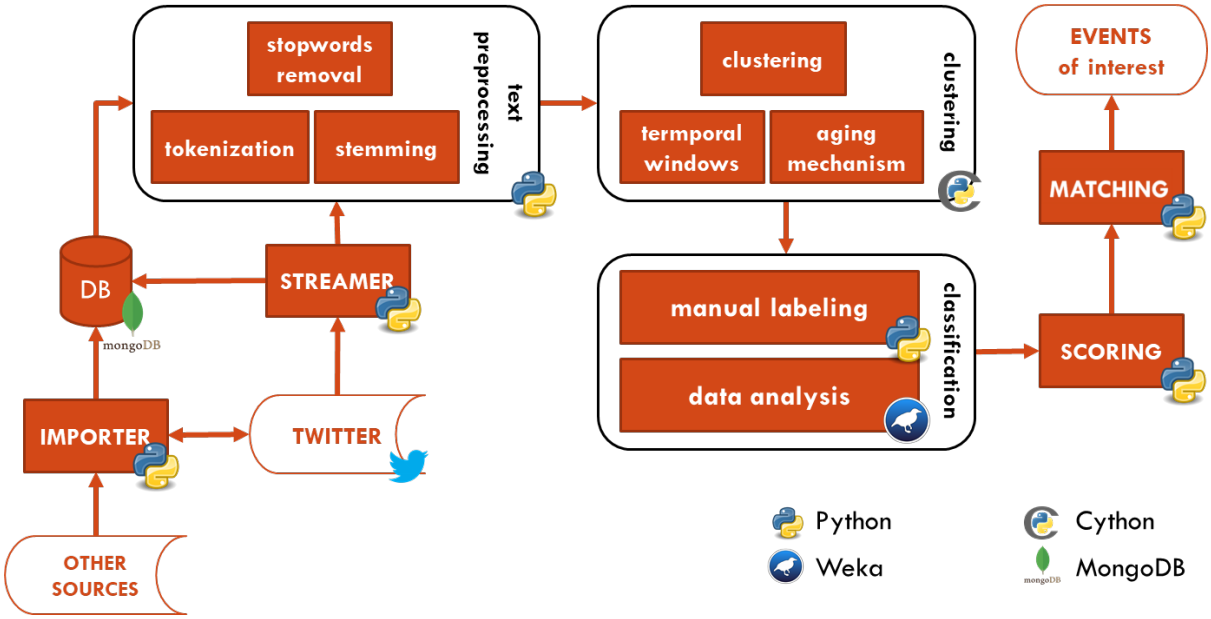


Figure 2. Block diagram of the implementation.

We use the Twitter Streaming API to gather Tweets in real-time (Andypiper and Niall 2015; Morstatter et al. 2013), knowing that this API gives up to 1% of the entire Twitter stream and that it can be filtered using several criteria, including keywords, language, position, etc. A common approach is to specify a set of words in order to limit the volume of messages but, as explained before, it is not viable for our goal that is to implement a generalized event

[1]https://twython.readthedocs.io/
[2]https://www.mongodb.com/
[3]http://cython.org/
[4]https://www.cs.waikato.ac.nz/ml/weka/
[5]https://www.continuum.io/
[6]https://www.scipy.org/
[7]http://www.numpy.org/
[8]http://scikit-learn.org
[9]http://pandas.pydata.org/

detection. Instead, we request all geolocalized messages (i.e., Tweets having latitude and longitude coordinates) in a specific language. The language is required because we use either a *stemmer* or a *lemmatizer*, both of which are language dependent, while the geolocation can help to identify where detected events take place and, at the same time, to reduce the number of Tweets to be processed.

For evaluating the implementation we capture and analyze in real-time an Italian stream from the 4th October 2016 to 15th March 2017[10].In order to train the binary classifier, we manually label 2000 randomly selected temporal-windows of 15 minutes (about 20 days). Using this training set, we apply a subset evaluation(Witten et al. 2016) which uses a greedy forward search to select the best feature set.

As a result, we find the following features as the most significant ones:

- $\mu(\{|c_j| \, \forall c_j \in C\})$: mean clusters size
- $\mu(\Delta_C)$: mean number of new tweets in the clusters
- $\max(\Delta_C)$: max number of new tweets in the clusters
- $\mu(TFIDF)$: mean TFIDF over the cluster set
- $\max(TFIDF)$: max TFIDF over the cluster set
- $Var(TFIDF)$: variance of TFIDF over the cluster set
- $\mu(norm(TFIDF))$: mean $norm(TDFIDF)$ over the cluster set
- $Var(norm(TFIDF))$: variance of $norm(TDFIDF)$ over the cluster set
- $\max(norm(TFIDF))$: max $norm(TDFIDF)$ over the cluster set
- $\min(\Delta_{\%new})$: minimum percentage of new elements in a cluster over the total number of new elements
- $Var(\Delta_{\%new})$: variance of the percentage of new elements in a cluster over the total number of new elements
- $\mu(\Delta_{\%new_C})$: mean percentage of new elements in a cluster over the total elements added to the same cluster

We try several binary classifiers and we select Random Forest (Biau 2012) using a ten fold cross-validation on the manually labeled training set, because it achieves the best results in term of Accuracy and F-Score, which are 94.6% and 86.7%, respectively.

The positive class represents the presence of an event in the analyzed temporal window and the negative class the absence of it.

The chosen parameters for the algorithms are:

- Slot time $T = 15min$;
- Clustering attach threshold $Th_s = 0.6$;
- Clustering aging threshold Th_{a1} (max time to live for a cluster) = 20 T (5 hours);
- Clustering aging threshold Th_{a2} (max time slots without receiving messages) = 2 T (30 min);

These parameters allow to keep under control the number of cluster (below 500), thus enabling a fast execution also on commodity hardware (we use a desktop computer[11]).

We report here the results achieved with three different event types. In detail we analyze:

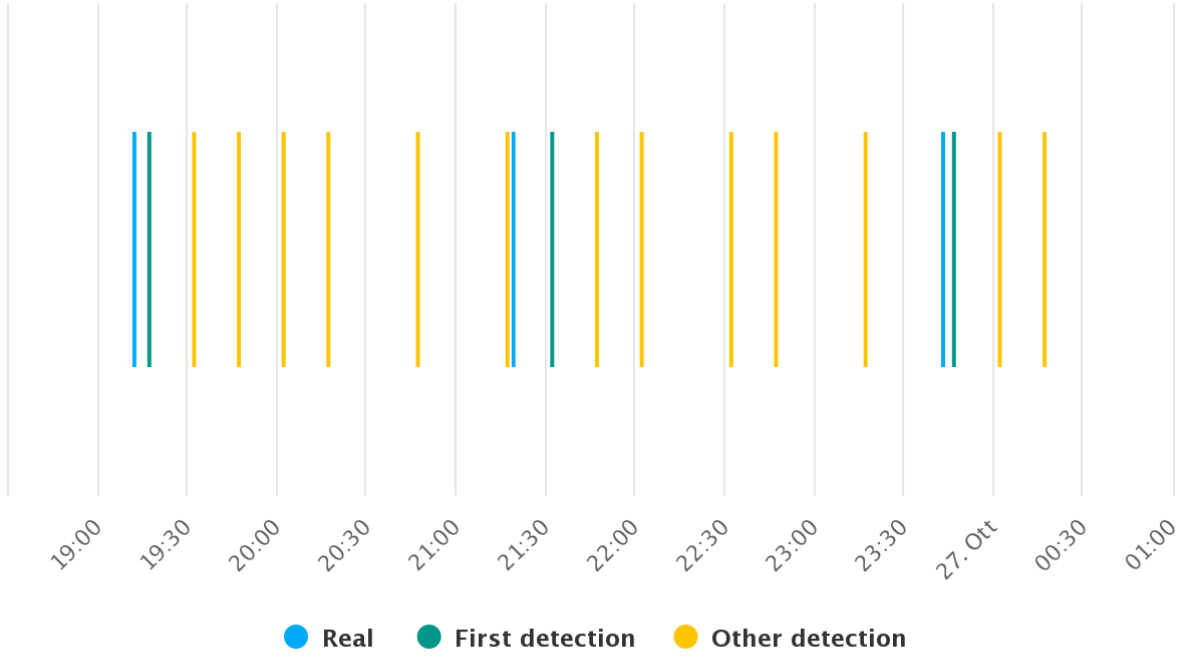
- One unplanned events - 26th October 2016: Earthquake in Central Italy;
- One recurrent events - 7th March 2017: nothing happens in the morning except the awakening of people that write “good morning to their friends”;

[10]On average 38000 tweets per day
[11]Intel® Core™ i5-7400T (3 GHz) - 16 GB RAM - Windows 10 - Python 3.5.2 64 bit

- One planned events - 7th March 2017: a Champions League match between Napoli and Real Madrid was played in the evening.

In the first case, we use the keyword *earthquake* in our final Matching module. This earthquake had 3 strong shakes in the same day[12], which are represented in Fig. 3a with blue lines. In the same Fig., we represent with green lines the first detections after each real shake occurred, while all subsequent ones are shown in yellow. In Fig. 3b and Fig. 3c we report the word cloud of the first and second shake, respectively.

(a) Earthquake - 26 October 2016 (Central Italy)



(b) Word cloud after first shake.

(c) Word cloud after second shake.

Figure 3. Earthquake Detections and Word Clouds

The word clouds can be effectively used to understand the topic of the event. In Fig. 3b (first earthquake shake) the biggest words are “terremot” and “scoss” that are the stemmed version of the Italian words “terremoto” and “scossa”, which mean “earthquake” and “shake”, respectively. Another relevant word is “fort”, which is the stemmed version of “forte” that means “strong”. In Fig. 3c we can see “ancor”, which is the stemmed version of “ancora” that is “again”, and this helps to understand that we are speaking about a new shake. The first shake is detected after 5 minutes, while the second shake is detected after 13 minutes. The third, and last, shake is detected after 4 minutes but its word cloud is very similar to the second shake and it is omitted for brevity.

[12] https://en.wikipedia.org/wiki/October_2016_Central_Italy_earthquakes

We report in Fig. 4 the other two cases (recurrent and planned event), for which we use for the matching the word "buongiorno" ("goodmoring") and "Napoli" (name of one of the two teams playing the match), respectively.

In Fig. 4a we show the volume of Tweets and the corresponding number of clusters over time. We represent with a yellow bar the timeframe in which the detections of the "buongiorno" event occurred. We count 11 detections in a timeframe of 2 hours. A clear peak is correspondence to the start of the football match is clearly evident from the graph. We note also that the total number of clusters stays well under 500 also in correspondence of the volume peak, confirming the robustness of our aging procedures. In Fig. 4b we plot the word cloud of the "buongiorno" event, which is dominated by the keywords "buon" and "giorn": the stemmed version of "buon giorno" that is "good-morning".

In Fig. 4d and Fig. 4c we show the detections of the football match and the word cloud of the first detection. The detections happened in proximity of the match kick-off (20:45) and end (22:15), while the word cloud are dominated by the stemmed names of teams that played the match, i.e., "Napol" and "Real Madrid".

CONCLUSIONS AND FUTURE WORKS

We have proposed a methodology for detecting any kind of event in real-time using Twitter streams. We allow the user to select the event topics to be detected by inserting a set of keywords and a matching rule for each topic of interest. We realized an implementation of such methodology and tested it with real data in three different cases. We verified that our approach is able to quickly detect all tested events and that the implementation was able to smoothly run on common hardware (desktop pc).

Future work will include a wider evaluation, an additional labeling for the event classifier, an optimization of the thresholds in order to improve the performances in terms of detection speed and reduce the clustering complexity. Additionally, we will test our solution with different similarity metrics and with word embedding techniques to evaluate eventual performance improvements. Finally, we will try to detect the location of the recognized event based on the tweets and to produce a panic map in near real-time.

ACKNOWLEDGEMENT

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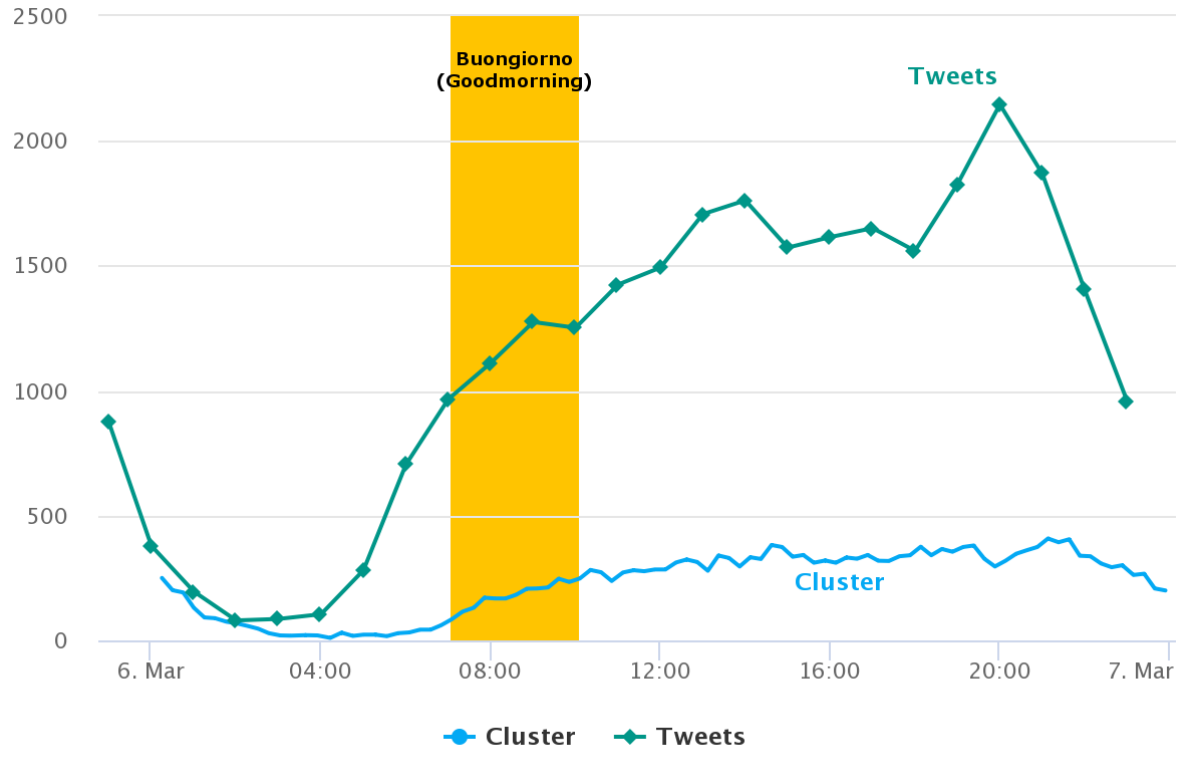
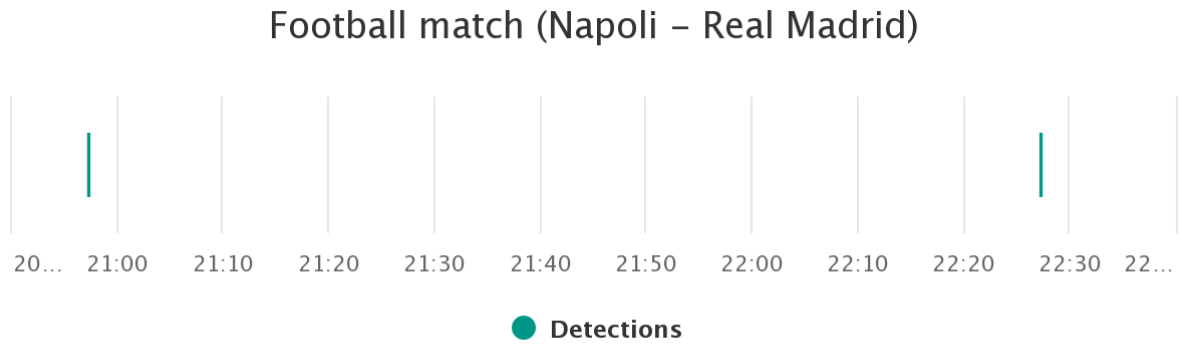


(a) Tweet volume and cluster number over time. The yellow bar represents the temporal window in which the the Good-morning event was detected (11 detections within 3 hours).

(b) Good-morning detection - Word Cloud

(c) Football match detection - Word Cloud



(d) Football match detections

Figure 4. Detection without filter module

Intelligent Utilization of Dashboards in Emergency Management

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ABSTRACT

Effective decision-supporting visualization is critical for strategic, tactic, and operational management before and during a large-scale climate or extreme weather emergency. Most emergency management applications traditionally consist of map-based event and object visualization and management, which is necessary for operations, but has small contribution to decision makers. At the same time, analytical models and simulations that usually enable prediction and situation evaluation are often analyst-oriented and detached from the operational command and control system. Nevertheless, emergencies tend to generate unpredictable effects, which may require new decision-support tools in real-time, based on alternative data sources or data streams. In this paper, we advocate the use of dashboards for emergency management, but more importantly, we propose an intelligent mechanism to support effective and efficient utilization of data and information for decision-making via flexible deployment and visualization of data streams and metric displays. We employ this framework in the H2020 beAWARE project that aims to develop and demonstrate an innovative framework for enhanced decision support and management services in extreme weather climate events.

Keywords

Emergency Management, Natural Disasters, Dashboards, Business Intelligence, Decision Support Systems.

INTRODUCTION

2017 saw an onslaught of natural disasters in North America, including a series of devastating Hurricanes Harvey, Irma, and Maria, a severe earthquake in Mexico, wildfires in California, and a massive-scale blizzard that struck the entire central-eastern part of the USA. This trail of devastation caused thousands of casualties, hundreds of billions of dollars in damages, and massive disruptions of normal life – and has shown the difficulty in coping with natural disasters in developing countries like Mexico and Puerto-Rico as well as super-developed countries like the USA. The difficulties and tremendous efforts needed for preparation, absorption, and recovery, have further raised the global awareness of the need for holistic national emergency management agencies, that would be equipped with state-of-the-art technology to run the operation – before, during, and after the emergency, in order to reinstate normal routine as fast as possible, and to prevent the emergency from escalating towards a disaster or a crisis.

beAWARE is an EU-funded project (#700475) to deliver a prototype disaster management system for extreme weather conditions. beAWARE focuses on flood, forest fire, and heatwave scenarios. The beAWARE platform is an end-to-end solution for collecting information from multiple data sources – such as end users, social networks, sensors, and data providers – analyzing it, predicting and assessing emergencies, alerting the public, and managing first responders' activities. (beAWARE 2017).

As part of beAWARE, we were required to provide a comprehensive solution to visualize decision-supporting information to senior authority officials, decision-makers, and stakeholders (e.g., mayor, chief inspector, or head of emergency services). This resulted in the need to consider various options for advanced visualization that would cover the various requirements made by the operational stakeholders who participate in the project.

We decided to tackle this problem as a management problem similar to the one faced by decision-makers and managers in everyday business contexts, through the use of Business Intelligence & Analytics (BI&A) –

techniques, technologies, systems, practices, methodologies, and applications that analyze critical business data to help an enterprise better understand its business and market and make timely business decisions (Chen, Chiang, and Storey 2012).

BI&A is mostly used in business-related applications, such as financial analysis, sales predictions, supply chain management, operational performance tracking. This is mostly due to the compelling need for quantitative metrics in the decision-making processes associated with these business practices, and the availability of the underlying data in enterprise information systems, including Transaction Processing Systems (TPS), Management Information Systems (MIS) Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM) solutions.

Applying BI&A to emergency management is not as trivial and straightforward as one would assume at a first glance. The challenges include real-time data and data-source availability, decision-making and analysis dynamics, and visualization challenges. All of these may be present in business contexts as well, but are not supposed to be resolved under pressure and time-critical life-saving decisions do not depend on them. This is also probably one of the reasons for the scarce literature on the application of business intelligence dashboards to emergency management in general and in the context of natural disasters specifically.

With a platform like beAWARE in place, the problem of data and data-source availability is significantly reduced, due to the interconnectivity that beAWARE provides among multiple sensor and sources of information, analytic services, and presentation services – all of which are interoperating as a system-of-systems to deliver value to decision makers, control center officers and analysts, rescue teams, and the public.

The main turning point in our approach is the facilitation of a generic architecture, which allows for the reception of any data stream into a consolidated database, flexible definition of data visualization and display settings for each interesting data stream, and an extendable set of services to conduct processing and analysis of the incoming data streams in order to create new, enhanced information streams that provide greater value for the decision-makers.

The rest of this paper is organized as follows. First, we provide an overview of related work in the area of emergency management systems and business intelligence dashboard applications in this domain. Next, we review the publicly-available operational requirements for decision-supported visualization derived from the associated beAWARE Project deliverable. Third, we describe a **framework for effectively delivering and visualizing decision-supporting information to the decision-makers in real-time, before and during an emergency,** which utilizes the end-to-end collaboration facilitated by the beAWARE technology platform. Finally, we conclude the paper and outline further research plans.

RELATED WORK

Emergency Management Systems (EMS)

Emergency management (EM) is the iterative and comprehensive handling of emergency-related tasks, including pre-emergency mitigation, near-emergency preparedness, in-emergency response, and post-emergency recovery. A Command & Control Center (C3) is typically in charge of coordinating the activities of various workforces – police, firefighters, medical teams, and crisis response teams (e.g., hazardous material squads, collapsed building rescue and evacuation forces, etc.) (Dusse et al. 2016).

A study of the command and control (C2) architecture in the wake of the Kobe earthquake in Japan, 1995, has argued that the main goal of the C3 (a.k.a. Emergency Room) is to maximize the efficiency of the disaster response field teams (Kuwata, Ishikawa, and Ohtani 2000). This can be done by: a) real-time map and map-placed object sharing; b) informative image sharing for enhancing situational awareness; c) supporting multi-modal communication including voice (live and recorded), text (typed and handwritten), and map cues; d) monitoring the safety and security of the field team members.

The proposed monitoring, collaboration, and control mechanisms call for the implementation of complementary mechanisms on the side of the C3, including map-based functionality and data visualization and interaction. This has been the dominant approach to emergency management command & control over the past two decades. A similar approach could be found in a command and control system for emergency management, called Command Post, proposed for integrating and visualizing data from different information sources on a single visualization interface, as well as providing a communication and coordination medium for different First Responder Team members (Bakopoulos et al. 2011). The architecture relied on a central Real-time Information Merging and Visualization C2 application. The C2 supports the command team in interactions with First Responders, and controlling the reaction to events during an emergency.

On the other end of emergency response system functionality, the strategic purposes and goals of emergency response decision support systems (ERDSS) are in assisting the authorities to enhance their emergency response capabilities mainly through early warning, contingency planning and plan evaluation, coordinating and commanding emergency response activities, and managing critical resources, and provide *knowledge* (Shan et al. 2012). Considering these roles, the following processing centers (with corresponding modules) and their capabilities were proposed, on top of the tactical management functionality:

- **Emergency Early Warning Service**: collect safety, risk, and asset information; analyze data and predict trends; determine security thresholds; provide continuous risk estimation.
- **Emergency Plan Management Module**: analyze emergency risks and requirements; classify emergency, disaster, and crisis conditions; prepare, model, and simulate emergency plans; test, validate, and analyze emergency plan effectiveness; supervise emergency plan execution; gather improvement requests.
- **Command and Coordination Center**: identify and confirm the severity of the emergency; monitor the emergency response effort; make emergency response decisions; coordinate multiple organizations to conduct rescue work; assess the level of victims' satisfaction; determine the necessary rescue measures.
- **Emergency Relief Supplies Management Module**: determine relief supplies categories and quantities; provide routing algorithms, modeling and simulation; provide logistics operation and coordination; manage relief supplies distributions; collect relief supplies and victims' satisfaction feedback; provide instructions on how to execute emergency rescues.
- **Emergency Knowledge Bank**: store and retrieve emergency management knowledge: procedures, protocols, plans, statistics, historical data and reports, lessons learnt from similar cases, specialist and specialty directory, emergency services directory, population directory.
- **Emergency Finance Budget Management**: provide financial planning, budget allocation, costing, accounting, and overall cost estimates.

Information Visualization (InfoVis) is a research area that focuses on design and development of new presentation approaches, visual layouts, visual interaction methods, data manipulation and transformation, and insight generation for information search, information exploration, and knowledge acquisition, for the purpose of performing various heterogeneous analysis tasks (Nazemi et al. 2015). A study of InfoVis applications in EM classified and ranked the sources of information, visual paradigms, visualization techniques, and interaction techniques used in studies on EM systems for various tasks and scenarios (Dusse et al. 2016). Not surprisingly, the interactive 2d-map was found to be the most common interactive visualization technique. Another interesting finding is that the common techniques of information visualization can be applied in response to any emergency scenario, as most of the studies were generic and only a small portion of them focused on specific scenarios. A significant portion of the applications is around pre-emergency mitigation and preparation, and not only around the response to an ongoing emergency situation. However, the applications for the post-emergency recovery phase are the least-addressed.

The authors did not include clear definitions of the classified techniques; hence it is difficult to understand what exactly is meant by some of the terms they used. The classification of cognitive tasks, such as information searching, event management, task assignment, decision making, data analysis, or interaction with other users, is clearly missing in this study. Hence, the findings cannot be attributed to cognitive tasks that are performed during each phase.

Studies have shown that bombarding the user with information is not necessarily helpful in closing knowledge gaps, and may even generate stress and discomfort among the users due to their inability to cope with the flow of information (Saaty 2008) . Strategies for information visualization to improve clarity and reduce uncertainty include clustering, partitioning, 2D-binning, and abstraction – usually in 3-4 layers (Novotny 2004).

Risk Management

One of the primary purposes of EMS is to reduce risk, which explains why "emergency management" and "risk management" are often used interchangeably. EMS can assist in risk management by promoting decision making for risk probability and impact reduction. Therefore, each object or concept that generates significant risk or could be severely impacted by risk should be clearly visualized to the user, as well as the risk magnitude, in order to promote prioritized treatment. Sources of risk should be clearly distinguished from objects at risk, including persons, assets, and processes.

The Risk Management (RM) literature comes mostly from domains in which RM is a primary and critical activity, e.g., project management, systems engineering, and information technology. Various associations and large-scale organizations have developed RM frameworks, both as part of general management frameworks and as dedicated risk-centered approaches. Leading standard providers are the Project Management Institute (PMI), International Organization for Standardization (ISO), National Association of Space and Aviation (NASA), National Institute of Standards and Technology (NIST) and International Council on Systems Engineering (INCOSE). The ISO 31000 Risk Management Standard defines a framework for risk management, which includes an iterative risk analysis process, and concurrently, ongoing communication and monitoring (Conforti et al. 2011; SRA 2015; Purdy 2010). An illustration of the ISO 31000 framework is shown in Figure 1.

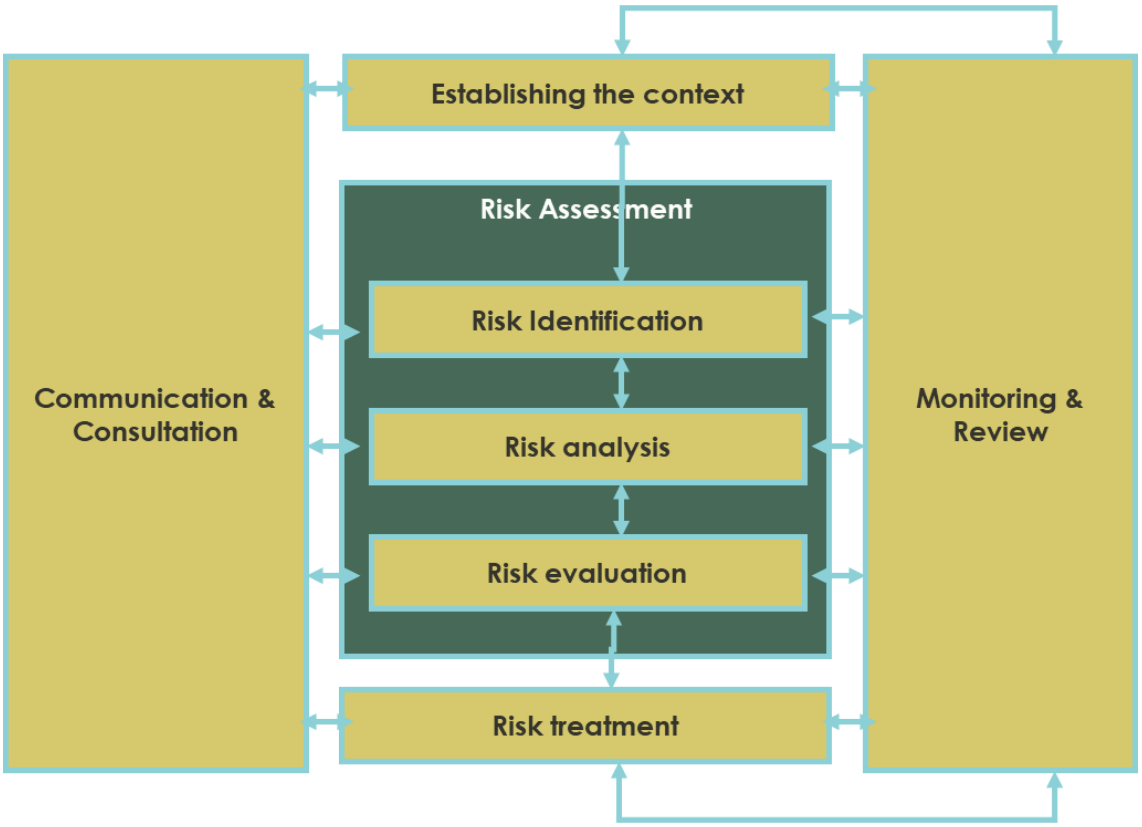

Figure 1. The ISO-31000 Risk Management Process

Business Intelligence and Dashboards in Emergency Management

Business intelligence & Analytics (BI&A) technology, often called "dashboards" by professionals and users alike – due to the resemblance of some of the common metric displays to analog gauges or light panels – has been a critical decision making tool in organizations for the past two decades (Chen, Chiang, and Storey 2012), and has gone through various evolutionary phases, especially reaching new peaks of applicability due to the "big-data" revolution of the past several years.

However, BI&A applications in emergency management remain scarce. This is due to several reasons, according to (Schlegelmilch and Albanese 2014): First, Emergency Management Agencies (EMAs) overemphasize the aggregation and consolidation of information for static presentation, and at the same time underemphasize the requirements for data management and insight creation. Second, available analysis or data presentation available in EMS platforms is typically limited to two-dimensional static data analysis based on end-user uploaded or manually-entered data. This does not allow real information-reliant decision making or insight generation.

A study of interactive dashboards to assist foodbanks in countries struggling with food insecurity, found that users need not only static, raw information to be presented to them, but also the ability to explore, connect, and filter data and data artifacts using the dashboard user interface (Desai, Jiang, and Davis 2016). While these conclusions are probably applicable to dashboards in general, the foodbank case is an interesting combination of economy and emergency that considers the unique characteristics of the food insecurity domain. Food banks receive donations

of food and distribute the food through various channels to provide for hungry populations. Making decisions is difficult due to uncertainty on both the supply and demand, and lack of access to structured information at different organization levels.

A study on the communication and visualization of emergency information in emergency management systems in Australia (Surakitbanharn and Ebert 2017) found that the authorities used an on-line dashboard to provide information to the public about the current state-of-affairs, including some counters (number of emergency news reports, road closures, weather warnings, power outages), an on-map display of events, and useful information like contact details and advice to the public on how to react to various incidents. Reportedly, this application has led to the overall situational awareness of the public. However, the study does not indicate whether dashboards were used for enhancing situational awareness among emergency managers and supporting their decision-making processes at various levels.

Finally, trying to balance the amount of information delivered to decision-makers in emergency control centers, to account for the dynamics of presentation and visualization needs, an architecture for emergency management dashboards has been proposed in (Nascimento, Vivacqua, and Borges 2016). The authors observed emergency control centers and learned that: a) emergency managers are overwhelmed with reports and data from multiple sources, b) they often ignore information that may be relevant to the decisions they make, c) information is stored without filtering or processing, d) visualization is static by design, with no possibility of customization, and e) new information requirements are generated and in the absence of supporting functionality the gap is closed by other means such as auxiliary applications, spreadsheets, and workarounds or manipulations on the available functionality. Considering these observations, the authors searched for an architecture that would allow users to do the following functions: 1) Access information from multiple data sources, 2) Analyze information, 3) Visually explore information, 4) Change or customize views according to context, and 5) Share visualizations and interact with teammates.

The architecture proposed by (Nascimento, Vivacqua, and Borges 2016) is illustrated in Figure 2 below. It consists of the following modules: "Extractor Module", "Collaboration Module", "Storage Module", "Presentation Module", "Selection Module", and "Interface Module". Excluding the "Interface Module", which runs on the Client, all other modules run on a Server. This architecture is a good basis but has some limitations that we address in the next section.

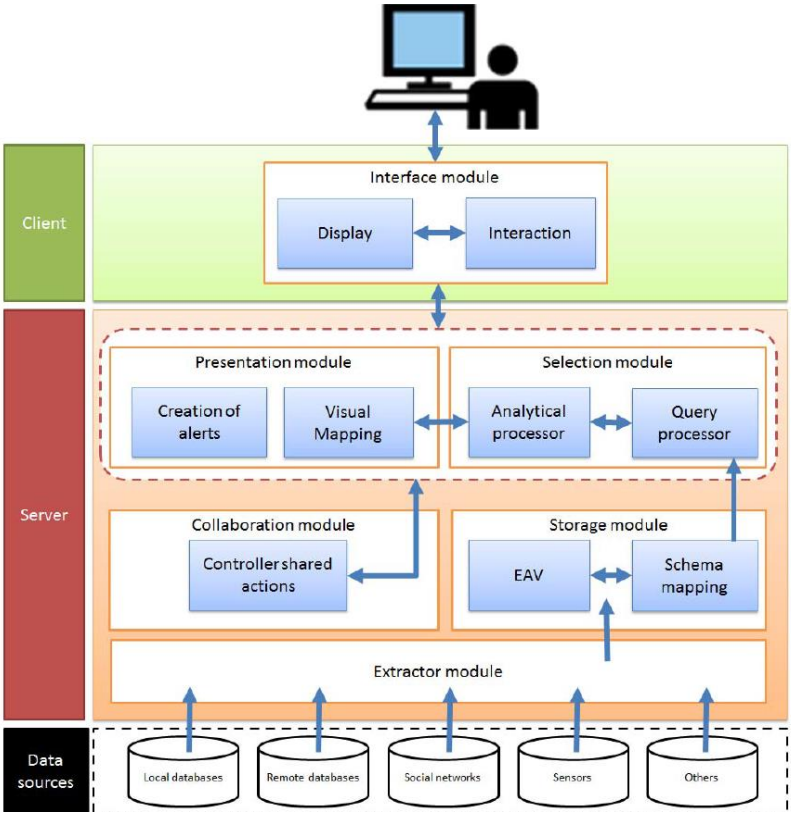

Figure 2. Emergency Dashboard Architecture, as proposed in (Nascimento, Vivacqua, and Borges 2016)

EMERGENCY DASHBOARD OPERATIONAL REQUIREMENTS

In this section we review the requirements for decision-supporting information visualization, which culminate in the decision to provide an emergency dashboard as the component of the solution that covers these requirements. The requirements were filtered out of a complete list of User Requirements, defined in beAWARE Deliverable D2.1 (beAWARE 2017). In addition to the original text of each requirement, we have drawn a visualization approach to match each requirement, comprising one or more ways to visualize and display the information to the decision-maker.

Table 1. Initial User Requirements for Decision-Supporting Visualization (beAWARE 2017)

ID	UR#	Requirement name	Requirement description
1.	UR_103	Flood warnings	Provide authorities with warnings on river levels overtopping some predefined alert thresholds, based on forecast results
2.	UR_112	Detect element at risk from reports	Provide authorities with the ability to detect the number of element at risk and the degree of emergency from mobile app and social media reports
3.	UR_118	River overtopping	Provide authorities/citizens with the ability to know if the river level is overtopping predefined alert thresholds
4.	UR_128	Risk Level Evaluation	Provide authorities with the ability to evaluate the forecasted level of risks (based on all the available dataset)
5.	UR_303	Forest-Fire Risk Assessment	Provide the authorities with a risk assessment regarding the probability of a forest fire to occur during or in the upcoming period after a heatwave. The relevant authorities will have an assessment of a fire risk based on the weather forecast during a heatwave and especially during the following days
6.	UR_306	Number of people affected	Provide the authorities an estimation of the people that might be affected from the heatwave and in which areas
7.	UR_313	First responders status	Provide to the authorities the current status and location of all first responders when they are performing their tasks
8.	UR_316	Capacity of relief places	Provide to the authorities the current state of the available capacity of all relief places provided to the public
9.	UR_320	Hospital availability	Show to the authorities the current availability of the hospitals.

EMERGENCY DASHBOARD ARCHITECTURE

Based on the end-user requirements and their analysis, and along the main insights drawn from the review of related literature, we determined the set of the functional requirements for the Emergency Dashboard system. The guidelines of a model-based requirements-driven architecting framework proposed in (Mordecai and Dori 2017), which used Object-Process Methodology, OPM (Dori 2016) as its underlying modeling language. This cyclic process consists of four phases:

- Recording stakeholder requirements
- Eliciting system requirements from stakeholder requirements
- Defining the system architecture
- Reviewing the outcome with the stakeholder and improving it

Stakeholder Requirements

Shown in the previous section, our end-user requirements constitute an initial set of stakeholder requirements. The next step is to form a list of well-defined system requirements based on the stakeholder requirements, when *the system* is defined as the Emergency Dashboard System (EDS).

System Requirements

A set of system requirements for the EDS has been constructed based on the Stakeholder Requirements. This set is shown in Table 2. Transforming stakeholder requirements into system requirements includes several aspects. First, we try to infer which system-level capabilities the EDS should exhibit to satisfy the stakeholder requirements. Second, system requirements should be as decoupled from each other as possible and lead to a modular solution. Third, system requirements should be reused and refined to cover as many user requirements as possible, so that, in general, the system requirements set would be as minimal and concise as possible. Finally, system requirements should be well-defined, well-phrased, and easy to understand by both the stakeholder, who reviews and approves them, and the system architect, who transforms them into features, functionalities, and functional requirements, and later allocates those to system components.

Table 2. Initial System Requirements for Emergency Dashboard System

UR#	SysReq ID	System Requirement
UR_103	EDS_01	EDS shall provide a User Interface for displaying metrics based on external measurement reports
UR_103	EDS_02	EDS shall provide an interface for external metric data providers to send their data to
UR_103	EDS_03	EDS shall provide a metric display showing a time-series within allowed warning thresholds
UR_103	EDS_04	EDS shall provide a way to bind a data stream to a metric display for presentation to a specific authority, role, or user
UR_103	EDS_05	EDS shall provide a way to associate a metric with a position on a map
UR_112	EDS_06	EDS shall provide a metric showing a "traffic light" with a number for each color category.
UR_118	EDS_07	EDS shall provide a metric display showing a warning or alert when predefined warning or alert thresholds are violated
UR_118	EDS_08	EDS shall provide a metric display showing a time-series within allowed warning thresholds
UR_128	EDS_09	EDS shall provide a metric display showing a given number relative to minimum and maximum values (gauge)
UR_303	EDS_10	EDS shall serve multiple authorities, in multiple geographies, with interests in multiple scenarios
UR_306	EDS_11	EDS shall provide means to display aggregate data based on available datasets (pivot charts)
UR_313	EDS_12	EDS shall provide means to breakdown aggregate metric displays into multiple category-divided metric displays
UR_316	EDS_13	EDS shall provide means to display the latest update available in a time-series as a separate metric display (e.g. progress bar)
UR_320	EDS_14	EDS shall provide access to metrics according to user pertinence to an authority, user role, and/or user identity.

System Functionality

Based on the system requirements we derived the main functionalities of the EDS. The top-level functionality of the system is **Displaying Decision-Supporting Functionality**. The main beneficiary of this functionality is the **Decision-Maker**, who uses the outcome of this functionality – the **Dashboard** – in the **Decision-Making** process. Additional agents are external data providers, who feed data stream messages into the system. Other external processes include **Managing System Definitions** (by an administrator or administrative superior system); external **data analytics services** that may be utilized for data analysis by the system (such as web-based format convertors,

service algorithms, etc); and external applications' **map-based information display**, which complements the dashboard application and provides a detailed map with events and tactical layered information.

The top-level functionality consists of four *feature functionalities* and two *support functionalities*. Each functionality can be further decomposed into several sub-functionalities, functions, or objectives. These help clarify the roles of each functionality and ensure its relevance and necessity.

Feature functionalities are the functionalities that provide direct value:

- Receiving data streams
    - Receiving data stream messages through an API
    - Storing data stream messages' content in database
    - Informing the system on updates to the data stream
- Analyzing data sets
    - Running selected common analysis techniques on raw data streams according to data analysis definitions and storing the results as a new data stream
    - Running external analytic services on existing data streams, as defined in the data analysis definitions, obtaining the results
    - Sending analyzed data streams for storing
- Staging data sets for presentation
    - Marking data streams for presentation according to data display definitions
    - Checking data stream availability for presentation
    - Fetching latest available information for data stream to display
- Displaying the dashboard
    - Fetching staged data streams
    - Drawing the user interface
    - Drawing the dashboard frame
    - Deploying the metric displays according to the tenant, role, and user connected and according to the metric display definitions

Supporting functionalities are the functionalities that provide indirect and usually internal value:

- Routing data sets
    - Transferring notifications and pointers to data from originators to consumers
    - Tracking information flow in the system
- Managing data access
    - Providing user registration and access permissions for users
    - Responding to data access requests for display to specific users
    - Tracking user activity in the system

System Architecture

In order to facilitate a viable solution, the next step is to define a robust architecture that covers the system's functionalities. For each functionality we allocated a dedicated conceptual component. A conceptual component contains functions that can be implemented in various forms. The feature components are: Receiver, Analyzer, Stager, and UI. The support components are: Router and Authorizer.

All the components in our EDS are intended as software components. As a good practice, they should employ reusable technologies, software libraries, on-line services, micro-services, and open interfaces. In addition, the system is designed, developed, and incorporated using techniques that cover the relevant requirements and

integrate them all into a working system, while reducing risk and assuring performance. However, this elaboration is beyond the scope of the present paper.

An Object-Process Diagram (OPD) of the architecture is shown in Figure 3. This OPD shows the following elements and aspects:

- the top-level functionality of the system, decomposed into the main functionalities, as listed above;
- external agents and processes that feed input into the EDS or consume/handle its output; and
- data objects that are provided as inputs to the system or one of its subsystems or as outputs of the system or its subsystems.

The ellipses represent the processes in the model – functionalities and services, while the rectangles represent the objects – users (human or machine), software components, or information objects. Processes and objects that are defined as external to the system are indicated by dashed contours. Physical or actual objects, such as humans, systems, or agents, are shaded, while informatical objects – data and information – are not. These are typical OPM language notations that help distinguish objects – things that exist or might exist, from processes – things that occur or might occur; internal things from external things, and physical things from informatical things. In addition, we have used white background for feature functionalities and components, and grey background for support functionalities and components. External beneficiaries are colored in deep purple while external functionalities and processes are colored in light purple. Data objects are colored in yellow.

The diagram also shows potentially-needed computation resources, such as databases, application servers, authentication server/service, and routing server/service, for each functionality. For example, the "**Receiving Data Streams**" service of the **Receiver** component requires **Database** and **Application Server**. These computation resources may eventually become sub-components of the conceptual components that own each functionality. These resources appear at the lower layer of the OPD. While some resources play a potential role in more than one functionality, in practice we may decide to deploy multiple, separate, and independent instances of these resources in order to optimize performance, cost, robustness, availability, or a combination thereof. However, such considerations are beyond the scope of the present paper.

The diagram was created with OPCAT 4.2 – OPM's free modeling and simulation software. As a major part of the OPM language, which is simultaneously graphical and textual, OPCAT also provides a machine-generated text in Object-Process Language (OPL) – OPM's textual modality. The text provides simple, readable explanation of each element and construct in the diagram, including the objects, processes, and links among them. The OPL textual specification of the diagram is available as Appendix A.

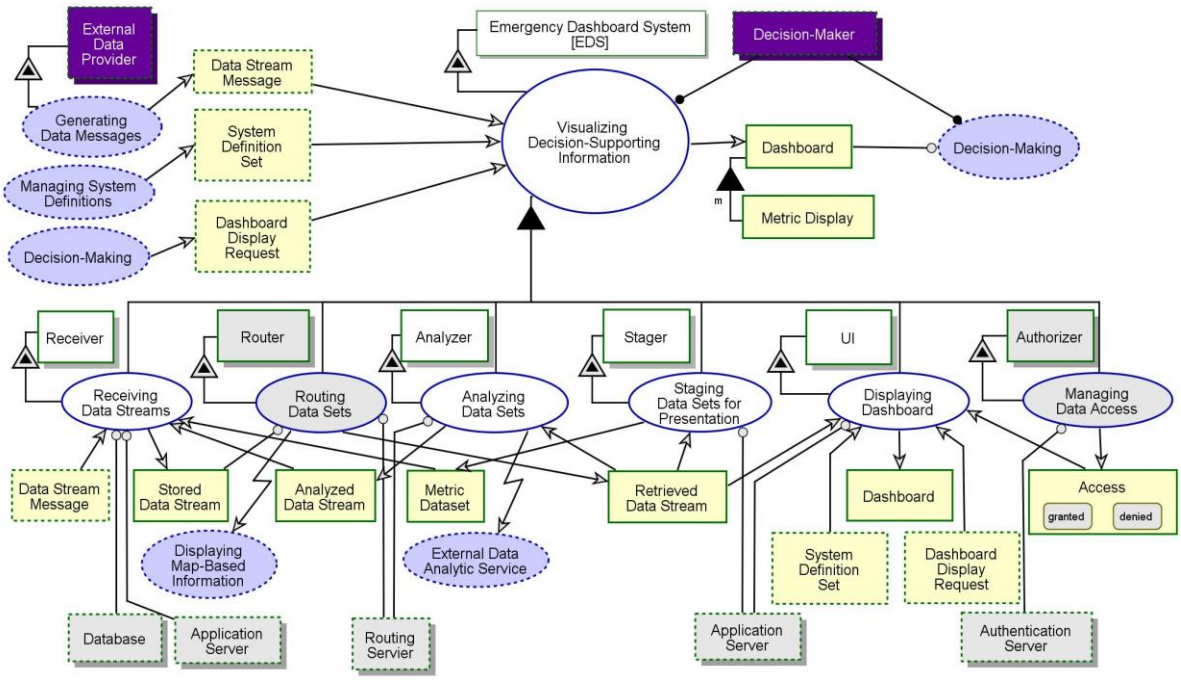

Figure 3. Proposed Emergency Dashboard System Functionality – an Object-Process Diagram

CONCLUSION

In this paper, we have proposed an Intelligent Utilization of Dashboards in Emergency Management, which carefully derives a robust functionality-supporting structure from a set of well-defined generically-oriented system requirements, based on but not bounded by or directly implementing an authentic set of end-user requirements. Rather than try to implement each end-user requirement for decision-supporting visualization directly and in a tailor-made fashion, our approach is to understand the underlying mechanisms needed to support not only the present requests and expectations of the end-users, but also their future needs and challenges with processing and using data for decision-making during emergency scenarios.

Our proposed functional decomposition and preliminary conceptual structure extends the functionality and scalability offered by previous frameworks. Our system requirements and functionality definition approach attempted to facilitate, apart from direct compliance with the immediate end-user requirements, that our solution would be robust, flexible, and applicable to the problem at hand – i.e. enhancing decision support in emergency management via information visualization, while considering the dynamics of the problem and the need to allow flexibility across the board – in data reception, in data processing and information extraction, and in data and information visualization to support evolving decision making processes.

In future research, we intend to elaborate this framework into a feasible architecture, implement and demonstrate a prototype solution, and study the solution's usability when coping with the genuine dynamics of emergency management. We intend to study the growth in operational needs on the one hand and the growth in delivered capability on the other hand, and propose ways to refine and improve the described solution to better support the effort to optimize the dashboard as a critical decision-support tool.

ACKNOWLEDGMENTS

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APPENDIX: OBJECT-PROCESS LANGUAGE SPECIFICATION OF THE PROPOSED EDS ARCHITECTURE

1 Emergency Dashboard System [EDS] is physical.
2 Emergency Dashboard System [EDS] exhibits Visualizing Decision-Supporting Information.
3 Visualizing Decision-Supporting Information consists of Receiving Data Streams, Routing Data Sets, Analyzing Data Sets, Staging Data Sets for Presentation, Displaying Dashboard, and Managing Data Access.
4 Receiving Data Streams requires Application Server and Database.
5 Receiving Data Streams consumes Metric Dataset, Analyzed Data Stream, and Data Stream Message.
6 Receiving Data Streams yields Stored Data Stream.
7 Routing Data Sets requires Stored Data Stream and Routing Servier.
8 Routing Data Sets yields Retrieved Data Stream.
9 Analyzing Data Sets requires Routing Servier.
10 Analyzing Data Sets consumes Retrieved Data Stream.
11 Analyzing Data Sets yields Analyzed Data Stream.
12 Analyzing Data Sets invokes External Data Analytic Service.
13 Staging Data Sets for Presentation requires Application Server.
14 Staging Data Sets for Presentation consumes Retrieved Data Stream.
15 Staging Data Sets for Presentation yields Metric Dataset.
16 Displaying Dashboard requires Application Server.
17 Displaying Dashboard consumes Access, Dashboard Display Request, System Definition Set, and Retrieved Data Stream.
18 Displaying Dashboard yields Dashboard.
19 Managing Data Access requires Authentication Server.
20 Managing Data Access yields Access.
21 Visualizing Decision-Supporting Information consumes Dashboard Display Request, System Definition Set, and Data Stream Message.
22 Visualizing Decision-Supporting Information yields Dashboard.
23 Data Stream Message is environmental.
24 Dashboard consists of many Metric Displays.
25 System Definition Set is environmental.
26 Dashboard Display Request is environmental.
27 Receiver is physical.
28 Receiver exhibits Receiving Data Streams.
29 Router is physical.
30 Router exhibits Routing Data Sets.
31 Analyzer is physical.
32 Analyzer exhibits Analyzing Data Sets.
33 Stager is physical.
34 Stager exhibits Staging Data Sets for Presentation.
35 UI is physical.
36 UI exhibits Displaying Dashboard.
37 Authorizer is physical.
38 Authorizer exhibits Managing Data Access.
39 Access can be granted or denied.
40 Decision-Maker is environmental and physical.
41 Decision-Maker handles Decision-Making and Visualizing Decision-Supporting Information.
42 External Data Provider is environmental and physical.
43 External Data Provider exhibits Generating Data Messages.
44 Generating Data Messages is environmental.
45 Generating Data Messages yields Data Stream Message.
46 Database is environmental and physical.
47 Application Server is environmental and physical.
48 Authentication Server is environmental and physical.
49 Routing Servier is environmental and physical.
50 Decision-Making is environmental.
51 Decision-Making requires Dashboard.
52 Decision-Making yields Dashboard Display Request.
53 External Data Analytic Service is environmental.
54 Managing System Definitions is environmental.
55 Managing System Definitions yields System Definition Set.

Posters

ID: 159
Format: Poster

Using Metrics of Stability to Identify Points of Failure and Support in Online Information Distribution during a Disaster

Halse, Shane (1); Kropczynski, Jess (2); Tapia, Andrea (1)
1: The Pennsylvania State University, United States of America; 2: University of Cincinnati, United States of America

See ISCRAM DL for final poster document:

http://idl.iscram.org/

ID: 173
Format: Poster

Optimal UAV 3D Path Planning in Mountainous Environments for Post-Earthquake Multi-region Search

Deng, Lizheng; Yuan, Hongyong; Huang, Lida
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, China, People's Republic of

See ISCRAM DL for final poster document:

http://idl.iscram.org/

ISCRAM 2018

Rochester Institute of Technology
Rochester, NY, USA

POSTER: SOCIAL MEDIA STUDIES

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

"Visualizing Crisis"

Workshops and Doctoral Symposium May 20th, 2018

Conference May 21nd-23th, 2018

Rochester New York - USA

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INTRODUCTION TO THE POSTER

This poster contains work related to an ongoing PhD research project in developing a crowdsourcing platform called Cartoscope. Cartoscope is aimed at understanding crowd motivations and incentives in providing volunteer work, as well as optimizing volunteer contribution and experience, using elements such as interface and task design, with applications to disaster response. Cartoscope's main focus is analysis of aerial imagery, as well as visualization of data of interest. This work is supported by a Northeastern University TIER 1 grant and Google.

POSTER SUBJECT

During a natural disaster, major damages to critical structures such as bridges or power lines can severely disrupt community functions for long periods of time, making the task of swiftly identifying this type of damage vital for response and recovery. However, survey flight paths are often designed with a main focus of complete and quick coverage of affected areas through aerial photography, which is then assigned to volunteers to aid in damage report and labeling. We designed a crowdsourcing interface that focuses on locating points of interest and assessing damage using images from survey flights. We tested our design using a disaster and a non-disaster application by recruiting volunteers on Amazon Mechanical Turk. We found that the type of structure may cause difficulties for crowd workers in providing accurate assessments and that designing flights to also target structures may provide higher quality imagery for this type of task.

POSTER PRESENTERS

- Sofia Eleni Spatharioti is a PhD student at the College of Computer and Information Science at Northeastern University, advised by professor Seth Cooper. Sofia's previous experience includes two publications on related work at ISCRAM 2017 in Albi France [1,2], a presentation at the Citizen Science Association Conference 2017 [3], as well as a poster presentation at the Fourth AAAI Conference on Human Computation and Crowdsourcing (HCOMP 2016) [4]. Sofia will be the main presenter and plans to attend ISCRAM 2018 with a conditionally accepted Work in Progress paper and has a Best Student Paper nomination for [2] at ISCRAM 2017.
- Dr. Sara Wylie has a joint appointment between health sciences and the Department of Sociology and Anthropology as part of Northeastern University's Social Science and Environmental Health Research Institute. Wylie develops citizen science tools for the study of the oil and gas industries. She is a co-founder of Public Lab and the Environmental Data and Governance Initiative (EDGI). Prior related work includes, but is not limited to, [1,3,4].
- Dr. Seth Cooper is an Assistant Professor in the College of Computer and Information Science and a member of the Playable Innovative Technologies Lab. His research examines using citizen science, crowdsourcing, and video games to solve difficult scientific problems. Prior related work includes [1,3,4].

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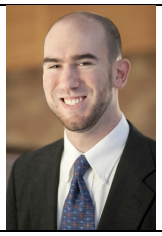	Seth Cooper scooper@ccs.neu.edu Northeastern University

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[1] Sofia Eleni Spatharioti, Rebecca Govoni, Jennifer S. Carrera, Sara Wylie, & Seth Cooper. (2017). A Required Work Payment Scheme for Crowdsourced Disaster Response: Worker Performance and Motivations. In eds Aurélie Montarnal Matthieu Lauras Chihab Hanachi F. B. Tina Comes (Ed.), *Proceedings of the 14th International Conference on Information Systems for Crisis Response And Management* (pp. 475–488). Albi, France.

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[3] Sofia Eleni Spatharioti, Rebecca Govoni, Jennifer S. Carrera, Sara Wylie, Seth Cooper (2017) Cartoscope: A new Platform for Citizen Science and Disaster Response, *Individual Talk in Citizen Science Association Conference, St. Paul, MN, 2017*

[4] Sofia Eleni Spatharioti, Rebecca Govoni, Jennifer S. Carrera, Sara Wylie, Seth Cooper (2016) Exploring Required Work and Progress Feedback in Crowdsourced Mapping, *Work in Progress Poster in The Fourth AAAI Conference on Human Computation and Crowdsourcing, Austin, TX, 2016*

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Incorporating Digital Volunteers into Exercises: A Case Study on CAUSE V

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"Visualizing Crisis"

Workshops and Doctoral Symposium May 20th, 2018

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INTRODUCTION TO THE POSTER

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) and Canada Department of National Defence's Centre for Security Science conducted its fifth Canada-U.S. Enhanced Resiliency Experiment (CAUSE V) on November 15 - 16, 2017 along the border between the Canadian province of British Columbia and the state of Washington. The experiment tested emerging technologies to promote more effective communication and information sharing for emergency management officials and first responder agencies on both sides of the border in response to a Mt. Baker volcanic eruption and lahar mudflow scenario. The CAUSE V experiment explored the use of trained digital volunteers to provide operational and public information support to emergency management professionals. These digital volunteers were assigned to monitor simulated social media platforms,

identifying information according to pre-assigned mission assignments, including misinformation and rumor control, and reporting this information to emergency management officials and first responder agencies. Researchers from the University of Washington were in attendance to specifically observe the efforts of the digital volunteers during the experiment. Research observations, and the benefits of integrating the research and practitioner communities, will be highlighted on the poster.

POSTER SUBJECT

This poster is a practitioner-driven work-in-progress that highlights the value gained by incorporating social media into the scenario for CAUSE V and recommends inserting researchers within the planned exercise environment. The recommendation is based off successes experienced having researchers present to observe social media analysis during CAUSE V. The intention of having researchers present is to gather reactionary undocumented visual and auditory cues of social media analysts (digital volunteers) within an environment that closely resembles an operational response to a real-world disaster. The benefits of this approach can help break down barriers between the two communities and provide a feedback loop between research and practical operations.

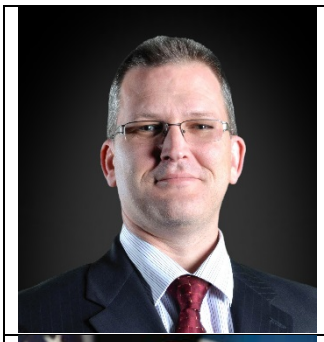
The authors suggest forming the researcher-practitioner relationship far in advance of an exercise/experiment so mutually beneficial, measurable topics and desired outcomes can be identified. These relationships may also reveal previously unknown or underexplored areas of study in crisis response and management which could provide further justification of the value of social media for practitioners during the response and recovery phases of an emergency.

POSTER PRESENTER

Mr. Peterson is the chair of the U.S. Department of Homeland Security Social Media Working Group for Emergency Services and Disaster Management. He attended the ISCRAM 2016 Conference in Rio de Janeiro, Brazil where he presented on recommending researchers study concurrent usages of information systems. Mr. Peterson has presented on various dimensions of the social media phenomenon. His conceptualizations address not only the current state of social media, but its potential to positively impact the effectiveness of emergency management operations.

Mr. Gusty is a program manager for the U.S. Department of Homeland Security Science & Technology Directorate (DHS S&T) and leads the Social Media Working Group for Emergency Services and Disaster Management and the Canada-U.S. Enhanced Resiliency Experiment series. He has presented at past conferences including RESCON and the Natural Hazards Center on information sharing and digital communications tools including social media.

Mr. Peterson will be in attendance at the conference.

	Steve Peterson steve.peterson@nih.gov National Institutes of Health, Division of Emergency Management
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POSTER: Identifying Semantic Domains in Emergency Scenarios

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

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I am submitting the poster document as a follow-up to the "Accept WiPe paper submission as a poster"

INTRODUCTION TO THE POSTER

Provide a brief description of the context of the poster. For example, is it dedicated to present a PhD research work, a funded collaborative project, the contributions of a research team… around 10 lines of such description should be provided.

This poster presents part of a PhD research work which is focused on improving the communication between organizations in emergency response scenarios by tackling semantic interoperability problems. To do so, we are applying ontology matching techniques enriched with domain information and domain specific terminologies. Due to the

heterogeneity between agencies in emergency scenarios, it is difficult to identify the domains which are involved in these situations. In this poster it is presented a categorization of emergency domains that has been identified by analysing papers published in proceedings of ISCRAM and ISCRAM-med conferences. The main value of this resource is that it can be used to identify the terms which are specific of a particular domain. This sets of terms will be used to carry out word sense disambiguation to reduce ambiguity in emergency scenarios.

POSTER SUBJECT

Provide an abstract of the content of the poster. If possible include the big-picture of the subject.

Emergency scenarios are characterised by the participation of multiple and diverse organizations which come from different areas. This diversity is enriching in terms of expertise and approaches to tackle problems, however it also provokes misunderstandings caused by semantic interoperability problems. There are some approaches which propose tackling these problems by using domain adaptation algorithms. Nevertheless, it is not trivial their application in emergency scenarios where the term “domain” is used in many different ways, not being clear either what it means or which domains are involved in these scenarios. In this poster, we identify semantic domains involved in emergency scenarios by analysing papers published in proceedings of ISCRAM and ISCRAM-med conferences.
As a result, a categorisation of these domains has been developed, with the aim of providing a resource that can be used by domain adaptation algorithms to tackle problems such as those involving semantic interoperability.

POSTER PRESENTER

Describe the previous experience of the presenter(s) at ISCRAM or related meetings, and any other qualifications for this responsibility, such as recent papers on the topic you propose. In addition you should note which presenter plan to be at the conference.

	*Francisco José Quesada Real ** *s1580097@staffmail.ed.ac.uk* *University of Edinburgh* He is a PhD student at the University of Edinburgh focusing on improving the exchange of information between agencies in ER scenarios, by using domain-aware matching techniques. During his PhD, he has interacted with different agencies such as the Resilience Department of the Scottish Government or the Spanish 112 organization. He is ISCRAM member since 2017. Last year he attended to the SNACMAN Thematic School at Paris and to ISCRAM 2017. He participated in the Doctoral Colloquium and presented the paper “Improving Dynamic Information Exchange in Emergency Response Scenarios”.

**Corresponding Chair*

ISCRAM 2018

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POSTER: Informing decision makers: facilitating communication and trust for decision makers during crises

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

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INTRODUCTION TO THE POSTER

This poster describes the basis for a three-year project on facilitating communication during crises by integrating dynamic data matching with provenance information, which is being funded by the Office of Navel Research. The project is lead by Heriot-Watt University with co-investigators at Newcastle and Coventry Universities. The project focusses on helping decision makers access data from multiple heterogeneous sources and then assess the quality of the returned data by considering the approximations made during the matching process as well as provenance information associated with it. The project builds on and integrates

substantial existing work by the investigators in the fields of data matching and integration, and in provenance. The poster outlines our early work developing the theory of how these orthogonal aspects should be integrated to best support the decision making in analysing what data they wish to use in the decision-making process.

POSTER SUBJECT

There are a number of reasons why automated data sharing during crisis management is difficult. We are developing a tool that will address two key ones. The first aspect is that data in different organisations (or even within an organisation) is mismatched in that different terminology, structure, specificity and data formats are used, meaning that automated comprehension of data from other organisations is problematic. The second aspect is that it is hard to assess the trustworthiness of data from other organisations. We have developed a data-matching solution to the first of these problems and a provenance-based approach to the second. We discuss how these approaches can best be integrated so that decision makers can quickly and automatically be presented with data to match, or approximately match, their data needs, together with the right information for them to understand the quality and meaning of this data, and introduce the CEM-DIT (Communication for Emergency Management through Data Integration and Trust) system. Potential data is ranked according to its quality and relevance from both a matching and provenance point of view, with only highly ranked responses being returned to the decision maker.

POSTER PRESENTER

Fiona McNeill, f.mcneill@hw.ac.uk, Heriot-Watt University
Fiona has been involved in the fields of data interpretation and matching for many years, and has a particular focus on the application of this work to crisis management. She has presented papers at previous ISCRAM conferences on this work, as have her students in this field. This poster introduces a new dimension to this work, with the integration of work on provenance with colleagues Paolo Missier at Newcastle University and Jeremy Bryans at Coventry University. She has also co-chaired the ISCRAM Doctoral Colloquium since 2015.

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POSTER: beAWARE: Enhancing Decision Support and Management Services in Extreme Weather Climate Events

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

"Visualizing Crisis"

Workshops and Doctoral Symposium May 20th, 2018

Conference May 21nd-23th, 2018

Rochester New York - USA
Rochester Institute of Technology (RIT)
https://iscram2018.rit.edu/

INTRODUCTION TO THE POSTER

In every disaster and crisis, incident time is the enemy, and getting accurate information about the scope, extent, and impact of the disaster is critical to creating and orchestrating an effective disaster response and recovery effort. The main goal of beAWARE framework is to provide support in all the phases of an emergency incident. More specifically, we propose an integrated solution to support forecasting, early warnings, transmission and routing of the

emergency data, aggregated analysis of multimodal data and management the coordination between the first responders and the authorities.
beAWARE is tackling ambitious objectives in order to address the challenge of rapid response during a crisis. beAWARE deals with the whole lifecycle of emergency call management from mobile devices, where issues such as data analysis, forwarding to first responders have been addressed by the partners and efficient solutions have been proposed. This paper presents the framework of a novel crisis management system. Future work includes realization of the components, development of an integrated platform and testing with realistic pilots.

POSTER SUBJECT

One of the main issues and problems during a climate crisis is the management of the end users forces. How can we efficiently have the proper forces to the right place in order to face a disaster? Although several solutions have been tested, many issues and problems are unsolved. These issues concern all the main participants of an emergency call: the users, the Public Safety Answering Points (PSAPs) and the first responders.
Instead of focusing on a specific part of the crisis management problem (e.g. information routing), beAWARE proposes a holistic approach (Fig. 1) to the realization of crisis management framework that it will support all the phases in an emergency call sequence. The overall objective of beAWARE is to provide an integrated solution for new decision support services based on aggregated analysis of multimodal data and previous crisis management records. beAWARE will address the needs of the main sectors of the security emergency procedure, namely first responder and PSAP. Moreover, beAWARE aims to bring first responders, PSAP centres and forecast services to collaborate together in order to explore new ways of working and delivering more effective outcomes. The beAWARE will perform a research study on the requirements for emergency services given the current digital landscape and the special needs of the people in danger during a crisis. These requirements will be the base for all the forthcoming implementations and methods.

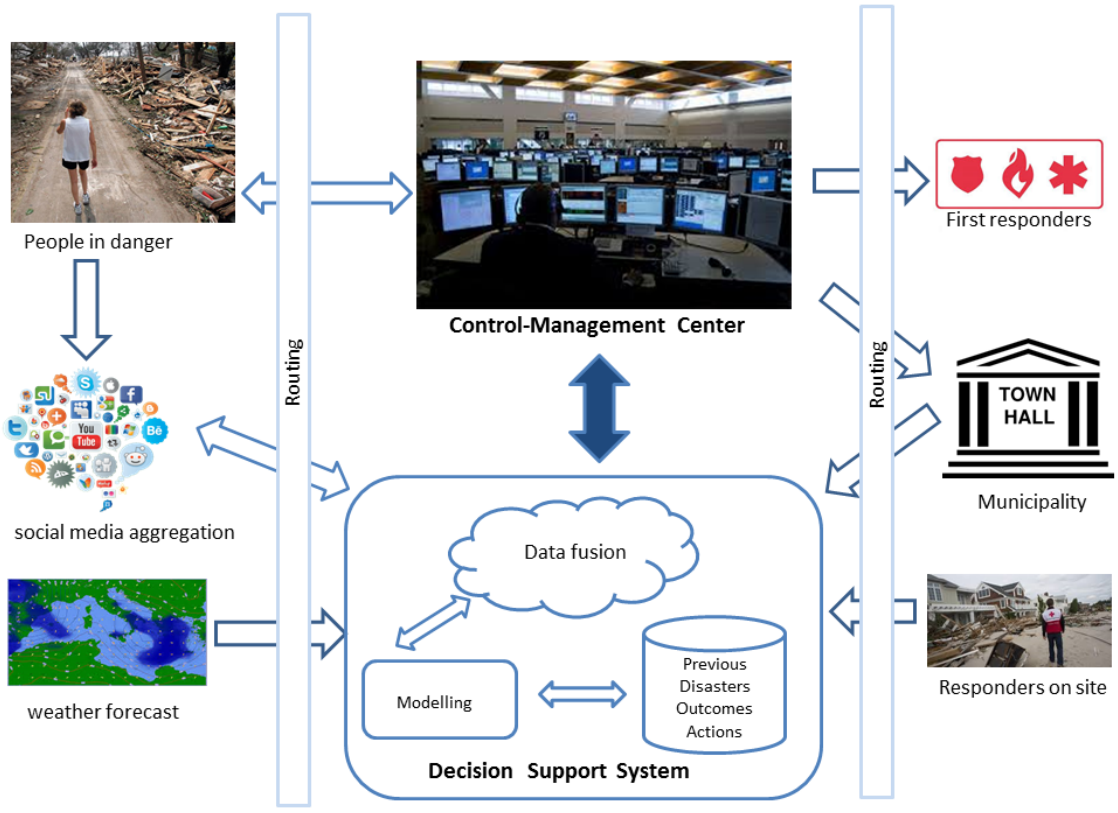
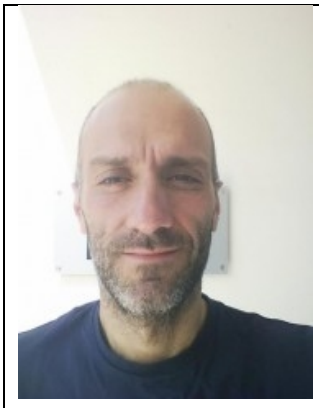


Figure 1. beAWARE approach for integrating the disabled back into workforce
The people in danger will be able to make an emergency call using specific applications that will allow the transfer of multimodal information. The emergency call will be transferred through the control management centre. Moreover data from the weather forecast and social media aggregation will provide as much of the needed information to the PSAP centre as possible. beAWARE decision support system will combine all the above data sources and compare them with previous crisis management situations in order to provide PSAP centre with the proper guidelines and advices. Finally, the PSAP centre will be able to organise the first responder and inform all the local authorities.

ACKNOWLEDGMENTS
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 700475.

POSTER PRESENTER



Anastasios Karakostas*

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Information Technologies Institute - Centre for Research and Technology Hellas

Dr. Anastasios Karakostas (m) received the Degree in Computer Science and the PhD degree in Computer Science Aristotle University of Thessaloniki Greece. He is a Researcher with ITI-CERTH. Currently, he is scientific manager of the H2020 DRS project beAWARE. beAWARE proposes an integrated solution to support forecasting, early warnings, transmission and routing of the emergency data, aggregated analysis of multimodal data and

	management the coordination between the first responders and the authorities. He has also participated in numerous European and national research projects and is the author of more than 60 publications in refereed journals and international conference. His research interests include decision support systems, semantic multimedia analysis, ontologies and semantic information modeling and reasoning. He has served as a reviewer in international Journals such as Computers and Education, IEEE Transactions on Learning Technologies and as Technical program committee in well reputed conferences and workshops such as CSCL, IEEE ICALT. He has been one of the organizers of the IEEE International Conference on Intelligent Networking and Collaborative systems (INCoS 2010) and 2018 IEEE Image, Video, and Multidimensional Signal Processing (IVMSP) Workshop. Anastasios Karakostas will be present at the ISCRAM conference and the ICMT workshop.

**Corresponding Chair*

ISCRAM 2018
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Rochester, NY, USA

POSTER: A new approach of monitoring system for Supply Chain management during crisis

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

"Visualizing Crisis"

Workshops and Doctoral Symposium May 20th, 2018

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INTRODUCTION TO THE POSTER

This poster is dedicated to present a PhD research work based on sensitive products supply chain, focusing on transportation steps. Applied to the French Blood Establishment, we are working with, we aim to develop a monitoring module able to detect transportation anomalies and propose adaptations. This poster is submitted after a Wipe Paper submission rejected.

POSTER SUBJECT

Sensitive products supply chain and supply chain facing with crisis management share several aspects. In both cases, several decision makers have to choose the best options most of the time under pressure, often in emergency and need to access numerous information from the

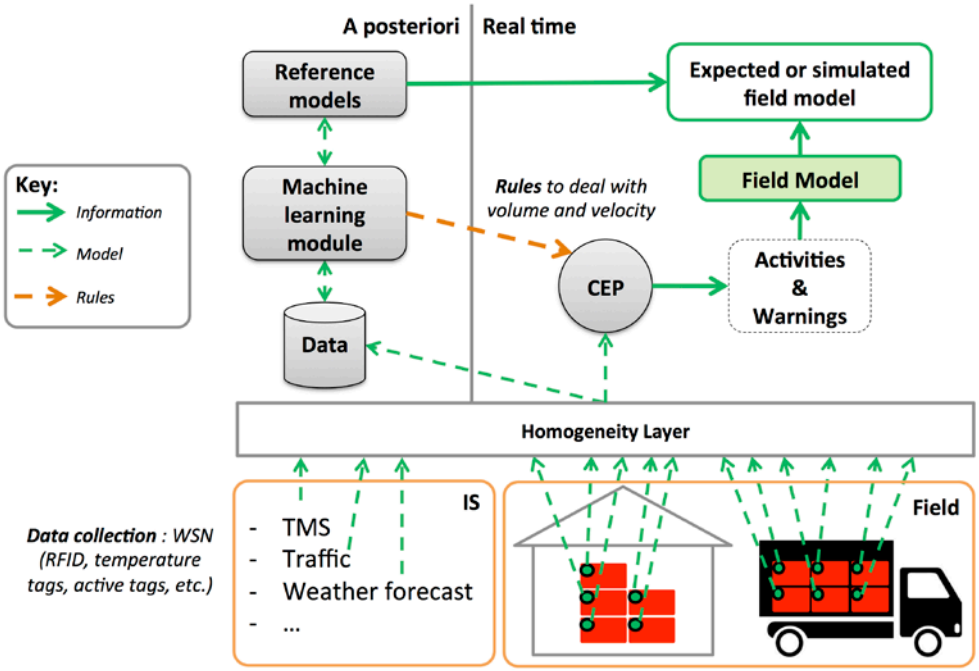
field. This shared monitoring aspect put forward the visualization need to consider in each decision all the crisis potential impacts. Unfortunately, for the transportation steps we focus on, the current transport management systems do not reach these requirements. In this paper, focusing on supply chains during crises, we present a new monitoring system with adapted functionalities to feed in real time a shared model with reliable data from the field.

Thus, our objective is to define a predictive/early detection model of transportation anomalies and a dynamic rescheduling model of transportation steps. We currently work with the French Blood Establishment to develop a monitoring module and use their supply chain to illustrate the proposition.

The approach we present here focuses on the containers (and products) to be transported, considering the vehicles as "potential load displacement". In fact, considering the hyper-connected and more collaborative world we are about to live in it seems relevant to focus on the goods to be transported and not on the means, as Transport Management Systems do. In order to support the transportation steps and monitor them it is necessary to:

1. Collect relevant data
2. Transmit and exploit reliable data to build information
3. Encourage exchanges around a shared picture
4. Anticipate and foresee to help the decision making

The big picture below presents a model of an information system able to support supply chain management during crisis.



POSTER PRESENTER

Describe the previous experience of the presenter(s) at ISCRAM or related meetings, and any other qualifications for this responsibility, such as recent papers on the topic you propose. In addition you should note which presenter plan to be at the conference.

<Presenter picture>	*Aurélie Conges* *Aurelie.conges@mines-albi.fr* *IMT Mines Albi – GIND* *Works on these topics in the research team for 1 year*
<Co-presenter picture>	*Matthieu Lauras* *Matthieu.lauras@mines-albi.fr* *IMT Mines Albi – GIND* *ISCRAM member for around 10 years*

**Corresponding Chair*

ISCRAM 2018

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POSTER: A flying localization system for the rescue of buried victims

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

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INTRODUCTION TO THE POSTER

The Institute of Rescue Engineering and Civil Protection at TH Köln (University of Applied Sciences) participates, together with further universitarian and industrial partners as well as prospective end users, in the joint research project FOUNT². FOUNT² aims at developing a flying localization system for the rescue of buried victims after building collapses that can support urban search and rescue teams (USAR). In addition, the implementation of the system is intended to enhance the safety of USAR teams responding to building collapses. The FOUNT² system consists of an unmanned aerial vehicle (UAV) equipped with an autonomous landing site detection and a bioradar that detects the breathing movements of victims that are buried under the debris. Important elements of the project are the technical optimization of system components, the implementation of the FOUNT² system in the existing command and operation structures and the adaption of the information processes. The three-year development process is supported by an evaluation on a laboratory scale and a validation in a large-scale field exercise. FOUNT² is funded by the German Federal Ministry for Education and Research (Program: Research for Civil Security – Innovative Systems for Rescue and Safety).

POSTER SUBJECT

The poster shows the current status and future development stages of FOUNT² and highlights important elements of the process on a timeline. In addition to the research topic, the methodology used so far, the identified system requirements and the results of the scenario development are mentioned. The requirements are subdivided into four topics: “tactical implementation”, “incident related information”, “UAV design” and “user interface design”. As the research project is about to reach its half-way mark in 2018, an outlook on future project objectives is provided, such as evaluation, user training and validation.

A flying localization system for the rescue of buried victims

Schmitz, Sebastian; Landsberg, Lennart; Brüstle, Tim; Barth, Konrad;
Weinem, Johannes; Mudimu, Ompe Aimé

TH Köln (University of Applied Sciences), Institute of Rescue Engineering and Civil Protection

research topic

- development of a flying localization system for the rescue of buried victims after building collapses
- support urban search and rescue teams (USAR)
- enhance the teams' safety during emergency response
- unmanned aerial vehicle (UAV) equipped with autonomous landing site detection and bioradar

identified requirements

tactical implementation
- semi-autonomous action
- integration into established emergency management structures and standard operating procedures
- multiple user access to collected information, but only one access to mission planning and UAV control

incident related information
- high quality images (bird's eye view) of incident locations in the initial phase of operation
- ensure information validity and accuracy
- information should be able to be used with existing knowledge of emergency personnel

UAV design
- compact structure for transport in aircrafts
- redundant control and sensor technology
- lightweight antenna design integrated in landing gear

user interface design
- flexible information layers
- simple and safe to operate
- indicator for the reliability of bioradar measurement results

2016

methodology

- analysis of past events with building collapses
- interdisciplinary workshop: 40 participants in the fields of civil protection and UAV design (end users, developers, scientists)
- expert interviews: emergency managers from different fire departments and relief organizations
- analysis of national and international standards for USAR
- development of an application scenario

scenario development

- national scenario: gas explosion
- international scenario: earthquake

evaluation on a laboratory scale

user training

validation in a large-scale exercise

2019

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FOUNT2

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Technology
Arts Sciences
TH Köln

POSTER PRESENTER

Lennart Landsberg began his professional career in the field of emergency services by joining the fire department of the city of Cologne in Germany in 2009. With his Bachelor's degree in rescue engineering, he has deepened his research in the field of incident management. His current research deals with the amendment of the German command and control system for fire service operations (FwDV 100). In addition, he conducts research in the field of education and training of emergency response personnel.

Sebastian Schmitz's research focuses on the areas of emergency and crisis management, particularly on mass casualty incidents and urban search and rescue operations. Currently, he manages the joint research project FOUNT². Sebastian began his professional career as a paramedic in pre-hospital and emergency medical care and received a Bachelor's degree in rescue engineering from TH Köln in 2016.

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	Sebastian Schmitz *sebastian.schmitz1@th-koeln.de* *Institute of Rescue Engineering and Civil Protection* *TH Köln (University of Applied Sciences)*

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POSTER: Universal Design of ICT for Emergency Management: A Research Agenda

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

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INTRODUCTION TO THE POSTER

This is a WiPe paper accepted as poster. It presents work in progress on a research agenda for Universal Design of ICT for Emergency Management, based on a literature study. After the co-authors, coming from Universal Design and Emergency Management research backgrounds, wrote a paper together on "*Universal Design of Information Sharing Tools for Disaster Risk Reduction*" that was successfully presented at the 2nd IFIP Conference on Information Technology in Disaster Risk Reduction ITDRR2017, it was decided to move forward with the collaboration. ISCRAM was considered a suitable venue for the next step, and the authors have therefore proposed a special track as well as this poster on the topic, in the hope to spark interest on the topic. The items on the research agenda proposed in the poster is already used as a source of topics for Master thesis for students in Universal Design of ICT at Oslo Metropolitan University.

POSTER SUBJECT

Information and communication technologies (ICT) are becoming increasingly important in emergency management and crisis communication. ICT tools are developed and adopted in all phases of the emergency management cycle. On the one hand, these tools contribute to better disaster preparedness and effective response. On the other hand, the lack of consideration of universal design in these tools also creates new barriers for different stakeholders, particularly the elderly and people with disabilities. The primary objective of this paper is to give an overview of the current state of the emerging research field of Universal Design of ICT for emergency management and provide a Research Agenda to highlight ways to uncover how the increasing introduction of ICT in emergency management can contribute to removing barriers instead of adding more barriers.

We argue that the design for all should be a central concept when educating and training designers and engineers for developing ICT systems for emergency management.

We use both the Sendai Framework for Disaster Risk Reduction 2015-2030 and the lessons learned from our literature review as a point of departure to derive a future research agenda concerning universal design of ICT for emergency management.

The concepts of inclusion, universal design and accessibility have been internationally recognized and incorporated in SFDRR to empower people with disabilities in disasters. Nevertheless, there are gaps between a perfect framework for actions and how these universal design principles should be operationalized in practice. Particularly, on universal design of ICT for emergency management, there are some gaps and research opportunities that can be laid down as future research challenges. For example: Have the ICT solutions enabling early warning and alerting people on likely catastrophe taken into account people that have hearing, visual or other impairments that may not notice the alerts? Are the ICT tools for communication and aiding the information exchange between the first responders, the public and the victims, as well as media for information dissemination universally designed? Have ICT technologies for suggesting the first responders or decision makers on various life-saving decisions and aid considered universal design? Have the ICT technologies to support event detection, and assessment which typically are used for disaster prevention, early response and damage mitigation taken into account the vulnerable groups? How can we make more accessible the electronic/ interactive maps and GIS tools that increasingly used for disaster support e.g. to obtain a common operational picture, to inform evacuation route, to assess damages?

There are many ICT tools that have been used for both the first responders and general public for training, navigation, evacuation that should be accessible for all.

Based on the gaps in the current research literature, there is also a significant need for research efforts on the following:

- Improved evaluation methods and framework for universal design of ICT for Emergency Management, taking into account the impact of non-conformance,
- Research on impact of situational disabilities in emergency situations,
- Barrier removal methods and strategies,
- Design/development/acquisition principles for ensuring Universal Design of ICT tools for Emergency Management.
- Universal design of:
    - ICT tools in all categories and all parts of the emergency management cycle, and in particular recovery and mitigation
    - web/mobile-based crisis communication platforms,
    - social media-based crisis communication platforms,
    - emerging technologies for emergency management.

POSTER PRESENTER

Dr. Terje Gjøsæter is Associate Professor at Oslo Metropolitan University, and active member of the research group for Universal Design of ICT. He has previous experience from co-organizing and co-chairing a Workshop on Web Accessibility and Metamodelling in Grimstad, Norway in 2005, with 15 participants and 5 poster presentations, and participants and invited speakers from Italy, Egypt and Germany as well as Norway. He also co-edited the proceedings from the workshop containing peer reviewed abstracts published by University of Agder (previously Agder University College). He was Session Chair for a parallel session at MODELSWARD 2016) and is currently a member of the program committee of NISK2017. Together with co-authors Jaziar Radianti and Weiqin Chen, he has a paper under publication in the proceedings from ITDRR2017 on "*Universal Design of Information Sharing Tools for Disaster Risk Reduction*".

Dr. Jaziar Radianti is the head of CIEMlab at Centre for Integrated Emergency Management, University of Agder. She has wide research experience in the area of emergency management, mobile sensing technology, and disaster resilience. She has co-authored some papers related to web-Accessibility. She also has laid out a research agenda on usability and accessibility of information visualization, and command and control room for emergency management. In addition, she has done a preliminary research on technology for better access in crisis communication, and methodologies for harmonising crisis terminology. Jaziar has been active and serves as a reviewer in various international conference and journals since 2010.

Weiqin Chen is Professor at department of computer science at Oslo Metropolitan University and leader of the research group for Universal Design of ICT. She has many years of teaching and research experiences in human computer interaction, assistive technology, and universal design of ICT. She has organized and chaired a number of conferences, workshops, special sessions/tracks, panels, and other academic events, including executive chairs for ICCE 2015-16, workshop chairs for LA 2014-7, EP4LA series, Doctoral Student Consortium chairs and co-chairs for ICCHP2018 and ICCE2011-14, local organization committee for Design Education 2012.

All three co-authors are co-chairs of Track T9 Universal Design of ICT in Emergency Management, and plan to participate in the conference and contribute to sessions connected to the proposed track as well as the poster presentation.

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	Prof. Weiqin Chen *Weiqin.Chen@hioa.no* Research Group for Universal Design of ICT, Department of Computer Science, Oslo Metropolitan University, Norway

**Corresponding Presenter*

ISCRAM 2018

Rochester Institute of Technology
Rochester, NY, USA

POSTER: "Geographic Information Capacity (GIC) Across International Scales: Comparing Institutional Structures of Germany to the United States"

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Workshops and Doctoral Symposium May 20th, 2018

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https://iscram2018.rit.edu/

INTRODUCTION TO THE POSTER

This research was funded through a grant from the US National Science Foundation and the project International Research Experience for Students: Quantifying Disaster Risk Reduction Geographic Information Capacity with United Nations University Institute for Environment and Human Security and University of Bonn Germany (NSF OISE-1559450). Each student chose an independent topic of interest that was related in some nature to the overall

research project. This poster will contain the results of one of these independent research projects. It was conducted by an undergraduate student. The primary investigator for this overall project is Brian Tomaszewski, PhD.

POSTER SUBJECT

Over the last three decades, the number and severity of natural disasters all across the world has been increasing exponentially (Basher, 2006). This poster will present the information found in regards to geographical information capacity (GIC) as it relates to government, government regulated organizations, and international organizations, including the United Nations, and their involvement in disaster risk reduction and management. Capacity is defined by the ISDR as the combination of all the strengths, attributes and resources available within an organization or community to manage and reduce disaster risks and strengthen resilience (ISDR, 2009). The poster aims to understand similarities and differences and the connection between two governmental disaster management organizations, FEMA in the United States and BBK and THW in Germany, and how they relate to GIC. This poster will present a comparison of the two countries in terms of their organizational structures, how their structures affect geographic information capacity and how geographic information capacity is related to disaster risk reduction and disaster response. The poster will also examine the international organizations and partnerships that also effect global disaster risk reduction and GIC.

The preliminary conclusions found in this research will be presented on the poster. Through comparison, it is clear that the institutional structures of Germany and the United States differ greatly in regards to disaster risk reduction and disaster response. A chart will be included on the poster to show quick comparisons of different figures. A countries governmental structure, and the way it interacts and collaborates with international partners can play a huge role in how effectively and efficiently it responds during a disaster. With the number and severity of natural disasters increasing around the world in the last few decades it is imperative that we understand how these structures effects preparedness and response (Basher, 2006). Specifically, by comparing the US and Germany, and in the future more countries, we can get an understanding of how these governmental structures affect geographic information capacity (GIC). Many similarities and differences exist between the two governmental disaster management organizations, FEMA in the United States and BBK and THW in Germany, that were compared in this poster, however we can still see that they can be effective in managing their disasters, and in most areas throughout their country have a high level of GIC. As analysis continues, we can make recommendations on what structural changes can be made in government entities to help increase GIC when disaster strikes, in both developed and developing countries.

POSTER PRESENTER

Tayler Ruggero is an undergraduate student at Rochester Institute of Technology studying Criminal Justice and Public Policy with a minor in Geographical Information Systems

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ACKNOWLEDGMENTS:
This research was funded through a grant from the US National Science Foundation and the project International Research Experience for Students: Quantifying Disaster Risk Reduction Geographic Information Capacity with United Nations University Institute for Environment and Human Security and University of Bonn Germany (NSF OISE-1559450).

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POSTER: Intelligent Wireless Infrastructure Management for Emergency Communications

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

"Visualizing Crisis"

Workshops and Doctoral Symposium May 20th, 2018

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Rochester New York - USA
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https://iscram2018.rit.edu/

INTRODUCTION TO THE POSTER

In 2012, the Congress authorized the creation of FirstNet to develop, build and operate a highly reliable broadband wireless network that will provide first responders advanced communication and collaboration technologies they need to help them do their jobs safely and effectively.

This poster describes the research of a collaborative faculty-led research that will enable first responders to identify and visualize geo-located quality of service and coverage gaps in wireless and deployable networks during an emergency event and support the deployment additional LTE base stations within FirstNet to augment network coverage and capacity.

POSTER SUBJECT

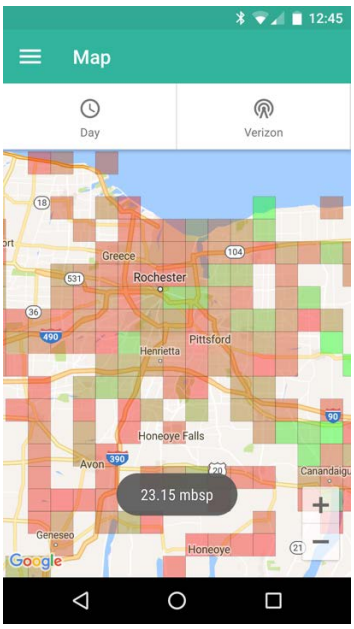
Reliable high-speed connectivity is essential for first responders. However, the demands on the network dramatically increase during an incident. Moreover, the availability of the wireless network is often impacted in the aftermath of a natural disaster.

Our crowd sourced cellular metrics system uses big data analytics to detect changes in coverage and usage patterns and recommends where to deploy additional communication assets. The approach uses machine learning methods to measure and model coverage gaps and automatically implement bandwidth prioritization on whatever communication assets are available.

The deliverables include a GUI that provides the incident manager with information regarding operational performance in the geographic region managed by the deployable including:

- A real-time coverage map showing geo-located QoS
- The location of the individual user equipment within the coverage region
- The typical coverage in a specific area and where that coverage has now failed
- Determining and displaying the effective coverage gap – i.e. how much geo-located bandwidth is currently available versus how much is typically needed for this class of disaster
- Collection of QoS data over time for analysis and future capability enhancements

Example screen shots are shown below.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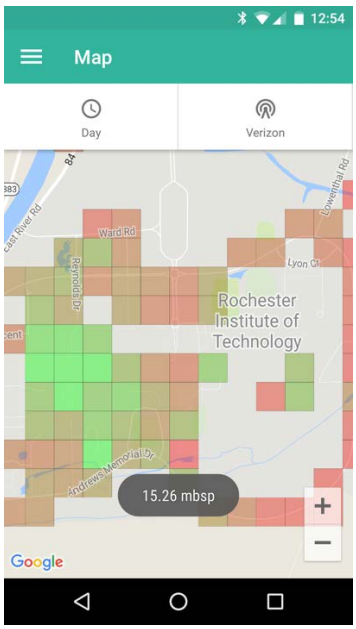
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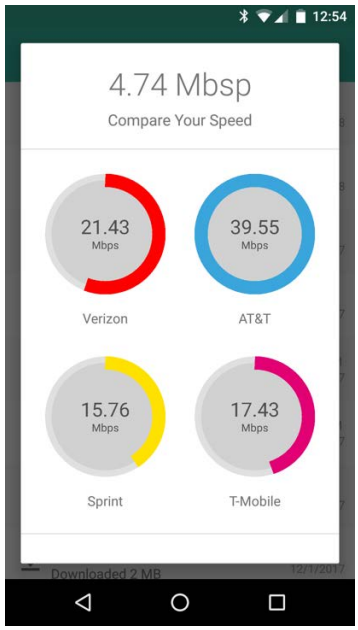
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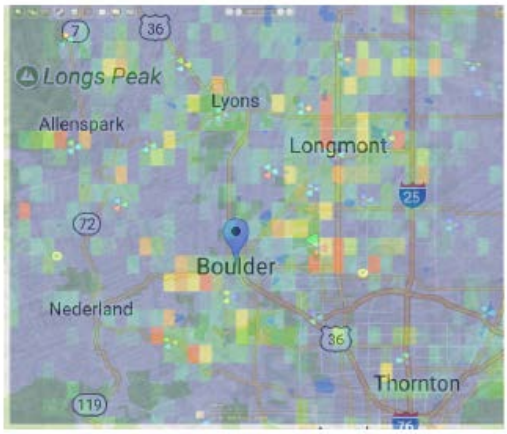
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Nederland
Thornton

POSTER PRESENTER –

Dr. Nygate has over 30 years experience in telecommunication systems working for AT&T, Nortel, and Amdocs. He has developed emergency communications systems based on cellular technology for several countries.

*Dr. Hochgraf is a co-founder of the RIT cellular metrics group which has developed a system for crowdsourced measurement of QoS in cellular networks. He has published on smartgrid and vehicle to vehicle communication and was a participant at the 2017 NIST PSCR Next Generation Deployable Networks Summit.

**Corresponding author*

Dr. Johnson will present.

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Rochester, NY, USA

POSTER: OPEN TRACK

15th International Conference on INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

"A Model for Assessing Label Quality in Crowdsourced Crisis Mapping Systems: A Case of 2010 Haiti Earthquake"

Workshops and Doctoral Symposium May 20th, 2018

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TITLE OF THE POSTER

A Model for Assessing Label Quality in Crowdsourced Crisis Mapping Systems: A Case of 2010 Haiti Earthquake

INTRODUCTION TO THE POSTER

This poster is dedicated to present our research work on the application of crowd and crowdsourcing platforms to crisis situations. In particular, it focuses on crowdsourced crisis mapping solutions. Crowdsourcing has become a popular avenue of research dealing with crisis mapping systems. Crisis mapping systems enable collecting and disseminating crisis information. The contribution of this research is to create a model to assess label quality in the context of crowdsourced crisis mapping. The model was devised in three phases: (1) collection of crisis reports from a crisis mapping platform, (2) crowd-sourced empirical approach to capture labels at scale, and (3) a theory-guided approach for feature selection to create a machine learning model. In the first phase, we collected crisis reports from the Ushahidi platform during the 2010 Haiti earthquake. In the second phase, we utilized CrowdFlower – a crowdsourcing platform for labeling crisis reports based on the input from five crowd volunteers. In the third phase, we adopted situation awareness lens for selecting contextual and collaborative features.

POSTER SUBJECT

In the context of crowdsourced crisis mapping, extant literature has focused on labeling of crisis reports (i.e. assigning meaningful tags to crisis reports), including the problem of (low) labeling quality. Much of the prior work in label quality on crisis mapping platforms has focused on the accuracy attribute of labels, which involves comparing labels with known ground truth or “gold” labels. There are other attributes of label quality such as consistency, completeness, usage, purpose. Since ground truth may not be available in the context of crisis mapping, in this paper, we focus on the consistency attribute of label quality, which deals with consensus across labels from multiple crowd volunteers. Prior literature in this area is missing an investigation of how collaborative content (created as a result of crowd volunteer interaction) affects label quality. Utilizing situational awareness as a theoretical lens, we create a model to assess label quality based on contextual and collaborative features derived from the crisis messages from the Ushahidi crisis mapping platform. The model focuses on labels in the context of Haiti earthquake of 2010.

POSTER PRESENTER

This poster extends previous work as identified below:

Valecha, R., Oh, O., Rao, H. R. (2014). Collaborative Information Processing in Crisis Situations: A Study of 2010 Haiti Earthquake. Conference on Information Systems and Technology (CIST) 2014. San Francisco, California.

Valecha, R., Oh, O., Rao, H. R. (2013). An Exploration of Collaboration over Time in Collective Crisis Response during the Haiti 2010 Earthquake. Proceedings of International Conference on Information Systems (ICIS) 2013. Milan, Italy.

Rohit Valecha will be presenting the poster at ISCRAM 2018.

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