January 2015

Developing a Framework for Stigmergic Human Collaboration with Technology Tools: Cases in Emergency Response

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Abstract. Information and Communications Technologies (ICTs), particularly social media and geographic information systems (GIS), have become a transformational force in emergency response. Social media enables ad hoc collaboration, providing timely, useful information dissemination and sharing, and helping to overcome limitations of time and place. Geographic information systems increase the level of situation awareness, serving geospatial data using interactive maps, animations, and computer generated imagery derived from sophisticated global remote sensing systems. Digital workspaces bring these technologies together and contribute to meeting ad hoc and formal emergency response challenges through their affordances of situation awareness and mass collaboration. Distributed ICTs that enable ad hoc emergency response via digital workspaces have arguably made traditional top-down system deployments less relevant in certain situations, including emergency response (Merrill, 2009; Heylighen, 2007a, b). Heylighen (2014, 2007a, b) theorizes that human cognitive stigmergy explains some self-organizing characteristics of ad hoc systems. Elliott (2007) identifies cognitive stigmergy as a factor in mass collaborations supported by digital workspaces. Stigmergy, a term from biology, refers to the phenomenon of self-organizing systems with agents that coordinate via perceived changes in the environment rather than direct communication. In the present research, ad hoc emergency response is examined through the lens of human cognitive stigmergy. The basic assertion is that ICTs and stigmergy together make possible highly effective ad hoc collaborations in circumstances where more typical collaborative methods break down. The research is organized into three essays: an in-depth analysis of the development and deployment of the Ushahidi emergency response software platform, a comparison of the emergency response ICTs used for emergency response during Hurricanes Katrina and Sandy, and a process model developed from the case studies and relevant academic literature is described.

DEVELOPING A FRAMEWORK FOR STIGMERGIC HUMAN COLLABORATION WITH TECHNOLOGY TOOLS:

CASES IN EMERGENCY RESPONSE

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Dissertation

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in *Information Science and Technology*.

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August 2015

Acknowledgements

I would like to first acknowledge my co-advisors, Jeffrey Stanton and Jason Dedrick. No student could ask or hope for two better advisors during the incredibly demanding and challenging process of producing a successful dissertation. Their guidance has been invaluable and my work has been improved immeasurably through their efforts. In fact, they deserve at least as much credit for this dissertation as I do. I would also like to thank my other committee members, Nancy McCracken and Patricia Longstaff, for their help, support and encouragement during the lengthy process. Many thanks as well to Steven Sawyer and Barbara Kwasnik, Chairs of the PhD program during my progress. Both were enormously helpful to me during my studies. Also, my two dissertation readers, Arthur Thomas and Kendall Phillips, and the examination chair, Philip Good, made my defense experience resemble a stimulating and enlightening discussion, for which I am forever grateful to them. I am also very grateful to the faculty and staff of the School of Information Studies (the iSchool), who did everything possible to help me succeed. Through my time in both the master's and PhD programs, I have come to know these dedicated people as consistently helpful and positive. Their performance and talents are a credit to the university.

I would also like to thank David Chandler, my research mentor in the department of Civil and Environmental Engineering. His encouragement and faith in my abilities made a huge difference in my progress and eventual success.

My family and friends, especially my husband Keith, deserve commendations for their unfailing patience and love, and for their continued confidence in me, especially during the times when I doubted that I would ever finish.

Thank you all so much.

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Preface

This dissertation is composed of three essays exploring how information systems evolve spontaneously and by design. Not unexpectedly, this style of the presentation is generally referred to as the 'three essay format', a series of essays bounded by introductory and concluding chapters. The first essay examines the development of the Ushahidi emergency response software platform. The second essay compares two cases in emergency response: Hurricane Katrina and Hurricane Sandy. The third essay presents a conceptual framework and process model of how information and communications technology (ICT), human cognitive stigmergy, mass collaboration, and situation awareness are related in the context of emergency response. The essays are related to each other via the overarching themes of information systems as complex adaptive systems, how the evolution of information and communications technologies has shaped and been shaped by social action, and the application of information and communications technology to the challenges of achieving effective emergency response.

The inspiration for this study began with a graduate seminar in Information Systems in which Free Libre Open Source Software (FLOSS) development and the related areas of virtual collaboration and virtual organizations were discussed. As an IT professional, computer programmer, systems analyst, designer and developer for over twenty years, I was intrigued by similarities between open source and traditional systems development projects. My years as an analyst and programmer led me to see the systems environment itself as the basis of shared communications between participants in the development process. Working on co-located teams to coordinate program coding, testing and debugging within a shared development environment and working directly with end users to certify and implement systems and applications for many development projects at first seemed quite different from open source collaborations; but I realized the collaborative process was similar whether the development took place in a physical or virtual workspace. I learned that the phenomenon of self-managing agents collaborating via changes in a shared environment is called stigmergy in biological science and cognitive stigmergy in computer science, where it is used to refer to both human and non-human agents. Stigmergy has been observed in many other contexts besides software development, as well as in many species other than humans.

I began looking for technologies that were designed to support context and coordination in digital workspaces through visual and other cues, like the CyberTracker software developed in South Africa for recording wildlife movements in the bush. My longstanding interest in organizational behavior, motivation and instructional design led to my involvement with NSF-sponsored research on virtual organizations as sociotechnical systems, giving me a solid foundation for investigating ad hoc collaboration and the phenomenon of human cognitive stigmergy in technology-enabled digital workspaces.

My selection of emergency response as the context for investigating this aspect of human social behavior was caused by the disaster that occurred during the inundation of New Orleans by Hurricane Katrina in 2005. During and following Katrina, the lack of effective emergency communications technology and essential situation status information where and when it was needed caused devastating damage and ultimately preventable loss of life. I felt that this was an area where change was essential. Looking for solutions, I began studying technological aspects of communications and interoperability, but soon realized that social structures like policies, protocols, standards, laws, and regulations made the problem more complex. I also thought the strong motivational factors inherent in emergency situations could lead to the kind of innovation and creativity in technology use that might overcome those communication and collaboration barriers.

During the response to the Port-au-Prince earthquake in Haiti, an article I came across describing the use of the Ushahidi software platform led me to begin a multi-layered investigation of the development of Ushahidi. I found many significant aspects in the development process. The first deployment of the platform was essentially completed in a week by developers, many of whom did not know each other in advance, using mashed-up open source components. The platform was developed in Kenya (not exactly Silicon Valley), during a period of political unrest and its purpose was to give oppressed people in Kenya a voice during a government-imposed media blackout (Ushahidi means 'testimony' in Swahili). With a failure rate of one in three for traditional software development projects, it was clear that something unusual was happening. Other factors that I thought were interesting and significant were the extensive use of maps to provide context and visual interfaces, the platform being based on free, open source software, the rapid adoption of the platform for a wide range of purposes beyond its original intent, and the regular release of new components that expanded its accessibility and utility as well as how easily it could be deployed.

I attended the IEEE's inaugural conference on Cognitive Methods in Situation Awareness and Decision Support (IEEE CogSIMA 2011) and presented a poster describing my planned research into the role of ICTs for stigmergic coordination in situation management. Micah Endsley was the keynote speaker and I was introduced to her situation awareness (SA) model as generalized for NIST's PRIDE (Prediction In Dynamic Environments) research. Endsley's SA model became the basis for the conceptual framework of the stigmergic mass collaboration model for emergency response developed in the course of this research.

My combination of experience in emergency planning, risk management, information systems, and technology led me to the conviction that innovative technologies for communication, collaboration and access to information were needed in both formal and ad hoc emergency response. The research approach is based on the recognition that although many disasters are inevitable and some are unpredictable, effective emergency response can mitigate the negative effects of such disasters, and technology tools greatly expand our capacity to respond effectively. The ability to respond effectively to emergencies involves preparation, planning and training, learning from our own and others' experiences what works and what does not, and sharing knowledge and best practices at all levels of the community.

The Ushahidi case study was written in winter 2012 and published in 2013, followed by the Katrina and Sandy case studies written in 2014. The appearance of Ushahidi in 2007 between the two hurricanes is significant as a marker of ICT advancement between Katrina in 2005 and Sandy in 2012. The study of the development of Ushahidi provides important insights into the phenomenon of ad hoc emergency response utilizing advanced technology tools. The occurrence of Superstorm Sandy in 2012, a devastating storm with many areas of comparison with Katrina, created opportunities to trace changes that occurred on multiple levels during the intervening years, and identify areas where advances that might be expected did not occur.

Because of the limitations of publication rules the literature review for the Ushahidi case is included as an appendix. A comprehensive reference list for the entire dissertation is also included as an appendix.

Chapter 1

1.1 Introduction

Recent advances in information and communication technologies (ICTs) have created a new conceptual landscape of technology-enhanced, ad hoc, collaborative responses to emergency situations. Contemporary ICTs, including geographic information systems (GIS) applications and social media, have enabled powerful possibilities for emergency response that incorporate "human cognitive stigmergy" – a form of distributed, scalable multi-agent collaboration. Human cognitive stigmergy (HCS) describes the activities of people engaged in self-organizing collaborations based on the perception of changes or traces within the environment. Two important factors to be aware of in understanding the phenomenon of stigmergy are: First, participants are self-organizing, i.e. they participate without central control or directed coordination; and second, participants act in response to environmental cues rather than solely based on direct interaction or communication. Notably, HCS enables collaboration in the absence of a command and control structure and without the benefit of broadcast communications.

The biological phenomenon of stigmergy was originally described in the 1950's by the French entomologist Grasse in his observations of social insects engaging in simple actions based on cues within their shared environment that resulted in complex activities, e.g. nest-building by termites. The term "cognitive" stigmergy is used in computer science and applied to artificial intelligence and robotics to describe the actions of so-called intelligent (sense-making) agents responding to cues in the environment.

With respect to HCS, Elliott (2007) examined ICT-enabled collaboration in open source software development projects. Elliott characterized these projects as stigmergic mass collaborations, defining stigmergy as a method of communication in which individuals communicate indirectly by modifying their shared environment. Anyone who has used an audit trail in a document or comments in computer code has, in effect, left stigmergic traces in the environment for the benefit of coordination with other agents. Elliott (2007) characterized stigmergy as an intuitive, easily understood theory that explains how uncoordinated, disparate, distributed, ad hoc contributions could lead to the emergence of large-scale collaborative enterprises (e.g., the creation of the Linux computer operating system). Elliott (2007) considers HCS applicable to many types of web-based communications.

As various ICTs have become widely available via the Internet, two types of applications are generating important innovations in emergency response: geospatial technologies and social media. In emergency situations, environmental information can be rendered in near real time and can be delivered and shared via map-based interfaces using free, open source and commercial social media, thus leading to the possibility of ad hoc collaborations on a massive scale. The effectiveness of these collaborations for information sharing has led to their adoption for formal emergency communications. The newness and rapid development of these technological advances calls for a thorough exploration of their capabilities and applications to date, to serve as a benchmark for future research to advance. The research presented here is a preliminary exploration of the new conceptual landscape that has arisen, focused on advancing existing models to comprehend the changes that have occurred.

This dissertation investigates stigmergic mass collaboration enabled by ICTs in the context of emergency response in the US and internationally. Case studies describing three emergency response events are presented using human cognitive stigmergy as a theoretical lens to show how ICTs can improve the effectiveness of emergency response by raising the level of situation awareness and increasing opportunities for mass collaboration. In one essay, the uses of ICTs during the events and responses to Hurricane Katrina in 2005 and Superstorm Sandy in 2012 are compared to understand how planned and ad hoc digital workspaces are created in response to a crisis and they can contribute to improving situation awareness and emergency response. Differences in the infrastructure and technological capabilities during Katrina and Sandy and the resulting impacts on emergency response are examined critically. In another essay, the development of an open source, map-based information sharing platform called Ushahidi is explored from its inception during a sociopolitical crisis that occurred after a Kenyan presidential election in 2007, to its adaptation for multiple emergency situations, including the Port-au-Prince, Haiti earthquake in 2010. Finally, the dissertation contains an essay that builds from the cases to develop a new conceptual framework based on situation awareness, human cognitive stigmergy, and the use of information and communications technologies in emergency response.

1.2 Problem statement and research goals

Providing effective emergency response is a massive and complicated problem. The Homeland Security Act of 2002 defines ‘emergency response providers’ as fire, police, and emergency medical personnel, including federal, state and local public safety and related personnel, agencies, and authorities (FEMA, 2006). These providers are usually termed ‘first responders.’ The term ‘emergency responders’ could be used to broaden the category by including all personnel within a community that might be needed in the event of a natural or human-made disaster, potentially including utility workers, hazardous materials teams, urban and wilderness search and rescue, other specialized responders such as those associated with nuclear power plants or controlling wildfires, emergency management officials, municipal agencies, and private organizations responsible for risk assessment and management, transportation, communications, medical services, public health, disaster assistance, public works, and construction. Coordination of resources during an emergency event is a challenge that first and foremost requires information that is reliable, timely and available to those that need it. Failures of emergency response like the catastrophic outcomes of Hurricane Katrina in New Orleans need to be studied and understood in order to prevent recurring failures. Successful emergency responses also need to be studied so that we may understand what makes emergency response effective.

The primary research goal of this dissertation is to apply the principles of human cognitive stigmergy (HCS) to the analysis of successful and unsuccessful emergency response in order to gain insight into how to improve emergency response effectiveness. New, advanced ICTs including geospatial technologies and social media have been shown to enable mass collaboration. Location-based social network technologies have resulted in the spontaneous emergence of ad hoc virtual organizations. Heylighen (2014, 2007a, b) theorizes that stigmergic self-organization explains this kind of system development. The use of ICTs has become increasingly important and widespread in formal emergency response for disseminating emergency alerts and warnings and improving situation awareness. Human cognitive stigmergy (HCS) is a powerful phenomenon that enables ad hoc spontaneous collaboration and encourages innovation in the use of ICT to increase the effectiveness of emergency response. Other potentially relevant phenomena to be considered for understanding effective emergency response, both ad hoc and formal, include: the role of ICTs in supporting emergency response, the process of cognitive stigmergy and mass collaboration in emergency response, and the process of situation awareness for emergency response.

The research is also aimed at rigorously analyzing and clarifying the conceptual landscape relating to technology-enhanced ad hoc emergency response, a striking new phenomenon that has quickly become an important factor in effective emergency response generally. The phenomenon of technology-enhanced stigmergy is itself new and evolving; and the related phenomenon of technology-enhanced stigmergy in emergency response is new and barely studied. Further development of existing models of emergency response and situation awareness based on empirical data is needed. This research is, in essence, an exploratory exercise in model-building.

1.3 Research questions

The research addresses the following questions:

1. How has stigmergic mass collaboration emerged in emergency response?
2. How do people respond to emergencies using ICTs as aids to coordination in the absence of command and control structures (e.g. self-organizing digital workspaces)?
3. What distinctive characteristics/features of an emergency response define the presence and use of stigmergic mass collaboration?
4. What capabilities of ICTs could be added or enhanced to support the emergence and effectiveness of stigmergic mass collaboration?
5. How could formal command and control-based emergency response make better use of stigmergic mass collaboration?

1.4. Summary of the conceptual framework

The dissertation presents the development of a new model of stigmergic human collaboration based on advanced information and communication technology (ICT) enhancements**.** The development of the new model began with an analysis of the development of the Ushahidi emergency response platform (Chapter 2), continued through the comparison of the emergency response to the Katrina and Sandy hurricanes (Chapter 3) and was refined in a model-building process (Chapter 4). The conceptual framework began with some basic concepts: the phenomenon of human cognitive stigmergy, ad hoc participation in emergency response, and the role of advanced information and communications technologies (ICT) in emergency response.

1.4.1 The starting model

The initial framing, as presented in the analysis of the development of the Ushahidi platform for emergency response (Chapter 2), was based on mapping the Ushahidi development strategies of Rapid Prototype Model, Crowdsourcing, Visualization, Mapping, and Mobile Phone Platforms (Marsden, 2013) to the 10-factor VOSS (virtual organizations as socio-technical systems) model developed by Cogburn et al (2011). The construct of human cognitive stigmergy elaborated by Heylighen (2007,a,b), and applied to system software development by Parunak (2006), Ricci et al (2007) and Bolici et al (2007) was adopted from an analysis of the use of crowdsourcing and social media. Analyzing the evolution of Ushahidi and the use of the platform for other emergency events led to the insight that stigmergic mass collaboration enabled by ICTs can be applied in cases other than software development (Marsden, 2013; Elliott, 2007). This insight was confirmed by examining the role of ICTs for emergency response during Katrina and Sandy. A search for a more appropriate model led to the adaptation of the Prediction in Dynamic Environments Situation Awareness (PRIDE SA) process model to include environmental awareness, opportunities for collaboration, and ad hoc decision support and action as factors of human cognitive stigmergy and stigmergic mass collaboration (NIST, 2009).

1.4.2 The ending model

The ending model is an extension of the PRIDE SA process model developed by the National Institutes of Standards and Technology (NIST, 2009) into a conceptual framework of stigmergic human collaboration utilizing technology tools.

The PRIDE SA model is a generalized version of prior models of situational awareness that has been applied in many contexts, including management, traffic control and robotics. The PRIDE SA model uses ICTs to provide situation awareness, and assumes individual agents acting according to a definition in which SA is described as: “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley & Garland, 2000, p.5). In recent years the application of situation awareness (SA) to a variety of complex task domains including risk management, risk assessment, emergency management and emergency response has increased considerably (Gasaway, 2013). In the context of emergency response, SA has been applied according to its roots in performance enhancement training to teach first responders within their various specialties to react prescriptively in pre-defined scenarios (Gasaway, 2013).

The conceptual framework for the comparative analysis of Hurricanes Katrina and Sandy (Chapter 3) is based on the PRIDE SA model, the phenomena of human cognitive stigmergy and stigmergic mass collaboration, and the role of advanced ICTs as enablers for these phenomena. The PRIDE SA model was modified to explain stigmergic mass collaboration because it includes assumptions of non-human agents and a highly structured rule-based operational logic. However, its advantages included the assumption of multiple agents acting independently, based on individual cognition of events, within a shared, real world environment.

In this dissertation, the PRIDE SA model is extended to apply to the problem of increasing situation awareness on a group collaborative level regardless of first responder status within the natural environment during an emergency event, using advanced ICTs. From analysis of the Ushahidi platform deployment (Chapter 2), observations of the phenomenon of human cognitive stigmergy suggest that when presented with relevant information, many people respond spontaneously in emergency situations regardless of their first responder status (Marsden, 2013). This justifies extending the PRIDE SA model beyond individual agents adopting prescribed reactions to a group collaboration model of collective ad hoc participation, shared information and collaborative action. Group collaboration is based on the model of “observe, orient, decide, and act” (OODA), developed by military strategist and USAF Colonel John Boyd (1996). Information and communication technology enhancements generally increase SA levels and reduce errors related to incorrect or missing information (Endsley & Garland, 2000).

According to Elliott (2007), stigmergic collaboration augmented by ICTs creates opportunities for the emergence of mass collaboration. In practice, the PRIDE SA model is augmented by the use of social media for mass collaboration and contextualized with geospatial technologies to increase environmental situation awareness. Hypothetically, emergency response is made more effective by increasing situational awareness and opportunities for ad hoc collaboration. This hypothesis is supported by the analysis of the performance of Ushahidi (Chapter 2) and by the use of ICTs for ad hoc emergency response in both hurricanes Katrina and Sandy (Chapter 3).

A key aspect of the use of geospatial technologies to enhance situation awareness involves understanding the meanings and uses of certain types of visual displays and presentations: interactive digital maps, computer-generated images, aerial photographs, animations and videos that support the production and representation of temporal and location-based information. Extensive research in education, geography, psychology and other fields supports the importance of meaningful visual cues and information in multiple contexts (Marsden, 2013; Aragon et al, 2011; Dunleavy et al, 2008; Hakkareinen et al, 2007; Gersmehl & Gersmehl, 2007, 2006;

MacEachren & Brewer, 2004; Kraak & Ormeling, 2003; Kraut et al, 2003; Horita, 2000; Veinott et al, 1999).

Research in SA and emergency response is extensive (Zsambok & Klein, 2014, 1997; Adamski, 2013; Gasaway, 2013; Klein, 2008; Orasanu & Connolly, 1993), and considering how recently geospatial technologies and social media have been widely in use, there is a respectable amount of research on the use of social media and geospatial information for SA in emergency response (Marsden, 2013; Heylighen, 2007a, b; Van Aardt et al, 2011; Messinger et al, 2010). Research on the relationship between stigmergic collaboration and ICTs is not voluminous but is well established in management, social media research, computer supported collaborative work, artificial intelligence, and free open source software development (Marsden, 2013; Aragon et al, 2011; Cogburn et al, 2011; Elliott, 2007; Bolici et al, 2007; MacEachren and Brewer, 2004; Bonabeau & Meyer, 2001).The integration of these areas, however, is new and is part of the basis of the added value of this dissertation.

The conceptual framework for this dissertation was developed by investigating related field and experimental research via literature review to identify and define important constructs (stigmergy, situation awareness, mass collaboration, information and communications technology), then performing the case studies to build preliminary models, examine propositions and develop the model empirically. The use of geospatial technologies, such as geographic information systems (GIS), photogrammetry, and remote sensing through the use of interactive maps and imagery, is considered as a contextualizing factor for virtual collaboration. The role of social media in enabling mass collaboration via the provision of digital workspaces is examined. Wireless networks, including cellular telephones and handheld devices, are identified as resources able to address interoperability issues common in emergency response coordination.

The third essay in this dissertation, “A Conceptual Framework for Stigmergic Human Collaboration with Technology Tools”, discusses the development of the model (Chapter 4).

1.5 Research Methods

Case study with historical narrative was the primary research method used for all three cases. The specifics are more fully described in the summary of the essays that follows and in the essays themselves.

1.5.1 Case study method

According to Yin *(*2014*)*, a case study is an empirical investigation into a contemporary phenomenon. The strengths of a case study lie in its flexibility, in-depth examination, and real-life context. A case study is appropriate when a phenomenon is complex or incompletely theorized, and is most suitable for descriptive (‘what’) or explanatory (‘how’ or ‘why’) research questions (Yin 2014). Developing a good case study requires (at minimum) selecting the case or cases to be studied, choosing single- or multiple-case study, and deciding whether to apply a theoretical perspective.

There are several good reasons for using case studies for exploratory research. Case studies are especially useful for understanding those kinds of problems that are subject to complex external forces and events that can affect situations and outcomes. However, case studies are challenging (Yin, 2014). Because case studies are flexible enough to take advantage of a range of quantitative and qualitative data collection and analytic methods, careful evaluation and selection of relevant information is essential and the researcher’s ability to analyze data during the collection phases of the study is crucial to developing rich contexts supporting coherent arguments for action and convincing results (Yin, 2014). In this way, cases can serve the dual purpose of guiding research and generating results to be applied in practice (Corey, 1996).

An important consideration in conducting data collection and analysis for case study is performing triangulation, i.e. the discovery of independent sources of information that confirm each other to form robust support for conclusions. For explanatory or descriptive research Yin (2014) recommends selecting multiple cases that can serve to confirm each other, rather than a single case that may be unique or idiosyncratic.

The decision was made to utilize secondary sources in order to thoroughly understand the conceptual landscape as a necessary preliminary. The newness of the phenomena meant that there was no well-developed theoretical framework. To begin with empirically testing the phenomena via existing frames would ignore the recognition that technology-enhanced, stigmergic response to emergency situations called for a new model. Understanding and characterizing the phenomena and their significance, and defining a theoretical approach to guide future research, was a necessary step. Therefore, the use of interviews, surveys or focus groups with various informants was eschewed in favor of secondary sources, including contemporaneous first and second person accounts, relevant published research, and journalistic and media resources.

1.5.2 Historical narrative

Schutt (2006) explains narrative as an explanatory approach that uses descriptions of events and processes to build a chain of causes and effects. The researcher serves as an investigator and story teller, collecting the facts of the story as a detective would and integrating the information gathered into a cohesive narrative that elucidates the sequence of action or events being recounted. Yin (2014) recommends developing a historical narrative as a natural complement for a case study research design because it is effective for explaining relationships, cause and effect between and among events, temporal frames of action, and for rich descriptions of complex systems, histories and events. Historical narrative can be appropriate across many fields of study because it encompasses the origins, development, theoretical framework, etc. of that field, but is particularly appropriate for research which has an historical perspective, and any kind of quantitative and qualitative information can be used in the collection of historical information. Six steps are recommended for achieving a useful result when conducting historical research:

1. Identify the need for certain historical knowledge.
2. Gather as much relevant information about the problem or topic as possible.
3. If appropriate, form hypotheses that can explain relationships between historical factors.
4. Rigorously collect and organize evidence, verifying its authenticity and the veracity of its sources.
5. Analyze the most pertinent collected evidence, drawing conclusions.
6. Record conclusions in a meaningful narrative

Based on Yin’s (2014) recommendations for conducting case studies, steps four and five above would be combined together and analysis would take place throughout the data collection process.

1.5.3 Critical incident technique

The critical incident technique (CIT) was used for data analysis in the Ushahidi case. Originally developed as a type of case study during World War II by Col. John C. Flanagan, the critical incident technique (CIT) is a set of procedures used to identify and analyze critical incidents from a behavioral-cognitive perspective. The technique is based on detailed participant descriptions of critical incidents, defined by Flanagan as “any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made” (Flanagan, 1954).

Participants may be actors in or observers of the incident. In contrast to other research methods that examine normal practices and procedures, CIT focuses on unusual or abnormal incidents to quickly identify problems or opportunities. A critical incident is an incident that contributes an important or significant insight, whether positive or negative, about a particular activity or phenomenon of interest.

In the fifty years since its introduction, the critical incident technique has advanced in two ways: First, from a strongly behavioral approach it has shifted to include psychological and cognitive perspectives; second, it has shifted from direct observation of participants by researchers to a process of eliciting the beliefs, opinions and suggestions that shaped the critical incident (Borgen et al, 2008; Butterfield et al, 2005). The CIT has evolved into a method that "routinely uncovers context, captures meaning, explores incidents of personal significance, and focuses on eliciting the beliefs, opinions, and suggestions that formed part of the critical incident itself" (Borgen et al, 2008, p.2). The method usually follows five steps:

1. Identify the activity to be studied and the objective of the investigation, including developing the research questions.
2. Plan the investigation: Identify the critical incident, its relevance to the research objective, criteria for defining its significance to the research, and identify the data sources.
3. Collect the data: Gather information that is relevant and significant to the research about critical incidents, preferably directly from participants about an activity they have recently taken part in or observed first-hand. Participants describe one or several incidents that represent positive and/or negative aspects of the activity being studied, with an emphasis on providing factual reports, rather than interpretations, of what happened.

4. Analyze the data: This involves two steps, first, developing a frame of reference reflecting the aim of the activity, and second, the development of categories and subcategories supporting the frame of reference. The frame of reference may be developed inductively, but the analysis should also include investigating relevant literature to identify expert opinions, observations and theoretical constructs that support the assumptions.
5. Interpret the analysis and report the results: This step should demonstrate the alignment of the data analysis with the research objective. The analysis and the results should define the activity studied, the process followed for steps 1-4 should be fully explained and the results should clearly define how the findings apply to the research objective. (Borgen et al, 2008; Hughes et al, 2007; Butterfield et al, 2005).

Flanagan stated the strength of the CIT was demonstrated by its ability to be used in new ways, as a "flexible set of principles which must be modified and adapted to meet the specific situation at hand" (Flanagan, 1954, p. 335). For data collection, Flanagan preferred direct observation or individual interviews rather than written responses to survey questionnaires. He also recommended collecting data as quickly as possible following an incident. However, in the 1940's the richness and extent of information and communications technology, audio, video, social media and Internet archives was completely unknown. In these cases, the data collection was from secondary sources including newspaper, magazine, website, journal and social networking publications and archives; formal project documentation, such as published statements of mission, vision, goals and objectives; contemporaneous and retrospective communications (e.g. weblogs, text messages, emails, Tweets, and meeting minutes), memos, letters, discussion boards, chat rooms, transcribed or recorded telephone/internet conversations, etc.); maps and text materials produced and used by the participants; published media reports of events; and published interviews with participants, including audio and video recordings of TED talks with original participants and observers. These data were supplemented with a multidisciplinary review of relevant scholarly literature to provide context and support for the research.

To ensure the trustworthiness of the analysis and interpretation, Borgen, et al (2008) recommend a set of validation practices. Several of these follow general qualitative research guidelines for conducting interviews and participant observations. Because the interviews and other data used were collected after the fact from secondary sources, performing practices such as participant review of results was not possible. However, other recommendations for validating results such as citing expert opinions and finding theoretical agreement on the assumptions supporting the research by comparing the results to the relevant literature were more straightforward (Borgen et al, 2008). The critical incidents investigated were widely reported in the mass media and produced considerable amounts of academic analysis and research publications that were used for validation.

1.5.4 Visual analysis

There is considerable emphasis on the use of visual images, especially maps, as communication devices in all three of the essays. Visualization, visual methodology and visual methods as an area of research is new, but visual presentations of data and information have been practiced for centuries (Tufte, 2001). Technology advances in computer generated imagery (CGI) and associated processing capacity, largely driven by the computer gaming industry, have led to CGI adaptation to data-driven environments for scientific research and analysis. However, because of the high data demands and computational overhead of graphic interfaces, visualization as a mode of digital communication has been among the last to reach desktop and mobile computation.

Visual methods are used to analyze the visual images that provide context for virtual collaboration. Gillian Rose (2007) lays out a theoretical framework for understanding how the meanings of visual images are made in terms of situation (or site) and modality. Rose describes three sites of meaning: the site of production of the image, the site of the image itself, and the site of the audience. Rose also discusses three modalities to be explored for each site of meaning: technological, compositional and social. The weight and importance given to the sites of meaning and the associated modalities may differ depending on the type of image, its use and interpretation. Rose recommends mixing methods to better exploit the strengths and weaknesses of each for understanding an image's various sites and modalities.

Considerations include: how images are selected, chosen, and contextualized, the effect images have on those that see and use them, how images are produced and with what intentions, and the understanding participants have of what they are doing and why. All these areas should be examined by the researcher and explained in a way that makes the process of collecting, analyzing, interpreting and reporting research results transparent. The same considerations are also important in the production of maps and are generally included in any thorough map design or cartography course. Map production conventions and standards such as design of legends, scales, metadata, etc. are cognizant of these as well.

1.6 Summary of the cases

The case studies examine virtual collaboration and systems development via situation awareness and mass communications in the context of practices associated with ad hoc and planned emergency response. The three case studies are presented in two essays. The first in terms of chronological completion, “Stigmergic Self-organization and the Improvisation of Ushahidi”, analyzes the development of the Ushahidi software platform.

The second essay, “From Katrina to Sandy: Self-Organizing Digital Workspaces in Dynamic Environments” compares responses to Hurricane Katrina and Hurricane Sandy. Katrina and Sandy were analyzed together to show similarities and differences in emergency response and to compare and contrast practices and outcomes between the Katrina and Sandy cases. The studies of Katrina and Sandy examine processes associated with information use and the evolution of technologies and infrastructures for collaborative problem-solving over time. The cases present characteristics of existing information and communications systems and infrastructures, their development and usage, and reconstruct the use of various ICTs during and following the storms. The generalized collaborative PRIDE SA model augmented with geospatial technologies and social media is introduced as the basis of comparing the emergency response to Katrina and the emergency response to Sandy.

In the Ushahidi case, a series of critical events inspired the creation of several intermingled technology innovations within a limited time frame. In the Katrina and Sandy cases, each was a snapshot in time of a horrific event, the human response to it, the available tools and knowledge that were utilized, and how the response to the event changed in relation to the available technology. The goal of these studies was to reach a broad understanding of the overall evolution of technologies and human practices, both formal and informal, that were delineated by the events of Katrina in 2005, Ushahidi in 2007 and Sandy in 2012.

1.6.1 Ushahidi

The case study investigates the development of the ad hoc emergency response platform Ushahidi, initially deployed in Kenya in late 2007 and early 2008 during the political unrest generated by a contested presidential election and the resulting news and media blackout mandated by the Kenyan government. The name Ushahidi means “witness” or “testimony” in Ki-Swahili, and its creators originally envisioned the platform as a living document of the violence and repression exerted on the people of Kenya in the aftermath of the unrest. Using basic network technology, the platform allowed people to post reports of violence and unrest in their neighborhoods on a map of Kenya, creating a permanent record of events as they unfolded. Following its original deployment, Ushahidi was redeveloped as a downloadable open source platform and more applications were added. The resilience and scalability of the Ushahidi platform is demonstrated by its performance in many different hazardous environments, including war zones in the Middle East, remote areas of Africa and the 2010 earthquake in Port-au-Prince, Haiti, and Hurricane Sandy. It is likely that its development in Kenya, where access to infrastructure for electricity and networking is limited, during a period of political unrest with government news blackouts, is one of the key reasons for its success. From its beginnings, Ushahidi has been cognizant of infrastructure failures and designed for use in harsh environments with limited resources by using the most basic and readily available technology. The result is a platform that is highly utilitarian, with simple functionality that can withstand tough conditions and operate independently of the Internet.

The case study focuses on the period of time between late 2007 and 2011, the main period of the platform development. Data relating to the development of the platform was analyzed using critical incident technique (CIT) to identify and characterize the critical incidents that were the catalyst for the development effort. A model of the sociotechnical factors of effective virtual organizations was used to analyze the data related to the deployment of the platform. The literature review of sources used for the critical incident analysis is included as an appendix.

The Ushahidi case introduces the main constructs of the new model (as further developed in the analysis of Katrina and Sandy in Chapter 3), but mainly focuses on the stigmergic collaborative model in aspects of software development, using the VOSS model to anchor the social and technical interchange of emergency response via technology rather than the PRIDE SA model. The focus of the social and technical interchange of emergency response via technology is directed to the Ushahidi platform itself as a means of spontaneously forming an effective sociotechnical organization. Ushahidi marks one of the earliest appearances of advanced ICT uses (i.e. social media and geospatial technologies) during an actual emergency response to an event. Moreover, analysis of the Ushahidi case led to the recognition of the phenomenon of stigmergic human collaboration occurring widely among ordinary people in the course of emergency events. Up to this point, stigmergic collaboration had been studied among practitioners of computer programming or software development, and in limited digital workspaces or game spaces (e.g. Second Life, World of Warcraft, and Wikipedia). The broader contexts identified in the course of the Ushahidi case study are the basis of the examination of the phenomenon in the Katrina and Sandy cases.

1.6.2 Katrina

Hurricane Katrina, sometimes called the worst natural disaster in US history, occurred in August of 2005 and affected six states along the Gulf Coast in the US, mainly the city of New Orleans, Louisiana. Hurricane Katrina caused billions of dollars in damage and cost more than one thousand lives. The response to the emergency was an abject failure on multiple levels, calling into question the effectiveness of formal emergency management, planning and response policies and practices at federal, state and local levels. Years later, thousands of people displaced by Katrina have never returned.

In the aftermath of the storm, a striking phenomenon was the ad hoc response of thousands of citizens to various needs of victims and responders, from providing temporary housing, food, and other needs, to driving vans outfitted with computer equipment hundreds of miles to provide technology support at command centers. The participation of ad hoc volunteers was unprecedented in its scale, its effectiveness, and its reliance on advanced information and communications technology (ICT).

Hurricane Katrina occurred just over two years before the development of Ushahidi, and some of the innovations that were available when Ushahidi appeared were introduced just after the disaster in New Orleans and the Gulf Coast, such as Facebook, Google Maps and Google Earth. Other technologies such as Twitter, and OpenStreetMaps would take longer.

However, the striking observation is that regardless of the available technologies, within the affected area, the devastation was so complete that the use of any advanced technologies was limited to those attempting to assist from outside. The total loss of electricity and telecommunications infrastructure reduced those inside the affected area to the technology level of a century earlier. This is the true measure of the abject failure of the planning and preparation for Katrina; that the risks were fully recognized and documented in advance yet not communicated or acted upon at the time of the disaster.

1.6.3 Sandy

Hurricane Sandy, also known as Superstorm Sandy, affected eight states in the northeastern US, particularly New York and New Jersey, including New York City and Atlantic City, NJ in late October of 2012. There are many bases for comparison between Sandy and Katrina, including the unprecedented use of advanced ICTs during and following the storm. Ad hoc and formal collaborations enabled by ICT such as internet- or mobile network-based social media and interactive websites, and geospatial technologies such as interactive maps, visualizations, and imagery derived from geographic remote sensing systems (GRSS) data were compared. The impacts of greatly expanded ICT capabilities and more available tools resulted in a much expanded use of social media and geospatial technologies during Superstorm Sandy in comparison with Katrina, both formally by authorities and informally by citizens.

Despite the loss of electricity to even more people than during Katrina, and the similar reduction of communications capabilities to the levels of one hundred years earlier, the prior planning, warnings and notifications were tremendously superior to those produced during Katrina. The advance response for Sandy (a state of emergency was declared more than three days before the storm hit the coast) was a stark contrast to Katrina. However, the ad hoc response for Katrina, based on the spontaneous use of ICTs to coordinate (e.g. the mobile URISA GIS teams and blogs, websites and bulletin boards) that arose was different. Katrina caused a total breakdown in formal emergency response and ad hoc responders tried to fill the needs they were aware of, while during Sandy the ad hoc response happened much more in advance of the storm.

1.7 Concluding statement

The potential benefits of using information and communication technologies (ICTs) to enhance human cognitive stigmergy (HCS) for emergency response are investigated through the development of three case studies. The three cases empirically examine how digital workspaces for emergency response are created and used, looking for characteristics of development, usage and effectiveness. The case studies were selected as examples of events that could provide evidence of how multi-sited digital workspaces based on advanced ICTs operate on an ad hoc basis and are used by people during emergencies.

The case studies were used to develop a new model for improving emergency response using advanced geospatial technologies to augment situation awareness and social media to increase opportunities for mass collaboration. These advanced ICTs support human cognitive stigmergy, i.e. the ability of people to understand information within their shared environment and act collaboratively without centralized guidance or direction.

Chapter 2 Essay: Stigmergic Self-organization and the Improvisation of Ushahidi

Abstract. There has been considerable investigation into the nature, effectiveness and performance of virtual organizations, virtual teams and virtual collaboration (Cogburn, et al, 2011) based on the affordances of information and communications technology (ICT). The recent emergence of location-based social network technologies has resulted in new modes of ad hoc virtual organizations. Developers appear to improvise systems by cobbling together existing applications and technologies, almost overnight, with uncoordinated contributions rather than traditional designs or project plans. Heylighen theorizes that stigmergic self-organization explains this kind of system development (Heylighen, 2007a, b). As defined by the biologist Grasse, stigmergy has been defined as a sequence of indirect stimulus and response behaviors that contribute to the coordination of actions among insects through their environment, for example termites coordinating their nest building activities (Theraulaz & Bonabeau, 1999). Heylighen likens human cognitive self-organization to stigmergy. In recent years, the advent of distributed ICTs like worldwide internet computing and pervasive ubiquitous networks have made traditional top-down techniques of system development increasingly irrelevant for software application development. Instead, modular, adaptable and self-managing end-user components are combined in “mash-ups” (Merrill, 2009). Similarly, software development teams are spontaneous and ad hoc, functioning as virtual organizations. In this study, the actions leading to the creation of the Ushahidi software platform and its subsequent adaptations are identified using longitudinal case study methodology and content analysis methods applied to newspaper, magazine, website, journal and social networking publications. Based on a socio-technical theoretical framework, the Ushahidi system is framed as a dynamic, ad hoc virtual organization in the context of emergency response. The actions leading to the instantiation of the Ushahidi

system are examined as examples of human cognitive stigmergic response to critical incidents and naturalistic development of complex adaptive systems.

Keywords: human cognitive stigmergy, geocollaboration, information system development, complex systems, virtual organizations, virtual collaboration, situation awareness

2.1 Introduction

In late 2007 in Kenya, US educated Kenyan journalist Ory Okolloh became one of the main sources of information about the unrest and violence that broke out soon after the Kenyan presidential election. Because of the government's ban on live reporting and the censorship of mainstream media, Okolloh solicited information about incidents of violence from ordinary people in the form of comments posted on her personal weblog (blog). The mainstream media was not reporting on the violence because of the government ban, and Okolloh was quickly overwhelmed by the numbers of emails and messages that she received. In order to focus on the "immediate need to get the information out" (Okolloh, 2009), in early January Okolloh posted a request on her blog for help to develop a website where people could post anonymously online or via mobile phone text messages, the most widely accessible type of communications technology in Kenya. Within a day the Ushahidi ('testimony' in Swahili) domain was registered and the website went live within less than a week. Built by 15-20 mainly Kenyan volunteers using open source software based on Google Maps and Frontline SMS, the project was funded entirely by donations, with many volunteer developers. More than 250 people began using the Ushahidi site immediately to share information. Participants eventually grew to 45,000 users, and even included radio stations. Okolloh initiated a simple manual report verification process. If a reporter could be identified, they were contacted for verification; if anonymous, a certain volume of similar reports was considered verification (Okolloh, 2009). Because of the tense political situation and the mainstream media blackout, many people were reluctant to identify themselves. Unverified reports were posted in any case, but were tagged as unverified. Within weeks hundreds of incidents of violence had been documented in detail that otherwise would have gone unreported. The website received hundreds of thousands of visits from around the world, sparking global media attention (Goldstein & Rotich, 2008). Figure 1 shows the appearance of the Ushahidi website as it was originally used in Kenya.

Following the events in Kenya, Humanity United, a non-profit organization dedicated to ending modern slavery and mass atrocities, offered to fund redevelopment of Ushahidi as a broadly available platform for collecting and visualizing information. Ushahidi was transformed from its early origins as a personal blog by journalist Ory Okolloh, into a non-profit tech company specializing in developing free and open source software for information collection, visualization and interactive mapping (Ushahidi, 2012). The goals of Ushahidi the company are to "build tools for democratizing information, increasing transparency, and lowering the barriers for individuals to share their stories" (Ushahidi, 2012). Ushahidi defines itself as "a disruptive organization that is willing to fail in the pursuit of changing the traditional way that information flows" (Ushahidi, 2012). In late 2008 the alpha version was released and tested in the Democratic Republic of Congo, among other places (Okolloh, 2009). The beta version, utilizing Frontline SMS, free software that turns a laptop and a mobile phone or modem into a central communications hub, was released in 2009. The Frontline SMS software can be used on a single laptop computer without the need for the internet, allowing users to send and receive text messages with large groups of people through mobile phones. Since its original release in 2005, it has been widely adopted in the grassroots non-profit community and nominated for several awards (Banks & Hersman, 2009).

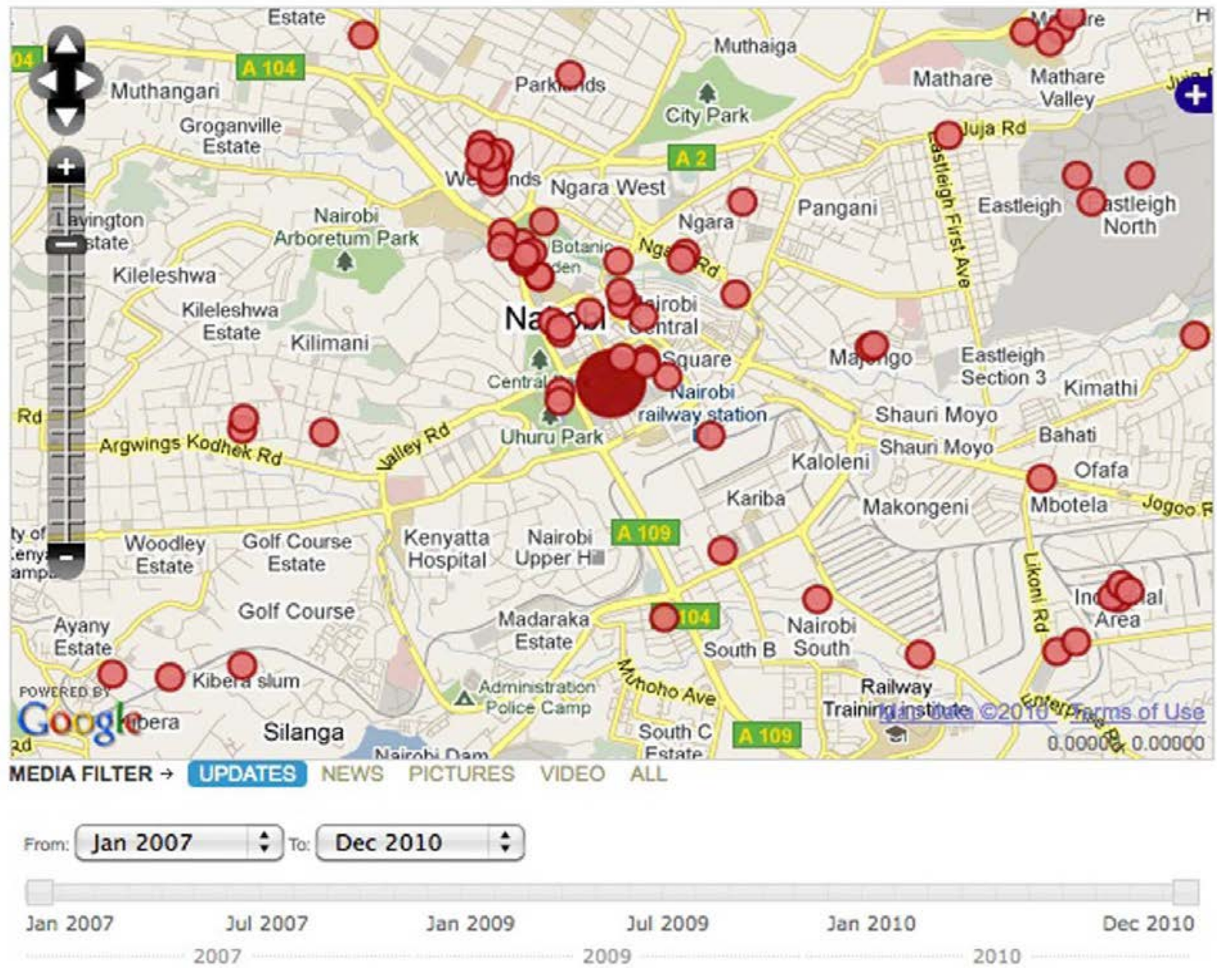

Figure 1. Screen shot of the original Ushahidi deployment

The development of the Ushahidi software has continued. Presently there are three free open source products available: the Ushahidi platform, the Crowdmap application, and the SwiftRiver platform. The basic Ushahidi platform is a downloadable software product that enables crowdsourcing[1] information using mobile phones, email or the internet; and uses OpenStreetMaps or Google Maps to create geocoded[2] event archives. Ushahidi is server-based (i.e. it must be installed on a server) and can be configured for different locations and situations.

[1] Crowdsourcing refers to taking advantage of the talent of the public for problem solving and work.

[2] Geocoding refers to the use of locational data to position information on a map. Locational data can be based on GPS (global positioning system) or addresses, zip codes, compass points, etc.

Temporal data is captured through the use of timestamping and geospatial data is captured through geocoding. The Crowdmap application is a version of the Ushahidi platform that is hosted by Ushahidi and is available via the cloud to allow the platform to be very quickly deployed without the need for a server installation. CrowdMap has an add-on feature similar to Foursquare to allow users to add their own tags to its sites.

The SwiftRiver platform is a downloadable software product built from real-time information processing APIs (application programming interfaces). The impetus for developing SwiftRiver was the need to rapidly handle the overwhelming quantities of data reported in the early hours of a disaster. SwiftRiver is designed to accomplish three tasks: structure unstructured data, conditionally filter and prioritize real time content, and provide context, especially location. SwiftRiver accomplishes these tasks through applications for natural language/artificial intelligence processing, SMS and Twitter data-mining, and information source verification. In 2008, Ory Okollah wrote, “We anticipate that the platform will revolutionize how many organizations handle their data and also democratize how information is collected and shared in crisis situations”. She characterized the Ushahidi development strategy as: “embrace the rapid prototype model and focus on pushing the boundaries of the various areas that the platform focuses on - crowdsourcing, visualization, mapping, and mobile phone platforms” (Okolloh, 2009).

2.2 Research questions

The purpose of this study is to empirically examine the role of human cognitive stigmergy in the rapid, spontaneous initial development of the Ushahidi platform and its evolution, including the SwiftRiver platform and the CrowdMap applications. The initial development of Ushahidi is remarkable for several reasons. First, Ushahidi in its original form was developed and implemented in a single week. Second, it was developed largely by Kenyans, in Kenya, an African country with minimal cyberinfrastructure, technical resources or computer literacy. Third, it was in use by thousands of people within days of being launched. Fourth, as of 2011, the Ushahidi and SwiftRiver platforms have been cited for effectiveness, robustness, and ease of use in multiple contexts, including crisis response and management on a staggering scale such as the Haiti and Fukushima earthquakes, by United Nations organizations specializing in crisis management for decades. The significance of these attributes lie in their applicability to two areas of interest: information systems development (particularly open source software development) and emergency response. These two areas are related by the affordances of the Ushahidi platform, and the process of Ushahidi's development offers valuable insights into both.

The research questions include:

What phenomena explain the development and success of Ushahidi?

What may we infer about information system development from the Ushahidi example?

Is the role of human cognitive stigmergy significant in the development of Ushahidi, and how is it apparent?

2.3 Theoretical framework and constructs

The theoretical framework and constructs used to frame the case study are discussed in the next sections.

2.3.1 Human cognitive stigmergy and information systems development

Information systems and software development have been investigated for many years, from many disciplinary perspectives, but there is not yet a strong theoretical framework of information systems, and much of the research is issue- rather than theory-driven (Avgerou, 2000; Kim, S.J. 2005; Kraut & Streeter, 1995; Lee et al, 2004). The advent of emergent and converging technologies has changed approaches to system design and development, making traditional top-down techniques increasingly irrelevant. Sophisticated end user tools offer new opportunities for rapid prototype development, while the emergence of location-based social networking has created spontaneous new modes of virtual organization. Recently, the migration of network connectivity to handheld smart devices utilizing pervasive ubiquitous networks have created an environment of distributed ICT and worldwide internet computing (Heylighen, 2007a). Developers can improvise systems by mashing together existing applications and technologies, almost overnight, with uncoordinated contributions rather than traditional design processes and project plans (Merrill, 2009). Increasingly systems are based on combining existing end user tools rather than original code development. Instead of meticulous requirements definitions and long hours of code testing and debugging, these modular, adaptable and flexible components are able to handle unanticipated dynamic situations. Similarly, software development teams are fluid, spontaneous and ad hoc, functioning as virtual organizations (Heylighen, 2007a).

Heylighen theorizes that stigmergic self-organization explains this kind of development and coordination, calling it an evolutionary process of human cognitive self-organization, or global complex system building driven by enlightened self-interest (Heylighen, 2007a, b). In Heylighen’s framework, this evolutionary progress is facilitated by stigmergy, which Heylighen defines as the unintended collaboration between agents resulting from their actions on a shared environment. Heylighen believes stigmergic self-organization reduces social friction through the creation of institutions; and that the Internet is a near ideal medium for stigmergic interaction because it transcends the traditional barriers of time and distance to enable virtual organizations to emerge (Heylighen, 2007b).

As originally defined by the biologist Grasse in 1959, stigmergy is a sequence of indirect stimulus and response behaviors that contribute to the coordination of actions among insects through their environment, for example termites coordinating nest building activities through scent trails (Dorigo et al, 2000; Theraulaz & Bonabeau, 1999). Marsh and Onof (2007) state that in its most generic sense, stigmergy refers to the phenomenon of "indirect communication mediated by modifications of the environment" and outline a framework for social stigmergy: "If social epistemology has the formation, acquisition, mediation, transmission and dissemination of knowledge in complex communities of knowers as its subject matter, then its third party character is essentially stigmergic". Bonabeau and Meyer (2001) apply the concept to solving business management challenges, terming it 'swarm intelligence'. Bolici et al (2007), investigating the role of self-organization in open source software development, found that "the qualitative analysis of this evidence shows the paradox that, even if the developers do not seem to communicate explicitly, the software is nonetheless built as the result of a collective effort, apparently without central coordination" and that "stigmergy explains how actors can affect the behavior of other members of the community through the traces that their activities leave in shared artifacts".

The role of cognitive stigmergy has been identified in both commercial and free open source software development (Bolici et al, 2007; Heylighen, 2007a; Parunak, 2006). The conceptual framework of this inquiry is based on Ricci et al's definition of stigmergy as a technique for creating coordination in multi-agent systems (MAS). Ricci et al (2007) distinguish human cognitive stigmergy as supporting "high-level, knowledge-based social activities" from traditional stigmergy as "antlike, nonrational". In terms of Ricci et al's definition, the agent-based working environment is provided by the Ushahidi software platform, including its components, interfaces and affordances to participants. The development environment used by the developers to build the software is the development agents' working environment, and the platform itself is a working environment for end user agents. We can distinguish several classes of agents at work in the environment, utilizing the available tools for their own goals: developers, users, managers, etc. There are multiple system artifacts of the development activity: development tools, software modules, utilities, webpages, map interfaces, etc., including the entity of the system itself. And there are content artifacts: text messages, reports, pictures, videos, etc., the products of the use of the system. Ricci's definition includes interactions between the artifacts and the world. To understand the complexities of the phenomenon of human cognitive stigmergy in the context of the development of Ushahidi, we must look beyond the system itself to the broader environment in which the Ushahidi system functions. For example, the end users perform their activities by orienting themselves through the system's stigmergic mechanisms, acting through the environment abstractions (e.g. messaging, texting, and map interfaces) provided by the Ushahidi platform artifacts. They may understand their work as an act of communicating information to emergency responders (for example), but they are working through and with the developers of the platform. The developers perform their activities through the affordances of the development environment, understanding their own efforts and the work of others through the apprehension of test results, a shared understanding of source code modules, and other environment abstractions that compose the artifact that is the system. These abstractions of the world are understood by participants as real interactions of knowledge sharing and coordination based on shared perceptions and understandings of the work environment, the external environment represented by the system, and the goals and purposes pursued within the functionality of the system.

2.3.2 Virtual organizations, virtual collaboration and human cognitive stigmergy

In their research on virtual organizations, Cogburn et al (2011) refer to the National Science Foundation's (NSF) definition: "A virtual organization is a group of individuals whose members and resources may be dispersed geographically, but who function as a coherent unit through the use of cyberinfrastructure". NSF uses the term cyberinfrastructure to describe "research environments that support advanced data acquisition, data storage, data management, data integration, data mining, data visualization and other computing and information processing services distributed over the Internet beyond the scope of a single institution" (NSF, 2011). At this point in time, the term can obviously be expanded to include many other activities beyond research.

Cogburn et al (2011) point to two key characteristics of virtual organizations: 1. Virtual organizations maintain their structure without sharing a physical space and 2. Virtual organizations use computer-mediated communication to function. Cogburn et al's (2011) ten factor socio-technical model is intended to guide the identification or the development of effective virtual organizations. The model combines social and technical elements identified through analysis based on a broad multi-disciplinary literature review of more than 400 peer-reviewed articles, including seminal empirical studies of virtual organizations. Table 1 shows the Virtual Organizations as Socio-Technical Systems (VOSS) Model.

Okolloh's identified development strategies: Rapid Prototype Model, Crowdsourcing, Visualization, Mapping, and Mobile Phone Platforms, appear to map perfectly to the technical factors of the VOSS model. Telepresence is the mediated environment created through a communication technology to provide an environment for shared activity. Ushahidi's map-based visual interface fulfils the telepresence factor. Technology Scaffolding refers to teaching people to perform a new task through demonstration and help when needed. By using simple text messaging in conjunction with a website map interface, Ushahidi leverages users' knowledge of two basic existing technologies to enable them to quickly master the skills they need to collaboratively build a visual archive of an event. Accessibility is the ability to provide access to information, resources and other people across a geographically distributed group. The Internet in conjunction with mobile phone platforms constitute the most readily and affordably accessible communications technologies anywhere in Africa and elsewhere (Fellett, 2009; Ericsson, 2010).

Virtual Organizations as Socio-Technical Systems (VOSS) Model	
Technical Factors	
Telepresence	An environment created by means of an electronic communication medium that provide a mediated environment for shared activities
Technology Scaffolding	A training method based on engaging trainees in a task above their skill level with demonstration and help when necessary
Accessibility	The ability to provide access to information, resources and other people to a geographically distributed group
Digital Literacy	An individual's ability to recognize when information is needed and to locate, evaluate, and use it effectively via digital technology
Social Factors	
Culture	The collective programming of the mind common among groups of people that facilitates communication and knowledge sharing, and which distinguishes one group or category of people from another
Motivation	Factors leading people to engage in a particular behavior
Trust	The willingness of a party to be vulnerable to the actions of another party irrespective of the ability to monitor or control that other party
Leadership	The ability of a person or persons to promote and engage in practices that establish team norms, facilitate relationship building and develop trust.
Collaborative Learning	The ability of a group to engage actively in a discovery process and collaboratively construct meaningful and worthwhile knowledge
Social System	The way in which individual members within an organization relate to each other and to the organization as a whole

Table 1. Socio-Technical Model for Geographically Distributed Collaboration in Global Virtual Teams (Cogburn et al, 2011)

The VOSS model's social factors are also effectively fulfilled. Digital literacy refers to an individual's ability to recognize when information is needed and to locate, evaluate, and use information via digital technology. The rapid and broad use of the Ushahidi platform in multiple situations points to a capable critical mass of participants, implying that Ushahidi's technology choices optimize digital literacy.

Culture is a complex construct, but as defined by Cogburn et al; it refers to a common, collective programming of the mind among groups of people that facilitates communication and knowledge sharing, and which distinguishes one group or category of people from another. The collective communication and knowledge sharing aspects of Ushahidi's culture are exemplified by crowdsourcing, a mechanism of self-selection and affiliation that brings like-minded people together virtually. This definition of culture coincidentally resembles Heylighen's definition of human cognitive stigmergy.

Motivation is a multi-faceted construct referring to factors that lead people to engage in a particular behavior. Herzberg, in his seminal article on intrinsic vs. extrinsic motivation, explains that external factors such as rewards and punishments (aka the stick or carrot approach) are not effective long term motivations for most people (Herzberg, 1987). Keller's four factor ARCS model (Attention, Relevance, Confidence and Satisfaction) of intrinsic motivation for instructional design is broadly applicable for stimulating intrinsic motivation in individuals, and is adapted here for group collaboration (Keller & Suzuki, 2004; Keller, 2008; Suzuki et al, 2004).

The Attention factor in the ARCS model is primary for a systems interface. People must first find something or know it exists to use it. As more people gain access to the Internet and social media as a means of distance communication and access to information, we observe that knowledge of websites like Ushahidi spreads more readily. The Relevance factor means users recognize the purpose and availability of the system at the critical time when they need it. In an emergency situation, people must know that the system exists and can meet their need. The Confidence factor refers to a person's belief that they will be able to use the system. Observation of others' activities and having the basic knowledge of how to perform the simple messaging, posting and tagging functions of Ushahidi meet the confidence factor. The Satisfaction factor is the user's fulfillment in accomplishing their task. The Ushahidi visual interface gives immediate acknowledgement that the task has been accomplished.

Trust is the willingness of a party to be vulnerable to the actions of another party irrespective of the ability to monitor or control that other party. Although Ushahidi has been used maliciously in some cases to spread false information and to mislead, crowdsourcing and the verification tools included in SwiftRiver have been effective for verifying reports and identifying false information (Goldstein & Rotich, 2008; Munro, 2010).

Leadership refers to the ability to promote and engage in practices that establish team norms, facilitate relationship building and develop trust. Ushahidi's demonstrated leadership is apparent in the company's history and mission of providing "Tools for democratizing information, increasing transparency and lowering the barriers for individuals to share their stories" (Ushahidi, 2012).

Collaborative learning is the ability of a group to engage actively in a discovery process and collaboratively construct meaningful and worthwhile knowledge. This construct is demonstrated in Ushahidi by crowdsourcing at the end user level and by the rapid prototype development model at the developer level. Crowdsourced information combines with the feedback provided by the visual reporting interface to enable collaborative knowledge construction among the participant users. The event archive that is created is available for observers, who can comment and otherwise participate. In the case of the development of Ushahidi, many of these non-participant observers became involved in other ways: as volunteer developers or funders of the development of the Ushahidi platform, or as supporters of emergency response.

Finally, the social system construct of the model refers to how individual members of an organization relate to each other and to the organization as a whole. Ushahidi’s complex social system has at least two levels: the not-for-profit software company, and the various social systems instantiated by end users on the Ushahidi platform. The social system enabled by the platform includes the relationships and interactions between the end users and the company employees, and the interactions and relationships among end users in the context of an event response. Multiple deployments of the platform with respect to emergency events and responses means that there are multiple instantiations of the social system. When the Ushahidi software platform is downloaded and installed on a local server, there is a new cadre of support and maintenance staff and a new set of users. Any of these organizational entities can be examined either separately or as parts of a whole. There is clearly a complex organizational entity known either singly or collectively as Ushahidi that operates virtually as well as physically, and includes multiple virtual collaborations at several levels. However, there is also a complex organizational entity enabled in each instance by Ushahidi and known variously as ‘the Fukushima earthquake’ or ‘the Haiti earthquake’ emergency response, for example.

In terms of Cogburn et al’s (2011) definition of virtual organizations, the Ushahidi platform has created and continues to create and support ad hoc virtual organizations in a variety of contexts. The social and technical factors of the VOSS model explain how human cognitive stigmergy is activated and enabled by the Ushahidi development strategies: the Rapid Prototype

Model, Crowdsourcing, Visualization, Mapping, and Mobile Phone Platforms. The Ushahidi platform provides easily accessible technologies that mediate participants' interactions, enabling virtual collaborations that produce the shared knowledge upon which the emergent coordination processes are based.

2.3.3 Crowdsourcing, situation awareness and system intelligence

Seminal work on situation awareness has been utilized for simulation, decision support, automation and intelligent system design. Endsley & Garland (2000) characterize the process of developing human cognition of situation awareness as essential for people to perform tasks effectively. Traditionally, people relied on experience and training to recognize cues provided in the environment to guide their responses to risk and emergencies. A major challenge is identifying and disseminating information crucial for decision making and action within the huge torrents of data produced by information systems today. In some cases, the volume of available information has overwhelmed people's ability to process and utilize what is needed for effective action. The disconnection between the available information and the needed information is termed the 'information gap', i.e. the ability of the system to provide what is needed when it is needed (Endsley & Garland, 2000). The perspective of this approach to emergency response relies on traditional top-down system development approaches which focus on identifying requirements, then designing, testing and implementing systems. However, in emergency situations, it is impossible to fully anticipate potential information and communication needs, as was demonstrated by the Haitian earthquake and the Fukushima tsunami. Emergency situations often occur in places where there is little infrastructure, or existing infrastructure may be destroyed. Exactly where and how a disaster will occur is often not predictable; and it is not feasible to have resources universally deployed ‘just in case’. What is needed is agile, flexible and portable response strategies.

The term "crowdsourcing" was first coined by journalist Jeff Howe in a *Wired* magazine article: ‘The Rise of Crowdsourcing’: "It’s not outsourcing; it’s crowdsourcing" (Howe, 2006). The term is a portmanteau of the words ‘crowd’ and ‘outsourcing’. Howe described the phenomenon of companies and others taking advantage of the talent of the public through technological advances and inexpensive consumer electronics narrowing the gap between professionals and amateurs in many fields. Problem-solving, scientific research and other work has been ‘crowdsourced’ using websites such as Amazon’s Mechanical Turk that matches online workers with human intelligence tasks (Munro, 2010). The use of the Ushahidi platform in the Kenyan election crisis is an example of the public replacing the traditional media though the use of cellular telephone and Internet-based electronic communications media on an ad hoc basis. Because the government ban on traditional news outlets rendered the normal news outlets non-functional, people turned to what was available and usable to share information and testimony with each other and the world at large about what was happening.

2.3.4 Maps, collaborating and virtual organizations

Maps, like letters and books, have undergone the same evolution from practices that were in place for centuries, to instantiation via information technologies and systems of geospatial technologies (GST) that enable virtual collaboration. Because of the computational and data processing demands, maps and geospatial imagery are among the last information sharing devices to migrate to the desktop and mobile devices. As information-rich simulations, models and visualizations, maps are essential problem-solving and collaborative tools for understanding the complex dynamic systems of our world.

Maps have been traditionally understood as legal contracts, political statements, historical documents and works of art. Like books, maps are often included in library and museum collections, and are considered to be both information repositories and communication tools. There is considerable evidence to support the belief that human use of maps predates any written language (Thrower, 2008), and are found in every human culture (Virga, 2007). Maps serve as a mode of communication and bridge language barriers across diverse regions, cultures and societies. In a real sense they are universal communication devices, offering great utility for representing any information that has spatial dimensionality, from neural networks to solar systems. Maps are truly pictures worth a thousand words. The recent development of digital geospatial technologies has fundamentally changed the production, maintenance and scope of spatial information in ways that are just as profound as the impact of information technology on letters or books. Similarly, these changes and how they may affect society, human interactions, and the future are not well understood at this time, even as they are changing us, our local and world views, and our work. Like other information systems, maps are highly abstracted representations of reality, using selected attributes of the reality they represent to construct knowledge, illuminate understanding, perform work and communicate (Goolsby, 2010). As artifacts of environment abstractions, maps mediate and contextualize communication and interaction, enabling coordination.

Although maps have served as human communication media for centuries, the production and modification of maps has traditionally been slow, laborious and time intensive. Recent advances in geographic information systems and technologies (GIST) have moved map production to the desktop and the network. This has led to an explosion of activity utilizing these technologies, but the work has largely focused on answering discipline-specific questions within different fields. Initiatives such as the National Spatial Data Infrastructure (NSDI) and the National Map (USGS, 2011; NSDI, 2004), have aimed at providing consistent and reliable data for research, focusing on information delivery in a direct flow from producers to consumers. Interactive mapping systems such as Google Maps and OpenStreetMap enable the general public to produce, share and use spatial knowledge, leading the recognition of maps as contextualizing, collaborating and co-orienting media by the public. GIST has advanced tremendously, with fundamental improvements in accessibility and interactive capabilities, making readily accessible to many technologies that until recently were largely the domain of subject matter experts.

In “Wanted: A Concise List of Neurologically Defensible and Assessable Spatial Thinking Skills”, Gersmehl & Gersmehl (2006) offer a set of ten spatial thinking skills which are cognitively based, three spatio-temporal thinking skills and two spatial model constructs. Their list is solidly grounded in a literature review of nearly 1000 articles from a broad range of scholarly journals dealing with cognitive and neurological research on spatial thinking skills. Based on their review of the literature, they characterize these skills as combining basic cognition of spatial information gained from early childhood with more complex and abstract understanding developed as people grow and learn (Gersmehl & Gersmehl, 2006, 2007). In terms of cognitive development, spatial thinking skills are analogous to language skill acquisition in that they begin to develop at a very early age: “Neuroscience research, however, is unambiguous about two facts: the human brain does every one of these kinds of spatial thinking more or less automatically, and it begins doing so in very early childhood... Moreover, the skills of spatial thinking, like those of mathematical or verbal reasoning, appear to be at least somewhat cumulative. People who begin to develop mastery of spatial-thinking skills in early childhood will be able to use those skills to acquire and organize additional information throughout their lives" (Gersmehl & Gersmehl, 2007). The use of a map-based visual interface for Ushahidi provides an intuitively meaningful collaboration environment.

In 2004 MacEachren and Brewer (2004) defined a conceptual framework for studying "geocollaboration": a "visually-enabled collaboration using geospatial information through geospatial technologies". The three elements of the framework: visualization of data and information, virtual collaboration, and the use of map-based interfaces for virtual collaboration, are enablers for advances in virtual collaboration. They predicted that "… developments in geographic information science, and in computer graphics and visualization, suggest that we are on the cusp of a substantial increase in the role of maps, images, and computer graphics as mediators of collaboration, in a range of contexts including scientific inquiry, environmental and urban planning, resource management, and education".

Couclelis and Monmonier (1995) advocate using Spatial Understanding Support Systems (SUSS), a map-based information system, as an analysis and communication tool for resolving contentious land use issues (Horita, 2000). Interactive scripts allow users to query, zoom, pan or review. SUSS is defined as a problem-structuring system rather than decision-making or decision-support systems, i.e. SUSS is meant to be used for understanding complex or contentious problems from multiple perspectives. The approach is to develop map-based interfaces and use them to test the role of geovisualization in contextualizing problem-based scenarios for virtual collaboration. In studies conducted on the use of simulations for teaching and learning, both teachers and students have reported that the use of information visualizations and simulations in a collaborative problem-solving situation can afford a highly engaging, collaborative learning experience that is compatible with multiple information-seeking and problem-solving styles (Dunleavy et al, 2008; Hakkareinen et al, 2007). The importance of visual cues for achieving cooperation and agreement in collaborative actions, either virtual or face-to-face, is well-documented (Kraak & Ormeling, 2003; Kraut et al, 2003; Veinott et al, 1999). The selection of a map-based, visual interface for the Ushahidi platform meets many of the accessibility challenges presented by the participants in an emergency event.

2.4 Technology review

Ushahidi is an example of an emergency response support system enabled by new and emerging technologies. Some of the APIs used for Ushahidi were first used for other purposes, and new geospatial, interactive mapping and social networking tools are entering the marketplace. This short technology review is not comprehensive. These examples are selected to identify a few relevant emerging technology trends.

The first is the CyberTracker software developed by Louis Liebenberg at the University of South Africa to enable Bushman wildlife trackers to record field observations (Liebenberg et al, 1999). Liebenberg wrote an icon-driven interface using images of animals instead of text so it could be used by illiterate or semi-literate trackers employed to observe wildlife and record data. In his published research, Liebenberg made it his practice to include his Bushman trackers as co-authors. CyberTracker is installed on a handheld computer and is available as a free download if used for conservation or education purposes. The software has proliferated beyond its original purpose as a software program used in the US called BioKIDS, developed to teach science to school children using a modified version of CyberTracker (Parr et al, 2002; 2004). A wireless extension to the software was proposed in 2006 to enable data uploads from the field (Peacock et al, 2006). The use of a visual interface with minimal text improves accessibility and utilization for a broad range of participants (Blake et al; 2002).

A reporting network based on handheld and cellular devices for epidemiological prevention and control in the Congo (Rouquet et al, 2005), and for managing public participation in community development in Cape Town, South Africa (Barry & Ruther, 2005) have been based on the FrontlineSMS API used for Ushahidi as well. Emerging technologies such as wearable mobile devices (deFreitas & Levene, 2003) that access cellular networks; and mobile video systems deployed from moving vehicles that capture video of buildings and structures, then use orthorectification[3] software to render three dimensional map images suitable for display (Hwang et al, 2006) suggest new capabilities. As these and other technologies migrate from servers in labs to desktops to laptops to smart phones to wearable devices; and as information system development becomes more and more the province of end users; the potential is ever greater for platforms such as Ushahidi to become even more accessible and ubiquitous, offering communications and connectivity anytime, anywhere.

2.5 Research methodology and methods

This study traces the evolution of Ushahidi from its original implementation during the Kenyan elections unrest in 2007-2008, through subsequent instantiations such as the earthquake in Haiti in 2010 and the recent earthquake and tsunami in Fukushima, Japan. The development of Ushahidi is examined in relation to the theoretical construct of human cognitive stigmergy and its role in the creation and function of information systems and the virtual organizations supported by them. There is a focus on understanding how the development strategies named by Okolloh (crowdsourcing, visualization, mapping, and mobile phone platforms) can be understood as tools to examine the role of MAS-based human cognitive stigmergy in information system development. The Ushahidi platform is used as an example of an improvised, adaptable system development driven by a loose, ad hoc aggregation of highly motivated contributors.

[3] Orthorectification is the process of adding spatial coordinates and correcting distortion in photographic images to make them sufficiently accurate for use as maps.

The methodology utilized for the study is a longitudinal case study based on a modified version of a literature search strategy, and includes contemporary first person accounts, recorded media interviews, news items, journal articles and historical documents. The selection of the data focuses on items recounting the development and use of Ushahidi, its precursors, projects and deployments, plus scholarly articles examining the effects and impacts of Ushahidi initially and as it evolved. Collected items fell into two main groups: 1) scholarly articles and research, and 2) news media reports, first and second person accounts and recorded interviews. Following data collection, a timeline of Ushahidi's development was constructed using the news and media items. For the scholarly articles, content analysis was used to analyze the selected studies.

2.5.1 The critical incident technique

The critical incident technique (CIT) is a set of procedures used to identify and analyze critical incidents from a behavioral-cognitive perspective. The technique was developed during WWII by Col. John C. Flanagan to better understand effective and ineffective behaviors for aviation training. The technique is essentially a semi-structured interview or questionnaire which asks participants to describe a critical incident in detail, defined by Flanagan as "any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made" (Flanagan, 1954). The participant may be an actor in the incident or an observer. In contrast to other research methods that may examine normal practices and procedures, CIT focuses on specific incidents which are unusual or outside of the norm to quickly identify problems or opportunities.

According to Butterfield et al (2005) "CIT started out as a task analysis tool and, although it is still used as such within industrial and organizational psychology, it has expanded its use in counseling psychology, nursing, education, medicine, and elsewhere to also become an investigative and exploratory tool". Since Flanagan's original publication in *Psychology Bulletin*, his article has been cited more frequently by organizational and industrial psychologists than any other. CIT has become a standard technique in counseling psychology, and over five decades of use the technique has expanded to measure and improve job performance and professional practice in a wide range of disciplines, including healthcare, education and business, and it has proved to be a robust and reliable research method. Since its development the technique has been applied hundreds of times in dozens of fields, with relatively few and minor changes to Flanagan's original procedure. In addition to its original application for task analysis and training improvement, today it is also recognized as an effective exploratory and investigative tool (Butterfield et al, 2005).

2.5.2 Data collection

Data collection for this study included searches of newspaper, magazine, website, journal and social networking publications and archives, including: Formal project documentation, such as published statement of mission, vision, goals and objectives; copies of contemporaneous and retrospective communications (e.g. text messages, emails, tweets, meeting minutes), memos, letters, discussion boards, chat rooms, transcribed or recorded telephone/internet conversations, etc.); copies of map and text materials produced and used by the participants; published media reports of events; published interviews with participants.

A multidisciplinary review of scholarly literature in which Ushahidi was a subject of study was undertaken and journal articles from political science, sociology, linguistics and communications, among other fields, were included in the data analysis.

2.5.3 Data analysis

Following data collection, the data was used to analyze the series of events and actions that led to the development of the Ushahidi platform. The first step was to construct a timeline based on first person accounts and other information sources. Next, critical incidents and resulting actions were identified. Table 2 shows the sequence of events and associated software development activities in phases.

Phases	Applications	Events
Inception (2007-2008)	Initial Ushahidi platform based on Google Maps, FrontlineSMS and email	-Kenya: political unrest during presidential elections
Expansion (2008)	Redevelopment of Ushahidi platform for use anywhere. Issues: language translation, cyberinfrastructure, local support, trust and security, information siloing	-South Africa: anti-immigrant violence -Kenya, Congo, Uganda, Malawi, Zambia: epidemiology, pharmacy stockouts
Deployment (2008-2009)	Global access via free downloads	-Gaza, Liberia: Political violence
Enhancement Phase I (2010)	Crowdmap - cloud-hosted service offering checkin (e.g. FourSquare) with a purpose and instant mapping	-Haiti, Chile: Earthquake -Kyrgystan: Ethnic violence -Washington, DC: Snowstorm -Russia: Wildfires
Enhancement Phase II (2011)	Swift River – crowdsourced information validation, translation	-New Zealand, Japan: Earthquake -Tunisia, Egypt, Libya: Political unrest -Australia: Floods -US: Occupy movement

Table 2. Chronology of Ushahidi development

2.6 Summary of results

In the course of analyzing the path of Ushahidi’s development, it became apparent that human cognitive stigmergy was involved in the function and affordances of the system with its users, as well as its development. The activities of the developers on the project are shown to demonstrate cognitive stigmergic self-organization in the context of free open source software development; and the manner of utilization of the Ushahidi software product by end users is shown to exemplify human cognitive stigmergy in the context of virtual communication and collaboration. Based on the VOSS model, the technical and social factors affecting virtual organizations are closely interconnected. Also, the VOSS model offers a convincing explanation for the success of both the Ushahidi platform and the Ushahidi not-for-profit company, in that the criteria the model identifies for an effective virtual organization are present in the Ushahidi not-for-profit company and the Ushahidi ad hoc virtual organization instantiations.

The following quote is from the Harvard University Berkman Center for Internet & Society case study of Ushahidi, “Far and away the most prominent and successful digital civic campaign was Ushahidi” (Goldstein & Rotich, 2008). Ory Okolloh initiated the project with the following post to her blog: “Google Earth supposedly shows in great detail where the damage is being done on the ground. It occurs to me that it will be useful to keep a record of this, if one is thinking long-term. For the reconciliation process to occur at the local level the truth of what happened will first have to come out. Guys - looking to do something - any techies out there willing to do a mashup of where the violence and destruction is occurring using Google Maps?” (Goldstein & Rotich, 2008).

David Kobia and Erik Hersman, two technologists with roots in Kenya, answered Okolloh’s request. Leading a small group of volunteers, they designed Ushahidi in one week and launched the initial Ushahidi platform. Ushahidi was originally a mashup or blending of two Internet applications, Google Maps and Frontline SMS. In its earliest form, Ushahidi used Google Maps’ mapping services to display manually added text messages and emails to map locations.

Ushahidi developers then added FrontlineSMS to the Google Maps interface to allow users to zoom in and view orthorectified satellite photography images of Kenya, and created tools for users to report incidents of violence on the map via mobile phone or Internet browser and to create visualizations of the data.

The FrontlineSMS messaging tool is an open source API released in 2005 that enables users to utilize any computer as a communications hub for simple text messaging via internet or cell phone. FrontlineSMS can operate without an internet connection. It was originally developed to monitor wildlife in nature preserves and parks, and has been adapted for use as to provide healthcare in Africa, the FrontlineSMS:Medic version of the API (Banks & Hersman, 2009; Freifeld et al, 2010; Fellett, 2011). “FrontlineSMS is free software that turns a laptop and a mobile phone or modem into a central communications hub, allowing users to send and receive text messages with large groups of people through mobile phones. The software – originally developed in 2005 and updated in 2007 - is being used around the world for a wide range of non-profit activities including the sending of market prices and other agricultural data to smallholder rural farmers in Aceh, Cambodia and El Salvador, the dissemination of news in Iraq, the sending of security alerts to fieldworkers in Afghanistan, for human rights work in places such as Zimbabwe, Pakistan and the Philippines, and the running of a rural healthcare network for 250,000 people in Malawi. Because the software can be used on a single laptop computer without the need for the internet, it has been widely adopted among the grassroots non-profit community and nominated for several awards. Real time situation awareness, visualization, verification” (Banks & Hersman, 2009). The accessibility of the technology is exemplified by the results in Kenya, where 45,000 people worldwide accessed the Ushahidi website in the first month, most of them international; but the greatest value is the ability to mobilize outside help, as demonstrated by the high number of international users.

Ushahidi was most strenuously tested in the aftermath of the earthquake centered in Port-au-Prince, Haiti. One of the biggest challenges was the need to translate messages to and from Haitian Kreyol, French, English, and other languages spoken by emergency workers. Very quickly, Ushahidi was able to crowdsource thousands of volunteer translators: “The average turn-around from a message arriving in Kreyol to it being translated, categorized, geolocated and streamed back to the responders was 10 minutes” … “In the first week alone more than 1,000 people came online to help translate the messages as they arrived” (Munro, 2010). According to the UN, Ushahidi was the only emergency reporting and response service available to people within Haiti following the earthquake; it saved hundreds of lives and directed first aid to tens of thousands (Munro 2010). As can be seen in Figure 2, Ushahidi assisted in directing aid through coordinating crowdsourced volunteers participating all over the world: “The translators and Ushahidi mappers were both aided by a parallel crowdsourcing effort. Volunteers combined satellite imagery, offline maps and reports from people in Haiti using GPS devices to add thousands of data points to OpenStreetMap, taking the number of labeled roads and landmarks from dozens to thousands in just a few days” (Munro, 2010).

These anecdotes illustrate what Yochai Benkler, a legal and political scholar from Harvard’s Berkman Center, calls the ‘networked public sphere’, the notion that our information environment is characterized by both the potential for many-to-many communications (instead of just one-to-one or one-to-many), and the near elimination of the cost of communication (Goldstein & Rotich, 2008). Benkler’s characterization aligns neatly with Heylighen’s characterization of stigmergic self-organization as a process of complex system building on a potentially global level.

Figure 2. Locations of interactions between people collaborating worldwide to translate emergency messages in the first week of Mission 4636.[4]

2.7 Conclusion

A study of the evolution of the Ushahidi software presents strong evidence of cognitive stigmergy at two levels. The first level is the development of the Ushahidi platform, both initially and through the creation of the SwiftRiver and CrowdMap enhancements. The development of the software using a Rapid Prototype Model and crowdsourcing on widely available mobile phone platforms follows examples of some FLOSS development teams that have been shown to use cognitive stigmergy as a tool to organize and coordinate work (Bolici et al, 2007; Crowston et al, 2007, Crowston et al, 2005; Clases & Werner, 2002). The utilization of the software by end

[4] Mission 4636 refers to the phone number (4636) established for the free use of text messaging by victims of the Haiti earthquake. SMS messages in French and Creole were simultaneously translated by thousands of volunteers all over the world to enable quick response.

users as volunteers and contributors demonstrates the role of cognitive stigmergy at the level of group action and virtual collaboration. The occurrences of crowdsourcing also demonstrate human cognitive stigmergy.

The reasons for the success of Ushahidi lie precisely in its *raison d'etre*: it was conceived as a way for people to give testimony to the world about a crisis they were experiencing. Although the aphorism: "Necessity is the mother of invention" is appropriate, there is more to Ushahidi's inception than simple necessity. Ushahidi was meant to empower, to give voice, and was specifically designed to do so, but a host of underlying technologies were necessary before Ushahidi's 'spontaneous' development could occur. Heylighen and Benkler point out that the inexpensive cost of information via the internet is a major force for the increase in all forms of information, easy access to it and voluntary creation and sharing of forms of it. The combination of easy access, low cost, and a compelling social concern lead to powerful motivations for many to participate. Use of the Rapid Prototype Model meant that the functionality was timely; it could be delivered while there was still an urgent need for it, before the crisis passed and life returned to normal. The use of visualization and mapping was crucial. Human cognitive stigmergy is based on people perceiving changes in their environment and responding to them. Visual images and information are more meaningful than text when the place is not known, but even more powerful when it is. Testimony has more power when it is visualized. The ability to present testimony visually is very powerful to participants, and draws outsiders into the experience. Crowdsourcing as a resource for development, support and the generation of information within the context of emergency response is an example of stigmergic self-organization; and the use of mobile phone platforms via FrontlineSMS effectively maximized crowdsourcing: "In Africa, cellphone penetration - the number of phones as a percentage of the population - is still the lowest in the world, but it is growing quickly. In 2010, an estimated 41 per cent of the population on the continent had cellphones, compared with 76 per cent globally. That's double what it was in 2005" **(**Fellett, 2011). Worldwide, it is estimated that there are five billion mobile phones in use as of 2010, and for many users, these are the only access they have to computing or telecommunications capability (Ericsson, 2011).

Heylighen, referring to stigmergic self-organization in open source software development, believes "These developments are revolutionizing our society. On the one hand, they put into question one of the foundations of the present-day market economy, the idea that intellectual property is necessary to stimulate innovation. On the other hand, they open up huge opportunities, which include: freely providing software, technical know-how, scientific knowledge and general education to the countries and people that need it most, but can least afford to pay for it; empowering and stimulating ordinary people to be intellectually creative and thus help others; reducing the danger of commercial monopolies that control software standards or news distribution; and creating and distributing information much more quickly and widely than before, when it is needed and where it is needed." (Heylighen, 2007a, p.2). To these should be added the democratization of access to information, volunteerism, altruism, and charity.

Chapter 3 Essay: From Katrina to Sandy: Self-Organizing Digital Workspaces in Dynamic Environments

Abstract: Situation awareness, the ability to share and disseminate timely, accurate and useful information where and when it is needed, is a significant challenge in emergency response. Within the last ten years, information and communications technology (ICT)-enabled digital workspaces based on social media and geographic information systems (GIS) have developed spontaneously and by design and become a transformational force by enabling mass collaboration and improving situation awareness in emergency situations (Heylighen, 2014, 2013, 2007a, b; Van Aardt et al, 2011; Cogburn et al, 2011; Messinger, 2010; Elliott, 2007, MacEachren and Brewer, 2004). Web-based digital workspaces create ad hoc virtual organizations in response to a crisis through self-organization and coordination, i.e. human cognitive stigmergy, offering potential solutions to emergency response challenges. This research explores the use of geospatial technologies and social media in response to a crisis, and their contribution to situation awareness and emergency response, by comparing planned and ad hoc ICT-enabled mass communications used during Hurricanes Katrina and Sandy. Ad hoc collaborations enabled by ICT such as internet- or mobile network-based social media and interactive websites, and their contributions to situation awareness and incident response are described with particular attention to the roles of social media, crowdsourcing and geospatial imaging technologies such as interactive maps, visualizations, and imagery derived from geographic remote sensing system (GRSS) data during the two events. Differences and similarities between the types of situation awareness and decision support challenges encountered are described, and how those challenges are met through the creation of self-organizing digital workspaces that arose in response to Katrina and developed in the years following.

Keywords: emergency response, emergency planning, social media, situation awareness, digital workspaces, mass collaboration, stigmergy, human cognitive stigmergy, geocollaboration.

3.1 Introduction

Two recent events, Hurricanes Katrina in 2005 and Sandy in 2012, have led to significant changes in emergency planning and response at the federal, state and local levels in reaction to the loss of life and damage to infrastructure and property (FEMA, 2006, 2013, 2014). Emergency response efforts during the two hurricanes are used to trace how information and communications technology (ICT) use and development changed and advanced, and follow developments in ad hoc and formal emergency response. Information and communications technologies (ICT) in emergency response have gained importance and attention as new capabilities, such as assisted GPS (Global Positioning System) for cell phones, have transformed the practice of emergency response (NRC-a, -b, 2013).

Multiple technological and social issues complicate coordination in emergency response operations. Technical issues abound in the aging infrastructures of the electrical grid, telecommunications and transportation. The poles and wires that deliver electricity to homes and businesses are among the oldest parts of the power grid. Power transmission and distribution, telephone networks, rail tracks, roads and bridges, are embedded physical infrastructures with inherent vulnerabilities to weather-related emergencies such as earthquakes, hurricanes, tornados, landslides, floods, fire, snow and ice (Wrobel, 2012). The dependence of telecommunications on the power grid complicates the reliability even of the wireless telecommunications infrastructure (Howard, 2012; Chang, 2009). Multiple layers of communications technologies of various vintages from radio to cellular networks are subject to many issues of incompatibility and lack interoperability. Equipment failures cause loss of communications within organizations impacting their ability to operate. Organizations adopt competing or divergent technologies, causing interoperability complications in interagency information sharing, coordination and communication (Peha, 2005). Many of the challenges of modern emergency response involve coordination, communication and management of resources - needed supplies reaching the place where they are needed, when they are needed - rather than issues of locating adequate supplies (FEMA, 2011).

Social barriers can cause as many problems as technical problems. Social and organizational issues include poor lines of communication between agencies with overlapping missions and responsibilities, rigid command and control protocols within departments, political conflicts and power struggles, competition rather than cooperation between organizations, and gaps between jurisdictions. Logistics in emergency response are particularly challenging, especially when local responders are overwhelmed and incoming responders are on unfamiliar ground, making it more difficult to respond to rapidly changing and/or unexpected events. Other challenges include locating and deploying resources in unfamiliar or radically altered terrain, coordinating local response from remote locations, dealing with social, cultural, language and political differences, and negotiating action among unfamiliar societies, cultures, markets and institutions (Miller, 2007)

Many of the challenges noted above relate to “operability” and “interoperability” in emergency response. In formal emergency response, operability exists when responders have a basic level of communications among users. For example, police officers achieve communications operability using departmental radios to communicate with each other in their vehicles and stations. Interoperability refers to responders and officials from different departments, jurisdictions or agencies being able to communicate with each other and exchange information in real time (Miller, 2006). Obviously, interoperability is not possible without operability. If equipment fails due to malfunction or damage, impacting operability, interoperability is likewise affected. But interoperability is not assured even when operability exists if protocols, signals, processing or equipment is not compatible (Miller, 2006).

In response to the recognized challenges, new approaches to emergency response and emergency response are emerging. One is the formal application of situation awareness research to emergency response, and the related development of dedicated decision support systems as integral parts of emergency planning. Another is the use of Internet-based social media by local and regional authorities for disseminating emergency warnings and advisories, and by citizens to create ad hoc emergency response platforms (NRC-a, -b, 2013). Technologies mostly developed within the last ten years have been spontaneously adapted to support mass collaboration for ad hoc emergency response based on curiosity, affinity, location, and the human motivation to help and assist (Marsden, 2013; Elliott, 2007). Examples of digital workspaces for mass collaboration include crowdsourcing sites like Amazon’s Mechanical Turk, Wikipedia.org, and OpenStreetMap, and platforms such as Google Maps, Google Earth, Twitter, and Facebook. Many digital workspaces are based on mash-ups of social media and geographic information systems platforms, such as the Ushahidi platform for ad hoc emergency response.

Elliott (2007) characterizes digital workspaces for mass collaboration as a form of stigmergic collaboration. Stigmergic collaboration (also known as human cognitive stigmergy) is spontaneous, self-organizing collaboration that occurs without central control or management in response to changes perceived in the environment. The cases of Hurricane Katrina and Superstorm Sandy are compared to analyze emerging uses of location aware digital workspaces and opportunities for meeting the challenges of effective emergency response through ad hoc and formal mass collaboration. The role of key infrastructures is analyzed, notably the electric power and telecommunications grids, and the impact of infrastructure failures on emergency response.

3.2 Research questions

How are digital workspaces created for ad hoc and formal emergency response? Are ad hoc and formal digital workspaces different in their development, usage or effectiveness?

What similarities and differences are there between the ad hoc and formal mass collaborations generated in response to Hurricane Katrina and Superstorm Sandy?

What is the significance of human cognitive stigmergy in mass collaboration for emergency response (ad hoc, formal or both)?

What could be the role of ad hoc, informal emergency response such as self-organizing digital workspaces and mass geocollaboration in traditional emergency response planning and practice?

How could ad hoc emergency response be supported by formal emergency response? Could ad hoc response practices be formalized or are they better left as spontaneous?

3.3 Theoretical framework

The theoretical framework is based on two well-defined constructs: situation awareness and human cognitive stigmergy. From this foundation, the cases provide empirical support for developing a new framework that reflects the role of ICTs in enhancing emergency response. The basic premise of the theoretical framework is that information and communications technologies can improve emergency response by enhancing situation awareness and increasing opportunities for stigmergic mass collaboration. Combining the Prediction in Dynamic Environments Situation Awareness (PRIDE SA) model (NIST, 2009) with human cognitive stigmergy expands the applicability of the PRIDE SA model beyond a single actor to a collaborative space. Observations of the phenomenon of human cognitive stigmergy suggest that when presented with relevant information, many people respond spontaneously in emergency situations regardless of their first responder status (NRC-c, 2013; Marsden, 2013).

3.3.1 Situation awareness

The application of situation awareness (SA) research for traditional emergency response, management and planning dates back almost as far as SA has been a formal field of research, about thirty years or so to the early 1980’s (Gasaway, 2013, Mendonca et al, 2007). Informal or ad hoc responses of victims or onlookers of an emergency as aspects of situational awareness have not been formally studied until recently, but the huge increase in the availability of social media, and its co-option for emergency response has led to increased levels of interest in the phenomenon (NRC-a, 2013). Social media used for emergency response include a variety of technologies including crowdsourcing websites and other online social networks, weblogs, microblogging and mashup tools. Examples include Twitter, Google Maps, Facebook, and Flickr (NRC-a, 2013). From the use of applications such as Facebook for locating missing pets or persons, to the development of the Ushahidi platform for the intended purpose of ad hoc emergency communications, information and communications technologies (ICTs) have changed how we think about and deal with emergencies.

At its most basic, situation awareness (SA), usually discussed in conjunction with decision support, is “Knowing what is going on so you can figure out what to do” (Adam, 1993). Situation awareness developed from human factors research in the 1980s. Its roots as a research discipline involved the development of highly realistic flight training simulations (Endsley & Garland, 2000). From this initial focus on fighter pilot training, in the 1990’s SA expanded into other domains, including basic research into its own cognitive processes and fundamental theoretical definitions. In recent years the application of situation awareness (SA) to a variety of complex task domains including risk management, risk assessment, emergency management and emergency response has increased considerably. Uses of the SA model for emergency response have been largely formal efforts aimed at training first responders (Gasaway, 2013).

The Prediction in Dynamic Environments (PRIDE) SA model is a generalized version of Endsley's original model that was adapted for use in real world environments (NIST, 2009). The PRIDE SA model has been applied in many contexts, including management, traffic control and robotics. The PRIDE SA model assumes individual agents acting according to Endsley's definition, in which SA is described as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" with an explicit dimension of resulting decision and action (Endsley, 2000, p.5). This definition forms the theoretical framework of meeting the challenge of anticipation, planning, intelligence, decision and action during dynamic emergency events. In emergency response, situation awareness as a basis for decision support involves the development of shared mental models among responders for effective decision making and action in an emergency situation (Adamski, 2013). The PRIDE model was developed specifically for application in real world scenarios using ICTs to augment environmental SA for naturalistic decision making (NIST, 2009). The use of ICTs to improve SA for emergency response in an uncertain and variable real world environment involves adapting the model from a traditionally tightly designed and controlled environment focusing on a single actor (e.g. a fighter pilot training in a flight simulator or a first responder learning a scripted response to a pre-defined scenario), to complex information and communications systems transferring environmental information, actions and communications in real or near-real time, among multiple actors, working in the real world regardless of their first responder status, and reflecting that intelligence in multiple parallel virtual spaces.

3.3.2 Human cognitive stigmergy and mass collaboration

Stigmergy, a biological behavior observed in many species, describes the coordination mechanisms of insects, birds and other animals in which traces of individual actions or alterations within a shared environment affects the behaviors of other individuals (Theraulaz and Bonabeau, 1999). Cognitive stigmergy, the coordination of intelligent agents through the signs they make or sense in a shared environment has been applied to engineered and natural environments and to human as well as non-human agents (Heylighen, 2014, 2007a, b; Ricci et al, 2007; Parunak, 2006).

Human cognitive stigmergy (HCS) refers to people using environmentally mediated signals to coordinate their activities, often without direct communication. Parunak (2006) says that HCS (which he terms “human-human stigmergy”) is ubiquitous, and despite being most often discussed in the context of computer-mediated environments, HCS actually predates digital computing. Parunak (2006) lists several examples of pre-computing HCS, including trail making, marketplaces, and document production (joint authorship). Elliott (2007) defines mass collaboration, the unplanned organization and coordination of collective activity on levels between that of the individual and the collective as a function of human cognitive stigmergy (HCS). Elliott defines mass collaboration as HCS occurring on a very large scale that is enabled by ICT-supported digital workspaces (2007). In large scale real world or computer-mediated environments, aspects of the state of the environment and the dynamics that govern changes to the state of the environment over time are accessible to the agents (people) within it, and are the most effective or even the only way for members of large distributed populations to coordinate themselves (Parunak, 2006).

The use of social media for mass collaborations such as Facebook and Twitter has become a familiar phenomenon in recent years. Social media encourage mass collaboration by supporting the explicit formation of participant groups via the functionality of digital workspaces (Elliott, 2007). High rates of group forming occur as participants tend to take part in and create new projects (form subgroups) that are directly relevant to their interests, applications and skills. Mass collaboration is encouraged by the open structure of the group forming workspaces. Utilizing an inclusive rather than exclusive, loosely structured crowdsourcing approach invites mass participation. While levels of participation may vary widely among participants, the sheer numbers of actors, their ability to enter and depart the group at will, and the capacity of the workspace to support virtually unlimited numbers of users working in concert make unprecedented levels of resources available. This is especially valuable in cases of large scale disasters. For example, during the Port-au-Prince, Haiti earthquake in 2010 the Ushahidi platform was used to crowdsource thousands of volunteer translators to translate messages to and from Haitian Kreyol, French, English, and other languages spoken by emergency workers. During the first week of the emergency alone more than 1,000 people in dozens of countries came online to help translate messages as they arrived, accomplishing an average translation time of less than ten minutes between the arrival of a message in Kreyol and its translation, categorization, geo-location as a data point in OpenStreetMap, and return back to responders (Munro, 2010). Volunteers also contributed to updating maps made suddenly obsolete by the earthquake, combining refreshed satellite imagery, offline maps and reports from people in Haiti using GPS devices to add thousands of data points to the OpenStreetMap platform, increasing the number of labeled roads and landmarks from dozens to thousands in just a few days (Munro, 2010).

3.3.3 Research method

The research method is case study based on historical narrative. Two emergency events, Hurricane Katrina in 2005 and Hurricane Sandy in 2012 are compared, and used to trace the development and use of information and communications technologies (ICTs) for formal and informal emergency response over the intervening years between the two storms. Data collection consisted of retrospective reviews of secondary sources rather than interviews, focus groups or surveys conducted directly with possible informants. This decision was made in order to focus the research on a thorough investigation of the conceptual landscape of technology-enhanced, stigmergic response to emergency situations. Contemporaneous journalistic and first person accounts and interviews were included in the data collection process where they served this purpose.

The use of geospatial technologies such as interactive maps, visualizations, and imagery derived from geographic remote sensing system (GRSS) data and ICT-enabled mass communications, internet- or mobile network-based social media, crowdsourcing and interactive websites used during the two events were compared. These uses of ICT for emergency response were explored through the analysis of contemporary and retrospective materials for each event, including first person and journalistic accounts, professional and governmental reports, and academic research. Differences and similarities in the use of ICTs, and the development and advancement of technologies are described.

The two cases were selected as comparable disaster events in terms of type, location, intensity, damage, and response, but separated in time by seven years. The seven year separation in time between the two storms happened to coincide with a significant set of technological advances. Several social media platforms were released that could be expected to have an impact on the use of ICTs for emergency response: Google Earth (2005), Google Maps (2005), Facebook (public access launch in 2006), Twitter (launched in 2006), and OpenStreetMap (2004 in the UK, global within three years, i.e. 2007) were all released during the seven year period between 2005 and 2012. The cases are compared to reveal what changed or did not change in the use of ICTs between the two storms, what ICTs were available for emergency response for Sandy that were not available for use with Katrina and the impact of that, and how advanced ICTs developed over the time span.

3.4 Story of Hurricane Katrina, August 2005

Hurricane Katrina, at its full strength, was a category 5 storm (category 3 at landfall) that was the deadliest and most destructive Atlantic tropical cyclone of the 2005 Atlantic hurricane season, and the costliest natural disaster as well as one of the five deadliest hurricanes ever in the history of the United States. Among recorded Atlantic hurricanes, it was the sixth strongest overall (Knabb et al, 2011). On August 29th 2005, Katrina's storm surge caused 53 different levee breaches in greater New Orleans, Louisiana, submerging eighty percent of the city. The American Society of Civil Engineers report on Katrina indicated that two-thirds of the flooding was caused by multiple failures of the city's floodwalls (ASCE, 2007). Because of New Orleans' location below sea level, the failure of the floodwalls and resulting loss of the massive pumps needed to remove the water, there were long lasting standing floodwaters. The confirmed death toll (total of direct and indirect deaths) stands at 1,836, mainly in Louisiana (1,577) and Mississippi (238), making Katrina the deadliest U.S. hurricane since the 1928 Okeechobee hurricane (Knabb et al, 2005). Over three million customer telephone lines and cell phones experienced loss of service or interruptions in the three most affected states (Kwasinski et al, 2006). Total property damage was estimated at $81 billion (2005 USD. Three million people were left without electricity in Louisiana, Alabama and Mississippi (Knabb et al, 2005). On Aug 28, the National Weather Service's New Orleans/Baton Rouge office predicted that the area would be "uninhabitable for weeks" (NWS, 2005). Over one million people were displaced, making it the greatest humanitarian crisis in the US since the Great Depression (Piper and Ramos, 2006). Katrina was also responsible for what could be considered as the most widespread critical infrastructure collapse to occur in any advanced country since WWII (Miller, 2006).

The slow and inadequate response to Katrina at the federal level was attributed in part to the events of September 11, 2001 (FEMA, 2006). That catastrophe led to the creation of a new cabinet level superagency, the Department of Homeland Security (DHS), which absorbed the Federal Emergency Management Agency (FEMA), traditionally responsible for domestic emergency response at the federal level. As a result of the reorganization, FEMA became subordinate to the new department. DHS’s focus was terrorism rather than natural disasters, and its head was a law enforcement and security officer not familiar with emergency response (FEMA, 2006). Without autonomy, FEMA was not authorized to act independently, while the new leadership was unaccustomed to handling natural disasters. As a result, there was confusion about roles and responsibilities and the emergency response at the federal level was incompetent, while state and local efforts were tardy and inadequate (US House, 2006).

Retrospectively, the lack of an emergency management or planning office in New Orleans was blamed for the poor local response (US House, 2006). Despite repeated warnings from the US Army Corps of Engineers and other state and federal agencies of the danger of severe storm-related flooding, no state or local level comprehensive emergency plans were developed in advance, leaving the entire responsibility for all decision-making, management and execution of emergency response actions, including evacuation orders, to the mayor's office, which was immediately overwhelmed and almost completely unprepared. An improvised emergency operations center (EOC) was established in a downtown hotel, but lack of power, communications and other resources rendered it largely ineffective (US House, 2006).

The September 11th disaster also led to the formation of the Wireless Emergency Response Team (WERT), comprised of dozens of volunteers from several wireless communications technology companies (including Lucent, AT&T Wireless, Verizon Wireless, Sprint, Nextel, Skytel, Arch, VoiceStream and many more), several government agencies (the FCC, NCC (National Coordinating Center for Telecommunications), NCS (National Communications System), the New York City Office of Emergency Management, FEMA and others (WERT, 2006). WERT was established for the purpose of coordinating wireless technology support for the search and rescue operations at Ground Zero in New York City. Once established, they continued their work and were actively involved in restoring emergency communications in New Orleans following Katrina. Following their involvement during Katrina with search and rescue operations and reestablishing communications, WERT issued a final report on Katrina noting potentially significant characteristics that complicated the emergency response:

a) There was plenty of warning before the hurricane, but no warning before the flooding.
b) The New Orleans affected disaster area encompassed hundreds of square miles.
c) The New Orleans affected disaster area resided inside a bigger disaster area of tens of thousands of square miles.

d) Following the hurricane and flood, the weather was generally clear and hot with high temperatures in the 90-degree range and low temperatures in the 70-degree range (Fahrenheit).

e) Much of the city of New Orleans had been evacuated, but thousands of people and pets remained trapped in the city.

f) The city contained several feet of water, flooding streets and buildings.

g) Very limited use of wheeled ground transportation in flood areas was possible. Most transportation was by boat or aircraft.

h) Significant amount of helicopter aircraft traffic over city.

i) Tens of thousands of people were stranded at evacuation shelters.

j) Large number of deceased people and animals.

k) Shortage of food and shelter items.

l) No normal transportation or medical services.

m) Hospital and critical medical patients were stranded.

n) The local airport (MSY) was closed.

o) Very limited commercial or city services available.

p) Extremely limited telecommunications available to majority of city.

q) Extremely limited electrical power and fuel available to majority of city.

r) Extreme danger of disease or sickness from contaminated floodwaters.

s) Significant personal security and safety risks.

t) No fuel, food, communications or support for first responders and rescuers.

u) Significant damage to radio and television broadcast capability.

v) Significant telecommunications network outages to Southern Louisiana.

w) Local and state governments unable to communicate easily for several days (WERT, 2006).

Conditions in the affected disaster area outside of New Orleans were similar to those within the city. Katrina's storm surge caused severe damage from Texas to the Florida panhandle. Voluntary and mandatory evacuation orders were issued for large areas of southeast Louisiana as well as coastal Mississippi and Alabama in advance of the storm covering about 1.2 million residents of the Gulf Coast. Despite the orders, an estimated 60,000 people were stranded in New Orleans mainly because of lack of transportation (Knabb et al, 2011).

3.4.1 Digital media

According to the Pew Research Center, the Internet was an important source of news, information and dialogue during and following the storm (Morris and Horrigan, 2005). About 73 million people (about half of all US online users at the time) used websites or blogs to get information about the storm and its impacts, mostly from the websites of major news organizations such as CNN or MSNBC (73%), or not-for-profit organizations like the American Red Cross (one third). Almost one quarter (24%) used email or messaging to share information, and about 9% used the Internet to check on someone's safety. The Internet was used by 13 million people (9% of all users at the time) to make donations of aid and supplies to victims of the storm, and about 5% (7 million people) reported using the Internet to coordinate their own relief efforts, creating blogs and newsgroups to get information out to people and coordinate relief supplies during and following Katrina (Morris and Horrigan, 2005; Loeb, 2005).

At the time, there was no Twitter, Instagram or YouTube; Facebook was less than a year old; there were few official social networks, and the Ushahidi ad hoc emergency response platform was not implemented until 2008. However, many individuals created digital spaces to provide emergency assistance. Tara L. Conley (2012) of Ms. Magazine wrote about the efforts of women: “I witnessed virtual volunteers, some of whom were also survivors of Katrina, posting resource information and organizing clothing and food shipments using blogs, list-servs and Yahoo! groups.” Conley reported on three web platforms: ‘Real People Relief’, ‘Katrina’s Angels in Action Forum’ and ‘Beyond Katrina’, all created and maintained by women to help Katrina refugees across the country. “These women not only used the platforms to exchange resources and information, but also found refuge in these online spaces. Women supported each other emotionally when it seemed as though their government and families had failed them after the most devastating natural disaster in modern U.S. history” (Conley, 2012).

In addition to coordinating supplies, finding lost loved ones was another critical need enhanced by the Internet. The ‘People Finder Interchange Format’ (PFIF) was created quickly in September, 2005 as part of the ‘Katrina PeopleFinder Project’, a nonprofit technology initiative implemented entirely by volunteers following the devastation. PFIF used an XML format for exchanging information about individuals found or identified in the aftermath. Google Person Finder is based on PFIF (Gertz, 2005; O’Connell, 2005).

NOLA.com, the web affiliate of New Orleans' *Times-Picayune,* became an international focal point for local news and a vital link for rescue operations, despite losing its presses and being forced to evacuate its building on August 30 because of flooding. For days, news coverage was carried only on NOLA's blogs, and four reporters, Doug MacCash, Manuel Torres, Trymaine Lee, and Mark Schleifstein later won the Pulitzer Prize for Breaking News (Pulitzer, 2006). NOLA.com also accepted and posted thousands of individual pleas for help on its blogs and forums (Glaser, 2005). Its posts were monitored constantly by rescue teams from volunteers to the Coast Guard that used the information in their rescue efforts and later for reuniting scattered residents. Trapped victims relayed information to friends and relatives outside the area via the SMS (Short Message Service) text messaging function of their cell phones, who then relayed the information back to NOLA.com. The spontaneous adaptation of the website as a collaborative response to the storm attracted international attention and was recognized as a “watershed moment in journalism” by the Pulitzer Committee, which for the first time opened all its categories to online entries (Steiger, 2006). The Times-Picayune shared the Public Service Pulitzer with the Biloxi-based *Sun Herald* (Pulitzer, 2006).

3.4.2 Telecommunications

During Katrina, alerts and warnings were mainly delivered by traditional means such as sirens, broadcast radio and television, reverse 911, the Emergency Alert System, the Wireless Emergency Alert Systems, and NOAA weather radio, but Katrina had a major impact on critical telecommunications and electric power infrastructures. Although the New Orleans central office building was intact and able to send and receive calls and Internet traffic from outside the city, few functional local lines remained in the affected zone, making intra-city communications largely nonfunctional. In many locations cell phone towers (as many as 2000) failed despite being built to withstand 150 mph winds (Kwasinski, 2006; Miller, 2006). Thousands of telephone poles were downed, and switch offices were non-functional due to flooding or lost power due to flooded backup generators. Bell South estimated 750,000 lines out of service and 180 central offices running on backup generators. Emergency 911 service was severely damaged and the functional parts of the system that remained were overwhelmed by massive call volumes. In many areas, only text messaging continued to work. Most public safety and emergency response systems were non-functional (WERT, 2006). Even key emergency response personnel were left with no way to communicate with each other. The New Orleans police department was reduced to using a backup radio system with only two channels to coordinate hundreds of officers (WERT, 2006). The architecture of the cellular network impacted cell phone service in unforeseen ways. Many cellular users evacuated outside of the affected zone could make but not receive calls because their location, based on area codes within the affected area, could not be verified by the network (Associated Press, 2005). Assisted GPS, a positioning technology available today for cellular phone location, was not yet in widespread commercial use, and in any case requires a functioning network to be used (Kwasinski, 2006).

In the hardest hit areas, the cellular phone antenna network was severely damaged and completely inoperable for several months (FCC, 2006). With the unexpectedly severe impact of Katrina on cellular communications, the Wireless Emergency Response Team (WERT) developed a plan to use helicopters carrying portable cellular network equipment to provide wireless network coverage in areas where the normal network was out of service. Following the initial helicopter mission, it was discovered that due to damage to critical infrastructure, many attempted 911 cell phone calls were failing to reach public safety access points (PSAPs). The team then had to reprogram the portable equipment to reroute calls going to the out-of-service PSAPs to the State Police barracks in Baton Rouge to continue the mission (WERT, 2006).

3.4.3 Radio and broadcast communications

In many locations broadcast radio antennas failed despite being built to withstand 150 mph winds, but emergency services radio towers, built to withstand sustained winds of 200 mph, mainly remained functional (Kwasinski, 2006). In areas where radio broadcasts continued many people were able to tune in on vehicle and battery-powered radios despite having lost electricity. Immediately after Hurricane Katrina, radio station WWL-AM (New Orleans) was one of the few area radio stations in the area remaining on the air, providing emergency information regarding access to assistance for hurricane victims. After the storm damaged the station’s main studios, employees were forced to improvise alternate facilities but continued to broadcast and were heard up to 500 miles (800 km) away. For several weeks while most stations were off the air, WWL-AM’s emergency coverage was simulcast on multiple frequencies of other stations as an emergency service called “The United Radio Broadcasters of New Orleans” (Stone, 2005). Many emergency radio operators within the affected zone made their volunteer services available to the Red Cross and government agencies. To reach them, WWL-AM was simulcast on shortwave outlet WHRI, owned by World Harvest Radio International (Bachman & Sanders, 2005).

The Amateur Radio Emergency Service (ARES) of the Amateur Radio Relay League (ARRL), aka ham radio operators, provided crucial emergency communications during the crisis where no other technology was left functioning (ARRL, 2005). The ARRL was founded in 1914 by Hiram Percy Maxim of Hartford, Connecticut for the purpose of creating a formally organized radio relay service. The ARES was started in the 1930’s for emergency communications. Today, ARRL is still the national association for amateur radio in the US, and the largest organization of radio amateurs in the world with more than 161,000 members. Its mission, based on Public Service, Advocacy, Education, Technology, and Membership, is "To promote and advance the art, science and enjoyment of Amateur Radio" (ARRL, 2015). An estimated 1000 volunteers from ARES provided communications in areas where the communications infrastructure had been damaged or totally destroyed, relaying everything from 911 calls to messages home. For example, in Hancock County, Mississippi, ham radio operators provided the only communications into or out of the area, and even served as 911 dispatchers (ARRL, 2005).

3.4.4 Geospatial technologies

Many volunteers with GIS knowledge and experience were spontaneously motivated to travel to areas affected by the destruction to set and operate temporary command centers with the ability to process and disseminate up-to-date geographic information (Boyd & Mills, 2005). Esri, the commercial GIS software company, donated software and equipment, and the not-for-profit professional and academic organization, URISA (the Urban and Regional Information Systems Association), coordinated volunteers from its GISCorps to man the Emergency Operations Centers (EOCs), creating and printing hundreds of maps on demand to help emergency responders understand the radically altered environment and locate and help victims (URISA GISCorps, 2005). According to Shoreh Elhami, director and co-founder of GISCorps, since 2004, the GISCorp's more than 900 qualified volunteers with GIS experience from all over the US have responded to disaster, humanitarian relief, sustainable development, economic development, health, and education efforts all over the world and supporting organizations including the Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers, Department of Homeland Security, state/local first responders, the Salvation Army, utility companies, the Environmental Protection Agency, National Oceanic and Atmospheric Administration, pipeline and oil companies, the Department of Health and Human Services, and the United States Postal Service, using GIS technology to help deploy personnel and equipment, evacuate communities, create models of damage, and restore crucial infrastructure and services (Brooks, 2005).

Emergency Operation Centers (EOCs) were established in Baton Rouge, Louisiana, Jackson, Mississippi, and in Florida and Alabama to assist in bringing GIS capabilities to the affected zone. Maps were produced for search and rescue operations and for situational awareness (Esri, 2005). Situational awareness maps included power outages and restorations, cell phone coverage as service was restored, flood areas, road closures, access routes, location of aid and comfort facilities such as shelters, kitchens, and water and ice distribution points, command and control areas for the National Guard, FEMA declarations of eligible aid areas, environmentally hazardous sites, locations of public infrastructure such as electric substations, and location of medical care facilities (Esri, 2005). Thanks to the foresight of Talbot Brooks, a professor and GIS practitioner as well as director of the Center for Interdisciplinary Geospatial Technologies at Delta State University in Cleveland, Mississippi, the Mississippi EOC was established and GIS analysis for situation awareness and preparation was begun on August 27th, before Katrina made landfall (Brooks, 2005). However, most GIS support was not initiated until several days after the disaster and continued for weeks in the aftermath (Esri, 2005).

Brooks initially recruited students and other volunteers from his university, then called for support from his colleagues at other Mississippi educational institutions. Volunteers converted a mobile classroom into a "brain bus" loaded with equipment, including computers, software, plotters, and printers to provide GIS analysis and maps. Volunteer resources were the basis of almost all GIS support throughout the affected zone. Because of the lack of planning for deployment of GIS resources and capabilities, first responders, state and local authorities were largely dependent on the volunteers for up-to-date maps. Mobile mapping used GPS in the field for damage assessments so that updated maps could be produced. "It was a true team effort," said Brooks. "GISCorps, GITA, Esri, Leica Geosystems, and volunteers from Mississippi agencies and the state education system all played significant roles in the response and rescue efforts using GIS technologies. Maps and analyses were prepared by all these agencies. All data represented draws from the pooled resources of Mississippi Emergency Management Agency, Mississippi Automated Resource Information System, Esri, and other responding agencies" (Esri, 2005).

Search and rescue operations were enhanced by the use of “geocoding”, a process of converting street addresses into global positioning system (GPS) coordinates. For rescue crews working in unfamiliar areas with streets flooded and street signs missing, street addresses were often not usable (Walton, 2005). "They would get phone calls, or the Coast Guard would come in with addresses in their hands and say, 'I need a latitude and longitude for this address.' So the GIS professionals would do a geocoding, give it to the Coast Guard who got on helicopters and saved lives," said Elhami (Walton, 2005).

The American Red Cross was accustomed to using GIS for emergency planning, and had coordinated with Esri in the past for several relief efforts. They used computer mapping, spatial analysis, and GIS Web services to both plan for and respond to Katrina, providing communities and displaced people with food, clothing, shelter, and other essential services (Tune, 2005). Using GIS-generated maps, the Red Cross strategically placed personnel, equipment, supplies, and other resources prior to Katrina making landfall. Preplanning included identifying counties at risk and counties that would serve as host sites for shelters, supply centers, and other forward operating facilities (Boyd & Mills, 2007). As the hurricane made landfall, updates were done on the fly using ArcView software's ArcMap application. In the aftermath, GIS was used to generate damage assessments, maps of the hurricane’s wind field, and reports of the number of people displaced or impacted by the hurricane. Esri specialists at its Redlands, California, headquarters and its offices in Washington DC helped coordinate the Red Cross’s Shelter Locator web site using Esri’s ArcWeb services. Greg Tune, lead program manager for disaster assessment and GIS at the American Red Cross explained "The types of work we do using GIS would have been very slow moving without the technology. What would have involved foldout paper maps and 'sticky' notes now is a fully automated, constantly updated process. Perhaps most important, the kinds of mapping and analysis we can do can be targeted based on need or request. We are more responsive and effective because of the technology" (Tune, 2005).

3.5 Story of Hurricane Sandy, October 2012

Hurricane Sandy (also known as Superstorm Sandy) was the second largest Atlantic hurricane ever recorded (after Hurricane Katrina), and at an estimated cost of over $65 billion, the second most expensive hurricane in US history (Ladislaw et al, 2013). Sandy was responsible for at least 159 deaths in the US, 72 caused directly by the storm. Twelve states in the US, mostly along the eastern seaboard, sustained physical and financial damage, with the greatest impacts in the most heavily populated areas of New York, New Jersey and Connecticut (FEMA, 2013). At least 650,000 houses were damaged or destroyed with most of the damage caused by heavy waves or storm surge. In the New York greater metropolitan area, the storm tide (a combination of storm surge and high tide) reached a peak of almost thirteen feet above normal high tide at King’s Point in western Long Island. Torrential rainfall, large waves and storm surges accompanied Sandy, causing extensive flooding that closed airports, roads, tunnels, subway systems and transportation corridors. About twenty-three thousand people were displaced by the storm (FEMA, 2014). In the US, 8.5 million customers lost electricity, with power outages that lasted for weeks or even months in some areas (Blake et al, 2013), including one million customers on Long Island, 1.3 million in New Jersey and more than 400,000 in Connecticut (Barron, 2012). The power outages impacted the restoration of communications, including cellular networks, cable TV, Internet and landline telephone service. The power failures to wastewater treatment plants also caused billions of gallons of raw and partially treated sewage to be released into the mid-Atlantic region's waterways (Abi-Samra, N., 2013).

There were notable changes in the way authorities dealt with Hurricane Sandy compared to Katrina. A full day before Sandy made landfall in New Jersey, President Obama signed emergency declarations for five states (Connecticut, Maryland, Massachusetts, New Jersey, and New York) and the District of Columbia, and authorized FEMA to transfer resources directly to state, local, and tribal organizations to make preparations in advance of the storm. This was possible due to legislation approved by Congress to restructure FEMA in the aftermath of Hurricane Katrina, restoring its autonomy within DHS (FEMA, 2006). On October 30th, the President directed FEMA to create the National Power Restoration Taskforce to rapidly restore fuel and power within the affected zone. The Taskforce had power to minimize red tape and improve coordination between the private sector and government agencies at all levels. In the days following Obama signed additional emergency declarations for other states, such as Delaware and West Virginia (Ladislaw et al, 2013).

In addition to benefitting from changes made in the wake of Katrina to emergency response at the federal level, New York City (NYC) was better prepared with long term emergency planning. Devastated by the events of September 11, 2001, NYC responded to the catastrophe by strengthening emergency planning, as did many cities and smaller communities across the US. Enhancements included a fully funded Office of Emergency Management (NYC OEM), elevated to the level of a full department (NYC OEM, 2013). Originally established in 1984 as part of the NYC Police Department, the NYC OEM started originally in 1941 as part of federal civilian defense, came under state jurisdiction in 1950, then moved to NYC control and was expanded to cover disasters and emergencies during the 1960's and 70's (NYC OEM, 1996). NYC OEM actively pursued the use of new technologies for emergency response as a result of the ad hoc volunteer work begun by the Wireless Emergency Relief Team (WERT) to provide robust, reliable wireless communications during the rescue efforts at Ground Zero. This effort was accorded great urgency due to the deaths and injuries suffered by hundreds of New York City firefighters and first responders, including volunteers. By the time Sandy emerged as a threat, NYC OEM (2013) had incorporated informal, ad hoc resources and new technologies into its emergency plans. Sandy's storm surge was more than 24 feet above mean high tide in the hardest hit areas. In New York City, streets, tunnels and subway lines were flooded with salt water cutting power to millions, but although some were still without power days and even weeks later, the New York Stock Exchange reopened in only two days (FEMA, 2013).

3.5.1 Digital media

In 2012 social media was a very different phenomenon compared to 2005. Facebook reached one billion active users as of September 2012 (Fowler, 2012). Twitter, sometimes called the SMS of the Internet, was launched in July 2006 and rapidly gained worldwide popularity. In 2011 Twitter began offering an integrated photo sharing service and reached 500 million registered users by 2012. In 2013, an estimated 500 million Tweets were sent per day (Twitter, 2015).

Traditional media was heavily accessed via the Internet during Sandy. According to the National Association of Broadcasters, nearly ten and half million unique visitors accessed the websites of local television stations between October 28th and 30th, viewing 76 million pages of content. This represents 2.5 to 3.5 times the normal level of use, indicating that local television websites have become equally important news and information resources as broadcasts.

Television stations are now considered and accessed as broadband-broadcast hybrids (Wharton, 2012).

A significant difference in the use of digital media during Hurricane Sandy compared to Hurricane Katrina is the overwhelming adoption of mobile and online technologies including social media by government agencies and institutions. The use of mobile and online technologies during Katrina was mainly non-government, private and individual use by individual online subscribers. During Katrina, alerts and warnings were mainly delivered by traditional means such as sirens, broadcast radio and television, reverse 911, the Emergency Alert System, the Wireless Emergency Alert Systems, and NOAA weather radio. The loss of critical communications infrastructure during and following the storm rendered mobile and online communications mostly unavailable within the affected zone. In contrast, before, during and following Sandy, government agencies and departments at the local, state and federal levels used multiple online technologies and social media to communicate with the public, coordinate with first responders, organize and direct resources where needed, share information, and maintain awareness of community actions and needs (Cohen, 2013). In December 2010 the U.S. Department of Homeland Security's Science and Technology Directorate (DHS S&T) established the Virtual Social Media Working Group (VSMWG). Recognizing that social media and collaborative technologies have become critical components of emergency preparedness, response, and recovery, the mission of the VSMWG is "to provide guidance and best practices to the emergency preparedness and response community on the safe and sustainable use of social media technologies before, during, and after emergencies" (DHS, 2013).

During Hurricane Sandy, organizations and municipalities delivered more than 10 million alerts, about 10% using SMS, 20% via email, and the remainder using phone services like reverse 911 (Ellertson, 2013). Universities sent nearly half 46% of their messages by email, 37% by text, and 17% by phone, while corporations sent 60% of messages by phone, 19% by email and 9% by text. The use of multiple contact paths to reach intended recipients, including landline telephone, email, SMS, mobile phones, etc. is now recognized as a key emergency notification best practice. Communications should be targeted to populations based on their demographics and convey easily understood critical information or instructions (DHS, 2013; Ellertson, 2013).

Twitter, Facebook, YouTube and even Pinterest were widely used by governors, mayors and emergency management officials from North Carolina to Massachusetts, cementing social media's role as an emergency broadcasting service. In addition this active use by government, social media was also used for enhanced situation awareness (Stone, 2013). Multiple Twitter accounts were used to post updates. According to Twitter, more than 20 million Twitter posts were sent that included the terms "sandy," "hurricane," "#sandy" and "#hurricane." The total number of tweets sent about the storm was likely higher, because of posts using other terms (Preston and Stelter, 2012).

Many websites volunteered to act as coordinators for resource sharing, like the vacation rental site airbnb (www.airbnb.com) coordinating temporary housing for displaced Sandy victims (Tam, 2014). The group Crisis Commons launched Hurricane Sandy Crisis Camps in locations across the US, coordinating tech community volunteers (e.g. Geeks without Borders, Hurricane Hackers) to assist relief organizations with high tech solutions (Howard, 2012; Ito, 2012, Stephenson, 2012). Crisis Commons is a group whose mission is "to advance and support the use of open data and volunteer technology communities to catalyze innovation in crisis management and global development" (Cloutier, 2013). Crisis Camps are events held to connect "a global network of volunteers who use creative problem solving and open technologies to help people and communities in times and places of crisis" (Cloutier, 2013). Crisis Campers include technical people with coding, programming, and geospatial and visualization skills, but also creative and smart people who can "lead teams, manage projects, share information, search the internet, translate languages, and apply intuitive and universal access interfaces" (Cloutier, 2013, DHS, 2013).

The Internet was also used by tech groups volunteering to help relief organizations. One notable example was the two day New York Tech Meetup conference organized between relief organizations FEMA, the American Red Cross, United Way, Occupy Wall Street and tech developers to produce solutions to the problems associated with the massive cleanup. Three applications: 'Voluntarily', 'Pingo', and 'uGov' were produced and deployed. Voluntarily helps relief organizations coordinate their door to door operations by centralizing canvassing data and making it easily accessible. Volunteers use the app to download walk lists of addresses and mark the needs discovered using a built in urgency metric to quickly note how badly help is needed for each home visited. Coordinators can centrally monitor the results gathered either on desktop or mobile. The goal is to help relief organizations quickly understand where help is needed and get it there, and prevent volunteer overlap and duplicate questioning. Pingo aims to solve the problem of being unable to contact relatives in affected areas after a disaster hits by allowing its users to drop a pin on a map in the location they believe their loved ones are. Pingo then asks people that are close by to help. The pins change colors when someone goes from missing to found and can be updated with information such as when the last attempt to contact the person was and whether they are believed to be safe. Finally, uGov is an app which gives volunteers a series of questions to ask that determine what government assistance programs affected households qualify for, and then instantly tells them what assistance is available based on the answers given (Kantrowitz, 2012).

3.5.2 Telecommunications

In 2005 when Katrina hit, most US cell phones were limited to 2G networks using circuit switching that mainly supported voice and text messages. The packet switching used by 3G networks that enabled streaming audio and video was just beginning to be implemented. Apple's iPhone, with digital music player, camera and Internet-enabled PDA functionality was still two years away. Assisted GPS technology that enabled enhanced 911 were not yet required. In 2012 3G networks were dominant, early 4G networks were deployed, and smart phones with greatly enhanced location, mapping, graphics and data capabilities were commonplace in the US. Unfortunately, these capabilities are only available if the cellular network is functional. During Hurricane Sandy, a quarter of the cellphone sites in ten states went down, affecting customers of all the major carriers for days or weeks, despite preparations in advance of the storm (FEMA, 2015). Service providers brought portable generators to cell towers ahead of the storm, and staged backup generators and disaster recovery trailers ready to move into flooded areas. However, the preparations did not prevent cell towers from being knocked out by high winds, and in New York City and other areas where severe flooding occurred, major switching offices with equipment located underground were wiped out, making all non-emergency service unavailable, including landlines. The phone companies advised people to send text messages to preserve diminished network capacity because text messaging uses minimal network resources compared to voice phone calls and Internet traffic. Millions of people along the Eastern Seaboard were left without electricity, cable or landline telephone service and sporadic or non-existent cellular service. The damage to the electrical grid complicated and extended the restoration effort for the communications network (FEMA, 2015; Smith, 2012).

Large parts of New York, New Jersey and Connecticut remained without power and communications for days. Ironically, traditional land line telephones using copper wires remained functional for the most part because their power is supplied from the telephone companies' central offices, but in areas upgraded to high capacity fiber networks, telephone, Internet and television services were useless without utility power. Following the profound post-Katrina telecommunications failure, the Federal Communications Commission (FCC) proposed new rules for all cell towers to have backup power similar to the traditional requirement for landlines, but the cellular industry fought and successfully resisted the rule citing cost, insisting that the need could be met with temporary backups (Rosen, 2012).

3.5.3 Radio and broadcast communications

When Hurricane Sandy knocked out power to millions on the east coast, large numbers of people in the hardest hit areas relied on the radio for information (Perry, 2012, Sisario, 2012). According to the radio ratings service Arbitron, when Sandy made landfall in New Jersey, radio ratings in the greater New York City metropolitan area increased 70% from the same time period the week before. The figures were even higher in coastal areas such as Stamford and Norwalk in Connecticut, where there was a 367% increase for the same period. In New Jersey, the increase was 247% for Monmouth County, and 195% in Middlesex, Somerset and Union counties. The numbers would likely have been even higher except that some major stations like WNYC and WINS in New York City lost their AM frequencies and could broadcast only in FM. With power outages limiting access to televisions, computers and the Internet for days, millions tuned in with battery-powered transistor and vehicle radios. Clear Channel in New York City had no power, ran its studios on generators, and changed the format of entertainment channel Z100 (WHTZ-FM) to serve as a public service and news channel, taking calls from listeners and broadcasting emergency information from authorities. In areas without power, the reliance on broadcast radio for information continued for days (Perry, 2012; Sisario, 2012).

Talk radio stations WABC and WOR also switched to an all-news format during the emergency. Reporters at news radio stations like WCBS and WINS stayed out in the storm to continue reporting, helping radio live up to its traditional role as the most reliable local news and information source in emergencies. “If everything else is gone, people still have a radio,” said Tim Scheld, news director at WCBS-AM, “It’s not just information. It’s a connection. Even music provides companionship and a sense of calm” (Hinckley, 2012). Scheld also reported that the use of Twitter as a news and information source was a major innovation during Sandy for staying abreast of the latest developments through reports made by thousands of listeners in the radio audience. Because of very accurate forecasting by the National Weather Service Hurricane Center, station management, reporters and engineers were well prepared with plans for continuing to serve the listening audience throughout the storm and its aftermath (Hinckley, 2012, Perry 2012, Sisario, 2012). However, there was a shortcoming in coordination and communication between local authorities and local media, with most news and updates sourced from listeners and media outlets rather than local authorities (FEMA, 2013, Perry, 2012).

Ahead of Sandy, FEMA advised people living in predicted affected areas to be prepared with battery-powered radios in order to be able to access local emergency broadcasting. Following Sandy, the New Jersey Broadcasters Association joined communications companies such as Emmis Communications and Clear Channel in lobbying the FCC to require radio chips in cell phones and to require universal enabling of installed chips in emergency situations as a safety measure. The cellular companies are fighting the requirement because Internet radio via cell phone is a data stream they charge for (Perry, 2012; Rosen, 2012).

There were nearly 5 million households without power across eight states (New Jersey, New York, Connecticut, Maryland, Delaware, Pennsylvania, Virginia and West Virginia) following Sandy. Radio towers are built to withstand winds up to 200 miles per hour and required to have backup generators with over a week of fuel on hand, but many were damaged by wind or flooded (FEMA, 2013; Perry, 2012). During the lengthy blackout, laptops and phones lost charge in hours so Internet access was lost, and battery-powered and vehicle radios became the last resort for millions. In areas without power, storm relief dominated the airwaves as long as it took to restore electricity (Ross, 2012). Top 40 stations like WJLK-FM on the Jersey Shore repurposed themselves as local news outlets, broadcasting listener testimonials, assistance resources, and emergency information updates, along with car dealer and supermarket ads. The news reports on commercial music stations underscore radio's local roots and accessibility. The response of local stations to Sandy was in contrast with the aftermath of the attacks of Sept. 11, 2001, when many turned their signals over to affiliated news channels for coverage from Ground Zero. Sean Ross, a radio analyst in New Jersey, noted in an online column for Billboard magazine that, "Radio still has an authority that not every tweet has" (Learmonth, 2012).

Emergency services and first responders relied heavily on radio communications. The American Radio Relay league (ARRL) reported that amateur (ham) radio operators from the Carolinas to Maine responded to requests for emergency communications assistance from utilities, state police, fire departments, emergency medical services, the Red Cross, hospitals and shelters, and activated local networks like the Hurricane Watch Net and the VoIP Hurricane Net (ARRL, 2012). In many areas, emergency services and first responders were dependent on amateur radio communications for dispatch, situation reports and coordination. State, county and regional Emergency Coordinators in New Jersey, New York, North Carolina, Delaware, Ohio and Connecticut were able to communicate and coordinate emergency relief. In New Jersey, emergency planning relies on amateur radio as the most reliable medium with the greatest longevity. All New Jersey Emergency Operation Centers are equipped with permanent amateur radio capability on 220 MHz radios aimed at the NJ2EM 220 MHz repeater that covers the entire state with radio, text messaging and high frequency transmission capability, and all New Jersey counties' emergency management plans include monthly testing of county and Red Cross emergency links (ARRL, 2012).

3.5.4 Geospatial technologies

The use of GIS and other geospatial technologies during Hurricane Sandy, particularly geospatial remote sensing systems (GRSS), aerial and satellite imagery, and visual interfaces, reflected long term efforts by FEMA, the state of New York, and New York City to improve situational intelligence for emergency response. The New York City Office of Emergency Management (OEM) was established in 1996 as a mayoral office, then was granted departmental status in the New York City Charter in November 2001 following the events of September 11th. OEM's mission is to "plan and prepare for emergencies, educate the public about preparedness, coordinate emergency response and recovery, and collect and disseminate emergency information" (NYC OEM, 1996). During Hurricanes Irene and Sandy, NYC OEM was actively engaged in leveraging crowdsourcing, humanitarian technology, participatory mapping, and microtasking for support during a crisis (NYC OEM, 2014).

The FEMA Modeling Task Force (MOTF) is experienced in modeling and risk assessment for complex events involving multiple hazard losses, including earthquakes, hurricanes, riverine and coastal floods (surges, tsunamis), winter storms and others. The FEMA MOTF is tasked with integrating data from federal agencies, universities, the national labs, and state and local agencies, and combining those data with observed information in real or near real time to develop evolving assessments of the impacts of events and "ground-truth" their assessments. During Sandy, the MOTF integrated National Hurricane Center (NHC) modeling and field observations, aerial and satellite imagery obtained from the Civil Air Patrol (CAP) and NOAA, and high water surface measurements from U.S. Geological Survey (USGS) surge sensors and field teams. Throughout the event, field observations were used to continually update situational awareness and impact assessments, and to validate the models with actual surge inundation measurements (FEMA MOTF, 2014).

Ahead of the storm, Google's Crisis Response Team, assisted by Ushahidi Crowdmapping (Leson, 2012), constructed a Hurricane Sandy Crisis Response map and a New York City Crisis Response map dedicated to residents in the city's five boroughs (Google.org, 2015; Google.org, 2012). The team used Google Maps for the base map, augmented by information from the NOAA National Hurricane Center, the U.S. Naval Research Laboratory, Weather.com, the National Weather Service, and the United States Geological Survey. Both maps could be embedded on a website or shared via Google+, Facebook, or Twitter. The maps were interactive and updated throughout the storm, presenting views of Sandy's path, public alert zones and Red Cross safety shelter locations. A side bar menu gave access to a radar overlay of precipitation, overlays of traffic conditions, estimates of neighborhood flooding areas, satellite-resolution cloud imagery, high wind probability graphics, local area webcams displaying conditions in real-time, links to associated YouTube videos, and additional information (Strange, 2012).

3.6 Answering the research questions

How are digital workspaces created and used in ad hoc and formal emergency response? Are there differences in development, usage or effectiveness?

The cases of Hurricane Sandy and Katrina show two important ways that digital workspaces are created in emergency response. The first is an ad hoc, reactive, informal effort undertaken by people acting spontaneously to fill a perceived need. A classic example of this kind of digital workspace is the development of the Ushahidi emergency response platform in Kenya in 2007-2008. In the case of Hurricane Katrina, blogs, listservs, newsgroups and web platforms such as the Katrina PeopleFinder Project, Real People Relief, Katrina's Angels in Action Forum and Beyond Katrina were developed and used by individuals rather than institutions in efforts to fill needs not able to be met by formal responders. These spontaneous responses to disaster in digital spaces are reminiscent of how physical locations like fences, posters and bulletin boards in the area around Ground Zero were used by many New Yorkers in the days after the 9-11 disaster to post information notices and messages for and about lost loved ones. The second way that digital workspaces are created is by agencies or institutions acting in traditional, preplanned, proactive and formal ways. An example of this kind of digital workspace is the Red Cross's use of web GIS for publishing locations of emergency shelters and other important resources in advance of a crisis.

These two types of workspaces may be used in different ways according to who develops them and for what purpose, but they share a single overriding attribute; they provide a virtual medium for communication and information sharing. In an empirical study of the behavior of millions of mobile phone users during emergency events, in addition to the expected spike in call volumes during an emergency, a universal pattern of emergency communications was observed:

people outside an affected zone prioritize communication with persons they know within the affected zone above dissemination of situational awareness (Gao et al, 2014). Understanding this phenomenon can assist emergency managers and planners in using digital workspaces effectively. In order to increase response effectiveness, first responders' overriding priority is situation awareness. The digital workspaces created by the FEMA MOTF, for example, are focused on enhanced situation awareness. Although Twitter was used during Sandy by governors, mayors and other officials to disseminate information, spontaneous ad hoc workspaces such as those on Twitter tend to focus on personal communications.

What similarities and differences are there between the ad hoc and formal mass collaborations generated in response to Hurricane Katrina and Superstorm Sandy?

With Katrina, there was a clear difference between the communications inside the affected zone and outside the affected zone: Inside the affected zone there was little or no modern communications, outside the affected zone, fairly normal communications. With Sandy, there was much less demarcation inside the affected zone and outside the zone. Those impacted by Katrina within the city of New Orleans tended to remain unconnected for much longer compared to people in the cities during Sandy. With Sandy, the people in more rural areas were affected for a longer time. The diaspora of refugees from Katrina caused families and friends to be separated socially as well as physically, in some cases permanently. There were many fewer displaced persons during Sandy, and very few were displaced permanently.

In parts of the Gulf coast hit hardest by Katrina, according to the FCC: "The destruction to communications companies' facilities in the region, and therefore to the services upon which citizens rely, was extraordinary. Hurricane Katrina knocked out more than three million customer phone lines in Alabama, Louisiana, and Mississippi. The wire line communications network sustained enormous damage—dozens of central offices and countless miles of outside plant were damaged or destroyed as a result of the hurricane or the subsequent flooding. Local wireless networks also sustained considerable damage—more than a thousand cell sites were knocked out of service by the hurricane. At the hurricane's height, more than thirty-five Public Service Answering Points (PSAPs) were out of service, and some parishes in Louisiana remained without 911 or enhanced 911 (E911) service for weeks" (FCC, 2006). Even first responders were left without reliable communications because of the complete devastation of the communications infrastructure (FCC, 2006). The near total regional communications failure degraded situation awareness and exacerbated problems with agency coordination, command and control, logistics, and search and rescue operations (Miller, 2007). Reliable communications are critical for establishing emergency services, maintaining situational awareness, preparedness and response to a catastrophic event. Without functioning communications systems, first responders and government officials cannot develop the situational awareness necessary to know how and where to direct their response and recovery efforts and respond effectively). Similarly, without the ability to call for help, citizens cannot seek emergency assistance, alert responders or others to their whereabouts and needs, or receive updates or instructions from officials (Miller, 2007).

Cellular communications and internet connections as well were inconsistent and unreliable for a long time, and people were forced to fall back on older traditional media (i.e. broadcast television and radio, and ham radio). Even though the interactivity of social media was relatively novel, the older communications' lack of connection in comparison to the many-to-many communications of the emergent social media of the time caused many to feel frustration and anguish at not being able to locate and communicate with loved ones. People expressed anger at the loss of accustomed services, especially because of the length of time it took for service to be restored. In both Katrina and Sandy, the disruption of communications – especially the cell phone network – revealed the limits of ICT-enabled communications within the affected area and the extension of ICT-enabled mass collaboration beyond the affected area where communications were unaffected.

Tables 3 and 4 show examples of ad hoc and formal mass collaborations generated in response to Katrina and Sandy. These are not exhaustive lists of all the examples that could be included; they point out differences and similarities in the responses to the two storms across several categories of ad hoc and formal mass collaboration. Generally, there are direct correlations between emergency response activities taking place before, during and after Katrina and activities before, during and after Sandy. Forensic investigations following Katrina resulted in lessons learned and actions taken on a national scale that made Sandy a very different event, even aside from the obvious social, political and cultural differences. However, there are also similarities, particularly in the emergency communications category which remained almost unchanged between the two storms.

Katrina 2005	**Situation awareness**	**Digital workspaces**	**Emergency communications**	**Geocollaboration**
Ad hoc	blogs newsgroups listservs forums websites	Real People Relief Katrina's Angels in Action Forum Beyond Katrina Katrina PeopleFinder	Local radio Ham radio email text messaging	URISA GIS Corps Esri
Formal	Esri Official websites Red Cross		Broadcast radio and television Reverse 911 Emergency Alert System Wireless Emergency Alert Systems NOAA weather radio	

Table 3. Ad hoc and formal mass collaborations generated in response to Katrina

Two big differences between the two hurricanes are: The use of new advanced technologies available for Sandy that did not exist for Katrina and the formal use of ICTs by government institutions. Although ad hoc use of ICTs for mass collaboration is evident during and immediately following Katrina, formal digital workspaces and geocollaboration were not seen in use during Katrina. However, both were in use for Sandy because they were incorporated into NYC OEM's and others' formal planning practices well in advance of Sandy.

Sandy 2012	**Situation awareness**	**Digital workspaces**	**Emergency communications**	**Geocollaboration**
Ad hoc	Local radio Ham radio Twitter	Twitter Facebook YouTube Pinterest Airbnb	Local radio Ham radio Twitter Google maps email text messaging	Google Crisis Response team Ushahidi CrisisMappers
Formal	Twitter Facebook YouTube Pinterest	Voluntarily Pingo uGov HurricaneHackers	Broadcast radio and television Reverse 911 Emergency Alert System Wireless Emergency Alert Systems NOAA weather radio	FEMA MOTF NYC OEM Red Cross Esri

Table 4. Ad hoc and formal mass collaborations generated in response to Sandy

In 2015, almost ten years after the events of 2005, the New Orleans Office of Emergency Preparedness and Office of Hazard Mitigation are both offices of the federal department of Homeland Security (NOHSEP, 2015; NOHM, 2015), established as part of the FEMA reform act passed by Congress in the aftermath of Katrina (FEMA, 2006). The New Orleans Emergency Preparedness office has recently adopted the use of Facebook and Twitter for community outreach (NOHSEP, 2015), but ironically, there is no evidence of interactive digital workspace development for formal emergency response, although this may change eventually with FEMA's adoption of the community resilience model for emergency planning supported by social media (FEMA, 2011). Because of legal and regulatory barriers to formal use of some social media (e.g. privacy and trust issues), ad hoc use of social media in emergencies has so far outstripped their use in formal emergency response planning and practice. This is recognized in the professional and government sectors, and ways to protect privacy and establish trust are issues that are being worked through in practice and ongoing research (NRC-a, -b, 2013).

A striking similarity between the two storms was that the loss of the electric power and the telecommunications infrastructures resulted in dependency on century-old technology (i.e. radio) for virtually all communications for extended periods.

What is the significance of human cognitive stigmergy in mass collaboration for emergency response (ad hoc, formal or both)?

The role of human cognitive stigmergy (HCS) as a driver of mass collaborations in virtual workspaces is observable in the ad hoc examples for both Katrina and Sandy. In both cases, existing technology created for purposes other than emergency response was spontaneously adapted by volunteers for innovative use in an emergency situation. The ad hoc rows of Tables 3 and 4 show examples of telecommunications, situation awareness, digital workspaces, and geocollaboration technologies adapted for emergency response through the spontaneous coordination of complex, collaborative activity by self-organizing groups, i.e. HCS. The basic premise of the theoretical framework, that information and communications technologies can improve emergency response by enhancing situation awareness and increasing opportunities for stigmergic mass collaboration, is well-supported by the results of the cases.

HCS is apparent in emergency contexts regardless of the social/communication media in use, and emergencies themselves appear to be catalysts for its appearance. HCS can be widely observed in multiple contexts, and its presence in the mass collaboration technologies of social media sites like Facebook and Twitter, and Internet tools like crowdsourcing and interactive maps is evident.

The adaptation of ICTs for mass collaboration in ad hoc emergency response, e.g. the use of FrontlineSMS, digital workspaces and geocollaboration by Ushahidi, preceded the development of formal digital workspaces for emergency response such as the ones created by FEMA MOTF during Sandy (Marsden, 2013; NRC-a, -b, 2013). However, although the formal digital workspaces and geocollaborations used during Sandy might have an ad hoc lineage, the adaptation of ad hoc to formal use did not flow directly from the ad hoc workspaces used during Katrina. Although several of the digital workspaces created for Katrina were used during Hurricane Rita which followed closely after Katrina in the same geographic area, none of them were used during Sandy. The enormous popularity of commercial social media sites like Facebook and Twitter, that were not yet available during Katrina, led directly to their adoption by government officials, news outlets and not-for-profit organizations for emergency mass communications during Sandy (Loeb, 2012).

The formal adoption of geocollaborative digital workspaces can be traced to the success of the Ushahidi ad hoc emergency response platform (Laituri, 2010). Observing the effectiveness of more sophisticated ad hoc emergency response digital workspaces based on ICTs during events after Katrina inspired organizations like NYC OEM and eventually FEMA to evaluate, adopt and formalize ad hoc approaches during Sandy (FEMA MOTF, 2014; NRC-c, 2013; Fraustino et al, 2012; Lindsay, 2011). Ushahidi was originally developed to support journalists and citizens reporting on riots and violence related to political unrest following the disputed presidential elections in Kenya in 2007, but was quickly adapted for other emergency response efforts, including Hurricane Sandy. Its use during the Port-au-Prince, Haiti earthquake for coordinating resources and providing emergency communications raised awareness of the potential of ad hoc emergency response worldwide (Marsden, 2013).

What could be the role of ad hoc, informal emergency response such as self-organizing digital workspaces and mass geocollaboration in traditional emergency response planning and practice?

Self-organizing ad hoc (or stigmergic) emergency response has been recognized as a valuable resource. The tremendous success of the Ushahidi platform has spawned many similar efforts, and the observed uses of ICTs for volunteer efforts during both Katrina and Sandy has become part of standard emergency response. However, the use of platforms like Ushahidi has been slow to be adopted by first responders for traditional emergency management and practice. Because mass collaboration is spontaneous and voluntary, it cannot be easily incorporated into formal emergency planning, which is focused on specially trained first responders, command and control structures, and well-defined protocols.

As of this time, the role of mass collaboration based on HCS in emergency response has been twofold. First, in the immediate aftermath of an event, it has filled gaps in formal emergency relief efforts, fixing problems and filling needs in an opportunistic fashion. This was especially true during and after Hurricane Katrina. Spontaneous volunteer efforts on the scene are important and valuable because a major emergency can overwhelm first responders. Second, in the longer term ad hoc efforts have brought practical and technical innovation to formal emergency planning and response. This can be observed in the ways that ICT use for emergency communications changed from Katrina to Sandy. Examples like the PeopleFinder website created during Katrina were strictly voluntary, spontaneous and ad hoc, but the efforts by HurricaneHackers, CrisisMappers and other volunteers were sponsored and encouraged by authorities before as well as during Sandy. The adoption of applications for emergency communications developed by volunteers has measurably improved formal emergency response and the use of social media like Twitter, Facebook and Google Maps by government officials and first responders for emergency communications with the public has become recommended practice (NRC-a, 2013). Another way self-organizing digital workspaces could be used would be for government and NGO (non-governmental organization) emergency response agencies to develop, deploy and support them as a way to monitor and coordinate with ad hoc volunteer efforts.

In addition, the use of these kinds of platforms and ICTs has been proposed for use in formal emergency response and by first responders and is being explored. However, the issues of verifiability, trust and privacy remain to be resolved (NRC-a, -b, -c, 2013).

How could ad hoc emergency response be supported by formal emergency response? Could ad hoc response practices be formalized or are they better left as spontaneous?

The ways that the NYC OEM supported and encouraged the efforts of HurricaneHackers, CrisisMappers and other volunteers in advance of, during and after Hurricane Sandy are a good example of how formal emergency response can support ad hoc emergency response. Another good example is the work of the FEMA MOTF in coordinating and combining many data streams into a reliable, usable and accessible source of timely information during Hurricane Sandy.

Both are practices that are either already formalized or in the process of being formalized. The NYC OEM has been forward looking over time in taking advantage of new technologies, seemingly a natural fit with NYC's status as a national technology hub. The predictive and impact maps and models produced by FEMA MOTF are initiated for any FEMA disaster event as needed. The provision of reliable information is one of the best ways formal emergency response can support informal, ad hoc efforts.

While some ad hoc practices may be formalized, as the use of Twitter and other social media for emergency communications has been by government officials, it is unlikely that ad hoc emergency response would go away as a result. Regardless of the levels of emergency preparedness that are reached, in any large scale event like Hurricane Katrina or Sandy, there will be needs that can best be met by informal or ad hoc volunteers, and that cannot be met by first responders alone. The maximum value lies in recognizing the best applications of formal and informal roles for emergency response.

3.7 Summary and Conclusions

Some striking differences between Sandy and Katrina include: Katrina caused more than 1800 deaths, over $100B in damages (in 2005 dollars), three million people lost power, and more than one million people were displaced. Of those displaced, thousands never returned. Louisiana lost over 4% of its population. New Orleans was a city of about 455,000 when Katrina hit; as of the 2010 census the population was still only 344,000. In contrast, Sandy caused 159 deaths, $65B in damages (in 2012 dollars), and displaced about 23,000 people temporarily, mostly in New Jersey on the shoreline and in New York City. Eight and half million people lost power. The biggest reasons for the difference between the two storms in damages and loss of life was a combination of geography, lack of preparation and planning, and poor engineering, particularly extensive housing development in low lying areas. About half of New Orleans is below sea level, and the city depends on a massive pumping system and steep levees to hold back the water during storms. The system, solely the design and the responsibility of the US Army Corps of Engineers, failed catastrophically during Katrina because of the loss of power to run the pumps, multiple breaches of the levees and the storm surge. Massive flooding occurred and without power, the ability to pump out the water was lost. The severe loss of life was attributed to abject failures in emergency planning and the execution of evacuation orders. Because of the dire consequences of Katrina, these failures instigated a major overhaul of emergency planning and response procedures across the US, particularly at the federal level, resulting in legislation being passed by Congress that benefited the states impacted by Sandy several years later.

However, an often overlooked but significant response to the crisis that occurred during Katrina was the spontaneous use of various ICTs including social media, the Internet, and geospatial technologies by ordinary people. The ad hoc adaptation of weblogs, listservs, websites, platforms and applications to help victims of the hurricane represented a new form of emergency response based on human cognitive stigmergy and ICT-supported mass collaboration. The volunteers from URISA GIS Corps and Esri that loaded computer equipment into vans and drove to the Gulf to create up-to-date maps on the spot for emergency response were spontaneously responding to a perceived need, and were not part of a centrally coordinated relief effort. Because of the transparency and public nature of the interactions, situation awareness as well as emergency relief on the ground was greatly enhanced by the efforts of both groups.

In the time immediately following Katrina, development and release of several advanced ICTs radically transformed telecommunications in the US and the world. These include free and open source applications for crowdsourcing, social media like Facebook and Twitter, and geospatial applications like Google Maps, Google Earth and OpenStreetMaps. Coupled with the advent of inexpensive, globally available cell phone service and Internet connectivity, the combination of these ICTs created access to information, the digital world, and computing for millions of people that never previously had access. The Ushahidi emergency response platform was created as an ad hoc adaptation of these ICTs for emergency communications and coordination. The performance of the Ushahidi platform in the aftermath of the earthquake in Port-au-Prince, Haiti in 2010 was a demonstration of how ICTs can be used to leverage human resources remotely through the deployment of digital workspaces. Similar ICT-enabled mass collaborations have since been observed during several major disasters, including the earthquake and tsunami in Fukushima, Japan, wildfires in California, and Hurricanes Irene and Sandy (DHS, 2014; Tierney, 2014; Rich, 2013; Yates & Paquette, 2011; Gao et al, 2011; Goodchild & Glennon, 2010). These are examples of digital workspaces supporting human cognitive stigmergic response to disasters. In formal emergency response, the use of social media has become a requisite mode of emergency communications, advisories and warnings from government officials at multiple levels. Digital workspaces supported by geospatial imagery rendered in near real time have become *de rigueur* on broadcast television, agency and NGO websites, etc.

There are important conclusions to be drawn from the observations noted above. First, there are several benefits to using advanced ICTs for emergency response, including alternative modes of communication and means of coordination between and among rescuers (whether first responders or volunteers), and those in need, increased channels to disseminate important and useful information by authorities, access to more and better information regarding status updates and reports, and the availability of more resources for emergency response by expanding emergency response beyond formal first responders. In contrast to emergency response as described by the PRIDE SA model, limited to single responders trained in a single specialty, the expanded model including HCS through the addition of advanced ICTs offers the potential for mass collaboration and the ability to bring to bear many more resources, including empowering those in an affected areas to help themselves and others without having to wait for first responders, and to have reliable information about their situation.

However, the benefits of advanced ICTs depend on their availability. In both the Katrina and Sandy cases, the loss of the power and telecommunications grids within the affected areas meant that advanced ICTs were not available and many people in the affected areas, including first responders, were reduced to using 1930’s technologies. Although it is not possible to state to what degree the presence of ICTs could have mitigated the severe loss of life and property damage during Katrina, there is no doubt that had telecommunications networks remained functional, the emergency response would have been more effective (Wrobel, 2012; WERT, 2006). The effects of losing the electric grid were devastating. First, because the loss of the pumping stations exacerbated the levee breaches and the flooding that was responsible for most of the deaths (ASCE, 2007), and second, because the resulting telecommunications failures severely hampered emergency response (Wrobel, 2012; ASCE, 2007; WERT, 2006). Traditional telephone networks can operate independently from electric grid power, but during both Katrina and Sandy, the loss of electric power resulted in the loss of telephone networks. Landline telephone central offices use low voltage DC to energize copper wire landlines. If they lose grid power, they can provide their own from backup generators (Barnes and Rosen, 2014; Ridley, 2012). During both Katrina and Sandy, central offices were left without emergency backup generation by floodwaters reaching diesel generators and contaminating fuel tanks located in central office basements and ground floor locations, and flooding in manholes and tunnels containing switches and wiring (Wrobel, 2012; ASCE, 2007; WERT, 2006). The landline infrastructure failure during both storms was compounded by losing thousands of mobile phone communications towers due to loss of grid power (Wrobel, 2012; ASCE, 2007; WERT, 2006). The impact on communications of Hurricane Katrina in 2005 led the FCC to propose a requirement for wireless companies to have backup power at all cell towers in the event of power outages, but the proposal was blocked by the telecommunications industry. For Hurricane Sandy, Verizon had temporary backup generators placed at cell towers ahead of the storm when and where they might be needed, but the plan did not prevent the loss of cell phone service for millions of people.

Despite the failures of the power grid and telecommunications infrastructure during the storms, the difference in outcomes between Katrina and Sandy, both during the events and in the recovery from them, points to the importance of having effective planning and response strategies in place ahead of a predictable event, and communicating risks and responses in advance. For other events, risk assessment, planning and management are effective in mitigating the impact of events that can be anticipated but are not precisely predictable, for example, earthquakes. Although the loss of the pumping stations in New Orleans was the major cause of the flooding that resulted in most of the fatalities from Katrina, underlying preparation and planning failures were also to blame, including the lack of an emergency management office such as the NYC OEM in New York City, inadequate evacuation plans, and extensive construction in flood zones (Wrobel, 2012; ASCE, 2007; WERT, 2006).

Ideally, the reliability of wireless telecommunications, including cellular networks, and the reliability of the power grid will improve as a result of post-Katrina and Sandy initiatives to reduce the number and extent of disaster-related communications blackouts, such as efforts to upgrade infrastructure and develop emergency alert systems for the 21st century (Barnes & Rosen, 2014; NRC-a,-b,-c, 2013). In the absence of the ideal, the question becomes, ‘Can technology-enhanced human cognitive stigmergy still be effective in situations where the basic ICT infrastructure is damaged or destroyed’? The question is important and deserves further study, but the Katrina and Sandy cases point to significant evidence of the value of ICTs even when infrastructure is limited or damaged. The evidence points to the conclusion that good information and communications support improves emergency response outcomes. Comparing the infrastructures in use and the outcomes of Katrina and Sandy suggests that emergency response planning should include the assumption that electric power and telecommunications networks could be unavailable in affected areas. To improve the effectiveness of emergency response, the cases of Katrina and Sandy primarily support the value of emergency planning prior to an event and the importance of ensuring reliable emergency communications prior to and during an emergency. Efforts to make electric power and telecommunications infrastructures more resilient are necessary because medical and other emergency services depend on them. Cellular networks are clearly important because they have become the most widely used telephone communications system in the US. In view of the increasing use of smart phones, should efforts to update emergency communications also include WiMax, broadband, etc.? Prioritizing infrastructure investments for the best outcomes is complicated and difficult, particularly at a time when technology is advancing so rapidly, and security, privacy and policy issues have become so challenging.

In summary, despite the failures of the power grid and telecommunications systems which remain works in progress, many improvements in emergency response were accomplished in the years between Katrina and Sandy. The results of the cases show that social media and geospatial information and communications technologies can improve emergency response by enhancing situation awareness and increasing opportunities for stigmergic mass collaboration. In contrast to Katrina, when GIS use was limited to URISA's GISCorps and Esri volunteers coming into the region to work with the Red Cross and other first responders after the fact, before and during Sandy there was complete public access to information in near real time with constant updates. Even more impressive, the technologies in play during Sandy were supported by Google, Ushahidi, FEMA and NYC OEM (among others) in an unprecedented collaboration between government, business, not-for-profits and individual volunteers. Institutional recognition of the effectiveness of ICTs for emergency response is demonstrated by the adoption and coordination of practices for formal emergency response before and during Sandy by NOAA, National Weather Service (NWS), FEMA, and state and city governments, that were ad hoc during Katrina. These formal adoptions improved situation awareness capabilities by making information generated by these agencies for formal emergency preparedness and management broadly available via mass collaboration platforms using digital workspaces, social media and geocollaboration. This development has the added benefit of transparency about the sources of reported information, helping to resolve trust issues and possibly reducing the ability of bad or self-interested actors to disseminate false or misleading reports.

Chapter 4 **Essay: A Conceptual Framework for Stigmergic Human Collaboration with Technology Tools**

Abstract. A new conceptual framework is developed on two well-researched theoretical constructs: situation awareness and the phenomenon of cognitive stigmergy. The relationship between situation awareness and human cognitive stigmergy offers insights into the effects of information and communications technology on emergency response. The foundational premise is that advanced information and communication technologies (ICTs) enhance emergency response systems by improving situation awareness and opportunities to collaborate, which support the phenomenon of stigmergic mass collaboration. Human cognitive stigmergy is the ability of people to spontaneously self-organize based on perceptions of change in their shared environment. Human cognitive stigmergy supported by ICTs enables mass collaboration, very large scale collaborations that occur in online environments including digital workspaces designed or adapted for emergency response. Three testable propositions are developed: 1) Advanced geospatial ICTs can improve environmental situation awareness through real- and near real-time data collection, transfer, processing, and image rendering capabilities, 2) Internet-based social media ICTs can expand the scale of stigmergic mass collaboration by increasing modes and means of communication, decision making and action, and 3) ICT-enhanced situation awareness and stigmergic mass collaboration can improve the effectiveness of emergency response. The components of the conceptual framework are presented in an overview of the role of ICTs in supporting emergency response, the process of stigmergic mass collaboration in emergency response, and the process of situation awareness for emergency response. A new situation awareness model developed for emergency response based on ICT-enhanced stigmergic mass collaboration is described. The model is based on the analysis of three case studies of emergency events and the use of ICTs for formal and informal response to them.

Keywords: situation awareness, mass collaboration, information and communications technology, information systems, stigmergy, human cognitive stigmergy, complex adaptive systems

4.1 Introduction

Since the beginning of the millennium, extreme events causing catastrophic loss of life and property damage have compelled new approaches to emergency response and planning. The terrorist attacks of 9-11, the Indian ocean tsunami of 2004, Hurricanes Katrina and Sandy, the environmental disaster of the BP oil spill, and the Haitian and Fukushima earthquakes have emphasized the logistical and situation awareness challenges of mounting adequate responses to foreseen as well as unforeseen events (NRC-c, 2013; Fraustino et al, 2012; Van Aardt et al, 2011; Laituri, 2010; WERT, 2006). In the US, FEMA established community preparedness and resilience (a community's ability to withstand and recover from disasters, including local critical infrastructure operators) as the primary goals of emergency planning (NRC-c, 2013). Community disaster preparedness involves government, business, not-for-profit organizations, volunteers, households and individuals in assessing and mitigating risk, establishing collaborations between stakeholders, and establishing response and recovery measures based on local skills and resources, prior to a disaster (NRC-c, 2013). These initiatives increasingly rely on advanced information and communications technologies (ICT) to provide intelligence, coordination and decision support (Barnes and Rosen, 2014; Adamski, 2013; NRC-c, 2013).

In concert with formal efforts like FEMA's, emergency response based on innovative applications of information and communications technology (ICT), particularly user-generated content via social media and crowdsourcing, and environmental information based on real time monitoring, has progressed from primarily ad hoc use to formal emergency management

(Adamski, 2013; NRC-a, NRC-b, 2013). The capability to quickly process and display remotely sensed geospatial data as interactive maps and meaningful visual images has contributed significantly to new intelligent systems and infrastructures for centralized and community-based information dissemination and knowledge sharing (Yates & Paquette , 2012; Van Aardt et al, 2011; Messinger et al, 2010). Mass collaborations enabled by social media have become an additional important resource (Adamski, 2013; NRC-a, 2013). The discussion that follows develops a conceptual model that frames the analysis in three prior case studies: the development and use of the emergency response platform Ushahidi, and the cases of Hurricanes Katrina and Sandy. Key concepts and processes are defined and integrated as the basis of the conceptual model.

4.2 Basic premise

The basic premise of the conceptual framework is that using advanced information and communication technologies (ICTs) to enhance situation awareness and increase opportunities for stigmergic mass collaboration can improve the effectiveness of emergency response.

4.3 Terms and definitions

Terms and definitions of significance for the new model of stigmergic collaboration for emergency response enhanced with technology tools are defined in the sections that follow.

4.3.1 Stigmergy and human cognitive stigmergy

As originally defined by the biologist Grasse in 1959, stigmergy is a sequence of indirect stimulus and response behaviors that contribute to the coordination of actions among insects through the natural environment, for example termites coordinating nest building activities through scent trails (Dorigo et al, 2000; Theraulaz & Bonabeau, 1999). Marsh and Onof more generically define stigmergy as a phenomenon of “indirect communication mediated by modifications of the environment" (Marsh & Onof, 2007, p.1). Bonabeau and Meyer (2001) apply stigmergy in a business context, noting its role in solving management challenges, and terming it 'swarm intelligence'. In an investigation of open source software development practices, Bolici et al (2007) cite evidence of the role of unplanned coordination and self-organization in successful open source software development projects: "the qualitative analysis of this evidence shows the paradox that, even if the developers do not seem to communicate explicitly, the software is nonetheless built as the result of a collective effort, apparently without central coordination" and "stigmergy explains how actors can affect the behavior of other members of the community through the traces that their activities leave in shared artifacts" (Bolici et al, 2007, p.1).

In computer science, cognitive stigmergy is characterized as supporting "high-level, knowledge-based social activities", while stigmergy refers to non-human agents described as "typically simple antlike, non-rational" (Ricci et al, 2007, p.1). Ricci et al (2007) characterize cognitive stigmergy operationally as rational agents sharing and using technology tools in an appropriately engineered working environment to accomplish individual goals within a group collaborative context.

The behaviors of people in a stigmergic context such as a software development environment or digital workspace are diverse and can be based on cognitive responses to many different kinds of cues, including directly experienced visual, audible, or tactile information, as well as information indirectly imparted via signs, symbols, instructions or other means (Bolici et al, 2007). Various content artifacts are produced by the use of the system: emails, text messages, reports, pictures, videos, etc. Ricci et al's (2007) definition includes interactions between these artifacts and the world, looking beyond the mechanics of the system artifact itself to the broader environment in which the system functions to understand the complexities of the phenomenon of human cognitive stigmergy. For example, end users perform their activities by orienting themselves through the stigmergic functions provided by the system's user interfaces, coordinating their actions through the communications tools provided by the platform (e.g. messaging, texting, imagery, audio, video, interactive displays). End users may understand their work as simply communicating with other users or viewing a satellite image, while the developers of the platform understand their own activities through awareness of the systems' purposes and the manipulation of the technology platform to satisfy them. These abstractions of the true state of the whole environment are understood by participants as real, rather than as abstract interactions of knowledge sharing and coordination. Their understandings are based on shared perceptions of their shared work environment, the external environment represented to them by the system, and the goals and purposes pursued by them within the functionality of the system.

4.3.2 Mass collaboration and virtual collaboration

A basic team or group collaborative process, adapted from the 'observe, orient, decide, act' (OODA) loop is shown below in Figure 3 (Boyd, 1996; Von Lubitz, 2008). The process does not distinguish between modes of collaboration, which may include verbal and non-verbal, face-to-face and virtual, discursive, and stigmergic (Elliott, 2007). Recognizing that communication may be manifested in multiple modalities, they are combined to demonstrate a generalized collaborative process.

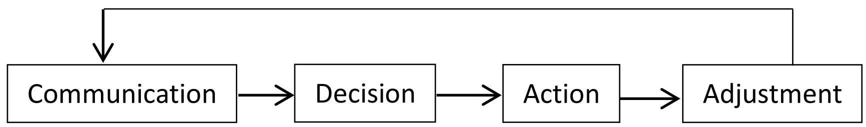

Figure 3. Group Collaborative Process

Although each collaborative situation is unique, the core components of the process are the same: communication among participants, group decisions leading to action, adjustment of strategy based on assessing the results of actions taken and relevant changes in the environment, then a new iteration of the process. Successful collaboration requires access to meaningful information that directly relates to the operational goals of the group and effective communication of goals and relevant information. These communications can be multi-layered and complex at times. If participants have sufficient data and understanding to agree on what decisions are needed, what are relevant criteria, and how to choose from different options, then they can act. Effective processes are action oriented and result in change followed by adjustment. Action is crucial; without implementation, the process is diminished to no more than a conversation. Throughout the process, there is course correction. Changes in the environment must be assessed and understood to guide subsequent decisions and actions (Boyd, 1996; Von Lubitz, 2008).

Elliott's (2007) definition of mass collaboration focuses on stigmergic collaboration that is augmented with ICTs that support "site-of-work mediated collaborative interactions" and allow collaboration to expand beyond normal spatial and temporal limitations to create virtual mass collaborations of thousands (i.e. virtual or digital workspaces). Elliott (2007) shows how stigmergic collaboration occurs in Internet-based workspaces offering highly contextualized environments that present lower barriers to participation than physical workspaces, and allowing individuals to more easily engage with communities and projects of interest. Elliott's (2007) definition of technology-enhanced mass collaboration distinguishes between 'discursive collaboration', i.e. sharing knowledge and ideas through discourse, and 'stigmergic collaboration', a material process of the alteration of actual and digital artifacts. Elliott's model traces a linear evolution of technology-enhanced collaborative processes from direct discourse, to augmented face-to-face, to stigmergic material manipulation, to the emergence of digital workspaces as a technology-mediated form of stigmergic collaboration, to mass collaboration, defined as stigmergic collaboration within digital workspaces with technical, social and cultural characteristics that enable extraordinary project scope and participation scaling. Elliott (2007) describes the emergence of mass collaborative projects such as the open source software development of the Linux operating system and Wikipedia.org as part of a natural progression of traditional stigmergic collaborative processes to become ‘digital stigmergic collaboration’. Elliott (2007) further states that these large-scale examples of coordinated Internet activity demonstrate that stigmergy is a deeply rooted phenomenon inherent in human collaborative practices and that stigmergic self-organization enables the extreme scaling seen in mass collaborative projects. Most importantly, the mass collaborative stigmergic workspace is optimally scalable. In face-to-face contexts the optimal number of participants is at best several dozen, while Internet-based digital workspaces can accommodate thousands or even millions.

ICTs for virtual collaboration have traditionally aimed at being ‘as good as being there’, offering technology-augmented versions of traditional practices, such as improved audio-visual and voice transmission, but not changing work or collaborative practices in a significant way (Hollan and Stornetta, 1992). In terms of reproducing a face-to-face meeting experience in a virtual context, research shows that it is difficult to reproduce the nuances of physical proximity in a way that people find satisfactory (Veinott et al, 1999). Hollan and Stornetta (1992) conclude that the meaning of ‘being there’ is evolving, and is not necessarily about how realistic a virtual workspace is. In certain situations, augmented reality or virtual simulations based on technology tools like geospatial remote sensing may be better than being there, for example, the ability to ‘see’ the extent of a storm surge over miles of shoreline, observe a volcano from a safe distance, or travel in space to watch the world turn.

Examples of virtual collaboration that have arisen recently include: online, blended and distance learning environments including webinars and massive online open courses (MOOCs), e-science and citizen science projects supported by online interfaces, people working on various non-co-located projects for governments, NGOs or large companies, people in virtual teams developing open source software, people adding to or updating huge wikis, web-based translation dictionaries and other crowdsourced collaborations, and scientists around the world accessing the same massive datasets for multiple investigations. These mass collaborations have resulted in digital encyclopedias too voluminous to print, expedited analysis of research results, and expanded access to education and learning. Several analyses of the quality of research in crowdsourced citizen science projects have indicated that the quality of crowdsourced results equal or exceed traditional results and are accomplished in much less time (Gross, 2012; Rosner, 2013). The technological advances that allow us to overcome the physical barriers of time and distance offer tremendous opportunities for collaboration and advancing knowledge.

4.3.3 Situation awareness and emergency response

At its most basic, situation awareness (SA) is “Knowing what is going on so you can figure out what to do” (Adam, 1993). Although situation awareness arose as a formal area of research from human factors research in the 1980s, it is easy to see that an accurate perception of one’s environment is critical for survival in many contexts. Historically, for a person to have good SA would depend on acute perception, extensive training, finely-tuned observation skills, and valuable, hard-gained knowledge and experience. As a research discipline, SA is usually discussed in conjunction with decision support, and has traditionally been involved in the development of complex, dynamic, highly realistic simulated environments for training fighter pilots (Endsley & Garland, 2000).

The formal definition of situation awareness is "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future", with an explicit dimension of supervisory control resulting in decision making and action (Endsley, 2000, p.5). The PRIDE (Prediction in Dynamic Environments) SA model, adapted in 2009 by National Institute of Standards and Technology (NIST), was selected from several SA models because it assumes the performance of prescribed sets of decisions and actions by intelligent agents within a naturalistic rather than an engineered environment (NIST, 2009).

Naturalistic decision making, defined as the cognitive process in which people use their training, knowledge and experience to make decisions and act in real world situations, either individually or in teams, arose as an area of research in the late 1980's (Zsambok & Klein, 1997, 2014; Klein, 2008). Zsambok & Klein (1997, 2014) note the importance of SA in naturalistic and real world decision making was recognized from the very beginning. Applying SA to emergency response in the uncertainty and variability of the real world involves additional complexity in information and communications systems and coordinating information, actions and communications among multiple actors in the real world, in real or near real time, and in parallel virtual spaces. Orasanu and Connolly (1993) identify eight key contextual differences between naturalistic real world and traditional decision support research: 1) ill-defined rather than well-structured problems, 2) dynamic environments rather than simulated settings, 3) shifting, competing and ill-defined vs. well-defined objectives, 4) incremental action/feedback loops instead of one-shot decisions, 5) time stress vs. ample time, 6) real world consequences for mistakes rather than low risk controlled environments, 7) multiple participants rather than single actors/decision makers, and 8) social/organizational goals and norms rather than individual performance and actions. Orasanu and Connolly (1993) assert that all decisions are essentially part of a larger context of goal seeking behavior, and must be seen as part of a process that involves values, recognition, information sensing, knowledge and expertise. Zsambok & Klein (1997, 2014) characterize the difference between traditional SA and decision support models and naturalistic decision making as a matter of greatly increased complexity, uncertainty and consequences.

In emergency response training, SA has traditionally involved the development in trainees of shared mental models specific to the defined responsibilities among first responders for effective decision making and action in an emergency situation (Adamski, 2013; Gasaway, 2013). As generalized from Endsley's original SA model, the PRIDE SA model (Figure 4) is designed to accommodate a wide array of potential real world situations, focusing on the cognitive process rather than closely defining external factors in advance.

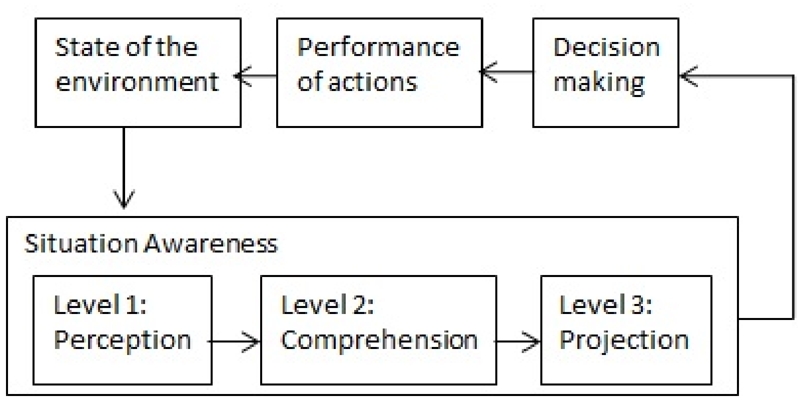

Figure 4 Prediction in Dynamic Environments (PRIDE) Situation Awareness Model (NIST, 2009)

The PRIDE SA model has three levels of "knowing what is going on": perception, comprehension and projection. As the SA level increases, the situation awareness also increases. Level 1 SA, Perception, is the most basic level. Information must first be perceived correctly in order to be processed correctly. Research has shown that Level 1 is where the great majority of SA errors occur (Endsley, 2000; Jones & Endsley, 1996). Errors in perception are caused by unavailable, incorrect or inadequate information, cognitive errors like misunderstanding or forgetting the available information, or errors of omission such as failing to observe or monitor the situation. Research also indicates that because SA levels are progressive, errors occurring at the perception level are carried forward to higher levels. Therefore preventing and correcting errors at level 1 is critical for optimal decision making and action.

Level 2 SA, Comprehension, involves the meanings that people attribute to the perceived information, how they combine, interpret, store and retain it, including how they integrate and interpret information and relate its relevance to their goals. Comprehension errors are usually caused by incorrect, incomplete or missing mental models. In other words, in order for people to have good SA comprehension, they have to understand the information they are perceiving and be able relate it to the right set of assumptions or correct cognitive framework.

The highest SA Level is 3, Projection, the ability to project into the future and make accurate forecasts of future events. The ability to correctly and accurately perceive, comprehend and then project information is directly linked to experience. Level 3 SA denotes those people able to operate with the highest level of situation understanding and the greatest ability to forecast situations and events into the future. Almost invariably they are also the people with the most experience (Endsley, 2000).

4.3.4 Information and communications technology

Sharing and disseminating timely, accurate and useful information where and when it is needed is a significant challenge in emergency response. Within the last ten years, information and communication technology (ICT)-enabled digital workspaces based on geographic information systems (GIS) and social media have developed spontaneously in emergency situations (Heylighen, 2007a,b; Van Aardt et al, 2011; Messinger et al, 2010) and become a transformational force in mass collaboration by enabling highly accurate, timely and comprehensive situation awareness (Marsden, 2013; Aragon et al, 2011; Cogburn et al, 2011; Elliott, 2007; MacEachren and Brewer, 2004). ICT-enabled self-organizing ad hoc digital workspaces offer potential solutions to situation awareness challenges. MacEachren and Brewer suggest a conceptual framework for interdisciplinary research combining virtual collaboration, information and data visualization, and geospatial technologies termed 'geocollaboration', calling for research into the role of visualization as an enabler for needed advances in collaboration: "…Developments in geographic information science, and in computer graphics and visualization, suggest that we are [also] on the cusp of a substantial increase in the role of maps, images, and computer graphics as mediators of collaboration, in a range of contexts including scientific inquiry, environmental and urban planning, resource management, and education" (MacEachren and Brewer, 2004, p.1).

Participation in ad hoc emergency response by victims or onlookers as an aspect of situational awareness has not been formally studied until recently, but there have been several investigations into the use of social media for coordinating ad hoc emergency efforts (NRC-a, 2013; Loeb, 2012; Lindsay, 2011) and the effects of those efforts on formal emergency response (NRC-a, 2013; FEMA, 2013). Social media technologies used for emergency response and management have included online social networks, weblogs, microblogging and mashup tools, and social networking platforms Twitter, Google Maps, Facebook, and Flickr. From the use of applications such as Facebook for locating missing pets or persons, to the development of the Ushahidi platform for the explicit purpose of ad hoc emergency communications, information and communications technologies have changed how we think about and deal with emergencies.

Recent advances in high processing capacity (HPC) computation and LTE broadband networks have moved geographic information systems and technology (GIST) from data centers to the desktop and the network, leading to an explosion of science research utilizing these technologies, but the work has been spread across many fields, and largely focused on answering discipline-specific questions (Pfirman et al, 2003; UN-GGIM, 2013). Initiatives such as the National Spatial Data Infrastructure (NSDI), the National Map (USGS, 2011), and similar global efforts have aimed at providing consistent and reliable data for research with the focus on information delivery in a direct flow from producers to consumers, usually within the scientific community. However, interactive systems that enable the general public to produce, share and use knowledge differ fundamentally from these initiatives. The convergence of geospatial technologies with Internet technology has increased the availability and quality of infrastructure datasets over the past decade, but access to the information remains complex and out of reach for decision makers without technological mediation.

The use of maps as contextualizing, collaborating and co-orienting visual media suggests common themes among multiple disciplines, including engineering, planning, policy, environmental science and agriculture to name only a few, and the need for a systematic conceptual framework to explain the types of virtual organizations enabled by geospatial information systems technology. Although many disciplines use and produce maps for research, it is in bridging disciplines that the collaborative value of maps as visual representations of data that cross disciplinary boundaries is best understood (Star & Griesemer, 1989).

In 2005, Google released Google Maps and Google Earth, the first web-based interactive geospatial visualization platforms available to the public, and in September of that year performed a special update of New Orleans in Google Maps showing the damage caused by Hurricane Katrina and the extent of the flooding there. In 2008, the Ushahidi website used Google Maps to create a map interface for reporting incidents of violence during the aftermath of the disputed presidential elections in Kenya, and released the software they developed as an open source emergency response platform. By 2010, the deployment of Google Earth Engine cloud computing platform for processing satellite imagery and other Earth observation data provided access to trillions of bytes of Landsat satellite access imagery and the computational power to analyze those images (Gardner, 2010). The Google Earth Engine was used in 2012 as the basis for the New York City Office of Emergency Management's web presence during Hurricane Sandy (NYC OEM, 2013). These examples show how geospatial information technologies such as satellite and aerial imagery, geographic remote sensing systems, and geographic information systems have advanced in recent years to make environmental situation awareness far more accessible and dynamic, enabling near real-time data processing, information analysis and forecasting. The integration of web-based geospatial imaging with social media has greatly increased the level and quality of available situational intelligence, participation and collaboration.

However, barriers to providing and accessing this information still remain. The infrastructure that provides these data represents a multi-billion dollar investment of several decades that continues. The supporting infrastructure required to maintain the resulting data stores is also a significant cost for government and businesses. Although open data has become much more common in recent years because of federal policy changes, there are still significant technological requirements involved in rendering the data in a format that is easily understood by the general public. As technology advances, challenges continue to arise in integrating new sources of data with existing information, making historic data compatible with modern formats, and accommodating ever growing volumes of information. The challenges include the need to constantly upgrade computing and storage capacities, improve accessibility for a growing number of interfaces as people utilize personal devices such as smart phones, maintain compatibility with increasing numbers and types of devices, and provide security and protection against cyberattacks.

4.4 A new situation awareness model for emergency response

A new situation awareness model for emergency response based on ICT enhancements is described here. The new model is based on expanding NIST's PRIDE SA model by integrating it with ICT tools to enhance opportunities for mass collaboration and sharing geospatial information in near real time. The enhancements to the PRIDE SA model are based on the analyses developed in three studies of emergency events and the effective and ineffective responses to them. Figure 5 presents a graphical view of the new ICT-enhanced model. The ICT-enhanced SA model supports stigmergic mass collaborative actions for emergency response via digital workspaces created with Internet-based social media and geospatial technologies. The ICTs add environmental information and mass collaboration enhancements to the basic model.

The new SA model begins with the PRIDE SA model. The PRIDE SA model is first enhanced by the integration of the general process of group collaborative action to enable mass collaboration. The collaboration-enabling ICTs, including social media, are indicated in the model by the collaborative processes shaded in blue. The dashed arrow indicates communications and decisions that flow through the SA process as information. Information is differentiated from communications and decisions resulting in actions. Actions are reflected in the state of the environment, shaded in yellow. The level of potential SA is further increased by integrating rendered environmental remote sensing data produced by geospatial technologies, indicated in the model by the block shaded in green. The block shaded in yellow indicates the ICT-enhanced state of the environment.

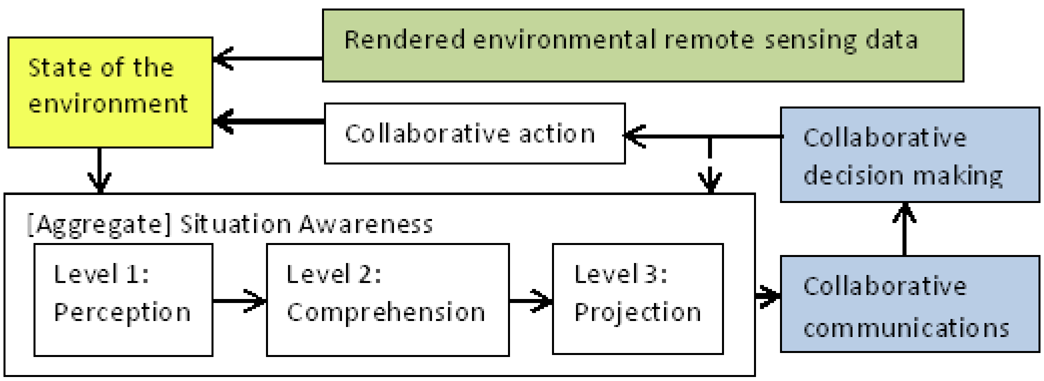

Figure 5. A new situation awareness model enhanced with technology tools for stigmergic mass collaboration in emergency response

The ICT enhancements greatly expand the available information in the system with an expanded potential increase in the overall level of SA, because of the increased amount and quality of information provided at Level 1 SA, Perception. Endsley's (2000) research has shown that up to three quarters of SA errors occur at Level 1, and that many of these errors are due to unavailable, incorrect or inadequate information. Like the PRIDE SA model, the new situation awareness (SA) model for stigmergic collaboration in emergency response, SA is variable and the overall level of SA depends on individual perceptions, observation skills, training and experience. The biggest difference in how the stigmergic collaboration SA model differs from the PRIDE SA model in its use of ICTs. The stigmergic collaboration SA model redirects the emergency response strategy to a community focus instead of a first responder focus. The new SA model supports a more integrated approach that includes ordinary people as potential responders by providing them with effective information for decisive action, and enabling communication and coordination to occur among participants regardless of their location, training, affiliation or status.

4.4.1 Social media tools for collaborative communications

The traditional application of situation awareness (SA) to emergency response has assumed first responders with different areas of expertise and levels of training, dealing with different kinds of events, in different places, and has been focused on individuals being trained in a specialty, whether fire protection, law enforcement, emergency medical treatment, etc. Traditionally, the SA model also assumed a command-and-control hierarchical structure with first responders trained according to scripted responses in a predefined emergency scenario. Endsley's (2000) SA definition is drawn from extensive human factor research based on individual responses to emergency situations in engineered training environments, using task and human factors to reference realistic simulations of high-risk environments such as the cockpit of a fighter jet in flight. This allows the trainee to become familiar with instruments, ranges and parameters in a low-risk training environment (Endsley & Garland, 2000). However, the traditional approach limits trainees' responses to the range of the included scenarios and the extent of the instructional content, with the risk that trainees could be ill-prepared for events not included in the pre-packaged training.

In order to reach more people in the event of an emergency, keep them informed and create an environment of self-help through access to information and communications capabilities, the new model enhances information sharing, collaboration and cooperation through the phenomenon of stigmergic mass collaboration. The ICT-enhanced SA model encourages stigmergic mass collaboration to occur through the use of highly scalable digital workspaces that expand collaborative communication, decision-making and action using Internet-based social media technology tools. The ICTs used by the new model are commercial social media platforms that enable mass collaborations of thousands or even millions of people to communicate, share knowledge and information, make decisions and report statuses, all without necessarily seeing or even knowing each other, or being in the same physical space at the same time, or at any time.

Social media platforms like Facebook, Twitter, Pinterest and Instagram are designed for ad hoc informal communication and collaboration based on affinities, preferences and connections at two, three or more degrees of separation. There are low or no barriers to participate in these virtual collaborative spaces, with only a smart phone or computer and a cellular network or Internet connection needed. In 2012, Facebook reached one billion active users, and Twitter reached 500 million members. Both Internet platforms were used extensively during Hurricane Sandy for emergency communications. SMS, the simple messaging system used on cell phones, was used extensively as well. Internet and mobile network based ICTs have reached a level of penetration that is more than half of the telephone market in the US, and as of 2013 there are estimated to be nearly six billion mobile phones in use worldwide, of which nearly two billion are smart phones (Fowler, 2012; UN ITU, 2014). In recent years, the utility of social media ICTs for emergency communications and response has been demonstrated repeatedly, and it is clear that for many people it is the best way to inform and include them. Whether used by first responders or ordinary citizens, SA is enhanced by increasing the knowledge of actions and changes related to the state of the environment.

4.4.2 Geospatial imaging tools for enhanced situation awareness

The ICT-enhanced SA model also encourages stigmergic mass collaboration through the use of highly scalable digital workspaces that enhance SA by providing important geospatial information visually. Endsley's SA definition based on individual responses to emergency situations in engineered training environments is applied to engineered virtualized imagery of the true environment with a map-based interface rendered in real or near-real time with data from weather stations, radar and aerial or space-based data collection platforms. Geographic information systems (GIS) use realistic computer generated imaging (CGI) to present dynamic maps for estimation, forecasting and response to emergency events. Individual factors are still relevant for achieving SA, but they are not controllable in a real world event, where response must be fluid, innovative and ad hoc. The application of technology tools to SA for emergency response assumes ordinary people working together with traditional first responders. Unanticipated or overwhelming needs can be met by allowing people with different areas of expertise and levels of training to coordinate responses to different kinds of events, in different places, each contributing according to personal ability or specialty. The provision of actionable information through the use of geospatial technologies increases the likelihood of correct decisions and actions.

The green-shaded block on the diagram could be shown inside a cloud figure to indicate the tremendous range of remote sensing, GIS and earth imaging systems available to contribute to environmental situation awareness enhancements. Web-based platforms such as Google Maps, Google Earth and OpenStreetMaps are candidates for supplying geospatial information. Other sources include geographic remote sensor systems (GRSS) data from environmental monitoring systems and imagery rendered from satellite and aerial platform data streams. Ideally, the stigmergic model's state of the environment is dynamically refreshed by computationally rendered remotely sensed geospatial data that is provided in real or near-real time, making a global range of information available within the system. Data refreshment rates can vary, but in a large scale storm or similar extreme event, updates would be based on maximizing information utility. Today's capabilities for dynamically rendering remotely sensed visual imagery and other information on the state of the environment allow the creation of web-based digital workspaces on the fly (FEMA MOTF, 2014; Marsden, 2013; Van Aardt et al, 2011). SA is enhanced by the provision of timely, accurate, useful information about the state of the environment.

4.4.3 The importance and value of the new model

The new model is based on empirical observation of changes in the practice of emergency response and designed to provide naturalistic decision support in an emergency according to the eight challenges identified by Orasanu and Connolly (1993). The new model addresses the increased complexity and uncertainty of naturalistic decision support by providing real world, real time information to the SA process during the actual response to an emergency event, in contrast with the traditional SA model of training to a scripted response in a pre-defined scenario.

The truly revolutionary change from the traditional model to the new model is that unlike the existing model, the new model is designed to provide decision support during the actual event, rather than attempting to anticipate the needed emergency response prior to the event. Recognizing that responding during an emergency often means dealing with problems without pre-determined outcomes as they unfold, the new model presents forecasts based on solid research and metrics of past events, feedback on prior actions and decisions, plus real or near real time status updates on the actual conditions of rapidly changing environments. Unlike the traditional model, the new model recognizes real world consequences for mistakes rather than assuming a low risk controlled environment. In a dynamic situation where objectives and priorities can change quickly, there is no time for ‘doing it over’ in the event of a mistake, but knowing the results of actions taken and potential outcomes, i.e. having the most and best information possible, is the best path for making a well-informed decision. The new model assumes multiple participants in multiple locations performing multiple actions rather than single actors/decision makers in a centralized location away from the action, and delivers important, actionable information to every location equipped to receive it, including mobile devices. The new model also recognizes that decisions and actions may be driven by participants’ own goals and values rather than prescribed by first responder organizations. The process presented in the new model involves participants’ ability to sense and process information, apply their knowledge and expertise, translate their own values, recognize the need for action, and act appropriately.

4.4.4 Limitations of the new model

There are issues with the new model that require further discussion. Some relate to assumptions associated with the existing constructs that may not be valid in the new model. The most challenging of these is the assumption of common goals among actors. This is a tacit assumption of SA and human cognitive stigmergy, and an explicit assumption of Boyd’s OODA group collaboration and Elliott’s stigmergic mass collaboration. SA and OODA are both products of the military, characterized by the classic command-and-control hierarchy that is defined by individuals working together toward a common goal. Although biological stigmergy does not ascribe motivations beyond basic instincts to actors, human cognitive stigmergy and mass collaboration assume that participation in an activity is driven by preferences, affiliations and common goals. This is a valid assumption in most cases but problematic in view of notable negative and even illegal behavior observable on the Internet, including the use of social media for criminal and terrorist activity, and instances of bullying, threats and intimidation on many sites, particularly those that allow anonymity. A problem noted during deployment of the Ushahidi website was the deliberate posting of false and misleading information, which in an emergency event could have dire consequences. The response of Ushahidi's developers was to tag posts as 'verified' or 'unverified', and provide updates as corroborating or contradictory reports were received. This demonstrates a transparent approach to information dissemination. Rather than assert their own judgement, the systems administrators simply reported the available information with an appropriate advisory. Clearly, there are issues of trust, reliability, verification and security that need to be addressed, and ways to identify and circumvent bad or self-interested actors are needed.

A related issue is cybersecurity. Because of infrastructure and security failures, theft, fraud and looting have been universal complications during emergency situations for decades if not centuries. Relaxed security protections, open access to information in the interest of assisting the public, and naïve users are all factors that can create vulnerabilities and attract hackers and phishers as well as traditional looters, robbers and fraudsters during an emergency situation. It is common knowledge that cybersecurity issues exist in most if not all businesses, government agencies and organizations utilizing web-based ICTs, which at this point is virtually every sector. While emergency response is an area where these concerns are important and legitimate, the benefits offered by the technologies are clear. The lack of perfect security should be considered as an impetus to develop and implement better measures for assurance and protection rather than as a reason to abandon this approach to emergency response.

Another concern is the dependency of the new model on the availability of advanced geospatial and social media ICTs, specifically whether the new model still offers benefits, or could it actually exacerbate the situation, if advanced ICTs are not available due to infrastructure damage or failure. During Hurricane Katrina in 2005, the almost total destruction of the electric grid and the telecommunications infrastructure made all but the most basic as well as advanced ICTs unavailable within the affected area. Despite this, the URISA team of volunteers used laptops with their batteries powered by their equipment-laden vans to collect geospatial data and produce maps of the new landscape configurations to assist rescuers in finding and helping those in need even without grid-provided electricity. There was a marked contrast between Katrina and Sandy in the much expanded use of advanced ICTs by both formal and ad hoc responders during Sandy, but the loss of the electric power grid and telecommunications infrastructure within the affected areas was comparable. The Ushahidi platform, in its initial deployment in Kenya during a government media blackout, subsequent deployments in the bush country in Africa where electricity, telecommunications and ICT infrastructure is almost nonexistent, and finally in Haiti during the 2010 earthquake, functioned and saved lives by making it possible for people to communicate, coordinate and share information under the most difficult of conditions. Clearly, although its potential benefit is greater when the supporting infrastructure is available, even with compromised infrastructure the new model still offers improved situation awareness and emergency response capacities compared with the existing model.

4.5 Propositions

Three testable propositions were developed in relation to the conceptual framework. The propositions are intended to suggest some possible avenues of research that could further improve emergency response through the use of advanced ICTs and better coordination between formal first responders and ad hoc or volunteer responders:

1) Advanced geospatial ICTs can improve environmental situation awareness through the provision of more and better information through real- and near real-time data collection, transfer, processing, and image rendering capabilities.

2) Internet-based social media ICTs can expand the scale of stigmergic mass collaboration by increasing modes and means of communication, decision making and action.

3) ICT enhancements of situation awareness through improved geospatial information imaging and stigmergic mass collaboration can improve the effectiveness of emergency response.

4.6 Conclusion

Emergency scenarios like natural disasters or accidents are often unique, unpredictable and highly variable according to geography, time and place, demanding a range of knowledge, training and experience response capabilities. Even for fairly predictable disasters, like wildfires, tornados, hurricanes or blizzards, effective emergency response demands event-related data from the affected area as soon as possible along with baseline data to track changes. The new situation awareness (SA) model for stigmergic human collaboration in emergency response reflects the use of advanced ICTs to enhance capabilities for environmental situation awareness and mass participation and collaboration. Advanced geospatial ICTs can quickly collect remotely sensed environmental data and render real- and near-real time imaging driven by high performance computing. The ability to present information visually makes it possible for many more people to understand events and respond, minimizes training and education requirements and reduces language barriers. Mass collaboration enabled by social media ICTs facilitates interactions between almost any number of participants regardless of their location and takes advantage of local knowledge. The state of the environment shared via visualizations, simulations and animations based on live data and the shared knowledge of what is happening and what others are doing, makes group decision making and coordination more effective. Many-to-many communication via social media supports stigmergic mass collaboration and increases the collective intelligence within the system. Emergency response is improved because of access to information about the state of the environment, including knowledge of others' actions, more adaptable because of shared knowledge and understanding among participants to guide their collective decisions and actions, and more effective because decisions and actions are based on better information and situation awareness.

Chapter 5 **Conclusion**

5.1 **Summary of the Results**

The research used three case studies in emergency response to examine the role of information and communications technology (ICT) in emergency response, in light of ICT innovations and the phenomenon of human cognitive stigmergy (HCS). HCS describes disparate, distributed actors self-organizing and collaborating based on indirect communications via environmental signals. Two of the cases that were examined were Hurricane Katrina in 2005 and Hurricane Sandy in 2012. Coincidentally and significantly, the period between the two storms was a time when considerable development and innovation in information and communications technology (ICT) took place. The third case was the development of the Ushahidi emergency response software platform in 2007-2008 in Nairobi, Kenya, and subsequently deployed in dozens of emergency events, including the recent 2014 ebola outbreak in West Africa. Ushahidi was not yet developed when Katrina occurred, but was used in the emergency response during Hurricane Sandy.

The results of the case studies led to the development of a new model of ICT-enhanced situation awareness (SA) for emergency response. The new model is based on the constructs of ICT enhancements, environmental situation awareness and human cognitive stigmergy (HCS), also termed stigmergic mass collaboration (Elliott, 2007).

5.1.1 Answering the research questions

The discussion below briefly outlines the results of the research.

How has stigmergic mass collaboration emerged in emergency response?

Beginning in the 1990’s, the phenomenon of cognitive stigmergy (also known as human cognitive stigmergy or HCS) began to be investigated by computer science, robotics and artificial intelligence researchers who theorized HCS could explain observed coordination activities in open source and formal software development projects that often relied on the Internet and ICTs to provide communications for coordinating the efforts of disparate participants that were usually spatially and temporally non-co-located (Beckers et al, 1994; Holland & Melhuish, 1997; Dorigo, et al, 2000). The development of the Linux operating system is considered a prime example of this type of self-organizing effort. As other Internet-related development phenomena such as crowdsourcing, wikis, and other social media began to emerge, the concept of HCS was applied in other areas, including computer-supported group work in various businesses and organizations, such as gift economies and large-scale peer production. HCS offers an intuitively understandable explanation for how disparate, distributed, ad hoc contributions could lead to the emergence of very large mass collaborations such as Wikipedia. As the World Wide Web and Internet technology became widely accessible, more people became accustomed to using them for everyday communications and information seeking (Heylighen, 2014, 2007b; Elliott, 2007, 2006). The capacity of the Internet to link hundreds, thousands or even millions of people together via social media was termed stigmergic mass collaboration by Elliott (2007). Turning to these resources as a natural response during a disaster has been widely observed. Following Hurricane Katrina in 2005, studies of the use of the Internet and social media during and following the disaster showed that millions of people relied on the Internet for news about the disaster, and thousands participated spontaneously with hastily developed websites devoted to relief and assistance (Morris and Horrigan, 2005; Loeb, 2005). Since then, usage has increased and even become institutionalized for emergency communications (Marsden, 2013; Stone, 2013; Ellertson, 2013; Preston and Stelter, 2012).

How do people respond to emergencies using ICTs for coordination (e.g. self-organizing digital workspaces) when command and control structures are damaged or overwhelmed?

During and following Hurricane Katrina, people used whatever technologies were available to them in an ad hoc fashion to reach loved ones, mount rescue efforts and coordinate relief aid: websites, blogs, email, cell phone messaging, and radio. The development of the Ushahidi software platform in late 2007 and early 2008 in Nairobi, Kenya was formally mounted as an effort to provide information sharing and communications during the government mandated media blackout ordered following the disputed presidential election in that country. Ushahidi used crowdsourcing, visualization, mapping, and simple messaging on mobile phone platforms to build a readily accessible, downloadable application that could be quickly and easily deployed. Since its original development, Ushahidi has been used for emergency response in dozens of disasters and emergencies, and because of its original development and deployment in Africa, it is ideal for situations where there are infrastructure challenges (Marsden, 2013).

In advance of Hurricane Sandy in 2012, the Federal Emergency Management Agency (FEMA) and New York City Office of Emergency Management (NYC OEM) purpose-built web-based applications to provide location-specific emergency flood warnings and other information about storm conditions, relief and assistance to citizens in affected areas. Governments and institutions, officials as well as ordinary people used Twitter, Facebook, Youtube, and various websites to communicate, coordinate and share information. Volunteers including Hurricane Hackers and Crisis Commons added ad hoc technical support (Kantrowitz, 2012; FEMA, 2013; FEMA MOTF, 2014; NYC OEM, 2013).

The case study analyses show that people use whatever means are at hand to communicate, coordinate and assist others. The use of crowdsourcing, visualization, mapping, and mobile applications led by Ushahidi has been widely adopted. The success of the strategy for mass collaboration has been demonstrated to be instrumental in enabling ad hoc emergency response and coordinating emergency communications (Marsden, 2013; Munro, 2010).

What distinctive characteristics/features of an emergency response define the presence and use of stigmergic mass collaboration?

Spontaneous ad hoc participation in an emergency response by ordinary people is a key characteristic of stigmergic mass collaboration (Marsden, 2013). During Katrina, this occurred when people repurposed existing ICTs for emergency relief; during Sandy, purpose-built emergency response ICTs like the Ushahidi platform were widely used. Another key characteristic is the size of mass collaborations, which can number in the thousands or even millions of participants. Collaborations require communication, coordination and action; without the use of technology, the size of a collaborative group has a smaller effective limit (Heylighen, 2014, 2007b; Elliott, 2007). Face-to-face collaborations depend upon social negotiations for success; mass collaborations depend upon stigmergy as a replacement for face-to-face social negotiation (Elliott, 2007). Beyond a certain sized group, direct social interaction becomes unmanageable and collaborations must be based on a shared knowledge of the state of the environment (situation awareness). Stigmergic mass collaboration occurs when participants can collaborate without knowing each other or planning in advance; they have sufficient modes for coordinating, and they have access to information via multiple media (Parunak, 2006).

What capabilities of ICTs could be added or enhanced to support the emergence and effectiveness of stigmergic mass collaboration?

The performance of digital workspaces designed to support mass collaborations for emergency response, such as the UN’s deployment of the Ushahidi platform during the Port-au

Prince, Haiti earthquake of 2010, and the activities of FEMA MOTF during Hurricane Sandy, suggests that the best way to support stigmergic mass collaboration is to combine formal and ad hoc functionality. Visualization is especially helpful for making information quickly available and accessible for formal and ad hoc response. Geospatial imaging rendered in near real time during emergency events is generated by federal agencies like NOAA and NWS because of the high overhead in equipment and expense involved, then disseminated across multiple platforms via mass communications media. Images, pictures, photos, and videos have been shown to improve understanding and communication among people that are semi-literate or illiterate or do not share a common language (Kraut et al, 2003; Kotlarski & Oshri, 2005; Veinott et al, 1999). Images, especially maps, contextualized with minimal text or audio interfaces are more readily understood across cultural, language and social boundaries (Aragon et al, 2008; Kraak & Ormeling, 2003; Liebenberg et al, 1999). The use of the Internet and the World Wide Web to communicate interactively with many people simultaneously in and outside of disaster areas has been shown to improve resource availability and allocation (Marsden, 2013; Munro, 2010). For future development, extending wireless broadband networks and cellular services into underserved areas, particularly remote and rural regions, would increase the reception of advisories and warnings, and improve emergency 911 services. ICT enhancement of location awareness capabilities for emergency communications could improve emergency response and search and rescue efforts, by enabling 911 emergency call centers to reliably and accurately determine locations of and track emergency calls made via the cellular phone network.

How could formal command and control-based emergency response make better use of stigmergic mass collaboration?

This is not as simple as it might seem on the surface because of issues of liability, privacy and trust (NRC-a, 2013). However, there are several ways that mass collaboration could improve emergency response. First, it is a quick response, second, its self-organizing characteristic provides processed information that assists in coordination, and third, it takes advantage of local knowledge for basic information about infrastructure, resources and hazards (Gao, 2011). Another way would be crowdsourcing missing or changed information affecting situation status reporting (Munro, 2010). Landscapes are not static; they change as roads and buildings are constructed or demolished, causing maps to be out of date or to contain errors. Streets are renumbered or renamed; and destructive storms may cause damage that radically changes large areas. People that live in an area are more familiar with these changes than non-locals, and are often better able to navigate and understand the changes caused by a major event (Messinger et al, 2010). Mass collaboration could assist first responders in affected areas in advising central management offices about the local conditions and activities. Assistance and resources in remote locations could be coordinated virtually with local responders, improving logistics, resource allocations, scheduling and coordination between agencies and organizations at local, regional and national levels (Munro, 2010). Virtual access to complete, accurate and timely situation reports for an entire affected region could be available to victims and responders in an affected area, as well as remote participants coordinating transport and deliveries of needed supplies and personnel (Van Aardt, et al, 2011).

5.1.2 A new collaborative situation awareness model for emergency response enhanced with technology tools

The new situation awareness (SA) model for stigmergic human collaboration in emergency response reflects advances in information and communications technology (ICT) resulting in greatly enhanced capabilities for environmental situation awareness and mass collaboration. Three testable propositions were developed from the research: 1) Advanced geospatial ICTs can improve environmental situation awareness through the provision of more and better emergency event information through real- and near real-time data collection, transfer, processing, and image rendering capabilities; 2) Internet-based social media ICTs can expand the scale of stigmergic mass collaboration by increasing modes and means of communication, decision making and action during emergency events, and 3) ICT enhancements of situation awareness through improved geospatial information imaging and stigmergic mass collaboration can improve the effectiveness of emergency response.

The process of developing theory from case research involves careful selection of cases that can provide empirical evidence for theorizing (Eisenhardt & Graebner, 2007). The process of building theory from the cases depends on the qualitative evidence describing how the social media and geospatial technologies were developed and used, and quantitative evidence of the mass collaborations that arose. The cases used to develop the stigmergic SA model were chosen because of their relevance to the phenomenon being investigated, i.e. the use of ICTs for ad hoc emergency response, because of the chronology of the events that shaped the cases, and also because the scale of the events could provide insights into stigmergic mass collaboration. The first case, Hurricane Katrina, took place at a time (2005) when social media and geospatial technologies were just becoming widely adopted at the end user level, and mass collaborations were beginning to be observed. The Ushahidi case was selected because of its unique relevance to the evolving phenomenon of ad hoc emergency response and the new phenomenon of ICT-enabled mass collaboration for emergency response. The third case, Hurricane Sandy in 2012, was selected for its similarities and contrasts with Hurricane Katrina. The Katrina and Sandy storm events neatly bookend the open source software development of the Ushahidi emergency response platform in 2007-2008. The three cases together trace the evolution of the development of ICTs for emergency response from 2005 to 2012. The development of Ushahidi and its subsequent deployments offer many insights for emergency response enabled by advanced ICTs, particularly the affordances of the Internet. The institutional adoption of Internet-based ICTs for emergency communications (FEMA, 2013; NRC-c, 2013, Adamski, 2013), and the development of formal systems for emergency management modeled after Ushahidi (FEMA MOTF, 2013; NYC OEM, 2013), suggest that the use of advanced ICTs for emergency response has become accepted practice in both formal and ad hoc emergency response.

5.1.3 The evolution of the new model

The initial framework was based on the analysis of the development of the Ushahidi platform for emergency response (Chapter 2). The Ushahidi development strategies Rapid Prototype Model, Crowdsourcing, Visualization, Mapping, and Mobile Phone Platforms were first mapped to the 10-factor model of effective virtual organizations as socio-technical systems (VOSS) (Cogburn et al, 2011), then to the PRIDE Situation Awareness (SA) model (NIST, 2009), a variation of the SA process model used for training emergency responders. The use of crowdsourcing and other social media was characterized by the construct of stigmergic mass collaboration (Elliott, 2007). Analysis of the use of social media and geospatial technologies during Katrina and the initial development of Ushahidi led to the insight that stigmergic mass collaboration enabled by ICTs is a more universal phenomenon than simply an agile methodology for software development, which was corroborated by the technologies deployed for Hurricane Sandy. This resulted in broadening the framework to include environmental awareness augmentation via geospatial technology and group collaboration factors.

5.1.4 The starting model

The conceptual framework begins with the Prediction in Dynamic Environments Situation Awareness Situation Awareness (PRIDE SA) model (NIST, 2009), the construct of human cognitive stigmergy (HCS), and the role of advanced ICTs, specifically social media and geospatial technology.

5.1.5 The ending model

The new model extends the PRIDE SA model (NIST, 2009) into an expanded conceptual framework of stigmergic human collaboration utilizing technology tools.

The PRIDE SA model is a generalized version of prior models of situational awareness that has been applied in many contexts, including management, traffic control and robotics. The PRIDE SA model uses ICTs to provide situation awareness, and assumes individual agents acting according to a definition in which SA is described as: “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley & Garland, 2000, p.5). In recent years the application of situation awareness (SA) to a variety of complex task domains including risk management, risk assessment, emergency management and emergency response has increased considerably (Gasaway, 2013). In the context of emergency response, SA has been applied according to its roots in performance enhancement training to teach first responders within their various specialties to react prescriptively to pre-defined scenarios (Gasaway, 2013).

For the comparative analysis of the Katrina and Sandy hurricanes (Chapter 3), the conceptual framework is based on the PRIDE SA model, the phenomena of human cognitive stigmergy and stigmergic mass collaboration, and the role of advanced ICTs as enablers for these phenomena. The PRIDE SA model was modified because it includes assumptions of non-human agents and a highly structured rule-based operational logic. However, to explain human stigmergic mass collaboration it had the advantages of assuming multiple agents acting independently, based on individual cognition of events within a shared, real world environment.

In this dissertation, the PRIDE SA model is extended to apply to the problem of increasing situation awareness on a group collaborative level regardless of first responder status within the natural environment during an emergency event, using advanced ICTs. From the analysis of the Ushahidi platform (Chapter 2), observations of the phenomenon of human cognitive stigmergy suggest that when presented with relevant information, many people respond spontaneously in emergency situations regardless of their first responder status (Marsden, 2013). A group collaboration model is used to extend the PRIDE SA model beyond individual agents acting in accordance with prescribed reactions to collective ad hoc participation, shared information and collaborative action. The group model is based on the decision cycle of observe, orient, decide, and act (OODA), developed by military strategist and USAF Colonel John Boyd (1996). Information and communication technology enhancements increase SA levels generally and reduce errors related to incorrect or missing information (Endsley & Garland, 2000).

According to Elliott (2007), stigmergic collaboration augmented by ICTs creates opportunities for the emergence of mass collaboration. In practice, the PRIDE SA model is augmented by the use of social media for mass collaboration and contextualized with geospatial technologies for increased situation awareness. Hypothetically, emergency response is made more effective through the increase of situational awareness and added opportunities for ad hoc collaboration. This hypothesis is supported by the analysis of the performance of Ushahidi (Chapter 2) and by the use of ICTs for ad hoc emergency response in both hurricanes Katrina and Sandy (Chapter 3).

A key aspect of the use of geospatial technologies to enhance situation awareness involves understanding the meanings and uses of certain classes of visual materials: interactive digital maps, computer-generated images, aerial photographs, animations and videos that support the production and representation of temporal and location-based information. Extensive research within the fields of education, mathematics, geography, computer science, data science, psychology and other fields supports the importance of meaningful visual cues and information in multiple contexts.

Research in SA and emergency response is extensive, including research on the use of social media and geospatial information for SA in emergency response, especially considering that geospatial technologies and social media are quite recent phenomena. Research on the relationship between stigmergic collaboration and ICTs is less voluminous but is well established in areas like social media research, computer supported collaborative work, artificial intelligence and free open source software development. The integration of these areas, however, is new and is the basis for the added value of this dissertation.

Wireless networks, including cellular telephones and handheld devices, are identified as resources able to address interoperability issues common in emergency response coordination.

5.2 Contributions of the Research

The three cases present compelling evidence of the utility of ICTs, including social media, crowdsourcing, visual media, mapping and mobile phone platforms, and the value of enhanced situation awareness and stigmergic mass collaboration for ad hoc and formal emergency response.

The new model of technology-enhanced stigmergic human collaboration for emergency response extends the conceptual framework for situation awareness (SA), incorporating stigmergic mass collaboration based on the enhancements to emergency response that can be provided by ICTs, specifically geospatial environmental information and social media for collaboration. The new model provides a framework for future investigations of the use of advanced ICTs for situation awareness, particularly in situations calling for naturalistic decision support, i.e. decision making occurring in the real world rather than a simulated environment. The use of ICTs to enhance situation awareness could be useful in fields other than emergency response, including education, planning, management and engineering.

5.2.1 Theoretical contributions

The theoretical contributions of the research include the extension of the existing National Institute of Standards and Technology Prediction in Dynamic Environments (NIST PRIDE) situation awareness (SA) model by incorporating ICT enhancements for collaboration and environmental situation awareness, and the development of three testable propositions in the theoretical progression of understanding human cognitive stigmergy (HCS) and situation awareness (SA). The extended SA model and the testable propositions are based on the analyses developed in three studies of emergency events.

A new model of situation awareness enhanced with technology tools

The research provides empirical support for the development of a new conceptual framework of ICT-enhanced situation awareness. NIST’s PRIDE SA model was extended for emergency response enhanced by integrating two kinds of ICT tools: collaborative digital workspaces (e.g. social media) and geospatial technologies. Social media tools enhance opportunities for mass communication, coordination and collaboration, while geospatial technologies enhance environmental situation awareness. Both kinds of ICTs support increased access to information and opportunities for knowledge sharing, collaboration and coordination in near real time.

Testable propositions to guide future research

Three testable propositions represent key elements of the new model that can be tested by further empirical research, including implications for improving emergency response, for example, testing how geospatial ICTs can improve environmental situation awareness (i.e. what are the optimum affordances of the technologies); and how Internet-based social media ICTs can improve communication, decision making and action. Further investigation on human cognitive stigmergy and mass collaboration should include addressing issues of trust, and information validity and reliability. Finally, research is needed to determine how and in what ways these different technologies can best be combined to create synergies of functionality and efficacy. Further investigation of these propositions is needed to realize the potential for improving emergency response, cooperation and collaboration. The model and the propositions also offer a framework for evaluating the utility of ICT enhancements to situation awareness and mass collaboration in areas other than emergency response.

5.2.2 Practical contributions

The research makes several practical contributions to those preparing for or involved in emergency response. Recommendations are presented that are generally applicable for traditional as well as ad hoc emergency response, and speak to the effectiveness of innovative approaches to emergency response that have arisen from the three cases, particularly the development of Ushahidi, which has been successfully deployed around the world since its inception. Other research indicates that advanced information and communications technologies are useful in emergency response for citizens as well as first responders (DHS VSMWG, 2014; Rich, 2013; Gao et al, 2011).

Situation awareness is extremely important for effective emergency response

One of the most important lessons of the studies is that the more people know about what to expect, how to prepare and how to react in an emergency, the better the outcomes will be. This is not a new insight but the empirical evidence presented of the different outcomes of Hurricane Katrina and Hurricane Sandy make this worth emphasizing. Related to this is the point that people as well infrastructure need to be prepared in order to respond effectively in an emergency situation, and information and knowledge are key resources for accomplishing effective emergency response. The results of the research indicate that these technologies are useful for citizens and first responders alike, and that the potential exists to develop them to greater advantage and improve the effectiveness of emergency response (DHS VSMWG, 2014; Rich, 2013; Gao et al, 2011).

In both cases there was widespread infrastructure failure, affecting both telecommunications and electric power and for first responders as well as citizens. In the case of Katrina, the most devastating infrastructure loss was the loss of electricity, which caused not only the loss of services like air conditioning and lighting, but the loss of the crucial pumping system that could have prevented the severe flooding that occurred, leading to the incapacitation of virtually all telephone and other communications media. Although more people were left without power by Sandy, the impact of the power loss in Katrina was much more devastating because of the geography of the city of New Orleans. However, another cause was simply the lack of actionable information at multiple levels. The government officials, the first responders, and the public at large were all left without the knowledge and information they needed to make the decisions and take the actions that might have prevented the terrible loss of life that occurred.

The extended model improves situation awareness for emergency response in several ways. First, situation awareness is expanded by incorporating environmental ICTs. Real time or near real time geospatial imaging, dynamic map interfaces and visual data representations in a web-based platform greatly increase the quantity, quality and accessibility of available environmental information. Second, situation awareness is expanded by ICTs for mass collaboration. Digital workspaces for crowdsourcing and social media increase access to emergency communications, advisories and warnings, local and expert information, knowledge sharing, and resources on location for action. Research has shown that the level of situation awareness (SA) is improved by having available, correct and complete information, and that improved SA leads to fewer errors in decisions and actions (Endsley, 2000). The availability of correct and timely information means that emergency response can be more effective, efficient and helpful, resulting in better outcomes overall.

Use flexible technology platforms and software development models

A study of the development of the Ushahidi software presents some guidance for successful use of the Rapid Prototype Model. Crowdsourcing the development effort and using the most widely available mobile phone platforms follows examples of some FLOSS development teams that have been shown to use cognitive stigmergy as a tool to organize and coordinate work (Bolici et al, 2007; Crowston et al, 2007, Crowston et al, 2005; Clases & Werner, 2002). The simplicity and flexibility of the software explains the high levels of utilization by end users and demonstrates stigmergic mass collaboration. Ushahidi's initial implementation in Kenya was successful because of the recent development of low-cost (in comparison to landline) mobile phone technology; its rapid development as a global platform was possible because of the existing deployment of the Internet. Heylighen (2014, 2007a, b) and Benkler (2013) point to the low cost of information creation and sharing via the Internet as a major force for the global increase, easy access, and voluntary creation and sharing of every form of information. The combination of easy access, low cost, and compelling social concerns lead to mass participation and collaboration. Ushahidi's initial deployment with mobile phone platforms using

FrontlineSMS was done in order to maximize accessibility for incoming messages because of the lack of Internet connectivity in Kenya. The platform can now be used with Twitter (called the SMS of the Internet for its simple basic interface and functionality) where the Internet is available. Google Earth and Google Maps were the first publicly available web-based geospatial systems, soon followed by OpenStreetMaps (a not-for-profit alternative). Prior to the deployment of these applications, access to timely and accurate geospatial data was extremely technically demanding and expensive.

The use of free (with an Internet connection), readily available technology rather than fee-based or licensed proprietary software solutions effectively maximizes crowdsourcing for obtaining free software, technical know-how, scientific knowledge and general education. This empowers ordinary people to help themselves and others, and in contrast with traditional emergency response, crowdsourcing can provide faster localized information for situational awareness and assistance.

Concerns about vulnerable infrastructure for emergency communications

The Katrina and Sandy case studies revealed significant physical and regulatory infrastructure weaknesses that need to be addressed. In many natural disasters electric power and telecommunications systems fail as they did during Katrina and Sandy, leaving millions without electricity or telecommunications for extended periods. The inherent weaknesses in the existing systems are barriers to effective emergency response because when they fail, they prevent the use of the advanced ICTs that support mass collaboration and enhanced situation awareness. The Ushahidi case shows that assumptions in the US about ICT cyberinfrastructure development and availability are quite different from Africa, where unreliable electricity and lack of network coverage and bandwidth are a given even under normal circumstances. The

Ushahidi platform was designed from the start to operate under severe constraints using very basic infrastructure requirements (Marsden, 2013). Effective emergency response should assume that power will go out in some emergencies. Short term solutions could incorporate *in situ* battery backups on communications towers able to recharge using solar PV (photovoltaics) or micro wind. Currently, battery backup systems for cell phone towers can supply power for eight or more hours between charges, and diesel generators require refueling. Since emergency events can result in power outages lasting days or even weeks, the ability to recharge independently from the power grid via renewable resource-based distributed generation would make cell towers more reliable.

In the long run, the power and telecommunications infrastructure need to be more resilient

There is no doubt that the major failure of both Katrina and Sandy was the failure of the electric power grid. Had power been available during Katrina, emergency communications would have been possible, and it is also likely that the flooding in New Orleans would have been less severe. Had power been restored quickly, police, fire and hospitals could have continued to provide services. In the US, the effort to improve the resilience of ICT infrastructure is underway and the electric power grid is in transition in several ways: From vulnerable poles and wires delivering electricity to building-generated power with integrated storage; from centralized to distributed generation; from high capacity fossil- and nuclear-fueled power plants to local alternative and renewable resource-fueled net-zero energy and combined heat and power (CHP) plants; from unidirectional, unintelligent and always-on to multidirectional, intelligent and on-demand; and from a single interconnected and interdependent grid to many independent, loosely connected microgrids. The transition is estimated to take two or three decades but is already underway in California, New York and other states (NYSPUC, 2014). As these changes add intelligence and resilience to the electric power grid, the severity and duration of power outages should be reduced, and the reliability of the telecommunications networks should improve as a result.

The telecommunications industry is also in state of transition as it moves away from traditional landlines toward wide adoption of wireless networks and mobile phone technology. Advanced data communications networks and the Internet have diminished the role of the landline telephone system, but in many areas landlines are still the standard for 911 emergencies and wireless telephone service for emergency communications has not been well-supported. In the devastation that followed Katrina, the FCC attempted to require cellular companies to install emergency power backup at all cell towers, but during Hurricane Irene and again during Sandy, thousands of cellular towers failed due to wind damage, loss of electric power and lack of emergency power backups, leaving millions without telephone service, including emergency 911. Another barrier is the limited ability of the cellular system to determine the location of the device and the lack of accurate geosynchronous positioning system (GPS) technology on many cell phones. With more than half of US households no longer using landlines and having only cell phones for telephone service, improvements to emergency call services are needed (Barnes & Rosen, 2014).

In 2013 the Hurricane Sandy Rebuilding Task Force was created to coordinate federal support to the states affected by Sandy, and their Hurricane Sandy Rebuilding Strategy recommends a regional approach to resilience and capacity building at the local level, including strategic investments in key infrastructures based on risk, and actions to minimize power outages and maintain continuous mobile phone service during emergencies through the adoption of resilient microgrids and distributed generation (FEMA, 2013; HUD, 2013). However, the transition from traditional landlines and emergency radio to emergency response for the 21st

century is complex both technologically and politically. During Katrina, alerts and warnings were mainly delivered by traditional means such as sirens, broadcast radio and television, reverse 911, the Emergency Alert System, the Wireless Emergency Alert Systems, and NOAA weather radio. During Sandy, Internet-based social media platforms like Twitter, Facebook, YouTube and even Pinterest that didn't even exist at the time Katrina were in wide use.

The transition from traditional telecommunications infrastructure based on landlines and broadcast media to wireless mobile telephony and Internet-based media has had unanticipated effects on emergency communications. First, the traditional landline system predates the modern electric grid. It was designed to supply its own low voltage DC power and remain operational even without the electric grid using generators. Although during Katrina many landline Public Switched Telephone Networks (PSTN) were knocked out due to loss of generators in flooded PSTN switching offices, during Sandy, it was the replacement of the copper wire landlines with fiber optic and coaxial cable requiring grid power that caused landline outages in many areas.

Second, because they are wired, all landlines are associated with fixed geographic locations, unlike mobile phones that can be in an entirely different location than a billing address. Accurate geolocation is possible with GPS-enabled smart phones, but many cell phones are not equipped with it. Mobile telephone locations can also be determined using the locations of the nearest cell phone towers in range, but not very precisely, making response to emergency calls from mobile phones potentially difficult and time consuming. Third, the continuing migration of the public from traditional broadcast media to Internet media has had a detrimental effect on the ability of authorities to issue emergency warnings. Today, many people consume information asynchronously via the Internet rather than tuning in to television or radio programming. Many of these non-traditional channels have little or no capacity for news or emergency reporting, especially locally for a particular event. Both of these transitions have created the need for new approaches to emergency warning systems.

The majority of people in the US now regularly use their cell phones for emergency 911 calls and expect to receive emergency notifications via cell phone. As a result, the need for new 911 and other emergency communications upgrades and retrofits designed for wireless telecommunications has increased dramatically (Barnes and Rosen, 2014; Ridley, 2012). Efforts are now being made to incorporate text messaging into 911 systems in order to increase communications options, and the ability to target warning messages and advisories to all phones in an affected area based on locational intelligence rather than the traditional area code has been implemented in many areas. However, the ability to quickly locate the origin of an emergency call in order to respond to a call for help to a specific geographic location is still unavailable on many devices and in many regions. Improving this capability will require investments in network upgrades and additional integration (Barnes and Rosen, 2014). In addition, the cell towers that are depended upon for cellular communications are not always equipped with emergency power backup and designed with the ability to withstand extreme conditions as emergency radio towers have been. During both Katrina and Sandy, the loss of electric power, Internet services and wireless networks, made ham radio (for two-way communications) and broadcast radio (for emergency advisories, warnings and reports), both 1930's technologies, the last resort for emergency communications in the affected areas. Emergency communications were crippled because of the transfer of communications technology to vulnerable infrastructure with inadequate backups.

Recognize the power of stigmergic collaboration as part of an overall emergency response

The value of geospatial and social media ICTs for creating an integrated framework for innovations in stigmergic mass collaboration using visualization, scenario modeling, participatory scenarios, and decision support tools to improve risk assessment, risk management and community preparedness for emergency events has started to become a topic of interest (Yates & Paquette, 2011; Goodchild & Glennon, 2010). There are changes happening in emergency response that indicate the advantages of ICTs for emergency response are being recognized and new approaches are being tested (FEMA 2013, DHS VSMWG, 2013). In New York before and during Hurricane Sandy, ad hoc groups (Hurricane Hackers, Crisis Mappers) developed Crisis Maps and special applications for emergency workers to use (e.g. Voluntarily, Pingo, eGov) in cooperation with the mayor's office and NYC OEM (Howard, 2014, 2012; Feuer, 2013; Kantrowitz, 2012).

In 2012, the Committee on Increasing National Resilience to Hazards and Disasters of the National Academies defined resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NRC-c, 2013). This community-based approach reflects the recognition of the impact of disasters such as Katrina and Sandy. In each case, failure of key infrastructures, including roads, bridges, sewage and water systems, energy systems, telecommunications, etc., impaired effective emergency response, leading to re-examination of the appropriate roles for federal, state, and local governments, philanthropic organizations, and the private sector (NRC-c, 2013). As a result, the focus of the debate on how to improve emergency response has shifted to the importance of recognizing known risks in a given local area, hardening infrastructure and developing effective response plans in areas often hit by disasters, like hurricanes along the Gulf Coast, tornados in the midsection of the country, wildfires in the southwest and earthquakes in California (NRC-c, 2013). The report of the committee recommends building a culture of resilience through “long-term collective approaches, individual and community involvement (for example, individuals serving as first responders), national leadership, accessible risk information, and community action and commitment” and concluded that “disaster resilience is a shared responsibility by civic society, the private sector, government, and all citizens” (NRC-c, 2013). As urban populations increase, natural disasters are causing increased challenges to public health, welfare, and safety. Informal methods, such as crowdsourcing, can provide real time data and enable quick response during natural disasters. Although geospatial information requires high overhead costs and expensive technology for data production, streaming and imaging computation, and is therefore usually commercially or institutionally generated, rendered geospatial imaging for enhancing environmental situation awareness is increasingly available via the Internet.

5.3 Limitations of the Research

There are several limitations of the research. First, the cases are all unique events that on many levels are not replicable. Even in the unlikely event that they recurred in the same place and at the same magnitude, the passage of time would still create many differences. It is arguable that because of this uniqueness that these cases are idiosyncratic and therefore their value beyond the circumstances of the particular case is limited. However, the selection of the cases was reasoned to support a strategy of comparable data to provide real world context supporting the observations and conclusions reached. Each case study was constructed from multiple sources of information to establish triangulation, and data were collected and analyzed to produce robust evidence supporting the assertions made. The selection of sources analyzed was limited only by their relevance to the themes of interest: the use of information and communications technologies for emergency response, the role of stigmergic mass collaboration, and the impacts of ICTs on situation awareness. The process of data collection and analysis was governed by the principle of saturation, which identifies ranges of possible meanings and answers discovered in the process of developing the study. In order to ensure the validity of the analysis, relevant academic literature as well as contemporary journalism and historical accounts were reviewed and cited to ensure rigor and avoid bias (Yin, 2014; Merriam, 2009; Eisenhardt & Graebner, 2007).

Another legitimate criticism of the research is its focus on emergency response alone. Although focusing the study on emergency response may limit the applicability of the results to that theme, the need for better and more effective emergency management, planning and response seem to be important enough to justify further investigation. Emergency events became the focus of the research because of the extraordinary ad hoc participation results seen on the use of the Internet and ICTs during the two hurricanes, and the success of the Ushahidi platform. In the US, the attention to improving emergency response on the part of government, the private sector and citizens has only increased in the ten years since Hurricane Katrina, and has become even more of a priority since Hurricane Sandy. In addition, the phenomena investigated have been extensively studied in other contexts, and their relevance to emergency response makes them more significant.

Finally, the question of using only secondary sources rather than including primary data collected directly from participants should be addressed. The events studied are not in a remote past and there are many people that could be surveyed, interviewed or gathered together in focus groups to share insights and perceptions. However, the process of data collection should be conducted in accordance with best meeting the goals of the research, and the research was exploratory, aimed at investigating a novel, innovative phenomenon that had barely been recognized, driven by technologies that were similarly new and innovative, particularly in the context of emergency response. The use of secondary sources offered far more breadth of information on each case. Several conceptual frameworks were used in the course of the investigation to build a new model that synthesized several empirically supported constructs.

5.4 Future Research

The new situation awareness model of technology-enhanced stigmergic mass collaboration for emergency response reflects observations of new practices based on the adoption of advanced ICTs seen in case studies of recent emergency events and the responses to them. Three propositions derived from the new model offer testable approaches for assessing the value of advanced ICTs to provide real world, real time information to address the complexity and uncertainty of effective emergency response. Through the use of social media ICTs the new model expands the situation awareness (SA) process from a single trainee or participant to a stigmergic mass collaboration. The new conceptual framework characterizes the use of geospatial technologies in real or near real time to expand environmental SA. There are many research questions related to the new model and the propositions that could be candidates for future studies:

Should advanced ICTs be considered as economic assets or social benefits (i.e. public goods) worthy of public investment, in addition to commercial products?

Are Internet-based commercial social media ICTs like Twitter and FaceBook the best choices for emergency response or should purpose-built platforms like Ushahidi be developed and deployed?

Given that advanced ICTs are expensive platforms to build and maintain, what might the criteria be for future public investments or enhancements to ICTs for emergency response?

How can the limitations of the new model, e.g. the problems of self-interested or bad actors taking advantage of available information to do harm, cybersecurity issues of privacy and security, and information validation and verification issues, be addressed?

How severe a liability is the dependency of the new model on the availability of advanced ICTs? Would the new model still offer any benefits if advanced ICTs became unavailable due to infrastructure damage or failure? Is it possible that emergency response plans based on the availability of advanced ICTs could actually make an emergency situation worse under circumstances of infrastructure outages?

Resilient and sustainable communities are those that can respond effectively to and recover from disruptions including natural disasters and other emergency events both in the short and long term (Tierney, 2014; Gomes, 2009; Chang, 2009). Related research could include investigations into how infrastructure systems for electric power and telecommunications could be made better able to withstand severe weather and other emergency events, and how to assist communities to develop effective emergency response plans. Exploring the relationship between resilience and sustainability could facilitate designing and implementing advanced ICTs for emergency response that could potentially enhance the development of systems for smart cities, buildings and infrastructures as compatible research goals.

Appendices

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Chapter 2 Literature Review

Sources: newspaper, magazine, website, journal and social networking publications and archives; project documentation, published statements of mission, vision, goals and objectives; contemporaneous and retrospective communications, transcribed or recorded telephone/internet conversations, etc.); maps and text materials; published media reports of events; published interviews with participants, audio and video recordings of TED talks with original participants and observers. Data supplemented with a multidisciplinary review of relevant scholarly literature

1. "FrontlineSMS and Ushahidi - A Demo"

Ken Banks and Erik Hersman, ICTD 2009

Abstract - FrontlineSMS and Ushahidi are both free and open source tools which allow for the collection, dissemination and visualization of data collected to and from the field. This paper outlines details of live demonstrations of the tools at the ICTD (Information and Communication Technologies and Development) 2009 conference in Qatar.

Key aspect is the low cyberinfrastructure requirements & high tech affordances: a computer and a mobile phone or modem, no Internet needed; can provide 2-way messaging and mapping (visualization)

Ken Banks is founder of kiwanja.net and developer of FrontlineSMS. Erik Hersman is an original developer of the Ushahidi platform and Technical Director at Ushahidi, Inc. Both have extensive experience working in the ICT4D field, and both actively maintain websites and blogs on the application of technology in the developing world.

2. "Participatory Epidemiology: Use of Mobile Phones for Community-Based Health Reporting"

Clark C. Freifeld-1,2, Rumi Chunara-1,2, Sumiko R. Mekaru-1,3, Emily H. Chan-1,2, Taha Kass-Hout-4, Anahi Ayala Iacucci-5, John S. Brownstein-1,2,6

1- Children's Hospital Informatics Program at Harvard-Massachusetts Institute of Technology, Division of Health Sciences and Technology, Boston, MA.
2- Division of Emergency Medicine, Children's Hospital Boston, Boston, MA.
3- Department of Epidemiology, Boston University School of Public Health, Boston, MA.
4- Public Health Surveillance Program Office, Office of Surveillance, Epidemiology,
& Laboratory Services, Centers for Disease Control and Prevention, Atlanta, GA.
5- Internews, Nairobi, Kenya.
6- Department of Pediatrics, Harvard Medical School, Boston, MA.

Report on how the use of cellular phones and mobile applications to report and collect epidemiological data improves public engagement, & makes data collection faster and more thorough, especially in remote & underserved areas. Lists promising applications (Usahidi & Frontline SMS, others)

PLoS Medicine 2010 (Public Library of Science)

3. "Digitally Networked Technology in Kenya's 2007–2008 Post-Election Crisis"

Joshua Goldstein and Juliana Rotich
Internet & Democracy Case Study Series
Berkman Center Research Publication No. 2008-09

Abstract - Written largely through the lens of rich nations, scholars have developed theories about how digital technology affects democracy. However, primarily due to a paucity of evidence, these theories have excluded the experience of Sub-Saharan Africa, where meaningful access to digital tools is only beginning to emerge, but where the struggles between failed states and functioning democracy are profound. Using the lens of the 2007–2008 Kenyan presidential election crisis, this case study illustrates how digitally networked technologies, specifically mobile phones and the Internet, were a catalyst to both predatory behavior such as ethnic-based mob violence and to civic behavior such as citizen journalism and human rights campaigns. The paper concludes with the notion that while digital tools can help promote transparency and keep perpetrators from facing impunity, they can also increase the ease of promoting hate speech and ethnic divisions.

Josh Goldstein is a research assistant at Berkman Center, Juliana Rotich is Executive Director of Ushahidi Inc, & original member of the development team of the Ushahidi platform.

4. "Crowdsourcing Risk Assessment: Wisdom of the Crowds" Patrick Meier

Abstract- Crowdsourcing represents a promising but still largely untested approach for assessing risk. Jeff Howe coined the term crowdsourcing in 2006 and defined it as "the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call." The key words here are "undefined," "large group," and "open call."

Patrick Meier, Director of Crisis Mapping and Strategic Partnerships, Ushahidi Inc, original member of the development team of the Ushahidi platform.

Produced by the World Bank. Proceedings of Understanding Risk: Innovation in Disaster Risk Assessment Proceedings from the 2010 UR Forum.

https://www.understandrisk.org/sites/default/files/attachments/Forum2010.pdf

5. "Crowdsourced translation for emergency response in Haiti: the global collaboration of local knowledge"

Robert Munro, Department of Linguistics, Stanford University, Stanford, CA

Abstract- In the wake of the January 12 earthquake in Haiti it quickly became clear that the existing emergency response services had failed but text messages were still getting through. A number of people quickly came together to establish a text-message based emergency reporting

system. There was one hurdle: the majority of the messages were in Haitian Kreyol, which for the most part was not understood by the primary emergency responders, the US Military. We therefore crowdsourced the translation of messages, allowing volunteers from within the Haitian Kreyol and French-speaking communities to translate, categorize and geolocate the messages in real-time. Collaborating online, they employed their local knowledge of locations, regional slang, abbreviations and spelling variants to process more than 40,000 messages in the first six weeks alone. According the responders this saved hundreds of lives and helped direct the first food and aid to tens of thousands. The average turn-around from a message arriving in Kreyol to it being translated, categorized, geolocated and streamed back to the responders was 10 minutes. Collaboration among translators was crucial for data quality, motivation and community contacts, enabling richer value-adding in the translation than would have been possible from any one person.

amta2010.amtaweb.org

6. “Ushahidi,or ‘testimony’: Web 2.0 tools for crowdsourcing crisis information”

Ory Okollah, US trained Kenyan journalist in Nairobi that initiated the Ushahidi development effort. First person account of the inception and development of the Ushahidi platform in 2008.

Introduction- This article reflects on the development of the Ushahidi website. The idea behind the website was to harness the benefits of crowdsourcing information (using a large group of people to report on a story) and facilitate the sharing of information in an environment where rumours and uncertainty were dominant. At the height of the post-election violence in Kenya in late December 2007 and early January 2008, my personal blog become one of the main sources of information about the flawed electoral process and the violence that broke out thereafter. There was a government ban on live media and a wave of self-censorship within mainstream media, which created an information vacuum. The government argued false or biased reporting would result in even more ethnic-based violence, and that it wanted the opportunity to review media reports before they went ‘live’. In response to the ban I asked people to send me information via comments on my blog and emails – about incidents of violence that they were witnessing or hearing about throughout the country, and that were not being reported by the media.

Participatory Learning and Action: Change at Hand – Web 2.0 for Development. The Ethnos Project: a research portal and resource database that explores the intersection of indigeneity and information and communication technologies (ICTs). 2009

7. “Phone tech transforms African business and healthcare” Melissa Fellett, New Scientist Tech. 2011.

Access to mobile phone technology is revolutionizing Africa. Innovative mobile development labs “mlabs” (funded by infoDev: Nokia, World Bank, and the Finnish government). Healthcare, agriculture, timekeeping.

8. “Ushahidi and Crowdmap: microstreaming as time-binding media”

Andra Keay, University of Sydney

Abstract- Ushahidi is a Web 3.0 open source crisis-mapping application, developed in 2008, which is being used for humanitarian purposes around the world. Cultural studies calls for a critical approach to 'the internet' and its applications. This article considers whether or not Ushahidi could be a 'liberation technology' or a 'disruptive technology' using Harold Innis's methodology and compares Ushahidi and Crowdmap with Foursquare and Facebook, to describe how the differences in the applications at the material, semiotic and sociopolitical levels, could help categorise and understand them. This involves a broad appreciation of many fields including the rapid technological shift from Web 2.0 to Web 3.0. An ethical evaluation of the balance of time-binding and space-binding characteristics in these applications is beyond the scope of this article, however attention is drawn to the ways in which life-streaming or micro-streaming applications like Facebook and Ushahidi are performing time-binding to great cultural and political effect.

3pm Journal of Digital Research & Publishing, session 12, 2010

9. "Social Media as Crisis Platform: The Future of Community Maps/Crisis Maps"

Rebecca Goolsby, Office of Naval Research

Abstract- Social media provides the means for creating new communities and for reenergizing old communities. Recently, a new kind of quickly formulated, powerful community has formed as existing social media communities, news organizations, and users have converged in social media spaces to respond to sudden tragedies. This article addresses the ad-hoc crisis community, which uses the social media as a crisis platform to generate community crisis maps.

"The most recent entrant to the social media field is the public-access crisis map, exemplified by the Ushahidi platform. It is open source, therefore easily adoptable by any agency or group no matter how small. Developed by a Kenyan activist, Ushahidi is a simple open-source solution for the developing world, originally designed to help activists blow the whistle on election fraud. Used in Kenya, Mexico, and Afghanistan, Ushahidi platforms provide the ability to accept text messages from a variety of sources such as phones, the Internet, email, and even other social media platforms like Twitter. (Other uses for Ushahidi include wildlife tracking, H1N1 monitoring and a host of other uses.). Users can also post photographs and videos to back up their claims of voter fraud (Ushahidi means "testimony" in Swahili). Each message is placed on the map as a flag that becomes a bigger and bigger blob as more reports pour in. Clicking on the blob brings up the message reports, the photos, and videos associated with that location."

ACM Transactions on Intelligent Systems & Technologies, Vol.1, No.1, October 2010.

10. "Collective Action and the Evolution of Social Norms"

Elinor Ostrom, The Journal of Economic Perspectives, Vol. 14, No. 3. (Summer, 2000)

“Both laboratory experiments and field studies confirm that a substantial number of collective action situations are resolved successfully, at least in part. The old-style notion, pre-Mancur Olson, that groups would find ways to act in their own collective interest was not entirely misguided. Indeed, recent developments in evolutionary theory-including the study of cultural evolution-have begun to provide genetic and adaptive underpinnings for the propensity to cooperate based on the development and growth of social norms. Given the frequency and diversity of collective action situations in all modern economies, this represents a more optimistic view than the zero contribution hypothesis. Instead of pure pessimism or pure optimism, however, the picture requires further work to explain why some contextual variables enhance cooperation while others discourage it.”

Suggests that collaborative action in service to collective interests is a more natural and normal response than the generally accepted principle of action in service to self-interest at the expense of the greater good.

11. “Collective Action and the Evolution of Social Norms”

Elinor Ostrom, The Journal of Economic Perspectives, Vol. 14, No. 3. Summer 2000.

“The "zero contribution thesis" (Olson, 1962): The idea that rational agents were not likely to cooperate in certain settings, even when such cooperation would be to their mutual benefit, was also soon shown to have the structure of an 11-person prisoner's dilemma game (Hardin 1971, 1982). Indeed, the prisoner's dilemma game, along with other social dilemmas, has come to be viewed as the canonical representation of collective action problems (Lichbach, 1996). The zero contribution thesis underpins the presumption in policy textbooks (and many contemporary public policies) that individuals cannot overcome collective action problems and need to have externally enforced rules to achieve their own long-term self-interest. The zero contribution thesis, however, contradicts observations of everyday life.”

12. Video: “How cognitive surplus will change the world”

Clay Shirky on Ushahidi: from tracking wildlife in Kenya to the moderation of elections in Mexico, from snow cleanup in Washington state to risk prevention around forest fires in Italy, Ushahidi is a website that offers a social networking platform for “democratizing information, increasing transparency, and lowering the barriers for individuals to share their stories.”
In this video, Clay Shirky talks about the creation of Ushahidi and examines what he calls “cognitive surplus—the shared, online work we do with our spare brain cycles and human generosity.” Video licensed under Creative Commons, has been shared by the University of British Columbia, recorded by TED@cannes (2010, June).

NYU, Distinguished Writer in Residence at the Arthur L. Carter Journalism Institute and Assistant Arts Professor in the New Media focused graduate Interactive Telecommunications Program (ITP). His courses address, among other things, the interrelated effects of the topology of social networks and technological networks, how our networks shape culture and vice versa.

http://www.ted.com/talks/clay_shirky_how_cognitive_surplus_will_change_the_%20world.html

13. Video: “How cellphones, Twitter, Facebook can make history”

Clay Shirky on YouTube:
http://www.youtube.com/watch?v=c_iN_QubRs0&feature=player_embedded

“While news from Iran streams to the world, Clay Shirky shows how Facebook, Twitter and TXTs help citizens in repressive regimes to report on real news, bypassing censors (however briefly). The end of top-down control of news is changing the nature of politics.” Video licensed under Creative Commons, has been shared by the University of British Columbia, recorded by TED (2009, June).

14. ‘Ushahidi’ from the website Ushahidi, viewed August 2010

http://www.ushahidi.com/

15. Video: “Is Ushahidi a Liberation Technology?”

Patrick Meier, from the blog iRevolution, 2010, thought leader on humanitarian technology and innovation. Author (2015): "Digital Humanitarians: How Big Data is Changing Humanitarian Response." Previously: Harvard Humanitarian Initiative, United Nations, World Bank

What is Liberation Technology? Larry defines this technology as,

“… any form of information and communication technology (ICT) that can expand political, social, and economic freedom. In the contemporary era, it means essentially the modern, interrelated forms of digital ICT—the computer, the Internet, the mobile phone, and countless innovative applications for them, including “new social media” such as Facebook and Twitter.”

Video and blog at: http://irevolution.wordpress.com/2010/08/08/ushahidi-liberation-tech/

16. Video: “The Crowd is Always There: A Marketplace for Crowdsourcing Crisis Response”

Patrick Meier, from the blog iRevolution, 2010.

“What I want to expand on is the notion of a “marketplace for crowdsourcing” that I introduced at the Summit. The idea stems from my experience in the field of conflict early warning, the Ushahidi-Haiti deployment and my observations of the Ushahidi-DC and Ushahidi-Russia initiatives.

“The crowd is always there. Paid Search & Rescue (SAR) teams and salaried emergency responders aren’t. Nor can they be on the corners of every street, whether that’s in Port-au-Prince, Haiti, Washington DC or Sukkur, Pakistan. But the real first responders, the disaster affected communities, are always there. Moreover, not all communities are equally affected by a crisis. The challenge is to link those who are most affected with those who are less affected (at least until external help arrives).

Video and blog at: http://irevolution.net/2010/08/14/crowd-is-always-there/

17. Video: "The Era of Open Innovation"

Charles Leadbeater, 2005

"Another title for this post might have been "Here Come the Crowd-Sorcerers…" I'll be following up with Crowd-Sorcerer sequels soon (to answer many readers who have been asking) but before I do, I want to look at a prequel. In 2005, Charles Leadbeater gave what is without doubt one of my all time favorite TED Talks ever. The examples he shares—mountain bikes, telescopes and computer games—provide excellent insights into the opportunities and challenges that companies like Ushahidi face. This talk foretells what may very well be the future of crisis mapping."

http://irevolution.net/2010/08/18/amateur-professional-and-what-that-means-for-crisis-mapping/

18. Video: "Collaborative Crisis Mapping: Ushahidi Haiti Deployment"

Patrick Meier, 2010

Red Cross Emergency Social Data Summit, slides at:
http://www.slideshare.net/iRevolution/collaborative-crisis-mapping

19. P. Meier and K. Brodock, "Crisis Mapping Kenya's Election Violence," iRevolution blog, 23 Oct. 2008.

"Are citizen journalists playing an increasingly important role in documenting violent conflict and human rights violations? I posed this question during the 2008 Global Voices Summit and answered affirmatively—but without more than a hunch and rather limited anecdotal evidence. Paul Curion took issue and David Sasaki recommended that someone carry out an empirical study.

I appreciated David's practical recommendation and decided to pursue the project since the topic overlaps with the Conflict Early Warning and Crisis Mapping project I've been working on at the Harvard Humanitarian Initiative (HHI). Supported by Humanity United, the project seeks to explore the changing role and impact of information communication technology in crisis early warning and humanitarian response.

Seeing that I was in Nairobi visiting my parents during the election violence, I chose Kenya as a case study to assess the role of citizen journalists in crisis environments as compared to the mainstream media. My colleagues Kate Brodock, Briana Kramer and I used event-data analysis to code reports of violent and peaceful events as documented by about a dozen citizen journalist bloggers between December 27, 2007 and January 27, 2008."

http://irevolution.net/2008/10/23/mapping-kenyas-election-violence/

20. Meier, Patrick. "Changing the World, One Map at a Time". Uploaded on May 3, 2011

"Maps are changing our world in ways we could hardly imagine just a few years ago? This presentation will explain why, giving a real world examples ranging from Haiti and Egypt to Libya and Japan. Today's maps are live maps that combine crowds and clouds to drive social change. The presentation will highlight the latest in the field of crisis mapping by drawing on the remarkable efforts of a new initiative called the Standby Volunteer Task Force."

Documentary video accessed January, 2012: http://www.youtube.com/watch?v=Hh_PiVqf8BA

21. "Mission 4636." (2010).

"Mission 4636 was a Haitian initiative that came together following the 2010 earthquake near Port-au-Prince. From 50 countries worldwide, we provided an online translation and information processing service that connected the Haitian people with each other and with the international aid efforts.

The main way that we connected with people within Haiti was by phone and text messaging, either directly or by a free phone number '4636′. After the earthquake, many cell-towers radio stations kept working, so we stayed connected to each other even when the government itself had effectively collapsed. We also used local radio to share information within the country and to advertise the 4636 number.

We worked directly with the relief workers on the ground in Haiti. Because many people coming into Haiti to help could not speak Haitian Kreyol, we translated communications between Kreyol and English, and helped the international emergency responders locate places that were not on any map."

Website accessed March 2012: www.mission4636.org/

22. Munro, R. "Crowdsourcing and the crisis-affected community"

Abstract. This article reports on Mission 4636, a real-time humanitarian crowdsourcing initiative that processed 80,000 text messages (SMS) sent from within Haiti following the 2010 earthquake. It was the first time that crowdsourcing (microtasking) had been used for international relief efforts, and is the largest deployment of its kind to date. This article presents the first full report and analysis of the initiative looking at the accuracy and timeliness in creating structured data from the messages and the collaborative nature of the process. Contrary to all previous papers, studies and media reports about Mission 4636, which have typically chosen to exclude empirical analyses and the involvement of the Haitian population, it is found that the greatest volume, speed and accuracy in information processing was by Haitian nationals, the Haitian diaspora, and those working closest with them, and that no new technologies played a significant role. It is concluded that international humanitarian organizations have been wrongly credited for large-scale information processing initiatives (here and elsewhere) and that for the most part they were largely just witnesses to crisis-affected communities bootstrapping their own recovery through communications technologies. The particular focus is on the role of the diaspora, an important population that are increasingly able to contribute to response efforts thanks to their increased communication potential. It is recommended that future humanitarian deployments of crowdsourcing focus on information processing within the populations they serve, engaging those with crucial local knowledge wherever they happen to be in the world.

Information Retrieval, April 2013, Volume 16, Issue 2, pp 210-266 Date: 03 Jul 2012

http://link.springer.com/article/10.1007/s10791-012-9203-2

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Papers: http://syr.academia.edu/JanetMarsden, www.researchgate.net

EDUCATION

SYRACUSE UNIVERSITY SCHOOL OF INFORMATION STUDIES
PHD INFORMATION SCIENCE AND TECHNOLOGY, EXPECTED COMPLETION 2015
Advisors: Dr Jeffrey Stanton and Dr Jason Dedrick

SHIZUOKA UNIVERSITY FACULTY OF INFORMATICS
Visiting Scholar, Summer 2011: Distributed generation in the wake of Fukushima
Visiting Scholar, Summer 2006: Community-based Waste Management
Sponsor: Dr Valerie Wilkinson

SUNY COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY
MPS Environmental and Community Land Planning, 2007
Thesis: Mapping Public Participation for the Onondaga Creek Sub-Basin Revitalization Plan: Using GIS for Environmental Land Planning
Advisor: Dr Richard Smardon

SYRACUSE UNIVERSITY MAXWELL SCHOOL OF CITIZENSHIP AND PUBLIC AFFAIRS
Graduate Certificate Environmental Conflict Resolution, 2007

SYRACUSE UNIVERSITY SCHOOL OF INFORMATION STUDIES
MS Telecommunications and Network Management, 1998
Thesis: *The Education of IT Professionals: Integrating Experiential Learning and Community Service*
Advisors: Dr Ruth Small and Dr Murali Venkatesh

ST. JOHN FISHER COLLEGE
MBA, 1993
Management Information Systems
Graduate Representative Enrollment and Retention Committee
Nominated for MBA Faculty Award
Advisor: Dr J. Jason Berman

UNIVERSITY OF RHODE ISLAND
BS Agricultural and Natural Resource Technology, 1980
Dean's List

RECENT PROJECTS

Save the Rain. Hydrology GIS, Green Infrastructure database development; PI: Dr David Chandler, LC Smith School of Engineering, Syracuse University; NSF Consortium of Universities for the Advancement of Hydrologic Science Inc (CUAHSI).

Socially Intelligent Computing for Qualitative Data. PI: Dr Nancy McCracken, Syracuse University School of Information Studies, NSF Grant no. 1111107

P2030.4 Working Group: Draft Guide for Control and Automation Installations Applied to the Electric Power Infrastructure. Metrics Task Force Chair, Executive Committee, IEEE Standards Association.

Peer Reviewed Publications

Marsden, J. (2013) "Stigmergic self-organization and the improvisation of Ushahidi", *Cognitive Systems Research*, Volume 21, March 2013, Pages 52–64. Available online at: http://www.sciencedirect.com/science/article/pii/S138904171200040X

Marsden, J., Treglia, J. and McKnight, L. (2012) "Dynamic Emergency Response Communication: The Intelligent Deployable Augmented Wireless Gateway", Proceedings of the 2012 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Management and Decision Support (CogSIMA 2012), New Orleans, LA

Marsden, J. (2011) "Distributed Generation Systems: A New Paradigm for Sustainable Energy". Proceedings of the 2011 IEEE Green Technologies Conference, Baton Rouge, LA.

Marsden, J. (2011) "Determining the Role of Geospatial Technologies for Stigmergic Coordination in Situation Management". Proceedings of the International Multi-Disciplinary Conference on Cognitive Methods in Situation Management and Decision Support (CogSIMA 2011), Miami, FL.

Wilkinson, V., Marsden, J. (2009) "Tacit Knowing and Presentation: The Gateway to Complexity", Proceedings of 2009 IEEE PCS, Honolulu, HI.

Editor Reviewed Publications

"Policy Guide on Community and Regional Food Planning", American Planning Association Policy Guide, adopted April, 2007, with Pothukuchi, K. et al. Available online at: http://www.planning.org/policy/guides/adopted/food.htm

Venkatesh, M., Small, R., and Marsden, J. (2003) Learning-in-Community: Reflections on Practice, Springer (Kluwer PBI), 2003.

Refereed Conference Presentations

"Distributed Generation Systems: A New Paradigm for Sustainable Energy". 2011 IEEE Green Technologies Conference, Baton Rouge, LA, April 15, 2011.

"Distributed Generation Systems: A New Paradigm for Sustainable Energy". 15th Annual Joint A&WMA/AIHA Technical Conference, Skaneateles Falls, New York, March 16, 2011.

"Tacit Knowing and Presentation: The Gateway to Complexity", IEEE PCS, Honolulu, HI, 2009.

"The Japanese Approach to Sustainability: Community-based Waste Management and Waste-to-Energy", SUNY Canton Environmental Sustainability Task Force, 2006.

"Learning-In-Community: An Extended Model for Professional Information Technology Education", 2005 Annual Conference on Excellence in Teaching and Learning, Associated Colleges of the St Lawrence Valley.

Venkatesh, M., Small, R., Marsden, J. (1998) "The Education of IT Professionals: Integrating Experiential Learning and Community Service", Proceedings of the International Academy for Information Management, 1998 IAIM Conference, Helsinki.

REFEREED POSTER SESSIONS

"Determining the Role of Geospatial Technologies for Stigmergic Coordination in Situation Management". Cognitive Methods in Situation Management (CogSIMA) 2011.

"Using Maps for Virtual Collaboration: Implementing a Conceptual Framework for Visually Enabled Geocollaboration", iConference 2010.

"Using Maps for Virtual Collaboration: Implementing a Conceptual Framework for Visually Enabled Geocollaboration", Imagining America: Publicly Engaged Scholarship Conference 2010.

AWARDS AND GRANTS

Anna K. and Mary E. Cunningham Research Residency in New York State Culture: "Achieving energy sustainability through the examination of past energy technology practices at historic sites in New York State", 2008

INVENTION DISCLOSURES, WHITE PAPERS, REPORTS AND STANDARDS

"Intelligent Deployable Augmented Wireless Gateway (IDAWG)" (2013). Joe Treglia, Lee McKnight, Tamal Bose, Janet Marsden, et al. Syracuse University Office of Technology Transfer & Industrial Development.

"P2030.4 Draft Guide for Control and Automation Installations Applied to the Electric Power Infrastructure". (2013) Initiated December 2012. IEEE Standards Association Project CA4EPI. Working Group, Executive Committee, Metrics Task Force Chair. http://standards.ieee.org/develop/project/2030.4.html

"Workplace as a Service (WPaaS): Creating a secure cloud services delivery framework needed to support Bring Your Own Device (BYOD) applications". January 2013. Prepared by the Enterprise Cloud Leadership Council Working Group, TMForum, and Syracuse University Wireless Grid Lab.

"Open Specifications for Wireless Grids Technical Requirements Version 0.3". March, 2015. Prepared by Syracuse University, University of Arizona, Rochester Institute of Technology, Tufts University, and WiGiT partners.

"Open Specifications for Wireless Grids Technical Requirements Version 0.2". March, 2013. Prepared by Syracuse University, University of Arizona, Rochester Institute of Technology, Tufts University, and WiGiT partners.

"Open Specifications for Wireless Grids Technical Requirements Version 0.1". March, 2012. Prepared by Syracuse University, Virginia Tech, Rochester Institute of Technology, Tufts University, and WiGiT partners.

"Assessing and Validating Spatial Thinking Skills: Visual Literacy, Geospatial Technologies and STEM Education", 2010. Syracuse University School of Information Studies.

"Bachelor of Technology in Information Technology Program: 2+2 eLearning Proposal and Plan", 2010. SUNY Canton, School of Engineering, Department of Information Technology.

"Final Report on the Future of Online Education at Syracuse University's iSchool", 2009. Report on current and future strategies, pedagogies and technologies for online learning. School of Information Studies (iSchool) Task Force on Online Education.

Research Experience

SYRACUSE UNIVERSITY DEPARTMENT of CIVIL & ENVIRONMENTAL ENGINEERING 2014-present

NSF Urban Resilience to Extremes Research Network (URExSRN), Computation and Visualization Working Group, Dr David Chandler

Save the Rain Green Infrastructure Project, Dr David Chandler, Onondaga County, City of Syracuse.

SYRACUSE UNIVERSITY SCHOOL OF INFORMATION STUDIES 2008-2014

NSF Socially Intelligent Computing for Coding Qualitative Data, Dr Nancy McCracken

NSF Advance Project, Dr Marie Garland (LC Smith School of Engineering)

NSF RAILS: Rubric Assessment of Information Literacy Skills, Dr Megan Oakleaf

NSF VOSS: Virtual Organizations as Socio-technical Systems, Dr Derrick Cogburn

Skaneateles Lake Milfoil Eradication Project, Dr Chris Scholtz (Heroy Geology Lab, Syracuse University), Skaneateles Lake Association. Accessible at: http://www.skaneateleslake.org/milfoil/index.php

SUNY COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY (SUNY ESF) 2004-2008

Onondaga Creek Conceptual Revitalization Working Group, Dr Richard Smardon (ESF), Dr Edward Michalenko (Onondaga Environmental Institute). Downloadable at: http://www.oei2.org/OEIResources_OCRPDRAFT.html

Auburn, NY Housing Inventory GIS, Dr Lee Herrington (ESF), Steve Lynch, Director, City of Auburn, NY Planning Office

Teaching Experience

SYRACUSE UNIVERSITY SCHOOL OF INFORMATION STUDIES 2008-current

Introduction to Information-based Organizations (undergrad, classroom), Qualitative Research Methods (grad, online), Professional Issues in Information Management and Technology (undergrad, classroom), Mapping Syracuse (undergrad, classroom)

STATE UNIVERSITY OF NEW YORK AT CANTON, CANINO SCHOOL OF ENGINEERING, INFORMATION TECHNOLOGY DEPARTMENT: ASSISTANT PROFESSOR 2005-2010

Introduction to Information Technology (online & classroom)
LINUX Operating System (online & classroom)
Data Communications (online & classroom)
Systems Analysis and Design (online & classroom)
Database Concepts and Applications (online & classroom)
Data Communications and Network Technology (online & classroom)

Network Technology (online & classroom)
C++ Programming (classroom)
Systems Analysis for Engineers (online & classroom)
Technical Writing and Communication for Engineers (online & classroom)

STATE UNIVERSITY OF NEW YORK COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY: TEACHING ASSISTANT 2002-2005

Computer Applications (classroom)
Introduction to GIS (classroom)
Environmental Impact Analysis (classroom)

PROFESSIONAL EXPERIENCE

2008 Managing Editor, *AIS Transactions on Human-Computer Interaction* http://aisel.aisnet.org/thci/

2002 Project Manager, Data Warehouse, Alcan Aluminum, Scriba, NY

2000-2001 Manager of Projects, Office of Planning, Design and Construction, Environmental Health and Safety Division, Cornell University, Ithaca, NY

2000 Senior Consultant, Data Warehouse, Underwriting Department, Blue Cross/Blue Shield of Massachusetts, Boston, MA

1998-2000 Supervisor Environmental Protection, Nine Mile Point Nuclear Station, Scriba, NY

1995-1998 Systems Analyst III, Niagara Mohawk Power Corporation, Syracuse, NY

1985-1995 Senior Consultant, General Electric Consulting Services, Syracuse, NY

1984-1985 Programmer/Analyst, Hartford Insurance Group, Hartford, CT

1983-1984 Programmer/Analyst, City of Hartford Data Processing Center, Hartford, CT

1982-1983 Programmer/Technical Writer, Naval Underwater Systems Center (NUSC), Newport, RI

1980-1981 Programmer/Technical Writer, National Marine Fisheries Service, Narragansett, RI

TECHNOLOGY SKILLS

Languages: Basic, Fortran, Cobol, PL1, PHP, Assembly Language (IBM), SAS, SPSS, C, C++, HTML, R, Java, SQL, PowerBuilder

Operating Systems: Unix, Linux, Windows, Mac, IBM mainframe, Unisys, VMS

Databases: DMS, IMS, VSAM, ISAM, DB2, Sybase, Oracle, MS Access, MS SQL Server

Applications: ArcGIS, Adobe: Photoshop, Illustrator, Dreamweaver, Epic EMS

LICENSES AND CERTIFICATIONS

ISO 140001: Environmental Management Systems

ISO 9001: Quality Management Systems

Radiological Effluents and Offsite Dose Calculations

Radioactivity in the Environment: Risk, Assessment, and Management

RCRA/DOT Certification

USPS REDRESS Labor Relations Mediator

NYS Office of Court Administration Community Mediator

Adult CPR/AED & Standard First Aid

PADI & SSI Master Scuba Diver

YMCA Red Cross Water Safety Instructor

Teaching with Spatial Technology

PROFESSIONAL AFFILIATIONS

Metrics Task Force Chair, Executive Committee, IEEE Standards Association, Washington, DC: P2030.4 Guide for Control and Automation Installations Applied to the Electric Power Infrastructure Working Group.

President & Administrative Director: CNY Section, Upstate New York Chapter American Planning Association

Member: American Association for the Advancement of Science (**AAAS**), American Statistical Association (**ASA**), New York State Association for Reduction, Reuse and Recycling (**NYSAR^3**), Institute of Electrical and Electronics Engineers (**IEEE**), Association for Computing Machinery (**ACM**), Technology Alliance of Central New York (**TACNY**), New York State Geographic Information Systems Association (**NYSGISA**), Air & Waste Management Association (**AWMA**), Union of Concerned Scientists (**UCS**), Water Environments Federation (**WEF**), US Green Building Coalition (**USGBC**)

COMMUNITY SERVICE

Zoning Board of Appeals, Town of Victory, NY.

New York State Odyssey of the Mind, Syracuse, NY: Science competition for middle and high school students.

New York State Science and Engineering Fair, Syracuse, NY: Science and engineering competition for middle and high school students.

Environmental Challenge, Syracuse NY: 7th & 8th graders present environmental projects

Museum of Science and Technology, Syracuse, NY: Game Jam, STEM Career Fair.

Women's Opportunity Center, Syracuse, NY: teaching office technology to homemakers reentering the workforce

Girls Get IT, Syracuse, NY: informal STEM (science, technology, engineering and math) education program for disadvantaged middle school girls

Literacy Volunteers, Syracuse, NY: installing MS office and internet; staff training

PARCC, Syracuse University: Program for the Advancement of Research on Conflict and Collaboration

Center for Dispute Settlement, Rochester, NY: Community mediation