Communications and Technology Challenges to Situational Awareness: Insights from the CR16 Exercise

Hans Jochen Scholl
University of Washington
jscholl@uw.edu

Karyn Hubbell
University of Washington
karyn22@uw.edu

Jeffrey Gene Leonard
University of Washington
leonardj@uw.edu

ABSTRACT

Saving and sustaining lives, stabilizing the incident, and protecting both environment and property from further damage are professional responders' first and foremost objectives when responding to any incident including a catastrophic one. Responders need to gain situational awareness (SA) to effectively direct the response. Yet, in a catastrophic incident, critical infrastructures, including response assets, are damaged and disrupted, which leaves responders without the badly needed complete and verified information for days and even weeks. Critical communication and technology infrastructures used by responders are among those damaged and disrupted critical assets, leading to both incomplete SA and a distorted common operating picture (COP). The lack of clear and comprehensive SA/COP and the disruption of communications and technology infrastructures seriously impedes incident commanders from efficiently directing the response effort. This study reports on *communication and technology-related* challenges that emergency responders faced with regard to situational awareness in a recent large-scale exercise under the name of Cascadia Rising 2016 (CR16). The exercise involved a total of 23,000 active participants in the Northwestern United States. Over four days in June of 2016, CR16 simulated the coordinated response to a rupture of the 800-mile Cascadia Subduction Zone resulting in a magnitude-9 earthquake and tsunami similar to the catastrophic incident in Eastern Japan in 2011. Responders at all levels were severely challenged, and the exercise revealed major vulnerabilities in critical communication and technology infrastructures. Situational awareness was very difficult to establish. The study documents deficiencies of currently used information systems, showcases their lack of interoperability and their functional constraints, and makes recommendations for mitigating the shortcomings.

Keywords

Communication challenges, information technology challenges, information sharing challenges, WebEOC, radio technologies, training and preparedness challenges.

INTRODUCTION

Overview

This is one of two papers dedicated to the phenomenon of first responders' situational awareness in response to a simulated catastrophic incident also referred to as extreme event in the Pacific Northwest of the United States. While the other paper covers organizational and informational dimensions, this paper focuses on communications and technology-related aspects of situational awareness when responding to a catastrophic incident. Although these dimensions are necessarily intertwined in practice, the separate publications provide the space necessary for presenting important details, which would otherwise not be covered, while maintaining the dimensional connection.

Only as late as the end of the 1980s geologists and other experts began to discover and understand that the Pacific Northwest of the North American continent had been affected by magnitude 8 to 9.5 earthquakes (Atwater, et al., 1995; Goldfinger, et al., 1992; Rogers, et al., 1991; West and McCrumb, 1988) with some recurring regularity. These studies revealed with disturbing clarity and irrefutable evidence that megathrusts had occurred on average about every 350 years over the past eight millennia in this geography. Research was able to even provide the exact date and time of the most recent megathrust, which was given as January 26, 1700 at about 2100 hours local time

(Obermeier, 1995; Satake, et al., 2003), that is, about 318 years before the publication of this study.

Before the devastating March 2011 Tōhoku earthquake and tsunami in Japan (Chatfield, et al., 2014; Hatamura, 2012; Hatamura, 2011) the general public in the US/Canadian Pacific Northwest greatly ignored the grave threat. However, by contrast professional responders in the area considered the implications of the research insights and began with preparations in their respective jurisdictions without delay.

The Cascadia Rising 2016 Exercise

However, informed by the complexity and extent of the response to the East Japan catastrophe, which even stretched that country's national resources, the enormity of the challenge when responding to a megathrust was better understood. As a result the US Department of Homeland Security and its Homeland Infrastructure Threat and Risk Analysis Center commissioned a simulation study (the so-called HITRAC study) the same year, which estimated in great detail the potential impact of a magnitude-9 earthquake and tsunami on the Pacific Northwest as a result of a complete rupture in the Cascadia subduction zone (Anonymous, 2011). With the results of the HITRAC study in hand, the need for a major effort in planning and preparedness had become painfully clear to officials and professional responders alike. A year after the catastrophe in Japan, the local newspaper *Seattle Times* then alerted the public that for the "Puget Sound and the Pacific Coast, the basic earthquake question is when, not if" (Anonymous, 2012). The Cascadia Rising 2016 Exercise, which involved a total of 23,000 participants from responder agencies of all levels in three Federal States (Oregon, Washington, and Idaho), the FEMA Region X, as well as the Military, was the acknowledgement of both the urgency of the need to prepare and the severity of the threat (Anonymous, 2016).

As stated in a previous study, "[r]esponse efforts on this scale are extremely complex undertakings, and they require enormous managerial, operational, and tactical skills on part of the responders" (Scholl, et al., 2017, p 2498) A catastrophic incident of the scale, scope, and duration of a complete Cascadia Subduction Zone rupture has not been recorded in recent history. In January of 2015, under the auspices of Western Washington University's Resilience Institute, a detailed exercise scenario document was published on the basis of the HITRAC study and other sources (Paci-Green, et al., 2015), (see also https://huxley.wwu.edu/files/Cascadia_Rising_high_0.pdf, accessed May 17, 2015).

The zipper-like rupture from one end of the subduction line to the other is expected to occur along the 800-mile-long subduction line resulting in five to six minutes of violent shaking impacting areas up to 100 miles away. A 30 to 40-foot high tsunami would reach the coastline about 20 to 30 minutes after the rupture. Several aftershocks of significant magnitude would be expected to follow the initial rupture inflicting more damage on the already heavily compromised and impacted infrastructure. According to the aforementioned HITRAC study, once this particular incident unfolded, it would likely inflict a major toll in terms of human lives lost and humans severely injured; it would also destroy critical and non-critical infrastructure alike.

The impact on human lives and infrastructure would be the greater the closer the location to the coastline in the West ranging from severe damage throughout the so-called Interstate-5 corridor to almost total annihilation along the Western shorelines (see Figure 1). Power outages would be widespread and lasting up to a year, or even longer. The impacted areas West of the Cascadian Mountain range would be inaccessible by ground transport or sea transport for extended periods of time leaving the engulfed populations and the local responders to mainly their own means of support and response for up to two weeks.

Relief would first come predominantly by air transport. Responders would find themselves stripped from using most modern information and communication technologies for the lack of power and intact communication infrastructures. Sustained communication infrastructures such as satellite phones or amateur (also, HAM) radio would provide only relatively low bandwidths, particularly, in data communications. Low-tech technologies such as T cards and other paper-based methods would be the tools of necessity for an extended period of time. Responders' "situational awareness" as the basis of a shared "common operating picture" would be hard to establish for at least the first couple of weeks after the incident.

Figure 1 *Cascadia Rising 2016 Exercise – M9.0+ Megathrust Impact Assumptions (Paci-Green et. al, 2015, p. 14)*

The Study Environment

An earlier empirical study had shown in detail how accurate and reliable information was the "most important and most scarce resource in early disaster response" (Scholl, et al., 2017, p. 2498). The study's focus was the March 2014 SR530/Oso landslide in Washington State, which was declared a national disaster. Many, if not most, responders and agencies involved in the real response of 2014 participated in the CR16 exercise two years later. Quite a few responders who had been interviewed for the SR530/Oso landslide study were willing to be interviewed again after the CR16 exercise providing an excellent frame of reference. Other responders and exercise planners from several levels of government were also interviewed. Furthermore, along with the interview transcripts the study analyzed the after-action reports from over 20 responder agencies. The overall methodology, the theoretical framework, the interview instrument, and the ex-ante codebook, and other tools used for this study incorporated slight adaptations to those used in the earlier study.

The paper is organized as follows: First, the academic literature on situational awareness during incident responses is reviewed, followed by a presentation of the resulting research questions and the methodology section. Subsequently, the study findings are detailed, leading to the discussion of insights from the findings. At last, conclusions are drawn, and the directions for future research on the subject are sketched out.

LITERATURE REVIEW

Situational Awareness

The academic literature has highlighted the indispensable role of actionable and integrated information in disaster response (Endsley, 2015; Mendonça, et al., 2007; Scholl and Patin, 2014). Based on this particular type of information, (individual) situational awareness (SA) leading to shared (group or team) situational awareness (SSA) can effectively be developed among responders, which then serves as a prerequisite for generating and maintaining a shared common operating picture (COP) (Endsley, 2015; Endsley, 1995; Harrald and Jefferson, 2007; Scholl and Patin, 2014). Both SA/SSA and a shared COP are foundational to any mission and any well-directed and effective response (Harrald, 2006). Interestingly, despite their extraordinary importance to the success of response and early recovery, systematic study of SA and SSA did not advance in Disaster Science first. It rather unfolded in other academic fields such as Behavioral Science, Human Factors Research, and Safety Sciences, particularly, in the context of the military, far earlier and much faster than in the study of disasters.

As an example, Endsley presented a comprehensive SA framework, in which she distinguished (1) perception, (2) comprehension, and (3) projection as three intertwined levels of SA (Endsley, 1995). The Endsley framework, which was first developed in the context of military combat aviation, has been found the most influential theoretical contribution to the understanding of SA and SSA (Salmon, 2016). The framework, however, despite its popularity and wide acceptance has been criticized for its alleged linearity, its lack of accounting for inter-level feedback relationships as well as for an unclear distinction between SA product(s) and SA process(es) (Salmon, 2016; Stanton, et al., 2001; Stanton, et al., 2015; Uhlarik and Comerford, 2002). In a detailed rejoinder Endsley refuted these criticisms as mainly misunderstandings and misconceptions (Endsley, 2015).

Critics of Endsley's approach to SA and SSA have proposed the concept of "Distributed Situation Awareness" (DSA) as an alternative (Stanton, et al., 2015; Stanton, et al., 2006), which claimed to employ a so-called system-theoretical perspective. "DSA is considered to be activated knowledge for a specific task within a system at a specific time by specific agents, that is, the human and nonhuman actors in a system" (Stanton, et al., 2015, p. 47). The inclusion of technology or information artifacts into the DSA framework as nonhuman "actors" has drawn serious criticism itself (Endsley, 2015). In DSA, nonhuman "actors" have been portrayed as triggering and informing each other, thus, along with human actors, representing the activated knowledge within the network; however, as Endsley pointed out, it would still always need a human actor to notice, interpret, and comprehend the technology alert, or the interaction, to make it an instance of SA. In terms of DSA it has also remained unclear, what exactly the "system" is, and what its identifiable system boundaries might be. In other words, no clear system definition has been found regarding what is considered part of or element inside the system, and what is not.

As pointed out before, in Disaster Sciences the notion of and discussion about SA/SSA was informed and influenced by advances in other disciplines, which over time have mainly adopted the Endsley framework (Harrald and Jefferson, 2007; Luokkala and Virrantaus, 2014; Seppänen, et al., 2013; Seppänen and Virrantaus, 2015; Son, et al., 2008). However, upon reviewing government documents on the subject as to when professional responders had gained "full" SSA in the early stages of a response to a major incident, the point in time when SSA was fully established appears to be somewhat in the eye of the beholder. For example, an official commission report on the response to a recent landslide disaster in Washington State claimed that SA was established after "several hours" (Lombardo, et al., 2014), while other documentation on the same incident stated that, in fact, SA was not fully established for "several days" (Scholl, et al., 2017). This substantial discrepancy in views ("hours" versus "days") demonstrates that what establishes, or what "is," situation awareness is still not well enough articulated. While the commission report might correctly refer to the SSA level of "perception," which was assumed after "hours," the other official documentation undoubtedly refers to the SSA level of "comprehension," also indicated by readjustments in the response mentioned in the document, which indeed took several "days."

In other words, research needs to address in more detail, which level of SSA is investigated, and how the three levels of SSA transition from one another (including feedback), which may, for example, include granular computational approaches (Loia, et al., 2016). A recent experimental study found evidence that "enriched" information, that is, summarized information rather than providing raw data, enhanced responders' SSA, and hence, would improve the effectiveness of a response (Van de Walle, et al., 2016).

Information Systems in Disaster Response

In general, modern information and communication technologies (ICTs) have been playing increasingly important roles in disaster response management (Hiltz, et al., 2014; Van De Walle, et al., 2014), and in particular, for assuming SSA (Betts, et al., 2005; Harrald and Jefferson, 2007; Luokkala and Virrantaus, 2014; Salerno, et al., 2003; Scholl, et al., 2017; Scholl and Chatfield, 2014; Son, et al., 2008), although with the progressive proliferation of ICTs new vulnerabilities, complications, and dependencies were also introduced (Quarantelli, 1997).

The requirements and design principles for so-called crisis information management systems (CMIS), also referred to as emergency management systems (EMIS), which are used in emergency operations centers (EOCs) and by incident management teams (IMTs), were analyzed in a comprehensive study and laid out in great detail (Turoff, et al., 2004). Among others the requirements included extreme ease of learning, usability by trained responders, conciseness, customizability to responders' specific needs, support for all EOC/IMT functions, independence from a particular physical location, and support for structured communication processes (p. 12). Real-time resource requesting and resource tracking were identified as other major functional features of any CMIS, which had also to be able to effectively pass on incident-relevant situational information between responder shifts (Henricksen and Iannella, 2010). With regard to SSA and COP, CMIS were also chartered with mitigating information overload, which would be facilitated by increased automation helping filter out and adequately represent decision-relevant information (Carver and Turoff, 2007).

In an account describing the practical experience with an operational CMIS during a County-wide snowstorm response, the researchers found that with certain limitations the system supported responders' coordinated decision making along the interpersonal and process dimensions (Chen, et al., 2014). However, they also surfaced a number of shortcomings in the use, usability, and control of the CMIS relative to the tasks at hand. At County level, due to insufficient information sharing on part of municipalities, SSA was incomplete, leading to suboptimal response and resource allocations (Chen, et al., 2014). Reflecting on the disruptive nature of large-scale incidents, other authors have called for flexible and adaptively interoperable CMIS that support more readily improvisation and adhocracy in disaster responses (Mendonça, et al., 2001; Mendonça, et al., 2007). Furthermore, in a study of the aforementioned March 2011 Tōhoku earthquake and tsunami in Japan, the development of "frugal" CMIS, which would incorporate the use of a range of extant devices such as personal systems and private smart phones, for accomplishing simple tasks in organizing the response (Sakurai, et al., 2014).

According to Fischer, emergencies can be categorized on a 1-10 scale from 1 equaling an everyday emergency (like a single home burning) to 9 equaling a catastrophe (like the 2011 Tōhoku earthquake and tsunami) and 10 equaling (total) annihilation (of a whole society) (Fischer, 2003). Against the backdrop of this wide range of emergencies, effective CMIS not only have to provide for improvisation and adhocracy but also for tremendous scalability, recoverability, and interoperability, which leads to the research questions presented next.

RESEARCH QUESTIONS

Given the response to a simulated category-9 catastrophe of the Cascadia Rising 2016 exercise:

Research Question #1 (RQ#1):

What are specific SA/SSA-related *communications challenges* to professional disaster responders on all levels in the early stages of response to a (simulated) catastrophe?

Research Question #2 (RQ#2):

What are specific SA/SSA-related *information and communication technology (ICT) challenges* to professional disaster responders on all levels in the early stages of response to a (simulated) catastrophe?

METHODOLOGY

Theoretical Lens

This study implements the so-called "information perspective." At its core this perspective is human actor and human action-centric, and it views information and communication technologies (ICTs) as facilitators of human information needs, information behaviors, and information flows. Human actors' (here: responders') information behavior and the information flows between them depend on so-called information infrastructures, which encompass formal and informal, organizational, technological, and social elements among others (Scholl and Chatfield, 2014; Scholl and Patin, 2014). In disaster management, when looking at the technological elements, ICTs as part of the information infrastructures have assumed important roles (Chua, et al., 2007; Kapucu, 2006) by providing high-quality, mission-critical, timely, and actionable information to responders in typically fast and dynamically changing environments (Kapucu, 2006; Kapucu, et al., 2010; Turoff, 2007)). On the downside, ICTs have also been found contributing to information overload, work overload, and other stressors to responders in disaster responses (Endsley, 2015). The information perspective allows a detailed investigation of actions and interactions of responders as they are mediated via the existing and emerging information infrastructures and their various elements.

Instrument and Coding Scheme

Based on the theoretical lens, that is, the conceptual framework of resilient information infrastructures (RIIs) (Scholl and Patin, 2014) a semi-structured interview protocol was devised upfront, which covered five topical areas of (1) management and organization, (2) technology, (3) information, (4) information infrastructure, and (5) RIIs/resiliency. The instrument administered was a shortened and adjusted version of the instrument used in a previous study (Scholl, et al., 2017; Scholl and Carnes, 2017). A total of twenty-five interview questions plus respective probes were incorporated.

Sample

The sample was purposive (Ritchie, et al., 2003) and included responders from eight different groups: the (1) City Emergency Operations Centers, (2) County Emergency Operations Centers, (3) Washington State Emergency Management Division, (4) WA State Agencies, (5) Health Districts, (6) Regional Aviation, (7) Washington State National Guard, and (8) Federal Emergency Management Agency (FEMA), region X. A total of seventeen individuals were interviewed. Furthermore, after-action reports (AARs) from twenty-three agencies from all eight responder groups were collected and analyzed.

Data Collection

Interviews were conducted in person between September 2016 and March 2017 and lasted between 33 to 107 minutes. Two interviews were conducted via Skype video conferencing. All interviews were audio taped, transcribed, and coded for analysis by at least two coders. During the interview notes were also taken, and participant interaction was observed and recorded. Moreover, besides the 23 after-action reports other documents such as press interviews were collected, reviewed, and coded as appropriate.

Data Analysis and Coding

The initial codebook, which was based on the aforementioned conceptual RII framework, contained six category codes (one for each topical area) and 141 sub-category codes. Additional codes were inductively introduced during data collection, in individual coding sessions, and inter-coder sessions (Glaser, 1999; Glaser and Strauss, 1967; Strauss and Corbin, 1998; Urquhart, et al., 2010). Since a codebook in a hybrid approach of deductive and inductive analyses (Fereday and Muir-Cochrane, 2006) is designed to be open to extension, it ultimately encompassed 176 sub-category codes in the six main categories.

At least two researchers coded each transcript and document by means of a cloud-based software tool for qualitative and mixed-method data analyses (Dedoose main versions 7 and 8, dedoose.com). The coded data were compared one by one and demonstrated high inter-coder reliability.

When analyzing the code frequency table, the highest counts of code applications were found in the areas of "management and organization" (2,763), "information" (1,705), and "technology" (1,111). For the purpose of the specific analysis on situational awareness-related information needs, information behaviors, and information flows the code intersection represented by the sub-codes of "situational awareness," "address challenges of information sharing," and "use of information and communication technologies for information sharing" was selected, which produced 1,558 excerpts.

For the most part, these excerpts were between two and three paragraphs in length. They were clustered by responder teams and then analyzed for emerging concepts in a grounded fashion. Recurring concepts and main themes were identified and labeled through keywords and key phrases. All excerpt clusters were concept-analyzed by at least two analysts, in most cases by three analysts, as well as by the principal investigator. The coded concepts were checked for inter-analyst validity and a convergence of interpretation was found. Converging concepts were identified and transferred to the "canvas" of a cloud-based mapping tool (CMAP, version 6.03). After reconciling the remaining inter-analyst discrepancies in interpretation as much as appropriate, the reconciled concepts were also transferred to the canvas. The concept clusters were inspected and sorted into topical "bins" or "buckets," in which chronological, logical, and other non-causal relationships were identified. Whenever evidence from the data supported it, relationship links between concepts were established, which were not interpreted as causal links.

Research Team and Processes

The research team consisted of the principal investigator (PI) and thirty-two research assistants (RAs), both for-credit and voluntary. The PI and RAs worked individually and in small teams to transcribe, code, and conceptually/contextually analyze, and map the concepts. The research team met weekly in person or online and communicated via the research project site and the project listserv as well as via individual face-to-face and group meetings. All weekly meetings were streamed and recorded, which kept the whole research team in sync over extended periods of time.

FINDINGS

Ad Research Question #1 *(What are specific SA/SSA-related communications challenges to professional disaster responders on all levels in the early stages of response to a (simulated) catastrophe?)*

The Partial or Total Loss of Electrical Power for an Extended Period of Time

Although not completely simulated during the four days of exercise to the extent, which this particular kind of catastrophe would most certainly impose in reality, almost all jurisdictions and levels of response investigated in this study were painfully aware of potential effects of a partial or complete loss of electrical power leading to serious delays to their respective response efforts.

The electrical grid in the Northern American Pacific Northwest (PNW) was not built under the assumption that it had to withstand major seismic shocks. The grid employs a mainly hierarchical structure, in which generating plants distribute high-voltage loads to substations, in which transformers convert the received load to lower voltages. From the substations with their delicate and relatively frail equipment, electrical power is redistributed to businesses, government facilities, hospitals, and residential homes among other recipients. In this architecture, the electrical capacity load has to always remain in balance between production and consumption. This critical infrastructure is particularly vulnerable if multiple substations are destroyed. In case of a megathrust in Cascadia Subduction Zone, more than 50 percent of electric facilities are expected to undergo serious and irreparable damage, resulting in power outages for the entire Cascadia region (Paci-Green, et al., 2015) for up to 12 months, or even longer. Even intact structures will most likely shut down due to capacity imbalances and overloads. Many response units will be able to continue operations for a limited period of time by means of fuel-operated electric power generators or other back-up systems. However, these sources of electric power will possibly be exhausted before replacement fuel arrives. As a consequence, response activities will significantly slow down. Along with the power outage come phone and communication network blackouts including the loss of Internet connectivity. Satellite phone connections, in-area radio communications including amateur HAM radio communications, as well as cellular networks might continue to operate for a limited period of time with low bandwidths until their respective power backups go down as well. With the Internet, cellular networks, and phone landlines down, communications will return to pre-industrial means with pencils, paper, daylight operations, and runners.

As a National Guard Commander puts it,

> "With alternate power sources you can plan to fuel generators to allow you to have more power. But then, power only gets you so far, it gets you lights. You have to have the connectivity, right? And that's the next big challenges, and how do you do that?" (quote #01)

And a City EOC director observes,

> "Information technology can also be crippling in the more that we become dependent on absolutely everything on an app or a system or something like that, the catastrophe will interfere with that and interrupt, and then what's your back-up?" (quote #02)

Another responder adds,

> "There's also a website that we have from the health department, where we can monitor, and I have access to that. But again, it's electronic. And if the power's not going, and when the services are not

> working, I can log on all day and get no information." (quote #03)

With the widespread loss of electrical power responders' ICT infrastructure will be unavailable for a considerable amount of time. As long as cellular networks are still available, or, once they slowly return to service during recovery, they will suffer from heavy traffic congestion. Some municipalities, the counties, as well as Washington State and Oregon have therefore joined in the effort of building and maintaining an independent responder-reserved cellular infrastructure, which as long as it remains operational, will provide a backbone infrastructure for responder voice and text communications. However, as expected by responders at County levels, the bandwidths even in this scenario might be so low, so that text messaging would be the preferred format of utilization. Whatever combination of pre-industrial and low-bandwidth voice/text communication methods will be predominantly used within the first couple of weeks after the incident, as a result of responders' inability to communicate laterally and vertically in any rapid and comprehensive fashion, situational awareness even at its lowest level (perception) will be very slow in coming for all responder groups.

One-to-Many Bottlenecks and the Importance of Embedded Liaison Officers

With most of the communication means unavailable or heavily degraded, it will be difficult for counties, the States of Washington and Oregon, as well as FEMA region X to establish and maintain situational awareness and develop a common operating picture, at least in the early response. During the exercise, although only partial and temporary losses of power and connectivity were simulated, municipalities reported that at times they were unable to establish even phone contact with counties, and counties as well as large cities were frequently unable to reach the WA State EOC (SEOC). One municipality responder describes the situation,

> "There was no information coming from the county to us. And the State, and I know the people at the State, and if I don't get information from them, I know the numbers to go, and I'm like "hey, you know, we're kind of sort of still alive. What's going on?" (quote #04)

Echoing the remark from the other end, Washington State's after-action report states,

> "In the exercise, peak participation was reached on the second and third day with over 15 counties communicating and coordinating with the SEOC and attempting to join the local jurisdictional conference call. The ability of the SEOC to collect and process information and act on it was overwhelmed." (quote #05)

Likewise, at the Federal level, FEMA region X was inundated by massive amounts of messages and raw data, which were difficult to cope with. As a FEMA director outlines,

> "How do we sort it all out? And I'm sure we're going to get into this here in a little bit, the profession has not solved this problem. You look at some organizations like law enforcement is a good one, they have a way to be able to take information in, and they get thousands of calls, you know, or hundreds of calls in a day, they have the ability to take that in real time emergencies, sort it out, be able to catalog it, and still be able to do follow-throughs as they are supposed to. And in an event like this it's so overwhelming, it's coming so quickly, we don't have the systems in place to be able to take the information in, categorize it, do the analysis, and then get it to the key leaders who have to be able to make decisions within a timely fashion. It's just, it's impossible to do." (quote #06)

Similar to the military, the problem of overcoming communication bottlenecks and coordination barriers has been addressed in responder circles for some time by deploying and embedding so-called liaison officers (LNOs) in each other's organizations. While the deployment in the real case might need to overcome certain transportation obstacles, during the exercise LNOs were able to help resolve numerous information sharing and resource-requesting/tracking problems among others. LNOs were also found effective in accommodating response units from outside the region. In particular, military LNOs embedded in EOCs and ECCs were able to make connections and provide resource-related knowledge, which would have otherwise remained unknown and unrequested. LNOs work most effectively with their target unit, when rank, expertise, and standing in their own organization provides them with clout and sufficient authority.

As one City EOC director put it,

> "So, I go to my liaison and say, 'reach back to your specific entity, and get that, make sure that it's vetted.' I always ask specifically, if you send me somebody to work in the EOC, it has to be somebody that has the knowledge and then the ability and the authority to make a decision. Don't be a secretary, that's gonna say, nothing against secretary, but that's gonna say, ok, let me make three more phone calls to figure out if this is true, or if I can say that, or if I can do that." (quote #07)

As stated before, directly after the incident the transport of LNOs to their destinations, that is, their physical deployment, might pose a tricky problem in itself. Also, the sheer number of personnel who would meet the above outlined criteria and are needed to fill all desirable LNO positions at County ECCs and City EOCs might exceed the respective sending organization's pool of candidates.

Pre-generated Procedures, Plans, Forms, Messages and Paper Redundancy

Unsurprisingly, the exercise revealed that jurisdictions that had engaged in ex-ante scenario planning were better off handling the situation. They had already prepared response plans and tools, which included detailed lists of contacts and resources along with detailed forms for requesting and collecting specific information, for example, for assessing damage of critical infrastructures. In anticipation of public communication EOCs had also pre-scripted public messages. These plans and tools helped bring some order into the chaos and curtail the information overload, although some of these tools had not been updated for some time, or they were new and difficult to navigate, rendering them less valuable.

As one County EOC director critically reflects in hindsight,

> "Some of that was definitely lessons learned in pre-planning. Some of the messaging, so pre-planning some of the scripts for some of the basic information getting out, it would be beneficial. There is a lot of that that could be pre-staged, and so you kind of have a menu and you say, we need to use this one and fill in a couple of blanks and it's ready to go. As opposed to trying to rewrite it every time." (quote #08)

Other response units had developed plans and put tools in place; however, these plans and tools were so infrequently reviewed or updated, that they had fallen into oblivion, and instead of using the existing ones, the units redeveloped and redeployed them in a time-consuming fashion during the response. As the case illustrates, even if these plans and tools were pre-generated, they would remain in need of regular maintenance and review, as one City after-action report remarks,

> "Many departments resources (plans, maps, contact lists, etc.) are very out-of-date. There is a lack of education within and between departments as to what resources are available, and who is responsible for maintaining them." (quote #09)

With the aforementioned specter of losing power for an extended period of time along all the unpleasant ramifications in regard to attaining situational awareness and targeting the overall response effort, these plans, maps, lists, and other tools cannot be just developed and stored away electronically. Rather paper-based versions need to be created, which not only have to be distributed in multiple copies, but also require the same regular updating as the electronic versions, which epitomizes yet another laborious but priceless undertaking for better preparedness. As the after-action report of one State agency concludes,

> "It was identified that all EOCs need to have ability to do everything without electronics, meaning that all plans, policies, reference manuals, and forms used during an EOC activation need to be available in hard copies within each WSDOT EOC." (quote #10)

In summary, under the assumption of the likely enduring loss of power in the entire Pacific Northwest region in the event of a megathrust and tsunami originating from the Cascadia Subduction Zone, modern time-style communications and ICT-based operations will be curtailed to an insignificant minimum, based on which a coordinated response from inside the affected geography cannot be assumed to be effectively organizable. While power as a prerequisite will be restored in small increments over time, initial in-area response management at all levels has to assume mainly paper-based and (slow) face-to-face and messenger-based communication mechanisms, which will last for a duration of days, if not, more likely, weeks. As a result, situational awareness will initially be spotty, and a common operating picture will only emerge slowly leading to a harshly constrained response environment.

Ad Research Question #2 *(What are specific SA/SSA-related information and communication technology (ICT) challenges to professional disaster responders on all levels in the early stages of response to a (simulated) catastrophe?)*

While the widespread blackout described above will immediately knock out most of the terrestrial wired network and server infrastructures, wireless devices such as handheld radios, satellite phones, and cell phones along with other wired or wireless battery and generator-powered communication devices including undamaged cell towers will initially still remain operable. Nonetheless, over time they will become unavailable as batteries turn dead and fuels run out. However, this way a precious initial window of much degraded communication and bandwidth will remain open before most electrically-powered communication and ICT infrastructures gradually dwindle and finally cease to function. In the following, the findings are presented regarding the challenges to ICTs and radio technologies as long as they are still usable in the initial grace period, and after they step by step return to operability when power is being restored.

Lack of Standardization, Information Integration, Compatibility, and Interoperability

The response units in the Cascadia Rising 2016 exercise used a range of different ICTs, which performed the same or similar tasks, but in different ways and on the basis of different protocols. Also, multiple media and data formats were in use, and the transformation or conversion from one format into another presented a challenge. For example, transferring information from a geographical information system (GIS) into a spreadsheet had to be performed manually, which introduced another potential source of error. On the other hand, several jurisdictions benefitted from the integration of GIS functionality into the respective incident management system, for example, the relatively popular, Internet-based, commercial off-the-shelf (COTS) system by name of WebEOC, although data might not have been readily updated between systems. As one City after-action report reveals,

> "Information was scattered in different reports from different departments. Those department reports were in various formats including Word, Excel, and hard copy formats. Picking through the reports and then entering the data took time and took talented people away from other priorities. The question is whether aspects of the information collection from departments could be automated and if so, to what extent that could be done in WebEOC. The exercise illustrated the challenges of incorporating department level damage assessment information into a single platform (WebEOC) or trying to leverage a geographic information system, such as ArcGIS Online. Part of that issue also includes how to display mapped features." (quote #11)

The same situation reoccurred at response levels up the chain unless certain organizational and technical standardizing measures had been taken. The WA State Emergency Management Division (EMD) has meanwhile developed a so-called Incident Snapshot form, which helps counties report back the overall damage without before completing a detailed analysis. As an WA EMD director explains,

> "They can just provide us with that Incident Snapshot and then we can basically consolidate that information and analyze it and then make the determination that, for example, communication infrastructure was hardest hit in these counties, transportation infrastructure was mostly impacted in these counties, but not in these counties, so just being able to do this Incident Snapshot prior to having in depth damage assessment. So that is an approach of developing and providing tools to the local jurisdictions that allows them to do this fairly quickly in a standardized format." (quote #12)

The lack of standardization of protocols and message exchange formats within jurisdictions and between jurisdictions led to delays in assuming SA/SSA and unnecessarily added another level of complexity to the already complex response undertaking. Besides the missing standardization of protocols and exchange formats, the wide variety of systems used on all levels of the response also led to limitations of basic interoperability up to the point, at which certain systems could not interoperate at all. As the FEMA after-action report describes,

> "These systems provided a wealth of functionality to support responders' missions. However, different versions, configurations, and implementations of these systems introduced varying functionality, a lack of compatibility, and different interfaces for the user, all of which lead to varying representations of incidents, tasks, resource requests, and related data. As a result, the exchange of information between systems of different versions and functionality became a cumbersome task." (quote #13)

Access, Functionality, and Other ICT-related Considerations

Quite a number of interviewees reported on serious problems with regard to accessing ICTs in use for organizing the response and obtaining much needed information. Some systems would not allow responders to log on at all even though authorization should have been established ex-ante. Others ended up logging on to the wrong systems. Yet, others were able to log on to the correct systems but were then barred from accessing any documents in the directory structure pertaining to their respective tasks. Or, the necessary GIS applications were not available on laptop systems, which prevented access to most up-to-date information. The list of access problems of different nature ranging from technical and connectivity issues to organizational and security problems could be extended; however, the result would always be a significant slowdown in response processes and activities including negative impacts on gaining SA/SSA. At times, the National Guard was able to provide a workaround by providing access to information, which the local civilian responders were unable to obtain from their own systems, even when the information was stored, but for some reason inaccessible on their very systems. However, besides the internal access problem, the important role of the military in disaster responses and the need for establishing working relationships between local responders and the military prior to any incidents have become abundantly clear through the recent 2014 SR530/Oso disaster and the CR16 exercise. As a City EOC responder discloses,

> "We came a long way to partnering with the military. Any large disaster response will be going to need them. But there is still a disconnect with that information sharing. It is just how they are normally used to share information. Normally the military doesn't share information with the local government, the local state. So, they are trying to figure out those things. So, on that way, this exercise was really great." (quote #14)

As mentioned before, information exchange between systems could present a functional challenge to responders, but so could system functionality itself in terms of a difficult-to-navigate user interface or cumbersome logic of operation. Also, electronic forms could be difficult to navigate. As a City after-action report laconically illustrates,

> "The Situation Report form is cumbersome and difficult to navigate. Not all essential elements of information were included in the situation reports."

Other ICT-related problems were reported with regard to insufficient scalability of ICTs given the enormity of the response effort, the lack of quantity of ICT equipment, phones of all kinds, and wireless bandwidth to adequately support responders, and the dearth of familiarity with the respective ICTs and radios among others.

WebEOC

As mentioned above, many response organizations in the PNW used one version or another of a Javascript-based COTS software application called WebEOC, as of 2018 a registered trademark of and licensed by Juvare of Atlanta, GA. As the name indicates, the application is Web-based and can be run on local servers and/or in the Cloud. During the Cascadia Rising 2016 Exercise WebEOC versions 7.3, 7.6, and 8.1 with an enhanced graphical user interface were in use. Among the WebEOC users were FEMA, Washington State agencies along with the State EMD, a number of County EOCs, as well as a number of City EOCs. However, quite a number of County and City response units relied on other incident documentation and resource tracking tools.

Functional Rigidities and Limitations

Almost all WebEOC users, regardless of the tool's version used, pointed at functional rigidities and limitations that influenced the response in one way or the other. Since the application is not self-explicatory nor intuitive to use in any way, quite some extensive training is necessary to be able to effectively handle and use it. Furthermore, since most responders in the EOC will not use WebEOC on a daily basis, training and re-training has to be conducted on a regular basis. Among the most serious functional deficiencies that were repeatedly mentioned was the lack of integration of GIS metadata from the popular ArcGIS software (which most recent versions appear to provide). As a City EOC director explains,

> "WebEOC training was absolutely critical, and still, we had some challenges not only with WebEOC but also in particular with the integration with other systems like GIS, as you remember, where we put the damage reporting and some of the data and GIS and needed to import them into WebEOC, and here are some of those points that we want to pay attention to, and then on top of that comes ... if things break down, that becomes even more tricky." (quote #15)

While the application readily logged all inputs into the system, it provided little sophisticated tracking =or data manipulation methods like sorting certain data. The application uses multiple boards such as "status update," "significant events," "task manager," among others along with user-generated ones. Some users found it hard to manually update boards as necessary. Furthermore, it was said that information was not easy to find on the various boards. As a State EMD director states,

> "And that was the origin of WebEOC in that it would basically allow you to chronologically track events. But, that in itself is not helpful in sharing information, sharing situational awareness, or sharing a common operating picture, because I do not want to have to read through a thread of 200 events from the previous shift to get an idea of what the current situation is." (quote #16)

Quite a number of users felt the user interface was cumbersome, and the visualization capabilities were insufficient. Boards, it was said, were hard to read and comprehend. For the lack of truly functional resource request and resource tracking capabilities one responder group used a different system for that particular purpose. If information needed to be extracted for further processing elsewhere from one of the boards, this task needed to be performed in a manual fashion. Some organizations reduplicated WebEOC-based data in spreadsheets for both redundancy and data processing reasons.

Interoperability Issues, Performance Issues, and Workarounds

Across responder groups WebEOC was reported for having capacity and performance problems, the latter of which might in part be related to the internal software design with its use of Javascript. Different versions of WebEOC appear to not have been able to interoperate at all. The customizability of the application might have added to inconsistencies and incompatibilities when used within a large-scale response too. However, responders also wondered how scalable the application really was. The State WebEOC system crashed under the load and appeared to have been unavailable for an extended period of time. Responders held that they were unsure about where and when the load-breaking point would occur. As another City EOC leader asserts,

> "Our biggest challenge, I think, is that our technologies are built for the 95% of the time response that we have. And so, those forty-four times we activated in the last ten years, none of those were actually

> catastrophic. None of those actually destroyed our ability to use WebEOC, or I guess we had one that started tampering with our ability to get to the Internet. But generally, our systems have been built for more the rearview-mirror type of disasters, more than for the futuristic, what's actually going to happen to us." (quote #17)

Since interoperability between WebEOC systems in different jurisdictions did not work well, or even not at all, responders found a workaround in providing each other direct access to their respective systems. So, cities would have accounts on county WebEOC systems, and vice versa, counties would have accounts on the State EMD WebEOC systems, and vice versa, and so on. While this workaround at least provides access to information, it also attests the lack of integration and interoperability of WebEOC. Operating with multiple systems in the tumultuous environment of a catastrophic incident response adds potential for error, reduplication, inconsistency, and increased network traffic on already downgraded network connection. As the FEMA after-action reports tersely states,

> "Exercise participants recommended that all jurisdictions consider extending access to their information management and collaboration systems to external partners as needed, while ensuring the appropriate moderation and maintenance required to sustain any increased access." (quote #18)

In summary, quite many participating jurisdictions in the exercise used WebEOC for assuming SA/SSA and the development of a COP among other aspects of the response such as resource requesting and tracking and task management. However, during this admittedly extreme test the system's rigidities, limitations, and other issues noticeably surfaced.

Radio Technologies

Traditional High-Frequency Radio Communications and the Lack of Radio Interoperability

Radio-based communications have been primary means of responder interaction and coordination, in particular, in a catastrophic event such as the one simulated in Cascadia Rising 2016. As long as electrical power is available on handheld and stationary devices as well as for the mobile and fixed high-frequency (HF) stations, basic communications between responders on compatible frequencies and equipment remain intact. However, for example, the 800 MHz Public Radio System used by responders in municipalities and counties was quickly overwhelmed, and voice and data transmission suffered from bandwidths problems. The use of HF radio in a multi-agency and multi-jurisdictional response faces also challenges with regard to channel allocation and radio interoperability. During the exercise, the military assisted local jurisdictions with allocating available frequencies and multiple channels for communications with the field and the County. Radio interoperability, however, requires both frequency or equipment compatibility. Even when operating on the same frequencies, different agencies used incompatible radios, so that interoperability remained a major problem until both frequency/channel allocation and equipment compatibility via standardization have been secured. As one City EOC responder remarks,

> "Since 9/11, we know that agencies cannot talk to each other *over the radio* <insertion by the authors>. And that has not been resolved, either. So, we spent a lot of money, federal government spent a lot of money but agencies do still not have the ability to talk to each other on the same radio system." (quote #19)

Besides the described interoperability and bandwidth problems, quite a few responders on municipality and County levels reported that the number of available radios and channels was insufficient and no alternate means of communication available.

Alternate and Auxiliary Communications

Several alternate (backup) and auxiliary means of communications were used during the exercise. For example, the State of Washington, maintains stationary HF stations at the SEOC and at all State Patrol district communication centers with eight assigned HF frequencies as secondary emergency back-up communications capability in case primary communication capabilities become seriously degraded or completely unavailable. In this backup infrastructure, in addition to the fixed infrastructure, mobile HF stations can be deployed as necessary. However, bandwidth problems and equipment incompatibilities can also hamper this backup infrastructure.

Satellite phones were used as another alternative to radio and other communications means. While satellite phones share the basic problem of ultimately needing a source of power, they nevertheless provide a low-to-medium bandwidth voice and data alternative to other communication infrastructures including HF radios. Similar to radios, satellite phones need unobstructed lines of sight for their signals to receive and transmit to the respective service satellites. Responders reported that connectivity from within buildings was difficult or even completely impossible. Also, thick cloud covers could impair this particular backup. Quite a few responders bemoaned the lack of a sufficient number of available satellite phones. However, cost considerations were cited as the main reason for only moderately relying on this particular backup type in the respective jurisdictions.

Amateur (or, HAM) radio was incorporated into the Cascadia Rising 2016 Exercise at municipal, county, State, and Federal levels as an auxiliary communication infrastructure, which served in part also as an important backup for other degraded or failed infrastructures. Uses included the transmission of essential elements of information (EEIs) both via voice as well as text and graphics, which helped gain SA/SSA despite the slow transmission speeds for the latter. HAM communications also provided information about areas, which were inaccessible on the ground. HAM operators, though, were found verbose and not trained in crisp emergency radio communication protocols. Overall, wherever HAM radio communication was used, it was found helpful, although specific protocols for HAM operations in the emergency response context were needed for future operations. Likewise, HAM operators would need training in professional emergency-related radio communications. Nevertheless, quite some optimistic comments from responders summarized the experiences made with amateur radio during the exercise. Yet, on a more cautionary tale, a State EMD director finds,

> "So, amateur radio equipment also uses power. So, this is only going to work as long as my batteries work. Then, once the batteries are dead, I'm dead in the water as well. Then, all of the antennas with my amateur radio—towers with amateur radio antennas—if the earthquake topples the tower, my antenna's toast as well. And then, the other thing—the big thing that I keep mentioning—there is no way the amateur radio community can backfill the bandwidth that we are used to using on a daily basis to communicate. So, while amateur radio may be the very first band aid that we apply, we, as quickly as possible, want to get back to reestablishing the communication infrastructure that we are used to using on a daily basis." (quote #20)

In summary, radio technologies (along with operational modern ICTs) provide the backbone of disaster response communications and operations, which are complemented by satellite phones and amateur radios as auxiliary means of communication in the response to a catastrophic disaster, all of which provide essential inputs for gaining and maintaining SA/SSA.

DISCUSSION

Gaining/Maintaining SA/SSA Under Circumstances of Massively Degraded Radio and ICT Infrastructures

Despite its artificiality, which, for example, basically disregarded the very likely complete and long-term power blackout in the entire Pacific Northwest region, the Cascadia Rising 2016 Exercise greatly demonstrated the enormous challenges, under which responders will find themselves in and after a catastrophic incident of the simulated kind, in particular, with regard to gaining and maintaining situational awareness, and more so, shared situational awareness. Even at the basic SA level of perception, it will be utterly challenging to identify in any comprehensive fashion the damage to critical infrastructures while at the same time engaging in the top-most priorities of saving lives and then sustaining lives. While the initial megathrust and tsunami will cause considerable structural damage to critical infrastructures, the expectable aftershocks will substantially add to the damage of these structures, which have already been compromised, all of which will lead to cascading effects such as multiple fires, downed high-voltage power lines, broken gas and oil pipelines, broken water mains, spills from damaged sewage systems, other hazardous spills, and landslides, to name a few. In other words, the incident will not be static, but rather dynamic in nature, while response capabilities, and, particularly, reconnaissance and intelligence capabilities, which would provide for SA/SSA, will be massively degraded. A major insight from the exercise was that responders and populations will find themselves in relatively inaccessible "islands" for some time due to the collapse of hundreds of bridges and overpasses making both ingress and egress other than on foot or by airlift virtually impossible.

According to the director of a County Department of Emergency Management, around sixty such "islands" were identified in that particular jurisdiction. For the entire PNW region, this number might go into the hundreds. From the 2014 SR530/Oso response responders learned that aerial reconnaissance would not reveal the full extent of damage witnessed on the ground. In particular, soil and ground conditions would not be exactly known until responders were able to inspect the terrain on the ground. For SA/SSA this means that even reaching the level of basic "perception" would need weeks rather than days, and "comprehension," as the second level of SA/SSA, will take weeks, if not months.

With modern ICTs unavailable, sheer necessity will dictate the response to be organized on the basis of paper, pencils, and face-to-face communication via runners, then the responder population will not perform well under these particular constraints unless substantial efforts have been undertaken ex ante to prepare for this particular scenario in terms of still accessible hardcopy-based tools such as checklists, essential elements of information questionnaires, contact information, pre-scripted public messages, and the like. This type of preparation will allow for some organizational effectiveness of on-site responses under uniquely reduced capabilities. However, a paper-based response will not scale well. Also, the information kept on, for example, T cards, will not easily be shareable. Nevertheless, all information collected in this pre-industrial fashion will need to be shared with other responders to become effective. In order to speed up the process for regaining the full capacity of the ICT infrastructure, which will be dependent on the local restoration of power, jurisdictions in the likely impact area might want to consider the creation of ICT mirror infrastructures in an outside safe area. Rather than waiting for equipment and power sources to be brought into the impact area, it might be faster, safer, cheaper, and more effective to fly out responders from the impacted jurisdictions who bring their detailed local expertise and knowledge of existing plans and ICTs into a fully functioning and well-known mirror ICT environment. With help of initially pre-staged or flown-in mobile battery-powered wireless long-range transmitters, information can be exchanged between the functioning remote mirror EOCs and the responders on the ground. Information can be converted from paper to electronic records at the mirror EOCs in various ways, which would not slow down the responders on the ground. In the remote mirror EOCs, information could be integrated into a more complete SA/COP than locally possible. The exchange of information would be provided on regular basis via airlift, which would provide laptop and other handheld devices with updated information from the remote mirror site to the responders on the ground. Instead of being confined to working on paper-pencil basis, ground-zero responders would increasingly work with equipment and technology, with which they are familiar. Since the impact area is a coastal region, the proposed mirror EOCs might best be stationed on maritime vessels just off-shore making airlifts short. Of course, such vessels must be stationed safely outside the impact area but close enough to be operational on-site within less than 72 hours after the incident.

State of Currently Used Emergency ICTs in Light of the 2004 DERMIS Recommendations

As mentioned in the literature section, in their landmark 2004 paper Turoff and colleagues presented and discussed premises and requirements for what they then generically called "dynamic emergency response management information system, or short, DERMIS" (Turoff, et al., 2004). Although it would go far beyond the scope of this contribution to compare the ICTs investigated in this study to the design principles and requirement specifications given in the DERMIS paper in a point-by-point fashion, it is insightful to review the currently used systems and contrast them to at least to a partial list of DERMIS principles and requirements.

Extreme ease of learning was seen as a foremost requirement as stated above. The ICTs investigated in this study including, in particular, the increasingly proliferated WebEOC, this specific and important requirement is unmet by each of the systems. On the contrary, as the findings showed, WebEOC, for example, requires extensive and recurring efforts of training for mastering its basic functions. The system is mostly used when EOCs and response units are activated, but it is not used on a daily basis.

Usability by trained responders is another requirement, which is certainly met in part by all investigated systems, although the lack of functionality for sorting, filtering out, and intelligently consolidating information for SA/SSA and COP purposes is certainly not a feature of WebEOC, which stands out.

Conciseness was a recommendation relating to a user interface, which makes it very easy for the responder to navigate the information with a minimum amount of effort and learning. None of the systems comes even close to matching up with this requirement.

Customizability to responders' specific needs is a requirement, which is in part met by WebEOC, which allows the creation of boards, which serve a user-defined purpose. However, these boards function in the fashion of a logging system. When increasingly populated they quickly lose their informational clout.

Support for all EOC/IMT functions is necessary to serve all tasks and needs in response management without the necessity to resort to other unintegrated applications or sources of information. At least until recently, major GIS-related information could not easily be integrated into a system like WebEOC.

Independence from a particular physical location is a requirement, which shields the system against disruption and a single point of failure. While, for example, WebEOC fulfills this requirement in theory, its lack of scalability evinced by the crash of its State EOC implementation indicated that certain harsh physical constraints and vulnerabilities exist.

Support for structured communication processes is a principle, which can be met by a number of the systems studied; however, these processes need to be organized by issuing, for example, standard ICS forms on part of the system administrators. Unfortunately, the lack of standardization in forms and processes is one of the major insights from this study, which hampers specifically system interoperation and the gaining of SA/SSA.

As the Washington State National Guard after-action report states, this is a widely unmet requirement, which would need a concerted effort of multiple parties. The Guard, which operated with a standardized system made an interesting proposal,

> "Standardization across all echelons of response requires heavy weighting in the decision criteria for that selection. A nationally maintained system that allows access to national, state, and local EMs for SA development, sharing of information, and knowledge management, should receive strong consideration. A current potential solution is the DAART system offered by National Guard Bureau (NGB)." (quote #21)

CONCLUSION

This study of the Cascadia Rising 2016 Exercise response suggests that communication infrastructures and dedicated emergency management information systems (EMIS) will be very vulnerable to and badly damaged by the impact of a catastrophic megathrust of magnitude 9 plus and following tsunami as the result of the rupture of the Cascadian Subduction Zone in the North American Pacific Northwest. Situational Awareness and Shared Situational Awareness among and between multiple responder groups and jurisdictions will be hard to establish in the real case.

The assumptions in the 2016 exercise represented some artificialities, which in the real case would likely not hold, for example, the assumption of only a partial loss of power or no severe after-shocks. On the other hand, the four-day exercise united responders in the Pacific Northwest in confronting and working together on a very likely future scenario for the first time. While the artificialities of the simulated incident may have made the real-world incident appear more manageable than it would be in all likelihood, the simulation helped uncover numerous areas for improvement, which would have remained unknown, had the simulation been conducted under the assumption of an even more severe scenario with stingier injects.

Nevertheless, the exercise has produced multiple inconvenient insights, which is why the planned repeat of the exercise on an even larger scale in 2022 involving the four States of Alaska, Idaho, Oregon, and Washington is consequential and necessary. If communication infrastructures are disrupted to the extent found in the exercise and described in this study, and if, as documented here, current ICTs are not ready for the prime time of a large-scale integrated response effort, then emergency management needs to engage in serious considerations and planning of necessary alternatives. These considerations shall be informed also by the results of the aforementioned second paper resulting from this study, which covers the organizational and informational challenges observed during the exercise. Future work will attempt to further develop recommendations for EMIS requirements and improvement of existing EMIS.

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