Information-Decision-Collaboration Assessment

An Integrated Requirements Approach for Emergency Management Decision Support Systems

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Abstract

Modern emergency management is a demanding profession characterized by accelerated decision-making, dynamic information needs, and complex collaboration to execute mission objectives. Decision support systems in this setting must be suitably optimized in turn, with clear requirements to inform such design. To date, comprehensive approaches to capture these requirements remain underdeveloped, per a defined need in the literature.

This pilot study establishes the *Information-Decision-Collaboration Assessment* as an integrated method for eliciting these requirements, in order to inform effective development of such systems. The method records key tasks across all three aspects, and captures emergent themes which may further contextualize this understanding. The method was developed through a review of similar frameworks for sociotechnical systems, and cohered with selected task analysis approaches, to arrive at a comprehensive means of assessment. The method was first trialled through a preliminary survey, then refined for the interview process presented as the central focus of this paper.

Results of this study produced a richly contextualized body of insights, which depicted critical tasks across information, decision-making, and collaboration needs of emergency management practitioners. Analysis of these results identified common themes, challenges, and success factors, concluding with directly stated requirements to serve such needs. In summary, the *Information-Decision-Collaboration Assessment* appears to be a suitable vehicle for understanding these requirements for the emergency management sector, and may be evaluated as a foundational approach from which to build further study.

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Contents

1. Introduction

1.1. Background

Contemporary risk and resilience literature offers an interpretation of the world that is *uncertain, complex, ambiguous and dynamic* (Renn et al., 2011, p.231; Becker, 2014, p.149). These properties echo a similar premise of VUCA – *volatility, uncertainty, complexity, ambiguity* – proposed by Bennis and Nanus (1985) in the context of strategic leadership and subsequently applied in military, business, and organizational settings. *Risk* in this context may be defined as "the effect of uncertainty on objectives" (ISO, 2009), while Aven & Ylönen (2018) characterize uncertainty as a key feature of the modern risk landscape.

The practice of emergency management, in this interpretation, may be considered through a similar setting of uncertainty and ambiguity across all phases of *mitigation, preparedness, response, and recovery* (Coppola, 2011). Such concerns are pointedly heightened during the response phase, which often requires accelerated decision-making and multi-actor coordination to meet multiple fast-moving objectives. Critical information must be quickly absorbed, cohering real-time "ground truth" with previously existing data, in order to maintain *situation awareness* of the incident at hand. Routinely, this information may be inaccurate, incomplete, or irrelevant, creating further impediments to mission objectives. Numerous contextual factors, such as existing mitigation efforts or societal vulnerabilities, may also affect any plan of action. Further, the COVID-19 pandemic has necessitated swift changes to many operational approaches across emergency management as a whole. Examples of these changes include updated WASH protocol for flood evacuees (Ishiwatari et al., 2020), alterations to the deployment and coordination of wildfire crews (Moore et al., 2020), and a pivotal shift toward remote collaboration and online work environments for many organizations.

In sum, these concerns may be placed before a backdrop of increasing climate variability, as outlined in the recent IPCC Sixth Assessment Report (2021). This variability introduces three key areas of uncertainty to the practice of emergency management – the potential for increased frequency and/or magnitude of relatively familiar hazards, the emergence and propagation of previously unfamiliar hazards, and the decreased ability to forecast or extrapolate from historic data given instability of regional weather patterns and larger global tendencies (Cramer et al., 2014, p. 988; Dow and Downing, 2011, p. 62).

Following the above, decision-making during active response is a highly demanding affair, which nonetheless must inform a succession of high-consequence actions and priorities (Brehmer and Allard, 1991). Further, common perceptual and cognitive constraints must be mitigated, compensated, or overcome for an increased chance of mission success (Kahneman, 2003; Klein, 2008; Uhr et al., 2018). Given these aspects, a decision-optimized environment may be characterized as that which supports *situation awareness* and the successful execution of mission objectives despite conditions of stress, uncertainty, and ambiguity.

A *decision support system* is defined by the Oxford English Dictionary (2021) as “a computer program or other system used to aid in decision-making”. In the emergency management setting, this may include a wide range of platforms, data streams, geospatial resources and analytical aids to support *situation awareness* as described above. Given the many challenges to decision making as outlined in this introduction, it is critically important that decision support and information management systems serving the emergency management sector be suitably designed and optimized to meet these needs.

1.2. Research Context

Requirements elicitation is the process of defining these needs, through direct engagement with system users as well as supporting techniques to understand task structures and further context (ISO, 2018). Despite the importance of this foundational design step, elicitation is often an overlooked or subjective process, with few consistent guidelines to date (Rodriguez et al., 2017). Further, few approaches address the user from an integrated systems perspective, nor do any specifically consider the emergency management context (Yang et al., 2014). Related study has been conducted on isolated topics which may pertain to emergency management, including cognitive task analysis and decision optimization (Brehmer, 1992; Crandall et al., 2015). Human factors research for similar fields – such as aerospace, maritime, and process control systems – may also yield partially transferable insights (Endsley, 1995; Nazir et al., 2014; Sandhåland et al., 2015). However, despite these efforts, integrated approaches remain less developed for the full spectrum of needs in the emergency management sector (Yang et al., 2014; O’Brien et al., 2020).

1.3. Conceptual Framework

Distributed situation awareness, or DSA (Stanton et al., 2006), is a relatively recent concept of network analysis that is concerned with the information environment of sociotechnical systems as a whole, and seeks to understand the nature of information transaction within these systems. The agents in the system may be human, technological, or involve junctures between human and technological agents. Viewing this information flow as a dynamic property of the system, continuously moving through and around its agents, speaks to the central conceptual premise of DSA. The importance of developing working models that grasp the complexity of the environment is repeatedly stated, and the relationship between complexity and multifactorial cause is highlighted (ibid, pp.16-17). Ultimately, emergent context may be generated from collaborative activity within the system, or between the system and the environment, which extends beyond the sum information or awareness of the involved agents. The premise of DSA may be traced from earlier work on *distributed cognition,* which addresses “cognitive processes that are distributed across the members of a social group, between people and their material environments, and through time” (Hutchins, 2001).

As a systems-focused perspective on situation awareness, *distributed situation awareness* has been chosen as the conceptual framework through which to approach this study. A review of foundational DSA literature and related methodology is provided in Section 3.1.

The following six assumptions, after Stanton (2016), outline the theoretical premises of the distributed situation awareness concept:

1. Situation awareness is held by human and non-human agents. Technological artifacts (as well as human operators) have some level of situation awareness (at least in the sense that they are holders of contextually relevant information). This is particularly true as technologies are able to sense their environment and become more animate.

2. Different agents have different views on the same scene. This draws on schema theory, suggesting that the role of past experience, memory, training and perspective. Animate technologies may be able to learn about their environment.

3. Whether or not one agent's SA overlaps with that of another depends on their respective goals. Different agents could actually represent different aspects of SA.

4. Communication between agents may be non-verbal behaviour, customs and practice (but this may pose problems for non-native system users). Technologies may give off non-verbal cues through sounds, signs, symbols and other aspects relating to their state.

5. SA holds loosely coupled systems together. It is argued that without this coupling the system's performance may collapse.

6. One agent may compensate for degradation in SA in another agent. This represents an aspect of the emergent behaviour associated with complex systems.

1.4. Research Purpose and Objectives

Per the above motivations, this work presents the *Information-Decision-Collaboration Assessment* (IDCA), an integrated elicitation approach informed by the DSA concept which seeks to capture the full spectrum of decision support needs in the emergency management setting. Three outcomes are defined to meet this objective. The first is to understand the individual user within three overlapping *environments*, or general contexts in which tasks may be executed. These *environments* address information, decision, and collaboration aspects respectively. The second outcome is to gain an understanding of emergent needs arising from the interaction of multiple human agents, which may extend and differ beyond those of the individual. The third outcome is to contextualize this teamwork within a larger system perspective, including technological agents and information flows to provide a more comprehensive overview of the sociotechnical system as a whole. Collectively, these aspects are meant to address a well-rounded consideration of the user, and reflexively inform elicitation from this perspective.

The research contribution may be described as *normative*, or prescriptive, by offering an intervention artifact (IDCA) intended to improve outcomes (system design) through a defined mechanism (requirements elicitation) in a given problem context (emergency management decision support systems) (Denyer et al, 2008).

Research Question: *"How should requirements elicitation for emergency management decision support systems be conducted?"*

1.5. Scope and Limitations

In order to approach the research interests above, this pilot study centers the *user interview* as a foundational method to better understand user needs and requirements. Selection of the user interview is motivated twofold – to collect empirical data regarding these requirements, and to further refine the IDCA for subsequent elicitation activities. The results of this study are intended as the first step of a larger requirements exploration, in order to progress a more comprehensive suite of methods which may be utilized in future research. Subsequent efforts in this regard may include teamwork observation, triangulating interviews between multiple team members, and participatory design activities.

Practical limitations to this work have included available sample size of interview subjects, as well as restrictions on travel and empirical data collection due to the COVID-19 pandemic.

2. Methodology

The study methodology is described as follows. First, foundational concepts of *design science research* are given in this section, and correlated with working components of the study. Second, the process of the literature review is described, from conceptual foundations through identification of potential study methodology. Third, the general premise of the method is presented, based on the preceding design science concepts and literature review. Fourth, the process of developing the inquiry method is described in detail, including the development of three question sets to guide the user interview process.

Continuing, the collection of empirical data is described, through selection of sources, a preliminary test survey, and the focal interviews. Means of analyzing this data are then described, as informed by the preceding design science concepts and literature review. Lastly, representation of the results are described through both visual and textual means.

2.1. Foundations: Design Science Research

The primary methodology of this study is characterized as design science research, after Wieringa (2014). This methodology is chosen in order to 1) operationalize the study from theory to practice, 2) provide a framework for development and refinement of the approach, and 3) provide a structure through which to assess the results. In Wieringa, the primary objectives of design science research are characterized as "designing an artifact that improves something for stakeholders" and "empirically investigating the performance of an artifact in a context." (ibid). *Artifacts* in this sense may include "methods, techniques, notations, and algorithms", while *context* refers to "the design, development, maintenance, and use of software and information systems" (ibid). These dual objectives are intended to inform system design through structured, iterative inquiry, with metrics for assessing performance of the artifact in-situ. Design of the artifact is closely informed by the *problem context* as well as *social context* of stakeholder needs and goals, while performance assessment informs – and is informed by – the greater *knowledge context* in which the project is situated (ibid). Overall, the iterative nature of this activity is a key function through which contextual insight is generated, in order to successfully address the problem space and adaptively refine solutions for stakeholders.

In the case of this study, stakeholders are defined as emergency management professionals, while the artifact in question is the *Information-Decision-Collaboration Assessment*.

Continuing to practical application, the design science process may be utilized to define user and system *requirements,* as above. The development of sound requirements compels a well balanced understanding of the problem context between stakeholder needs, system constraints, timeline concerns and other complex factors. The requirements cycle generally begins with *elicitation* of needs, continues through *implementation* in the system, and undergoes *validation* by the stakeholder(s) to confirm alignment with expectations. Clear communication is critical at each stage of development, and is ideally a dynamic process of discovery between end users and the design researcher. As the initial phase of the requirements cycle, *elicitation* is of vital importance in capturing stakeholder needs to ultimately inform system design. This activity may begin with engagements such as interviewing, task analysis, or observing stakeholders to collect primary data, and may continue through the development of supporting artifacts such as prototypes, A/B testing, focus groups and various user testing schemas. While such methods are commonly used in the development process, their description belies the somewhat nebulous task of the researcher in translating stakeholder feedback and communication to tangible design structures.

In the case of this study, the primary form of elicitation is the *user interview* as specified, with *task analysis* comprising a supporting means of data analysis. Beyond these methods, further engagement may be pursued through subsequent study, as specified in the scope and limitations of Section 1.5.

Ideally, successful elicitation extends beyond simple inquiry to a more holistic understanding of the end user – their motivations, impediments, and the contextual environments in which they execute tasks to meet goals. Wieringa characterizes the nuanced importance of this work as follows, with emphasis added (ibid, p.52):

"Stakeholders rarely if ever are able to specify requirements. Instead, specifying requirements is an important design activity of the design researcher. The requirements are not answers to questions that we ask the stakeholders. ***Instead, they are the result of design choices that we make jointly with, or on behalf of, the stakeholders."***

2.2. Literature Review

The premise of *situation awareness* was first explored as a conceptual basis for this study, in order to understand previous theoretical models, means of assessment, and existing research on optimal conditions to support this aspect. This exploration took place throughout previous coursework and research into the topic, arriving at the selection of *distributed situation awareness* (DSA) as a focal point for this study. More on this motivation may be found in Section 3.1.

In order to utilize the concept of distributed situation awareness through a design science process, and apply to the research question, it was first necessary to collect information on related methodology across key authors and foundational texts. This, in order to select suitable methods for the study as well as potential adaptations for the emergency management context. "Suitable" in this regard is defined as methods informed by the DSA concept, intended to provide an integrated, comprehensive, and systems-focused assessment of a given sociotechnical system.

A structured review was organized of DSA literature to date, with particular focus on outputs which 1) directly inform the development of practical assessment methods, and 2) explicitly set groundwork for further inquiry in the emergency management setting or related fields. To begin, a preliminary keyword search was conducted via the Publish or Perish software application for macOS. This citation tool assesses relevant texts across Google Scholar and Microsoft Academic Search. Initial terms included were "distributed situation awareness" and "distributed situation awareness AND emergency management", with patents and citations excluded. Duplicates and mis-citations were also excluded from this output. Key articles and authors were determined by number of citations and earliest appearance in the literature.

Existing methodology for applying the distributed situation awareness concept in practice was then identified through the assessment of these texts. While a more comprehensive treatment of the literature is found in the Results section of this paper, this review established the *Event Analysis of System Teamwork (EAST)* as the primary methodology in this regard, from which the thesis study is adapted (Walker et al., 2006). A refined search was then conducted using the term "Event Analysis of Systemic Teamwork", with patents and citations excluded. Duplicates and mis-citations were excluded from this output. Key articles and authors were again determined by number of citations and earliest appearance in the literature.

Next, a further free-text search was conducted to determine texts which explicitly cite the EAST framework in the context of emergency management operations. This, to determine suitability of EAST for this study, as well as identify research gaps or areas of improvement. Given the small number of outputs, "grey" and non-peer-reviewed literature – such as dissertations and conference proceedings – were included in this listing. This inclusion was intended to provide a more contextual overview of all academic interest in this topic, beyond a focus on empirical results themselves. All texts were then assessed for supporting concepts and potential iterations of the methodology by additional authors. Following, the discussion and conclusion sections of all articles were reviewed for indicated directions of further study.

At this juncture, an assessment was made of comparative frameworks encountered in the literature, in order to determine any more suitable than EAST for the purpose of this study.

Finally, individual components of the most current EAST framework were reviewed, to determine potential adaptations for this study. As task analysis is often a key component of requirements elicitation, specified in Section 2.1, further evaluation was conducted for this portion of the methodology. Based on the literature review above, it was noted that while EAST addresses many aspects of collaborative teamwork, decision-making, and information sharing –across human and technological agents – no explicit guidance is given for assessing tasks at the interface of these agents. Thus, a further search was conducted using the terms "interface AND task analysis", to determine the most suitable choice in this regard. Patents and citations were again excluded, as well as duplicates and mis-citations. Key articles and authors were again determined by number of citations and earliest appearance in the literature. Details on this review are provided in Section 3.1.4, with *ecological task analysis* selected as appropriate for the study objectives.

2.3. Information-Decision-Collaboration Assessment (IDCA)

Following the above premise and objectives, this study presents the design science artifact *Information-Decision-Collaboration Assessment* (IDCA), which is a requirements elicitation approach informed by the concept of distributed situation awareness, derivative EAST methodology, and premise of ecological task analysis.

Briefly, the current and most widely-used version of EAST takes a "network of networks" approach in understanding collaborative sociotechnical systems, as shown in Figure 1 (Stanton et al. 2019). Primary data is collected through task observation, interviews, documentation review, and supporting methods such as walkthrough analysis (ibid, p.6). The three areas of interest in the system are characterized as task, social, and knowledge networks, with pointed consideration also given to the dynamics between these networks.

As applied analysis, EAST is further decomposed as follows: *hierarchical task analysis* to depict a structure of the task network, *social* or *propositional network analysis* to understand the social and knowledge networks, and the *critical decision method* to contextualize cognitive aspects of all three networks (ibid, p.6-9). Network metrics play a significant role in the processing of this collected data, and include assessment objectives such as density, centrality, and sociometric status (ibid, p.9).

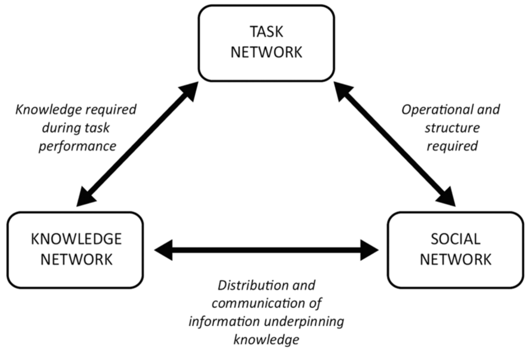

Figure 1: EAST after Stanton et al., 2019

From this foundational framework, IDCA continues with two adaptations proposed. First, as all areas of interest may be considered to involve tasks, the task element is converted to a *decision making* environment. Second, *ecological task analysis* is employed as an alternative to *hierarchical task analysis*, as a more integrative approach developed to inform adaptive-dynamic interface design (Kirlik et al., 1996). Further, ecological task analysis explicitly provides methods to assess the available information environment from a user perspective (ibid). Lastly, the critical decision method is continued from the original EAST framework, and social network analysis is again used to contextualize the collaborative environment.

These adaptations produce the model shown in Figure 2, which addresses the user from three overlapping perspectives in which they may execute tasks. As applied to this study, the model is used to guide the elicitation queries described below, in order to produce a contextualized understanding of these tasks which may in turn inform system design requirements.

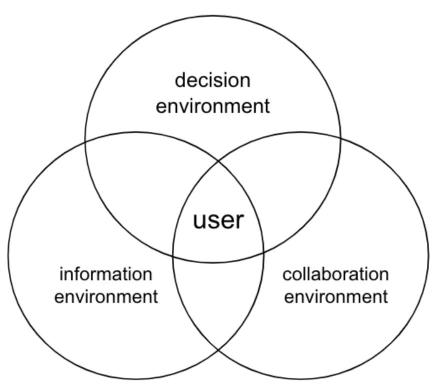

Figure 2: IDCA Model

2.3.1. Development of Inquiry Method

After the above model, the following areas of inquiry were developed in order to understand stakeholder needs, the three task environments as indicated, and interrelation between all elements. A full list of all questions may be found in Annex 1, although it is important to note that not all questions were answered by the interview subjects, and in some cases additional information was volunteered.

System Definition

As in the original EAST, an initial step of such efforts is to define the system in question (Walker et al., 2006). For the limited scope of this paper, the system of focus is represented by the *user* in the above model, in dynamic interaction with the three environments as described. Temporal parameters are defined as "a declared disaster event", from -12 hours to +12 hours, as specified by the United States Code of Federal Regulations 44, Part §206, Subpart B (eCFR, 2021). Further context may inform appropriate bounds for study, such as organizational structure or communication platforms in use. Lastly, it is important to note that system boundaries in this regard are not rigid, impermeable, or static – instead, the objective is to estimate a reasonable scope of study, given available time and resources, that depicts both needs of the user as well as foundational insights for larger system analysis.

User Profile

Preliminary inquiry established personal contextual information such as job description, affiliated organization, and specialized training, in order to position an informed user profile within the model.

Information Environment

The first main area of inquiry evaluated the *information environment* of the user, regarding availability of information needed to meet goals, as well as tasks and actions taken to engage or adapt this environment. Interview questions in this regard are informed by tenets of *ecological task analysis,* as referenced above, and seek to compare information needs as defined by the user with available sources of this information in the sociotechnical system. "Sources" in this setting may include technological resources such as databases, APIs, or social media feeds, as well as other persons in the organization or larger collaborative environment.

Decision Environment

Continuing, the *decision environment* of the user is addressed through questions derived from *the critical decision method,* which offers structured and well-established methodology for understanding key cognitive tasks. Further, information is collected regarding time pressure, perception of stress, and other context in which decisions and cognitive tasks are undertaken.

Collaboration Environment

Following, the *collaboration environment* of the user is queried in order to understand organizational structure and communication patterns, as well as barriers and hindrances in this regard. Formal protocol is assessed, such as use of radio prowords, as well as more nuanced dynamics around roles and hierarchies, information "siloes", timeliness of information sharing, and personal communication styles.

2.4. Methods of Data Collection

2.4.1. Selection of Data Sources

Selection of study participants was through *purposeful sampling* (Creswell, 2013, pp.154-157) using Twitter, LinkedIn, and active professional networking. Relevant documents and digital artifacts were collected directly from study participants as well as online resources including United States government websites and publications.

2.4.2. Preliminary Survey

An online survey distributed at the 2020 International Association of Emergency Managers (IAEM) conference produced ten respondents, who answered 16 questions derived from a preliminary *Information-Decision-Collaboration Assessment* concept. Responses to this survey were reviewed and used to refine the expert interview process below.

2.4.3. Expert Interview

Primary data was collected from six subject matter experts through a one-hour recorded interview conducted over Zoom. All experts were current or former emergency managers holding >10 years' experience, representing city, state, regional and federal governments as well as critical infrastructure entities. Participants were informed of the recording, and the general premise of the research. Interview questions were formulated as outlined in Section 2.3.1, however, the process remained semi-structured in nature (Creswell, 2013, p.160) to allow for emergent themes and sufficient narrative detail. This conversational, in-depth engagement was intended to provide a well-contextualized understanding of objectives, requirements, and workflows within the three task environments as described. The interviews were stored in MP4 format, and transcribed via Microsoft Word.

2.5. Methods of Data Analysis

2.5.1. Thematic Assessment

An initial thematic assessment was conducted through the following steps. The transcripts were first read and reviewed, organizing all responses by question and environment category. After light editing for mistranscription, the text was assessed for key themes and critical tasks across the three environments as specified. Further notation was made of emergent topics and/or those the subject addressed multiple times. Case examples and direct quotes were also identified, in order to further illustrate these outcomes. Lastly, direct recommendations for requirements were identified and noted.

2.5.2. Network Analysis

In order to assess key collaborative and informational relationships, between the subject and system agents, a representational graph was generated to depict these aspects. In this graph, nodes represent all stated sources of information, across both human and technological agents, while edges between these agents are weighted based on optimal or suboptimal information flow as reported. Technological agents include information management artifacts, such as collaborative documents, along with databases and other common components. Following the premise of ecological task analysis, all edges are assumed bidirectional.

2.5.3. Critical Decision Method

In order to understand key decision points and informational triggers, the critical decision method was used to both develop the inquiry technique and review the responses post-interview. This approach informed both the thematic assessment process, as described above, as well as content of the written thematic summary below.

2.5.4. Ecological Task Analysis

In order to further contextualize the information environment, an ecological task analysis was conducted as above in order to understand gaps between critical and available information, as well as self-reported tasks enacted to overcome these gaps.

2.6. Representation of Data Results

2.6.1. Collaborative Information Network

Results of the network analysis as stated are presented as a dendrogram graph, generated using the d3.js data visualization library as well as Adobe Illustrator. All nodes are labeled by number, and described by a table below.

2.6.2. Thematic Summary

A text summary was written of all thematic content, integrating key themes, critical tasks, emergent topics, and direct quotes from the assessment process above. This summary was organized by the three environments, in the order queried. A synopsis of all reported gaps in the information environment, as well as directed tasks to overcome these gaps, is provided in Section 4.3.

3. Results

3.1. Literature Findings

The structure of this section moves from foundational authors on *situation awareness*, to the more recent notion of *distributed situation awareness*, through the *EAST framework* as a means of operationalizing this concept, and finally addressing *ecological task analysis* as an adaptation to that framework for the purpose of this study. A summary of all findings, and direct bearing on the study design, is provided at close of the section.

3.1.1. Situation Awareness: Models of Assessment

Situation Awareness

Situation awareness is a term generally characterizing "a person's state of knowledge about a dynamic environment" (Endsley, 1995a). Continuing in Endsley, situation awareness may be further described through a well-cited model of three cognitive processes – *perception of elements in the environment, comprehension of the current situation,* and *projection of future status* (ibid). While the concept of situation awareness has many applications, it was first considered a measurable aspect of cognitive function in the context of military aviation during World War II (ibid). Since this time, multiple methods have been developed to assess individual situation awareness in both aerospace and military settings, as well as other safety-critical contexts such as nuclear and maritime control operations. This understanding of situation awareness is important in such high-performance environments, as it directly impacts decision making, cognitive task load, mitigation of human error, and optimal system design to support these factors (ibid).

Nguyen et al. (2019) provide a relatively current review of techniques for assessing and supporting *situation awareness* in high-performance teams, categorized into six approaches – freeze probe techniques, real-time probe techniques, post-trial self-rating, performance measures, observer-rating, and process indices. Given these six types of assessment, it is noted that no single technique is comprehensive, while all involve pivotal assumptions and tradeoff decisions made by the analyst. Concluding, the authors suggest "the combination of several measures when measuring SA is recommended to ensure concurrent validity." This statement establishes the viewpoint that an integrated, comprehensive suite of methods is necessary to best understand the support of situation awareness in these settings, a perspective that is continued throughout further literature assessment in this paper.

Team and Shared Situation Awareness

Continuing from this foundational concept, further inquiry has been conducted into the situation awareness of individuals in collaborative settings. In Endsley and Jones (1997), *team SA* is characterized as “The degree to which every team member possesses the SA required for his or her responsibilities", while *shared SA* is defined as “The degree to which team members possess the same SA on shared SA requirements”. Further outputs build on this line of inquiry, providing guidance for information displays and other devices to optimize team and shared SA per these conceptual premises (Endsley et al., 2003).

Though Endsley and colleagues have produced a prolific body of work on this topic, and additional authors are too numerous to cite in this paper, several texts may be noted regarding practical assessment of team and shared SA in the emergency management setting. With 44 subsequent citations, Owen et al. (2013) is a well-referenced output on multi-agency coordination, stressing the importance of shared mental models between not just team members but also organizations. Seppänen and Virrantaus (2015) present methods for discerning critical information needs but also the quality of this information as it contributes to shared SA. More recently, emerging technologies have been included in the literature, such as the role of sensor and data streams (Dubrow and Bannan, 2019).

Distributed Situation Awareness

While situation awareness is not a new term, it has largely considered the individual as primary locus of this aspect. *Distributed situation awareness* differs from *team* or *shared* situation awareness in that it assumes members of the same team may hold unique viewpoints of the same event, after *schema theory* (Stanton et al., 2009). Further, the unit of study is whole-system, which allows for the observation of emergent dynamics and properties of scale (ibid). Following, DSA examines dependencies and directionality, as well as allowing for weighting or further description of these linkages (ibid, pp.15, 20). Beyond simply mapping relationships, DSA is concerned with active information transaction along these pathways, and seeks to understand these dynamics across multiple scales.

Vu and Chiappe (2015) offer a critical assessment of DSA, realized through propositional network analysis, in comparison to other concepts of situation awareness as outlined above. In this assessment, the authors cite the system-level focus of DSA as providing broader insights than those solely focused on the individual, with potential to scale such analyses accordingly. To note, issues are raised about its lack of psychometric assessment, which renders human agents in the system something of a “black box”. However, overall, DSA is characterized as being highly suitable for distributed teams, such as those engaging in remote work or dispersed geographically, and the authors correlate this aspect to earlier work on *distributed cognition* by Hutchins (1995).

The earliest reference to "distributed situation awareness" in the literature may be found in Mayk et al. (1997), who address the process of deriving design requirements for military command and control (C2) decision support platforms. Over the next eight years, twenty-six papers reference the term "distributed situation awareness" in some fashion, with only one featuring the term directly in the title (Siemieniuch and Sinclair, 2004). The outputs span further studies on command and control, as well as brief forays into traffic, aviation, and maritime applications, but no authors appear to publish more than two works concerning the topic.

In 2005, Stanton, Salmon, Baber and Walker produced a short paper for the International Conference on Contemporary Ergonomics, simply titled "Distributed Situational Awareness" (Contemporary Ergonomics, 2005). While only featuring three subsequent citations, this represents a first output by authors who may be considered foundational to the concept, having collectively published twenty-two related works at the time of this writing. Over the course of these works, the conceptual tenets of distributed situation awareness have been continuously developed and refined, culminating in a practical methodology discussed in the next section of this paper.

3.1.2. Event Analysis of System Teamwork (EAST)

Evolution of EAST Methodology

To operationalize the concept of distributed situation awareness, *Event Analysis of System Teamwork* (EAST) is an evolving suite of methods developed to assess sociotechnical systems from a suitably integrated perspective (Walker et al., 2006). Initially, the EAST methodology was composed of "a hierarchical task analysis, a coordination demand analysis, a communications usage diagram, a social network analysis, and the critical decision method" (ibid). More recently, a streamlined version organizes this study into three categories of interest – a *task* network, *social* network, and *information* network as in Figure 1, Section 2.3. above (Stanton, 2016). These properties are taken as an interconnected whole, with emphasis on relationships and dependencies between both system agents and the networks in which they reside.

In the literature, the earliest reference to EAST is found in *Contemporary Ergonomics 2005: Proceedings of the International Conference on Contemporary Ergonomics* (Contemporary Ergonomics, 2005). This text includes three separate articles of note, all by foundational authors identified above. The first is "Event analysis of systemic teamwork (EAST): a novel integration of ergonomics methods to analyse C4i activity" (Walker et al., 2006). The second is "The event analysis of systemic teamwork (EAST): Methodology and Analyses of Railway Maintenance

Tasks" (Gibson et al., 2005). The third, "Integrating Human Factors Methods: The HF Methods Matrix" (Salmon et al., 2005) is an exhaustive review of existing human factors methods and their combinations, funded by the UK Ministry of Defence and the Defence Science and Technology Laboratory. This report concludes a lack of integrated, systems-focused methods in the human factors domain, and positions EAST as a suitable framework informed by this research. In sum, these outputs lay foundational groundwork for the methodology, through analysis of existing work, selection of techniques, and forays into practical application.

A new text was published the following year, in the journal *Ergonomics* – "Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology" (Stanton et al., 2006). This article extended and formalized the EAST framework, presenting a direct correlation between methodology and the DSA concept. At 547 citations, this text represents significant influence in the further development of EAST by both original and subsequent authors.

Over the next decade and a half, the foundational authors have been collectively prolific with 177 articles published on EAST at the time of this writing. Of these outputs, *Human factors methods: a practical guide for engineering and design* (Stanton et al., 2017) has had 1286 citations to date, and is a broader inventory of general methodology with a cumulative chapter on EAST at the close of the book. More recently, *Systems Thinking in Practice: Applications of the Event Analysis of Systemic Teamwork Method* (Stanton et al., 2019) is a text dedicated solely to the framework, with multiple use cases, and may reflect its most current and widely-used version.

While the above review traces the development of EAST per the original authors, it is also important to assess comparative perspectives and iterations of the framework by others. In the literature, out of 376 outputs addressing EAST, 199 have been identified as being published by subsequent authors. An exhaustive review of all such articles lies outside the scope of this paper, but several key outputs have been identified based on applied inquiry with relevance to this study (Annex 2).

EAST and Emergency Management

In the above literature, nine articles were identified which address the EAST framework through the specific context of emergency management. While foundational authors published two of these outputs, the remaining articles reference or extend the original framework in the context of further related research (Annex 3).

Perhaps best setting the course for further study, O'Brien et al. (2020) conduct an exhaustive search of all literature to date which applies concepts related to DSA in the context of multi-agency emergency response. While the results feature many outputs also cited in this paper, several additional findings are provided given divergent search terms and scope. These include inquiries into cognitive overload (Taber, 2013), shared mental models (Saetrevik and Eid, 2014), and the emerging use of social media (Bennett et al., 2013; Bunney et al., 2018). Findings of this meta-analysis conclude a distinct lack of systems-focused assessment for the emergency management sector, and little use of the DSA model to date. A pointed call is made for the use of EAST, to address evolving complexity which may arise from advances in communication and information technologies.

3.1.3. Comparative Frameworks

Regarding alternate methodology, a close relationship was noted with the related framework of *cognitive work analysis*, which provides a distinctly different approach but may be cohered with EAST to address gaps in either process (Oosthuizen and Pretorius, 2014; Read et al., 2018). In general, a cognitive work analysis addresses the domain, activities, strategies, social dynamics and worker competencies of a given team (ibid). Focus is placed on defining system constraints, as a statedly descriptive methodology. For the purpose of this study, most elements of cognitive work analysis were determined to be either redundant to EAST, beyond scope of the current work, or explicitly unsuitable in pursuing a normative requirements strategy. However, this framework may provide useful perspective for subsequent elicitation activities as specified in Section 1.4. In particular, the participatory activities proposed by Read et al.(2018) in the *Cognitive Work Analysis Design Toolkit* are of primary interest in this regard.

A second methodology considered was the *Situation Awareness Weighted Network* (SAWN) approach, as proposed by Kalloniatis et al. (2017). While this framework appears suitably comprehensive for the objectives of this study, the inclusion of assessment techniques after Endsley requires fairly extensive intervention beyond its scope. SAGAT, for example, involves a controlled observation environment where key tasks may be executed and assessed (Endsley, 1995). As with Read et al. (2018), further inquiry may be made into this work and related studies, in order to iterate the IDCA for subsequent elicitation activities such as teamwork observation.

3.1.4. EAST Adaptation and Task Analysis

Task analysis is a key component of much human factors study, as well as various methods of requirement analysis and user research to inform system design (Crandall et al., 2005). It is not enough to simply collect the data through observation or inquiry, further assessment must be conducted in order to decompose and synthesize the findings for practical application. In Endsley's SAGAT (1995b), above, *goal-directed task analysis* (GDTA) is the primary basis by which inquiry topics are shaped and subsequently assessed. GDTA is in turn a subset of *cognitive task analysis* (CTA), a commonly used method in the assessment of decision-making, cognitive load, and other mental processes required for successful human-machine interaction (ibid). The EAST framework primarily makes use of *hierarchical task analysis*, a standard and widely-used method for decomposing subject tasks and objectives into clear, diagrammatic workflows (Walker et al., 2006). The authors primarily employ this technique to "describe the relationships between tasks, their sequence and interdependencies" (Stanton, 2016). The use of HTA in this context assumes "sufficient data and subject matter expert (SME) access", and is intended to enhance further steps of the framework such as direct observation (Stanton et al., 2019, p.6). To note, EAST does not abandon cognitive assessment entirely with this choice, and chooses the *critical decision method* instead as a means to contextualize these taskflows and understand the cognitive processes at hand.

In adapting the EAST framework for this study, a review was made of these forms of task analysis as well as those specified in Section 2.2, to arrive at the alternative *ecological task analysis* (Kirlik et al., 1996). To note, this concept differs from another of the same name proposed by Davis and Burton (1991) in the context of physical education training. Ecological task analysis in this sense, after Kirlik, is a method specifically developed to inform interface design, and alleviate cognitive burden by supporting "fast and frugal" heuristic strategies (Kirlik et al., 1996; Bertel and Kirlik, 2011). It descends in part from the concept of *affordances*, or options an environment may provide for interaction (Gibson, 1979), and relates as well to Rasmussen's *skills-rules-knowledge taxonomy* in the context of *ecological interface design* (Rasmussen, 1985; Bennet, 2017). The primary objective of ETA is to understand both the *perceptual surface* and *action surface* of a system – available information and actions as perceived by the user – and compare these perceptions for notable incongruence. The primary assumption in this regard is that any dissonance to be overcome represents a cognitive demand, and should be minimized to the fullest extent possible. Further, ETA considers a dynamic-adaptive relationship between user and system, and takes into account manipulation of the interface, use of assistive technologies, and other actions that modify these surfaces – and in turn, user perception – through an ongoing feedback exchange. The central unit of study is this dynamic between user and system, which differs somewhat from user-centered design as informed by Endsley and others (Bourne, 2019). While academic literature on ETA is somewhat sparse, compared to other methods, it was pursued for this study given its emphasis on informing design requirements from this dynamic-adaptive perspective.

3.1.5. Summary of Literature Findings

Conceptual Findings

This literature review has first identified existing models of *situation awareness*, and common approaches to this study for teams and individuals in high-performance settings. A preliminary text by Nguyen et al. (2019) provided an encapsulated overview of such approaches, representing that no one method is likely sufficient to encompass the study of this complex and dynamic aspect.

Distributed situation awareness (DSA) was then identified as a suitable concept through which to address this study, providing more comprehensive means of assessment than the singular means outlined by Nguyen et al. (2019) or extended perspectives of the individual through *team* and *shared* situation awareness. “Suitable” is here defined as an integrated, whole-system approach, providing means for multi-level assessment across a holistic suite of methods. Vu and Chiappe (2015) provide support for this reasoning, through a critical review arriving at key advantages of DSA in this regard.

Methodology Findings

From this departure point, texts were assessed for current methodology informed by the DSA concept, arriving at the *EAST framework* as an explicitly defined means to operationalize this approach per the original authors of the concept.

From this initial identification of the EAST framework, further areas of the literature were reviewed to assess its suitability for this study. The first addressed application of EAST to emergency management settings, in order to understand existing research and potential gaps in this regard. The second addressed alternate frameworks similar to EAST, to determine whether a more suitable methodology could be chosen.

Lastly, with EAST established as the foundational methodology for this study, further inquiry was conducted into adaptation of the framework to best suit the aims of this research – i.e. developing an integrated and holistic requirements elicitation method. Task analysis was chosen as the focus of this inquiry, per motivations outlined in Section 2.2. The choice of *ecological task analysis* was the outcome of this assessment.

Conclusion of Literature Findings

In general, EAST is a well-cited framework for assessing collaborative sociotechnical systems, with current and active use by subsequent authors. Beyond purely academic pursuits, it may be important to consider the relationship between the quantity of information generated by EAST and practical application of such insights. Thorough consideration of study objectives may reflexively inform the data collection process, and assist in refining methodology when tradeoffs must be made based on available time, subjects, funding, or other resources. Further review of case studies, where results directly inform system or organization design, may be constructive in this regard.

While most texts addressing EAST in the emergency management setting did not apply or adapt the framework itself, a general consensus appears clear that applying a comprehensive and multi-level means of assessment is key, in order to approach dynamic teamwork and emergency management operations as a complex-adaptive system. Further, a running thread may be identified regarding a need to address evolving technology, as it may influence the complexity of information and communication environments.

These findings contribute to answering the research question of *"How should requirements elicitation for emergency management decision support systems be conducted?"*, by supporting a viewpoint that comprehensive, systems-focused assessment is recommended, which considers both human and technological agents. Further, the low amount of outputs applying EAST directly in the emergency management setting indicates a notable potential to contribute in this area.

In summary, EAST appears to be a suitable departure point from which to develop the study methodology, to approach the *distributed situation awareness* concept through practical application. From this basis, investigation and iteration of the single variable *task analysis* has produced a preliminary version of the IDCA, tailored to the research context and suitable for the short scope of this pilot study. Further intentions for the IDCA, involving elicitation beyond the *user interview*, may benefit from the iteration or integration of alternate methods found in the literature, such as those of the CWA or SAWN frameworks.

3.2. Empirical Findings

3.2.1. Subject Matter Expert 1

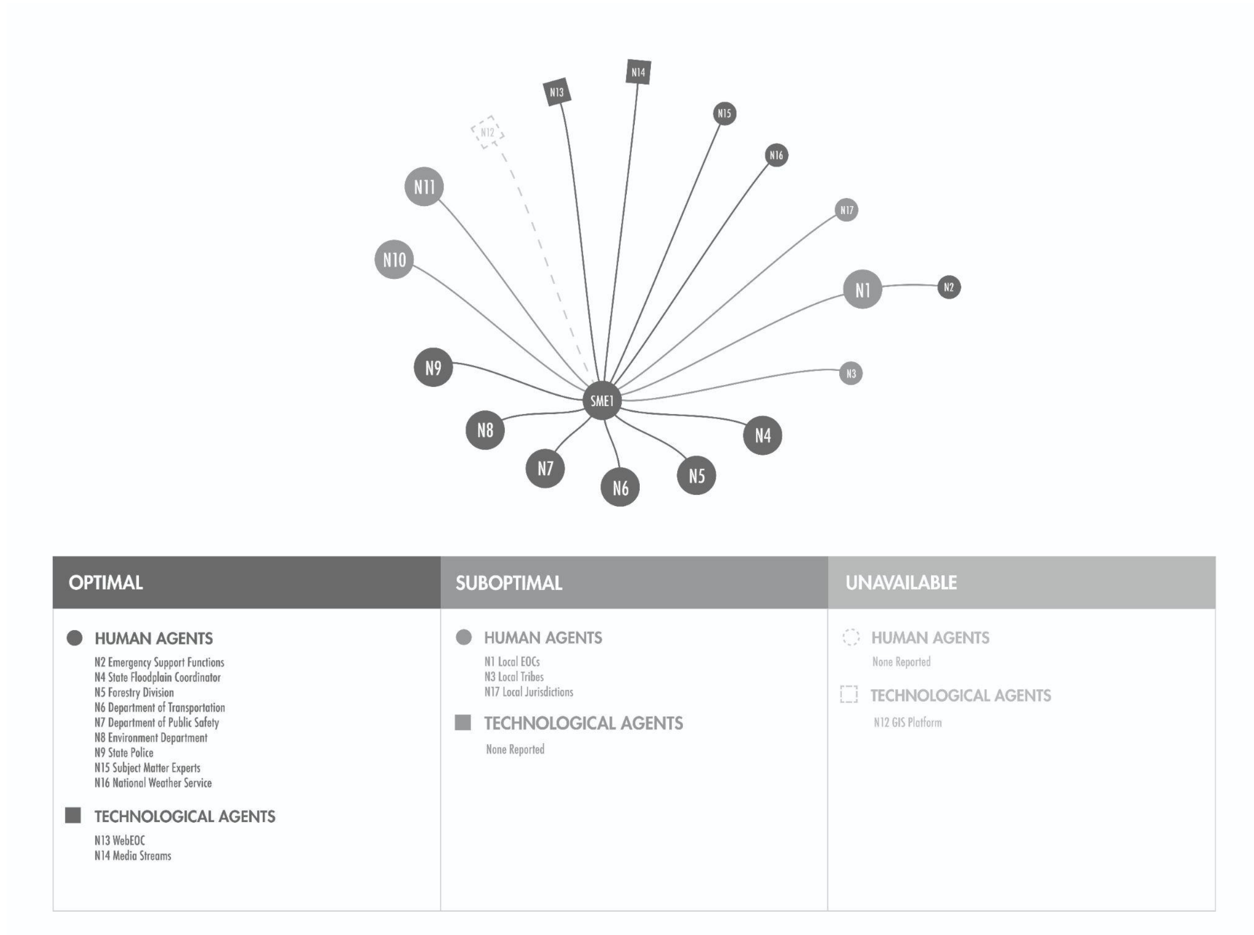

Figure 3: SME1 Collaborative Information Environment

Subject Matter Expert 1 (SME1) is the current Preparedness Bureau Chief at New Mexico Homeland Security and Emergency Management. In this role, they often serve as *planning section chief* or *situation unit leader* during active incidents, primarily those involving the natural hazards of flood, wildfires, winter storms, and high wind events.

SME1: Information Environment

Critical information needs are characterized as "on-the-ground" information, in order for the Preparedness Bureau to serve as a clearinghouse to support local emergency management functions. This type of information is generally sourced from local jurisdictions, tribes, and emergency management actors closest to the incident. In the event of a weather hazard, general and specialized data pertaining to the incident is also collected from the National Weather Service. An example of this specialized data is *site-specific microclimate analysis*, produced by NWS meteorologists on request from SME1. Depending on the incident, additional context may be solicited from adjacent state actors such as the forestry division office or floodplain coordinator. Given the demands of these incidents on local emergency management, as well as their dynamic and evolving nature, SME1 reports frequent difficulty in obtaining this critical "on-the-ground" information for Bureau and partner needs. A second obstacle in this regard is a noted lack of geospatial information products and support staff.

SME 1: Decision Environment

While SME1 stated they are "*not making decisions as the planning section chief",* broader input was provided about decision-making for unanticipated events by the Bureau at large. Primarily, increasingly extended wildfire seasons have compelled new considerations across all aspects of decision-making, including mitigation strategies and response resource management. Another area affecting decision-making was the advent of further-reaching hurricane impacts, as spinout from systems in the Gulf Coast approached New Mexico and intersected with monsoon season. Per SME1, fourteen hazards are officially identified as affecting New Mexico, which features highly variable topography and microclimate regions beyond its common perception as a "desert state". Winter storms and monsoon-driven flash floods were exemplified as hazards lacking sufficient public awareness, which may be compounded by changing, more frequent, or more severe climate-driven events.

SME 1: Collaboration Environment

Preferred method of communication was defined as email, given the ability to copy disparate parties and provide a "single source of truth" during an active event. Clear and efficient communication has generally been experienced between the Bureau and core partners:

"We have four or five agencies that we've worked with over the years and have a really good, solid working relationship."

Adversely, collaboration challenges have been noted with the advent of the COVID-19 pandemic, which has required complex and evolving inter-agency cooperation. A case example was provided on mitigation planning for public schools, which involved extensive coordination between the Bureau, Department of Public Health, and Department of Public Education as well as numerous supporting agencies. Planning tasks in this regard included opening schedules, capacity arrangements, and multiple logistical concerns such as the requisition and allocation of personal protective equipment for all public education employees.

3.2.2. Subject Matter Expert 2

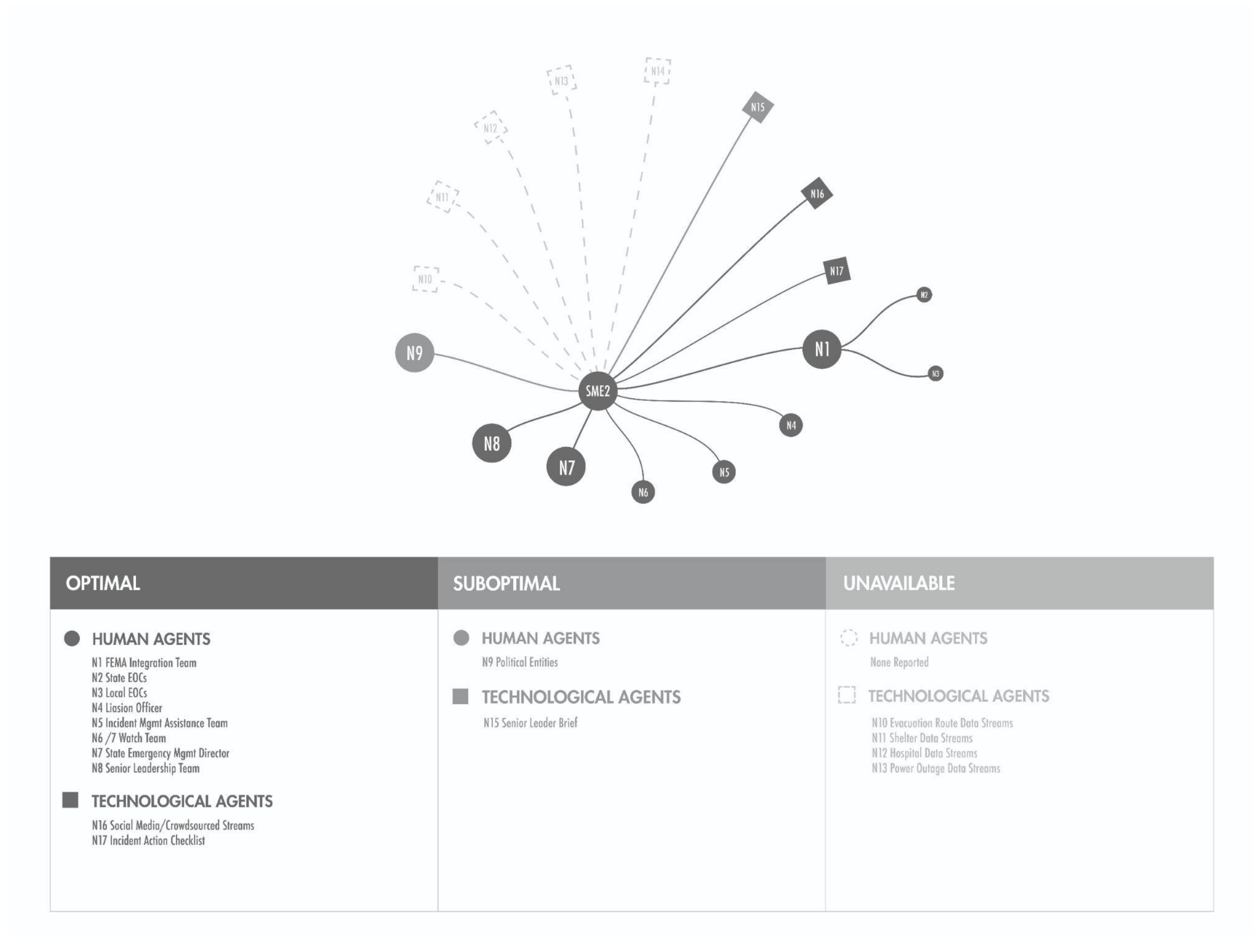

Figure 4: SME2 Collaborative Information Environment

Subject Matter Expert 2 (SME2) is a former Regional Administrator for FEMA Region 8. This jurisdiction encompasses a large portion of the western United States, including Colorado, Wyoming, Montana, North and South Dakota, Utah, and 29 federally recognized Tribal Nations. In this role, they were the senior leader administering all aspects of mitigation, preparedness, response and recovery for this region. While the events addressed in this role may be characterized as "all-hazards", floods and wildfires were identified as the most routine occurrences, and the COVID-19 pandemic was cited as the most significant emergent event.

SME2: Information Environment

Critical information needs during an active event were defined as those informing *"a situational awareness picture of what's happening out there."* Two categories of information were said to be immediately required – data regarding the significance of the event, and context informing the decision to declare a presidential disaster (eCFR, 2021). Key sources of this information were identified as designated human agents at the state level – the *FEMA Integration Team,* or *Liaison Officer* in the absence of this resource. Additional sources of information were characterized as *Emergency Support Functions (ESFs)*, or specified roles within an active emergency operations center (FEMA, 2020).

Social media was cited as another key source of readily available information, particularly Twitter, despite initial reservations by peers and colleagues: "*I'm gathering information from people that are on the scene in real time. So Twitter became an effective tool for me by accident… I discovered how valuable it is now."* Crowdsourcing was cited as another source of real-time information, however it was found more effective for "slower events like hurricanes" rather than "sudden events like earthquakes", owing to increased time for comprehensive insights.

In noting obstacles to collecting relevant and timely information, SME2 consistently described this process as *"just too slow"*. An example was given of the *Senior Leader Brief,* a document received from state and local entities twice a day, characterized as insufficient to support real time situation awareness. The most difficult information to obtain was often fatality and injury reporting, followed by evacuation intelligence, shelter and hospital capacity, and power outage data. Regarding customization of workflow and information environments, SME2 clearly stated *"The tools, we have to develop those ourselves"*. An example was given of the departmental *Incident Action Checklist*: *"We developed this from scratch for the exact reason that you're talking about. We needed an orderly process to guide ourselves through, finding out what the heck is going on."*

SME2: Decision Environment

As a division of FEMA, with relatively formalized incident command, decision points during an active event were described as clear and actionable with pre-defined triggers. An initial succession of these points was given as 1) involvement of FEMA Integration Team (or Liaison Officer), 2) activation of Regional Response Coordination Center, and 3) deployment of Incident Management Assistant Teams (IMATs). Contextually, IMATs were described as frontline responders entering into an active event, in order to assist local actors and report situational awareness back to the regional office. Following, information needs for the deployment of IMATs were characterized as highly important: *"That's a decision point for me… You don't want to throw them into a dangerous situation too fast, so there's all those factors that I need to consider."*

Continuing, two case examples were provided to illustrate unanticipated events of both a familiar and unfamiliar nature. The first involved decision-making during wildfires, characterized as somewhat routine yet entailing significant differences in resource needs, budgeting, and allocation concerns. The second addressed an unusual 2020 earthquake in the

Salt Lake City area, which necessitated structural damage assessment and other decision-making for which there was no defined protocol.

Overall, decision-making skills were seen as highly developed in the emergency management community, with particular value placed on quick, *satisficing* decisions that may be subject to change. Further, SME2 assessed their own decision-making as highly competent, given a previous 26-year career in the United States Air Force and status as Command Pilot with over 3800 hours of registered flying time. In summary, the perspective was given that emergency management professionals, including SME2, were competent, adaptive, and highly-skilled individuals who primarily lack accurate and timely information for optimal decision-making.

SME2: Collaboration Environment

Face-to-face interaction was highly preferred during an active event, although the mainstreaming of remote collaboration during COVID-19 has made this less common. Phone calls and text messaging were the next preferred means of communication, with email characterized as fairly obsolete. Clear and efficient communication was said to take place with key partners, defined as the *Senior Leader Team* and *State Emergency Management Director*. Accounts of suboptimal communication were given as both anecdotal case studies and generally observed patterns. An example of the former involved a state director who was quite reticent to communicate or build relationships in "blue-sky" periods. Further instances of suboptimal communication referenced political entities and elected officials: *"Some of them are really communicative, and some of them don't want to give you the time of day."*

In general, timely decisions were prioritized over extensive collaboration during an active event: *"I'm very good at collaborating when you have time to collaborate, and I prefer that – when you can get to a team together and work through it – but, you know, I'm not going to waste time if something needs to be made in the here and now."*

SME2: Additional Comments

In closing, SME2 noted that many issues addressed in this interview also pertain to information needs for the recovery phase, particularly at the intersection of damage assessment and funding allocation.

3.2.3. Subject Matter Expert 3

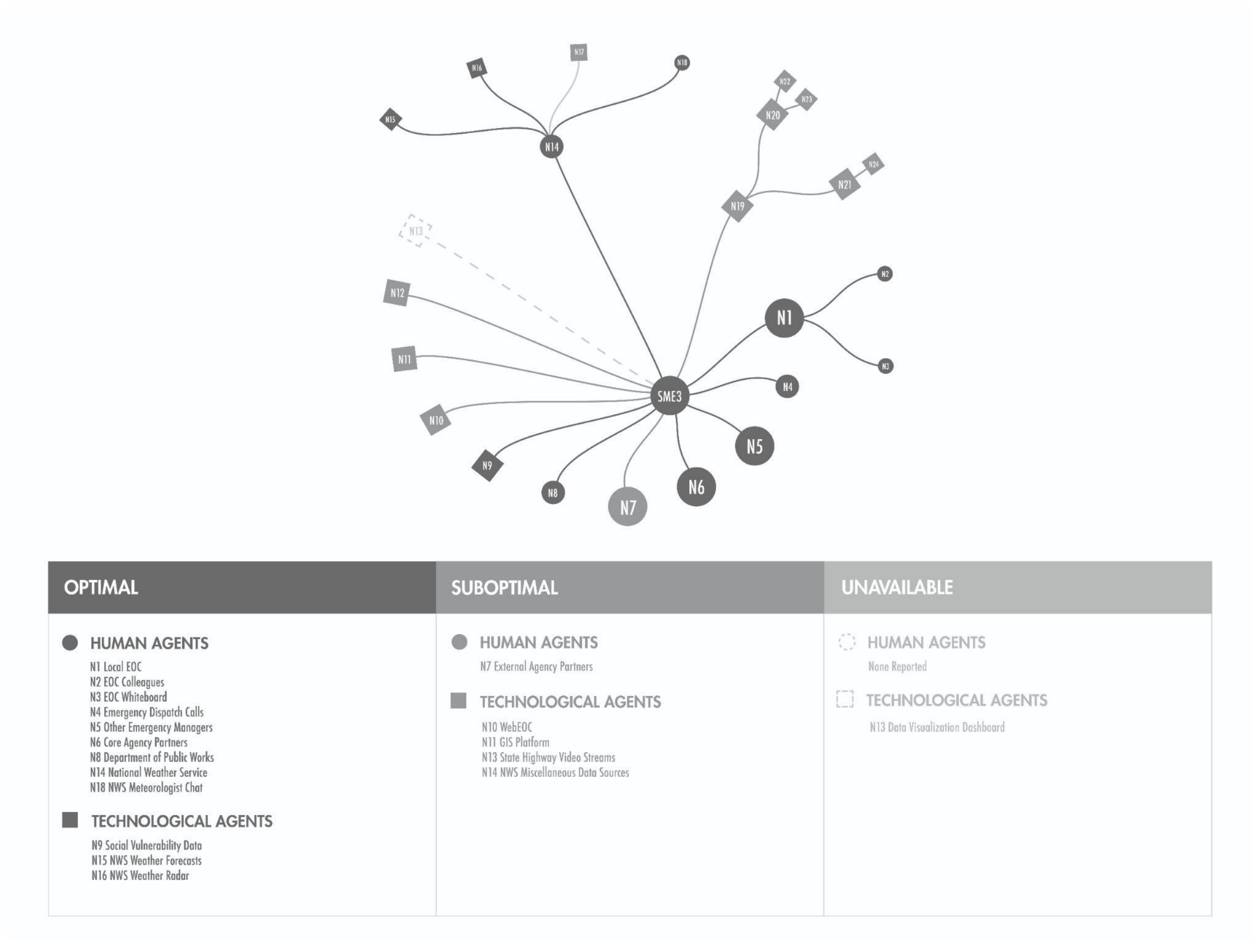

Figure 5: SME3 Collaborative Information Environment

Subject Matter Expert 3 (SME3) is the current Emergency Management planner for the Baltimore County Office of Homeland Security and Emergency Management. Primary functions were defined as creating emergency plans for all potential hazards, coordinating with partner agencies, organizing planning committees and meetings, and conducting corresponding exercises. Further responsibilities were given as community outreach engagement, public information messaging, and *"really, anything from hazard mitigation to preparedness to response to ESD duties to recovery."* Typical events addressed in this role were listed as flooding, severe storms, wind, tornadoes, and structure fires.

SME3: Information Environment

Critical information needs during an active event were characterized as *"weather related or not, just… the most situational awareness we can get."* Sources of this critical information were reviewed as fairly disparate, originating from multiple agencies, information systems, and monitoring networks. Sources of weather data were specified as official government entities only, including the National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). These sources of weather information were characterized as fairly easy to access, with ongoing, unimpeded communication between SME3 and the agencies via chat channel. Contextual information was also derived from existing *risk and vulnerability analysis*, which informed resource allocation during and after an active event. Obstacles to obtaining critical information were identified as organizational *siloes* and a lack of standardized process in exchanging information between various agencies. Additional impediments were the reticence by some agencies to share information if they did not know or understand the purpose of the request, or it was assumed to be a routine function. Useful information that was not always available included various geospatial and data visualization products.

Notably, SME3 has extensively customized their physical information environment through the following means. First, multiple screens are utilized to maintain situational awareness across diverse platforms and sources such as those cited above. Then, the screens are generally divided by "social and operational" streams of information, using multiple browser tabs, with social media feeds further organized through the use of TweetDeck or HootSuite. In the example of a severe storm watch, this typical setup features ongoing real-time feeds such as weather radar, chat channels, social media, Google Maps, and a WebEOC interface for internal communications. Lastly, a further point was made regarding not just the collection of information, but additional tasks in collating, organizing, and documenting this input for *Situation Reports* and other agency deliverables. These tasks were characterized as universally time-consuming and resource-intensive: *"I have to collect that data… so it's copy and paste, make a list, track that stuff... and I really don't like that because we're busy."*

SME3: Decision Environment

When queried about critical decision points of an active event, SME3 described a case-by-case process largely informed by potential impacts to the community rather than pre-defined triggers such as storm severity: *"I'm monitoring the data… I'm going to make the decision when people's lives are getting affected to a degree where they could be in danger or they're going to require recovery resources."* In terms of unanticipated events, SME3 felt that current forecasting resources were largely sufficient to avoid many "surprises". However, variability of impact was noted as a potential concern. In the longer term, climate-driven events were seen as an area of increasing uncertainty, particularly regarding urban flash flooding and waterfront sea level rise. Further perspective was offered on decision-making around these changing assumptions: *"I try to remind people – with climate, and especially with the flooding – a lot of our past data does not reflect all the changes that are going on now."*

SME3: Collaboration Environment

During an active event, SME3 largely preferred face-to-face debriefing in the context of a physical EOC. Advantages in this setting were given as easier and faster communication, increased context through overhearing ambient conversations, and the use of common resources such as a large whiteboard for timely visual updates. Clear and efficient communication was said to take place with core partners, defined as *"people we work the most with, agencies we plan the most with"*. Multiple instances were given of suboptimal communication, most notably regarding a shift toward virtual collaboration during the COVID-19 pandemic: *"It's very challenging for people to share information (solely) through technology… I just did not feel confident in the information we were sharing, the decisions being made, and I felt like there were huge gaps."* Suboptimal communication was also observed when working with supporting agencies on an infrequent basis, or with external partners who were generally unfamiliar with the emergency management system.

SME3: Additional Comments

In closing, SME3 reiterated a need for streamlined, cross-platform systems of data sharing, as well as standardized protocol for request and authorization of this information.

3.2.4. Subject Matter Expert 4

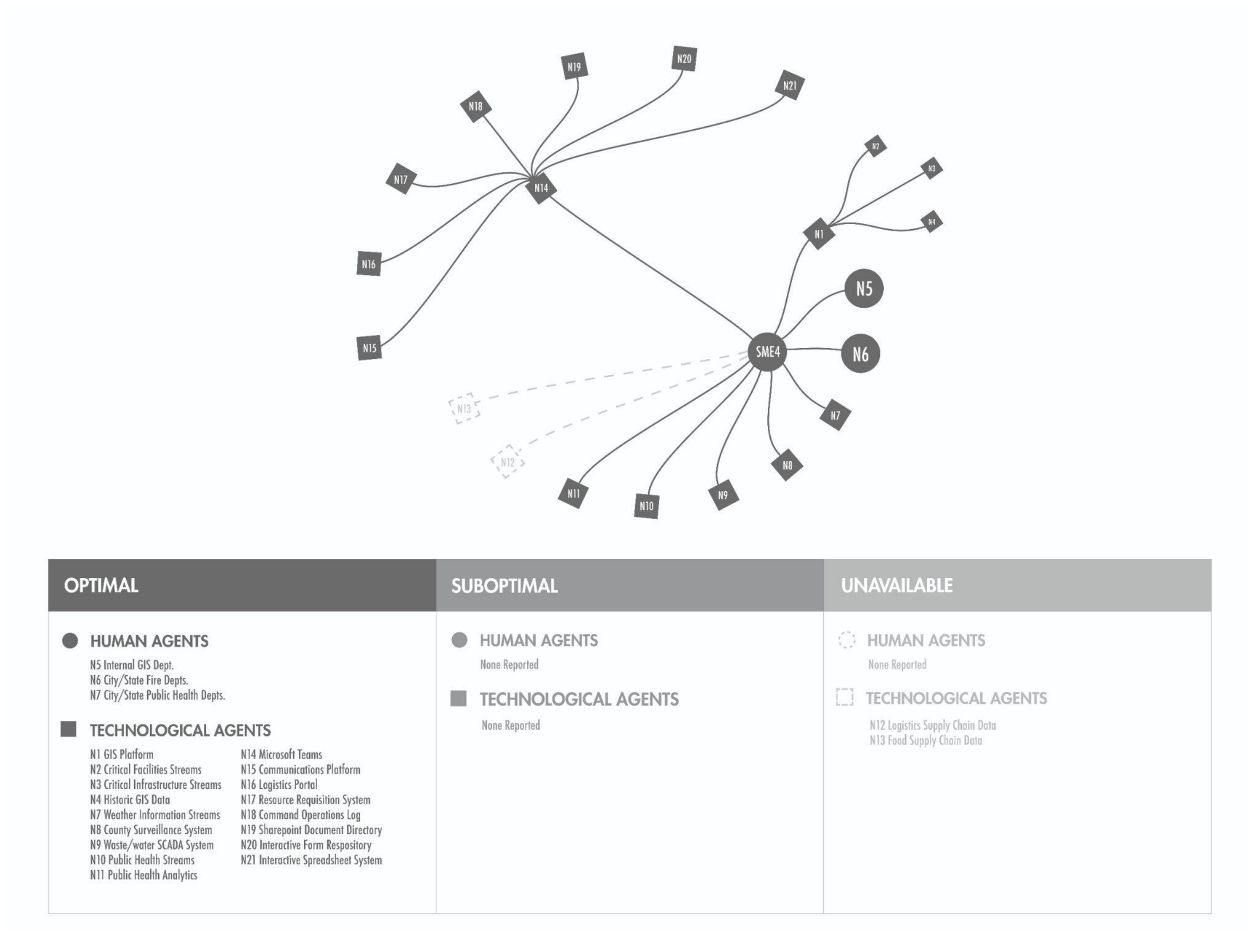

Figure 6: SME4 Collaborative Information Environment

Subject Matter Expert 4 (SME4) is the current Emergency Manager for the city of Ventura, California. Primary functions in this role include overseeing all emergency operations during an active incident, as well as preliminary training and subsequent after-action reporting. Further responsibilities include organization of the Ventura County Emergency Operations Center and associated Emergency Operations Plan. Additionally, SME4 is also involved in policy development to improve all-hazards readiness for the City and County of Ventura. A current focus at this time is using hazard and vulnerability assessment to refine formal mitigation strategy, with efforts centering around a “crucible” earthquake event which may inform planning for other incidents. In addition to earthquakes, other events addressed in this capacity include the ongoing COVID-19 pandemic and periodic wildfires.

SME4: Information Environment

During an active event, *"real-time intelligence"* was characterized as critically important from both an emergency management and public information perspective. Emphasis was placed on keeping the public optimally aware of unfolding events, to mitigate unrest and confusion such as that observed during the 2017 Thomas Fire event. Sources of critical information for the City of Ventura span a broad collection of data streams including real-time public health statistics, continuous monitoring of critical facilities, SCADA systems for water and wastewater management, and a comprehensive network of traffic cameras throughout the county. Further, the City of Ventura possesses dedicated geospatial resources and staff, enterprise GIS accounts for all 650 employees, and a four-decade history of proprietary data collection to support all city operations. Given these expansive resources, SME4 characterized many forms of critical information as easy to obtain, with highly refined granularity and insights available through intersecting and assesseing these feeds.

While most sources of critical information were said to be suitably accessible in this setting, two areas of information were found to be lacking: "*The one that's probably the missing link, a public-private kind of sector thing, is the logistics supply chain, or the food supply chain."*

Regarding optimization of the personal information environment, SME4 provided an extensive account of bespoke customization using the Microsoft Teams platform and associated resources such as Sharepoint and PowerApps. This setup was enacted by SME4 when the city's emergency operations center went entirely online at the advent of the COVID-19 pandemic. At the time of this interview, a team of 120-130 people had been using this system for over one year, reporting satisfactory execution of essential tasks requiring information sharing and collaboration. Constructed solutions in this regard included a logistic portal and resource requisition system, a command operations log, a well-organized directory of plans and reports, interactive forms such as the ICS214, and live embedded spreadsheets for real-time recordkeeping.

SME4: Additional Comments

Unfortunately, this interview ended after 30 minutes, and SME4 was unable to reconvene at that time or subsequently. However, multiple characterizations of the decision-making and collaboration environments were provided in this account, and will be addressed in the Discussion section of this paper.

3.2.5. Subject Matter Expert 5

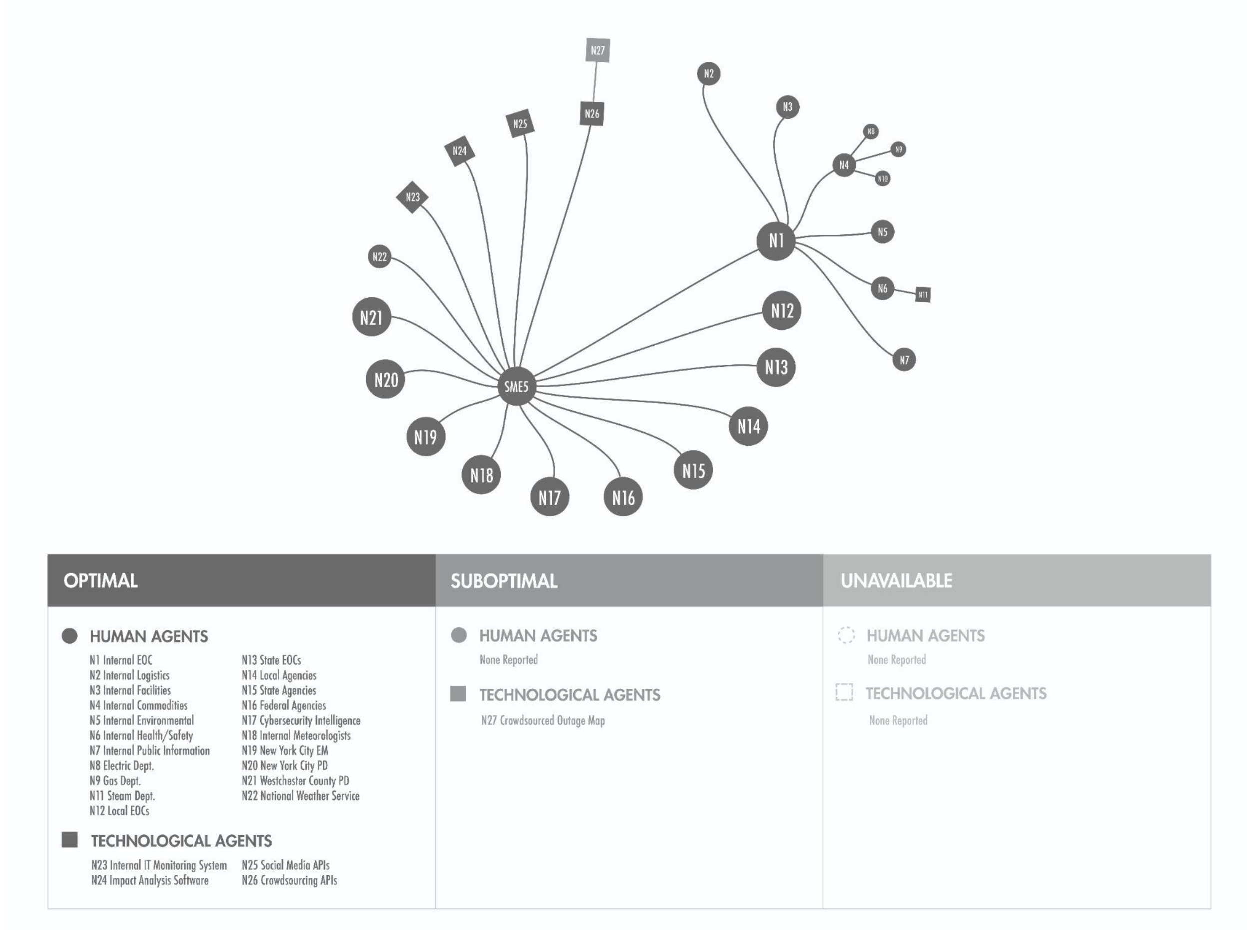

Figure 7: SME5 Collaborative Information Environment

Subject Matter Expert 5 (SME5) is the former Vice President of Emergency Preparedness and Business Resilience for Consolidated Edision of New York. This utility is one of the largest in the United States, covering the entirety of the New York City metropolitan area as well as many surrounding vicinities. Primary functions in this role were characterized as: *"Anything that had to do with any kind of emergency response."* Additional responsibilities involved serving as the lead liaison for the company to all federal, state, and local agencies during an active event response. Further, SME5 directed many response efforts during Superstorm Sandy, including the organization of mutual aid assistance between multiple public and private agencies. Other events addressed in this role were of an "all-hazards" nature: *"I dealt with everything from storms to cyber through pandemic planning through business continuity."*

SME5: Information Environment

Critical information requirements during an active event were generalized as *"situational awareness"*, with the specification of different needs depending on the hazard. In the case of severe weather events, ongoing meteorological information as well as impact modeling were said to be essential in maintaining effective awareness. Concerning cybersecurity incidents, real-time intelligence from key partners was said to be crucial in assessing and remediating the situation. An additional note was made on the importance of obtaining timely data for the purpose of public information, in order to dispel inaccuracies and provide consistent, unified messaging.

The above input was derived from a wide variety of sources, including multiple departments within the organization, key external agencies and partners, a robust corps of in-house analysts, and various social media and news wire outlets. Further, proprietary analytics were said to provide critically intersectional insights on cascading events and impacts, beyond simple ingestion of data feeds. A case example was given as follows: *"After a winter storm, I get information about how much salt they put down on the roads. We use that in an algorithm to determine if we're going to have burnouts, and that'll determine how many resources we need to keep on hand."*

Another source of information is collected through a public-facing map portal, where customers in the service territory may both view and report outage information. In all, while most sources of critical information were seen as fairly easy to obtain, minor impediments – and effective solutions – were described regarding this portal: *"We have people monitor it 24/7, and we have an internal outage management system, so they have a side-by-side view to compare."*

Regarding optimization of personal workflow and information environments, SME5 described a comprehensive, bespoke process initially organized by the company's IT team. Extensive protocol was enacted around the documentation of activity logs, liaison communications, and decision-point tracking, primarily through use of the Microsoft Sharepoint platform. Beyond core operations, this system was also used in the development and documentation of relevant training and exercises.

SME5: Decision-Making Environment

Critical decision-making during an active event was described as a largely collaborative process, owing to multi-agency stakeholders and many functional interdependencies involved in operating the utility. An initial decision process was characterized as 1) ingesting all available critical data, 2) estimating the severity and impact of the event, and 3) declaring the level of response based on this composite information profile. From this point, the category of event is derived from this level of response, and structured protocol is enacted through an internal emergency response plan as well as formal Incident Command System (ICS) guidelines. In the case of Superstorm Sandy, this process was illustrated as follows:

"Superstorm Sandy is a good example, we were talking about the amount of storm surge that was coming in. They want to know if we're going to shut down the network, which impacts the subway system. I call it 'the chicken or the egg' because they may shut that down before we shut down the network, so we're always communicating about those situations."

Decision triggers were said to be largely pre-determined, such as those documented in the *Emergency Response Plan* of various incidents. Triggers for weather-related hazards involved pivotal metrics such as wind speed, volume of rainfall, and ice accumulation. Cybersecurity triggers were generally enacted through control center monitoring, with alert notifications issued via SMS and email. Further, some degree of advanced notice was often provided in these cases, through key partners such as the Federal Bureau of Investigation (FBI) and Department of Homeland Security (DHS). In general, positioning for critical decisions during these incidents was described as wholly proactive.

While SME5 described comprehensive capabilities of forecasting and assessment, owing to the company's extensive risk management resources, one *unanticipated and unfamiliar* event was said to be an unlikely but potential earthquake impacting the New York City metropolitan area – such as that taking place at nearby Mineral, Virginia in 2011. *Unanticipated but familiar* events were characterized as security breaches, facility fires, and explosions. In all cases of unanticipated events, increased importance was placed on collaborative decision-making in order to assess and mitigate the situation through potentially novel means. Further, defining "known unknowns" in these events, rather than making estimations or assumptions, was seen to be highly important to an effective decision-making process.

SME5: Collaboration Environment

Critical communication during an active event was said to take place by *"any means possible"*, however, group texting and email were commonly used to reach multiple contacts in a time efficient manner. A case example in this regard was the re-energization of the network after Superstorm Sandy, which involved timed group texts and carefully orchestrated collaboration. Examples of clear and efficient communication were illustrated by the use of *"common lingo"* with steam, gas, and electric operators, a position that SME5 had previously held in their career.

Examples of suboptimal communication were said to be fairly infrequent, however the following anecdote was given of communication dynamics with a new colleague: *"You have to kind of 'meet him in the middle of the battle', and that's unfortunate. But I'm going to say that's probably few and far between."*

SME5: Additional Comments

Above all, SME5 emphasized the value of “blue-sky” relationship building, as well as regular exercises which improved organizational dynamics, tested all related hardware and software systems, and served to effectively integrate these two aspects. In closing, the following was given regarding optimal design of collaborative decision support systems:

It’s… intelligence of what's happening, situational awareness, but then it's collaboration and coordination. And how can we make it more effective. That's the golden nugget, right there.”

3.2.6. Subject Matter Expert 6

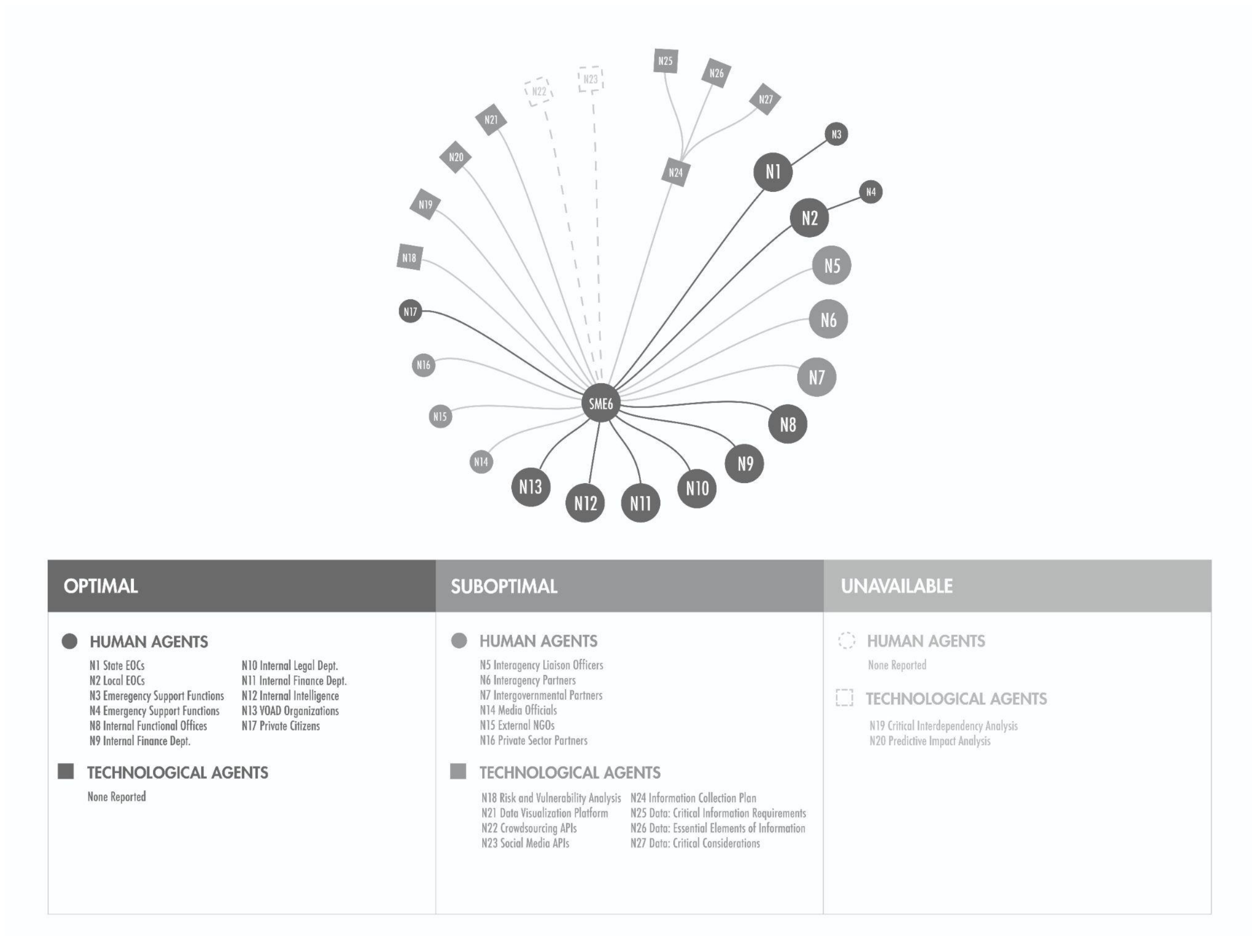

Figure 8: SME6 Collaborative Information Environment

Subject Matter Expert 6 (SME6) is the former Director for Incident Management Integration Policy at the White House National Security Council. In this role, they coordinated policy decisions between the Executive Office of the President and all pertinent agencies for major disasters and incidents. Further, SME6 oversaw multiple aspects of emergency management, as well as related training and exercises, for the U.S. Department of State, Defense Logistics Agency, and National Institutes of Health. Types of events addressed in this role were characterized as general incidents and all-hazards, taking place in both United States jurisdictions and territories as well as humanitarian settings abroad.

SME6: Information Environment

Information collected during an active event was formally delineated as *critical information requirements* and *essential elements of information,* per the *Information Collection Plan* (ICP) organized by the *Situation Awareness Section Lead:*

"The ICP is a matrix of information requirements that is keyed to the incident. This plan also lists sources, units of measure, and schedules for collecting various items. Information gathered based on an ICP can aid in the development of incident objectives." (FEMA, 2015, p.68).

Of this information, *ground truth* was characterized as crucial to maintaining effective situation awareness throughout the duration of the incident. Preliminary impact and damage assessments were described as imperative, to inform both initial response and recovery efforts following the event. Details in this regard included reporting on infrastructure status – such as communications, power grid, roadways, and port or airstrip capacity – as well as contextual information such as transportation and logistics capabilities, existing mandates, and political climate.

Important sources of critical information were given as *Emergency Support Functions* (ESFs), interagency liaison officers, community volunteer organizations, and various private sector partners. None of this information was characterized as particularly easy to obtain, and multiple challenges in this regard were described in detail. The first obstacles commonly encountered were existing political structures and organizational hierarchies, which often served to impede information flow, create *siloes*, and produce suboptimal communication patterns. Further, these impediments were said to be at times intentional, with access to critical information becoming a political leverage point. SME6 noted that this propensity directly impacted communities affected by disasters and incidents, as well as creating marked inequities in the response and recovery process.

Another impediment to accessing critical information during an active incident was said to be willful misreporting of vulnerability data, stemming from financial advantages that may be gained by infrastructure and facility owners falsifying this information. A case example provided was the 2017 *Hollywood Hills Incident* in Miami, Florida, during Hurricane Irma. This highly publicized power and air conditioning failure at a private care home resulted in 12 heat-related deaths, an extensive criminal investigation, and swift changes to emergency preparedness policy for such facilities.

Regarding critical information that was often missing or difficult to obtain, SME6 said: "*Analysis and visualizations to me are helpful to connect the pieces of the puzzle together,"* and further clarified *"No one is feeding that information into a central system where we can go in and look and see."* In reference to critical information gaps during the 2017 hurricane season, both on the US mainland and in the Caribbean, SME6 continued with the following: "*If we could visualize how the system is failing across this… system of systems, we might have had some better insight. If we had a better sense of that data and information and insight pre-event, then we would have been much faster to respond.*

Lastly, SME6 conveyed the importance of real-time collaboration in collecting critical information: "*Information is essential and critical, and if we don't have the information to inform our plans, our plans are incomplete or not possible to execute on. But it all requires cooperation on the ground."*

SME6: Decision-Making Environment

SME6 described well-defined decision triggers during an active event, generally initiated by the *critical information requirement* as outlined through the Stafford Act. This specification sets pre-determined threshold criteria for escalating an incident to the President, in order for a federal disaster to be declared. An example would be the request for federal assistance by a state governor, which invokes a damage assessment process by FEMA, who in turn submits this information to the President for consideration. While this structure described much of the decision process involving SME6, additional triggers for action and decision-making were said to be the severity and/or political nature of the incident.

Several case examples were given of unanticipated events, characterized in this setting as "no notice" disasters for which there is no pre-existing plan. Events of both an *unanticipated and unfamiliar* nature were given as the Oroville Dam breach, Colonial Pipeline incident, and widespread lead contamination affecting the public water system of Flint, Michigan. SME6 provided perspective on resources that would have aided this decision-making:

"If we at least had some type of flexible plan to respond to – focusing on building capacity around crisis management concepts and philosophies, versus being so narrowly focused on one specific hazard and how to respond to that thing. Because that's going to bias your thinking and decision-making investments in responding to future crises."

SME6: Collaboration Environment

During an active event, SME6 cited multiple means of communication including email, SMS, radio, and apps such as Teams, Slack, and WhatsApp. Clear and efficient communication was said to take place during "*events that are easier to mitigate, or ones that you… can at least influence the mobilization of a resource."* One case example in this regard was the loss of power and chilled water capacity at the National Institutes of Health, endangering the lives of many animal test subjects and additional study resources. Given the facility-based scope of the incident, and continuation of other supporting infrastructure such as communication systems, efforts to collaborate and resolve the incident were fairly swift and streamlined. Regarding suboptimal communication, multiple instances were cited during the restoration of power grid services in Puerto Rico after Hurricanes Irma and Maria in 2017. These instances involved a language barrier, heavily-impacted single phone line to the primary utility, and limited email bandwidth for sending critical files. Ultimately, an internal team was deployed to the site equipped with satellite phones and internet hotspots in order for communications to continue. Further, SME6 noted an aspect of organizational dynamics as well as sufficient technological capacity. Governance, roles, and command structure were all said to inform clear understanding of intended information flow: "*It all depends on your environment, and then of course it also depends on the discipline of the team. So this is both an infrastructure issue as well as a governance issue.*"

SME6: Additional Comments

In closing, SME6 stressed the importance of building adaptable, cross-functional, and well communicating teams, and underlined the perspective that technological solutions and information systems must be built to wholly support this objective.

4. Discussion

4.1. Intersectional Overview

While each interview was organized to address the three environments as specified in Section 2.4.3, key themes and critical tasks were also identified at various intersections of these areas. The following examples are not intended as rigid categorization nor exhaustive review, but serve to illustrate principal concerns that may be considered at these junctures.

SME1, responsible for data aggregation at the state level, conveyed the importance and difficulty of working with local authorities and teams on the ground to collect critical information during an active event. This task, and the inter-agency coordination involved, depicts a primary intersection of the *information and collaboration* environments. SME6 further elaborated on the importance of this intersection, providing multiple examples of both effective and suboptimal information-sharing as well as effects of this aspect on critical tasks and mission objectives. More on common challenges and obstacles to this information sharing are described in Section 4.2.1.

SME2 and SME5 addressed the juncture of *collaboration and decision-making*, from two comparative viewpoints based on differing roles and functions during an active event. SME2 characterized a need for swift if individual decision-making, subject to change after evolving communication. SME5 required multi-actor coordination from the outset, given the essential synchronization of multiple infrastructure control systems. Notably, each approach is unique to the incident and resources at hand, as well as individual SME responsibilities and contextual knowledge. This comparison underlines the highly case-specific nature of collaborative decision making in emergency management, and suggests a need to provide flexible, adaptive support solutions – with user-defined decision criteria – rather than assuming "best practices" or standardized taskflows.

SME3, SME4, and SME5 provided extensive accounts of the relationship between personal *information and decision-making* environments, with further applications to *ecological task analysis* as in section 4.3. SME3 described a wholly self-customized information environment, choosing and arranging various streams to support decision-making across a wide range of functions. Further, information resources from previous roles were described, and compared with the current setup to illustrate how decision-making was directly affected. SME4 and SME5 characterized a highly accessible information environment, which in combination with predictive analytics provided deeply granular insights to support optimal decision-making. Generally, all SMEs described a sufficient information environment as crucial to maintaining situation awareness and an optimal decision-making process.

In sum, this intersectional perspective may begin to contextualize user requirements in a more dimensional manner. Further, system architecture requirements may also be informed by this assessment – such as integrations at the juncture of information management and communication features, which may require specific configurations of role-based access control (RBAC) or other permissioning.

4.2. Common Themes

In reviewing all summaries, the following themes were identified as appearing more than once across multiple SME interviews. Identification of these common themes may be used to further inform user and system requirements, moving toward evidence of typical needs beyond singular edge cases.

4.2.1. Common Challenges

Consistently, organizational and departmental *siloes* were cited as a barrier to effective collaboration as well as the acquisition of critical information during an active event (all SMEs). Reasons for such obstacles included inherent hierarchical structures (SME1, SME2, SME6), miscommunication regarding urgency and priority of information (SME1, SME4), technological mishaps such as cross-platform incompatibility (SME1, SME4), and intentional obstruction for personal or political gain (SME3, SME6).

Further, the advent of COVID-19, and concurrent adaptation toward online and remote work environments, were said to compound many of these issues (all SMEs). Examples were given regarding shortcomings of existing platforms to serve these needs, such as WebEOC (all SMEs).

4.2.2. Common Success Factors

Conversely, multiple instances of clear communication were cited as the most common success factor in meeting critical tasks and objectives during an active event (all SMEs). Examples of this success were found in the use of common terminology (SME3, SME5), previous collaboration during exercises or active events (SME5, SME6), and partnerships with familiar or adjacent agencies trained in similar emergency management protocol (SME2, SME3).

A second defined success factor was accurate “ground truth” regarding the active event, of an ongoing and real-time nature (all SMEs). Further, sufficient data to analyze, forecast, and generate contextual insights beyond these streams was characterized as highly useful, to proactively inform tasks such as logistical planning (SM3), resource allocation (SME4) and impact assessment (SME5). Details on requirements for specific data streams are provided in Section 4.4.

4.3. Ecological Task Summary

Several instances were given of SMEs needing to customize, modify, or otherwise adapt their personal information environments in order to obtain critical data, support decision-making, and/or maintain effective collaboration during an active event. Following the premise of ecological task analysis, this effort represents a mismatch between needed information and availability of this information in the environment, with such adaptations suggesting increased cognitive taskload in their implementation and maintenance. Allusions to this taskload – as well as time-intensivesness – of these adaptations were clearly stated: *"The tools, we have to develop those ourselves"* (SME2) and "*I have to collect that data… I really don't like that because we're busy."* (SME3). While not explicitly stated, implications for both system and interface design may be inferred from such accounts based on the tools, workflows, and processes developed by the user to meet identified gaps. Following, these implications represent a move from general task context toward specified needs, and contribute to the shaping of more concrete and formalized requirements.

In this study, accounts of such adaptation included a wide range of constructed resources primarily described by SME2, SME3, and SME4. A first area of adaptation was the creation of live, shared collaboration assets, such as the *Incident Action Checklist* developed by SME2 to maintain situation awareness of teams, tasks, and information throughout the timeline of the event. Another area of adaptation involved data collation for reporting purposes, described by SME3 as a manual curation of multiple information streams into various Excel sheets, briefings, and other customized outputs. A third area of adaptation was given by SME4 in the extensive modification of personal Microsoft Teams and Sharepoint interfaces, to access information resources available in the larger organization. This last case, in particular, illustrates the difference between system and interface needs, and the importance of suitable design solutions for both sets of requirements.

4.4. Direct Recommendations

Lastly, the following requirements were directly stated in order to inform the optimal design of collaborative decision support systems to support SME needs.

Geospatial Visualization

Maps and related visual assets were requested multiple times by several SMEs. Dynamic information layers depicting assets, impacts, and other key points of information – updated in real-time – were said to be crucial resources during an active event. Further context provided by static data layers was also given as important, in order to better assess this information. This static data was said to include fixed assets such as critical infrastructure, as well as previous inputs from mitigation and preparedness activities such as formal risk and vulnerability analysis.

"*I want to see a map. I want to see it geographically, where the resources are, where the damages are, where other assets are placed around the state." (SME1)*

"*I'm very visual, so I want maps, I want dashboards. I want to be able to see where resources are and see the units and see what's open and closed." (SME3)*

Real-Time Data Streams

Following the above point, multiple real-time data streams were specified by all SMEs as critical to maintaining optimal situation awareness during an active event. The following categories of data were given in this regard:

- Weather status and microclimate analysis (all SMEs)
- Preliminary damage and impact assessment (all SMEs)
- Critical infrastructure status (e.g. power and roadways) (all SMEs)
- Critical resource status (e.g. hospital capacity) (SME2, SME4, SME6)
- Social media and crowdsourced context (SME2, SME3, SME5)
- Evacuation intelligence (e.g. traffic and shelter capacities) (SME2)
- Cybersecurity and internal incident monitoring (SME5)
- Fatalities and injuries (SME2)

Streamlined Collaboration Environment

This requirement was defined most clearly by SME5, who characterized an ideal collaborative platform as a "single pane of glass" experience, approximating live interaction in an emergency operations center as closely as possible. Streamlined and efficient solutions in this regard were said to be wholly necessary, in order to mitigate collaboration obstacles as cited in Section 4.2.1. As these difficulties may be fairly typical to many organizations, avoiding further impediment through ill-designed technology was of clear and critical importance. Specifically, support for multi-actor and inter-agency information sharing was outlined as crucial, and further specified through permissioning and system architecture requirements as posited in Section 4.1.

Information Management

Following the priorities of effective collaboration and optimized individual awareness, well organized and accessible information systems were said to be crucial in supporting these objectives. Clear requirements, derived from critical tasks, were stated by SME3 in this regard. Such requirements included functions to collate, organize, and document key data points from critical information feeds, as well as means to package these insights and share in a reporting capacity. Streamlined information sharing, aligning cross-platform and multi-format data, was a highly desirable feature and characterized as a system requirement for extract-transform-load (ETL) capabilities. Further, architecture to support standardized request and authorization protocol for this information was described as highly important.

Additionally, the resources described by SME4 for the City of Ventura were suggested as "best practice" examples of such features, given the high level of satisfaction and task success reported by this organization. These included a dedicated logistics portal and resource requisition system, a command operations log, a well-organized directory of plans and reports, interactive forms such as the ICS214, and live embedded spreadsheets for real-time recordkeeping.

5. Conclusion

This pilot study was intended to refine an elicitation method in order to answer the research question:

"How should requirements elicitation for emergency management decision support systems be conducted?"

A preliminary literature review, across models and methodologies to approach *situation awareness* in high-performance team settings, served to first address this question. Results of these findings cohered a perspective that comprehensive, systems-focused assessment is recommended, which is inclusive of both human and technological agents.

To this end, the *Information-Decision-Collaboration Assessment* (IDCA) was developed as a normative design science artifact and elicitation approach, to test these findings and collect user requirements in this context. Development of the method was informed by the *distributed situation awareness* concept, a holistic framework for assessing sociotechnical information systems, and related EAST methodology as authored by Stanton et al. (2019). From this departure point, the method was iterated for this study to include *ecological task analysis* after Kirlik (1996), in order to more pointedly define gaps, needs, and requirements for both system and interface design. This iteration produced the preliminary version of the IDCA, presented here, which diverges from previously published methods to better suit the research context and question as specified. Further iteration, such as the inclusion of adjacent methodologies specified in Section 3.1.3, may serve to refine the method for subsequent elicitation beyond the scope of this pilot study.

While the *Information-Decision-Collaboration Assessment* may be used – and is intended – to inform a larger body of analyses, the defined scope of this paper has focused on a pilot interview method suitable for capturing and contextualizing input to these analyses. Empirical results of these interviews encompassed a wide variety of content, first organized by the *information, decision-making,* and *collaboration* environments, then assessed at the intersection of these concepts, followed by a breakdown into common themes, challenges, and success factors, continuing through implied requirements via *ecological task analysis*, and finalizing with directly stated requirements.

Lastly, and importantly, the semi-structured nature of the interviews allowed for the capture and assessment of emergent themes and in-vivo terminology, which revealed important perspectives not previously considered at the outset of this study. Primary among these insights was a consistent thread on the critical importance of strong collaboration, for which any platform or technological solution must serve to support. The reported prevalence and commonality of information *siloes* and inter-organizational friction, during an active event, offers an important perspective that not all issues may be solved with technology. This conclusion serves to frame, and highlight, an essential takeaway of this study – that a first step in building effectively collaborative decision support systems may be to clearly understand **what is a software problem, and what is a social problem.** Given this key result, further iteration of the method may involve deeper social analysis, communication assessment, or study into peripheral activities such as “blue-sky” teambuilding.

In closing, the *Information-Decision-Collaboration Assessment* served to answer and refine the research question, by applying a comprehensive means of assessment which included human and technological agents, to produce distinct and actionable requirements. The methods utilized herein produced a comprehensively integrated body of data, including both specified system requirements and supporting contextual information regarding multiple task environments of the user. The pilot interviews were employed to test the method by collecting empirical data, and provided both support for its value as well as guidance for further iteration.

Following the design science process outlined in Section 2.1, further use of the method may address a next research question of *whether the artifact has improved things for stakeholders* (Wieringa, 2014). In this context of this study, that question may be defined as whether outcomes of the *Information-Decision-Collaboration Assessment* have in fact been applied to a decision support system used by emergency managers, resulting in a measurably beneficial experience. To that end, at the time of this writing, insights derived from this study have informed prototyping and design of the DICE decision support product currently in development by Disaster Technologies Incorporated, a public-benefit company providing situational awareness to emergency managers, utility owners, and other stakeholders with a vested interest in public safety. Most recently, the *Mission Manager* feature of this platform has been used to conduct training and exercise activities at Homestead Air Reserve Base, in Miami-Dade County, Florida, for the 2021 Atlantic hurricane season. While pandemic travel restrictions limited the ability to collect empirical data in this setting, and base security disallowed remote attendance, preliminary feedback was favorable regarding the support of critical tasks and objectives as executed through the platform.

Given this initial success, next activities are planned with key partners and city emergency management officials in order to observe collaborative workflows in an emergency operations center during a live event. The intended outcome of these activities is to further contextualize interview feedback, triangulate accounts between multiple members of the same organization, elicit additional data to conduct in-depth assessment – such as a *propositional network analysis* to better understand social and communication issues – and continue to refine and expand the methods presented in this study.

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Annex 1: IDCA Interview Questions

Respondent Profile

P-1. Demographics (Age, Gender, Level of Education)
P-2. Geographic Work Jurisdiction (City, State, County, Region, etc.)
P-3. What is your formal job title?
P-4. What is your affiliation, department, or agency?
P-5. What relevant positions did you hold previously?
P-6. What specialized training have you had in your current or previous positions?
P-7. In your own words, please briefly describe the primary functions of your position.
P-8. What types of events or ongoing situations do you address in your position?

Information Environment: Active Event

I-1. What critical information do you require during an active event?
I-2. From what sources do you solicit critical information?
I-3. When soliciting this information, what sources are often readily available?
I-4. When soliciting this information, what obstacles do you commonly encounter?
I-5. What information would be useful during an active event, that you are not always able to obtain?
I-6. To what extent are you able to modify your digital, virtual, or online work environment to best optimize your workflow?
I-7. What are these modifications, and how do you enact them?

Decision Environment: Active Event

D-1. During an active event, how do you know *if* you need to make a decision?
D-2. During an active event, how do you know *when* you need to make a decision?
D-3. What types of information generally trigger a decision, once you have received them?
D-4. How often is your decision-making an *unanticipated* process, involving *familiar* events?
D-5. How often is your decision-making an *unanticipated* process, involving *unfamiliar* events?
D-6. In your perception, how do these unanticipated and/or unfamiliar factors affect your decision-making?
D-7. In your perception, to what extent are you generally certain about the reliability of information you are using to make decisions during an active event?
D-8. In your perception, to what extent do you feel your decision-making is improvised, approximated, or a "best guess" given the nature of information you have available during an active event?
D-9. In your perception, how often do you feel you rely on past experience or similar situations to inform your decision-making?
D-10. How often do you receive further critical information or communication, after making a decision, that may have altered its outcome?

Collaboration Environment: Active Event

C-1. What methods do you use to communicate with others during an active event?
C-2. Where, how, and with whom do you generally experience clear and efficient communication during an active event?
C-3. Where, how, and with whom do you generally experience suboptimal communication during an active event
C-4. Do you employ any standardized protocol (such as radio prowords) when communicating with others during an active event?
C-5. How often do you need or request further clarification after receiving communication?
C-6. How often do you feel roles, hierarchy, or “siloes” are a barrier to efficient communication in your organization?
C-7. How often do you feel personal communication styles are a barrier to efficient communication in your organization?

Annex 2: EAST: Supporting Literature

Perhaps most notably, Kalloniatis et al. (2017) present results of an Australian Defence Force study using the Situation Awareness Weighted Network (SAWN) approach. This method merges network analysis elements informed by EAST and the DSA concept with Endsley's model of personal situation awareness, resulting in a richly contextualized analysis which extends beyond previous contributions of either framework. While the study concluded somewhat predictable information patterns given the organization's command-and-control (C2) structure, the authors assert the method could be applied to more complex systems for key insights regarding communication, cooperation, and management practices. Further, the method is proposed for the assessment of future systems which may include more fully autonomous technological agents.

Continuing, Oosthuizen and Pretorius (2014) reference EAST in a *cognitive work analysis* (CWA) study informed by system dynamics concepts. The study assesses a community policing forum and neighborhood watch group, who are using a new collaborative platform to manage organizational assets. The text is noted for its design science research approach, similar to the working methodology of this paper, and the artifact produced is a model of the sociotechnical system which encompasses all actors, assets, and means of information exchange throughout the platform.

Read et al. (2018) build on EAST in proposing the *Cognitive Work Analysis Design Toolkit* (CWA-DT), which is intended to inform system design from a participatory perspective. Notable departures from EAST include an emphasis on stakeholder involvement, design feedback workshops, and practical application of results to real-world infrastructure planning. The pilot toolkit is applied to instances in the public transportation, railway, and traffic design sectors, with an explicit intention to further develop the method in conjunction with elements of EAST and other systems-focused methods.

Lastly, Huang et al. (2021) reference EAST in the *distributed dynamic and team trust* (D2T2) framework, which seeks to characterize trust dynamics between human and semi-autonomous technological agents (i.e. virtual assistants) in addition to patterns of information exchange. This element is thought to have direct bearing on communication efficiency, throughout the team as a whole, and a call is made for "empirical, interdisciplinary research" on D2T2 methods to improve this aspect. As in Kalloniatis et al. (2017), the framework represents a small but growing body of inquiry into future considerations for sociotehnical systems, as component technology becomes more advanced.

Annex 3: EAST and Emergency Management: Supporting Literature

The earliest instance applying EAST to the emergency management setting was found to be Dwyer and Owen (2009), in the context of Australian bushfire response. This article cites "Modelling command and control: Event analysis of systemic teamwork" (Stanton et al., 2008) as a key text in exploring optimal team dynamics, as well as the organizational processes and information-sharing systems which support them. Echoing sentiments by previous authors in this thesis, opinions are expressed that integrated and comprehensive methods are necessary to examine this sort of teamwork, and a significant need is identified for insights derived from these methods.

Next, with the most subsequent citations overall, Salmon, Stanton and Jenkins (2011) address emergency management directly in "Coordination during multi-agency emergency response: issues and solutions". This text examines potential "siloes" impeding military-civilian collaboration, through application of the EAST framework to a training exercise by the UK Ministry of Defence. In this exercise, an extreme flood event was simulated, and the Military Aid to the Civil Authorities (MACA) body was observed and queried both during and after the exercise. Reiterating the viewpoint that comprehensive assessment is key, the authors state "The nature of collaborative activities is such that it is difficult, if not impossible, to analyse them in sufficient detail through the application of one human factors method alone." (ibid, p.143).

Continuing, Way (2013) cites this MACA analysis as a significant text in the response coordination literature, before progressing with the study "Requirements Analysis for a Context Aware Multi-Agency Emergency Response System". While this source may be considered "grey" material, as a doctoral dissertation, it has been noted for similarities to the premise of this thesis, and assessed for practical insights regarding methodology and clarification of results. Particularly, the use of interviews and observation through a grounded theory approach resonates with the motivations of this paper, and the capturing of emergent themes aligns with its intended outcomes.

Next, Dobias and Eisler (2010) make brief mention of "Modelling command and control: Event analysis of systemic teamwork" (Stanton et al., 2008) in the evaluation of an emergency operations center exercise concerning a major marine disaster. The text is mentioned as a footnote in relation to the statement "As a whole, the multi-agency response still suffers from a lack of understanding of the command and control (C2) structure across organizations, information flow and communications requirements." Again, while not directly working with the EAST framework, this post-exercise assessment continues to define the need for integrated and comprehensive assessment.

While not addressing the EAST framework directly, Landgren and Bergstrand (2016, p.4) cite "Modelling command and control: Event analysis of systemic teamwork" (Stanton et al., 2008) following an assertion that "Inappropriate and over-simplified models of military command and control are often used to explain or model command center and emergency response work". No further engagement with the text is offered, which may have been an interesting addition to this conference paper. However, this statement continues to support the contiguous viewpoint of the articles in this section that comprehensive assessment is key.

Kontogiannis and Malakis (2020) reference "Event analysis of systemic teamwork (EAST): a novel integration of ergonomics methods to analyse C4i activity" (Walker et al., 2006) in a comprehensive examination of accident theory with regards to polycentric control in emergency management organizations. While somewhat ambitious, pursuing a unified theory of polycentric control, the paper contextualizes EAST within a larger effort to understand the emergency management organization as a complex-adaptive system, and contributes topical viewpoints in this regard.

Moving to direct application, Saager and Harre (2020) combine EAST with the D3CoS method to produce the *DSA-HEC model*, specifically addressing "distributed situational awareness for handling emergency calls" (ibid, p.68). This paper, submitted as part of the 17th International Conference on Engineering Psychology and Cognitive Ergonomics, represents the first finding in the literature where subsequent authors appropriated the EAST framework for further emergency management research. D3CoS, or Designing Dynamic Distributed Cooperative Human-Machine Systems, is a framework resembling EAST in that it is intended to "address the design, development and evaluation of cooperative systems from a multi-agent perspective where human and machine agents are in charge of common tasks" (ibid, p.70).