Improving Information Exchange in Disaster Response: Responder Behavior and the Effects of Organizational Design

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Dedication

To my wife and best friend Lisa and my son Darren, you are my inspiration to make the impossible possible.

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Abstract of Dissertation

Improving Information Exchange in Disaster Response:
Responder Behavior and the Effects of Organizational Design

Effective disaster response is important for saving lives, minimizing suffering, and protecting property. Disaster responders depend on real-time (or near real-time) access to available information to make informed decisions. Organizational design is an important contributing factor in enabling information access, as decades of organizational research has shown. However, disaster response organizations are an extreme case: disasters bring significant amounts of uncertainty, dynamism, urgency and complexity that responders must manage and address. As a result, there is often limited a priori knowledge of what information is needed, where it will be needed, and where it will come from, which makes it difficult to design organizations for responders' emergent information exchange needs.

This thesis explores why and how responders exchange information in a disaster response organization and the collective impact of different design features on information exchange performance. Phase I describes and analyzes responders' information exchange behavior during realistic disaster response exercises, including the type of information behavior employed, the motivations for information exchange, the exchange setting type, and the type of information exchanged by responders. Phase II constructs an agent-based model to explore how organizational design features, combined with responder information exchange behavior, impact the information exchange performance of a response organization.

The findings largely validate that extant theory on organizational design, namely information processing system design can guide disaster response organization design.

Common design features such as network structures, databases or technical systems, and meetings are sufficient to support effective information exchange in disaster response organizations. However, disaster response organizations require the "right" mix of information exchange features (formal and ad hoc) to accommodate various levels of uncertainty for different contexts.

The findings highlight four important considerations for organizational design in the disaster response context: 1) the mix of information exchange behaviors is similar across disaster phases, suggesting that information-related design features can likely be consistent despite changes to organizational structures, 2) most information exchanged is explicit, suggesting that more response information can be codified into technical and non-technical information products, 3) most information exchange occurs in meetings, suggesting that they provide additional value for responders beyond simple information exchange, and 4) the "right" mix of information exchange design features depends on the "proximity" (or degrees of separation) of available information to need, suggesting there needs to be sufficient cross-functional linkages within the organizational design.

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Chapter 1: Introduction

Responders depend on real-time (or near real-time) access to available information about a disaster and the response to make informed decisions (Endsley, 1995; Seneviratne & Baldry, 2010; Von Lubitz, Beakley, & Patricelli, 2008). There are many contributing factors to improving access such as trust, relationships to others, congruent data formats, information quality, and technology employed (Altay & Pal, 2014; Borgatti & Cross, 2003; Curnin, Owen, Paton, Trist, & Parsons, 2015; Day, Junglas, & Silva, 2009; Ginige et al., 2014; R. A. Gonzalez & Bharosa, 2009; Marincioni, 2007; Turoff, Chumer, de Walle, & Yao, 2004). Organizational design is also an important contributing factor (Bigley & Roberts, 2001; Boersma, Comfort, Groenendaal, & Wolbers, 2014; Lin, Zhao, Ismail, & Carley, 2006; Pearson & Mitroff, 1993; Rimstad, Njå, Rake, & Braut, 2014; U.S. Department of Homeland Security, 2008).

However, disasters bring significant amounts of uncertainty, dynamism, urgency and complexity that responders must manage and address. As a result, in disaster response organizations, there is often limited a priori knowledge of what information is needed, where it will be needed, and where it will come from. To accommodate these challenges, disaster response organizations are designed to accommodate these externalities by incorporating formal and informal design features such as documents, roles, and processes to support information exchange ***and*** access among responders, and information diffusion across the organization.

In practice, the Incident Command System (ICS) is a common organizational design used by disaster responders to quickly and flexibly respond to complex, urgent, and rapidly

evolving situations (Bigley & Roberts, 2001). ICS specifies a set of standardized forms that need to be completed and shared (in a report) each operational period. It also specifies a series of meetings that should take place to exchange information and make decisions and provides a clear organizational reporting structure with specific roles and responsibilities. In some cases, disaster response organizations include pre-created plans or procedures that dictate when, how, and with whom certain information should be exchanged.

However, the degree to which these design features improve (or hinder) information exchange in disasters, including the influence of these different design features on responder's information exchange behavior such as seeking, sharing and discussing, is poorly understood. This thesis explores why and how responders exchange information in a disaster response organization and the impact of different design features on information exchange performance within a disaster response organization. The findings from this research provide important theoretical and practical insights that inform the design of disaster response organizations and improve information exchange and access.

1.1 Research Motivation

Improving information exchange for disaster response organizations requires designers to embrace the right mix of information exchange features. Decades of organizational design research suggest that achieving the right mix of features can help responders maximize the use of all available information and minimize the time and effort spent on information management and exchange so they can remain focused on critical actions and decisions (Bigley & Roberts, 2001; Boersma et al., 2014; Lin et al., 2006; Pearson & Mitroff, 1993; Rimstad et al., 2014; U.S. Department of Homeland Security, 2008).

Designing disaster response organizations to improve information exchange, though, is complicated by significant amounts of uncertainty about what information is needed, where it will be needed, and where it will come from in each disaster.

As a result, response organizations are typically designed 1) toward requirements that can be identified before a disaster; and/or 2) with many information exchange features to cover their bases. However, the former leaves a significant amount of information exchange needs unaccounted for and the latter risks unnecessary exchanges that waste responders' time or fail to provide needed information. In the extreme case, both designs could then lead to poorly informed or rushed decisions that risk safety, livelihoods, and the environment.

Designers of disaster response organizations require a better understanding of the trade-offs between different design features to improve information exchange in disaster response organizations. Extant literature on disaster response has focused a lot of effort on improving information exchange in disaster response, including the investigation of many organizational features (e.g., Altay & Labonte, 2014; Altay & Pal, 2014; Bharosa, Lee, & Janssen, 2010; Comfort, Kilkon, & Zagorecki, 2004; Day, Junglas, & Silva, 2009; Liu, Shaw, & Brewster, 2013; W.-T. Wang & Belardo, 2009; Wei-Tsong Wang & Belardo, 2005; Zhang, Zhou, & Nunamaker Jr, 2002).

Additionally, designers need to account for responders' information behavior, including motivations for exchange, in organizational design as their behavior can influence the choice of organizational design features employed and vice versa. For example, responders' information seeking and sharing behavior may affect the effectiveness of meetings, which support important cross-functional information diffusion.

However, if responders are well connected to responders in other functions, are meetings still an effective organizational design feature or a waste of critical time?

However, there is a minimal amount of research that holistically addresses organizational design for information exchange in disaster response (e.g., Egelhoff & Sen, 1992; R. Gonzalez, Verbraeck, & Dahanayake, 2010; Lin et al., 2006). Rather, the bulk of extant disaster literature focuses on specific aspects of design such as the impediments to flow (Day et al., 2009), technologies employed (Ginige et al., 2014; Marincioni, 2007; L. Yang, Prasanna, & King, 2009), technical requirements (Deng, Zhao, Zhao, & Yi, 2010; R. A. Gonzalez & Bharosa, 2009; Keßler & Hendrix, 2009; Liu et al., 2013), and network structure, including specific information roles (Altay & Pal, 2014; Kapucu, 2006; Pan, Pan, & Leidner, 2012). Additionally, extant disaster organizational design literature does not explicitly account for information exchange behavior.

1.2 Research Questions and Approach

Our research approach brings together the behavioral and organizational dimensions of information exchange to understand how response organizations can be designed to better accommodate and support information exchange.

We seek answers to two primary questions:

1. Why and how do responders exchange information in realistic disaster response organizations?
2. How do different organizational design features impact information exchange in a disaster response organization?

This research was conducted in two complementary phases. Phase I explored responders' information exchange behavior during realistic disaster response simulations,

including the type of information behavior employed, the motivations for information exchange, the exchange setting type, and the type of information (explicit or tacit) exchanged by responders. In Phase II, we constructed an agent-based model to explore how different organizational design features, combined with responder information exchange behavior, impact the information exchange performance of a response organization.

1.3 Organization of the Document

Chapters 1 and 2 motivate and frame the problem within practice as well as relevant literature. Chapter 3 contains the methods, results, and discussions for the first phase of research investigating responder information exchange behavior within a response organization. Chapter 4 focuses on the second phase of research exploring how organizational design features impact information exchange within a response organization. Lastly, Chapter 5 reviews the overarching findings, contributions, and limitations of this research, and areas for future research.

Chapter 2: Literature Review

Successful responses to emergencies and disasters depend on the ability of the response system to enable responders to exchange information as needed (King, 2005; Seneviratne & Baldry, 2010; Von Lubitz et al., 2008). Additionally, the literature emphasizes the view that better states of knowledge results in better decision-making (Endsley, 1995; Uitdewilligen & Waller, 2018), especially as responders combine this knowledge with other facts, intuition, and experience (Lipshitz, Klein, Orasanu, & Salas, 2001; Orlikowski, 2002; Schraagen, Militello, Ormerod, & Lipshitz, 2008; Todd & Gigerenzer, 2001).

Extant literature addresses information exchange from two distinct points of view: 1) behavioral, and 2) organizational. The *behavioral* point of view investigates how and why ***people*** exchange information directly with another. The *organizational* point of view focuses on how the intentional design of an organization, including its information technology systems, influences information exchange. However, the understanding about how ***people*** exchange information given the design features of the response organization is not very clear. This understanding is critical to designing response organizations that reflect human behavior and enable better information exchange across the response system, which includes many emergent and uncertain conditions that are hard to predict. The sections below discuss the two points of view, including the limited extent to which extant literature addresses our research questions.

2.1 Information Exchange Behavior

The information exchange *behavior* literature investigates how ***people*** exchange information irrespective of organizational design features. Extant research focuses on

individual exchange behavior as the unit of analysis. The research generally falls into two categories of investigation: 1) cognitive search, and 2) the processes and mechanisms by which people exchange information.

2.1.1 Cognitive Search

Extant non-disaster research on cognitive search focuses on how individuals seek information (Dervin, 1999; Ford, Wilson, Foster, Ellis, & Spink, 2002)(regardless of a response organization's design) in two ways: First, researchers study cognitive search for different situations: precautionary behavior to avoid possible future problems (Eastin, Kahlor, Liang, & Ghannam, 2015), to resolve uncertainty (Kuhlthau, 1993; Weary & Jacobson, 1997), and to perform tasks (Byström & Järvelin, 1995; Y. Xu, Tan, & Yang, 2006). Additionally, other researchers study how cognitive search occurs within the context of social networks such as organizations (Borgatti & Cross, 2003; Morrison, 2002; Sias & Wyeres, 2001). In some cases, these focus areas may be considered organizational influences on information exchange, but the findings are hard to generalize beyond the contexts investigated. Second, researchers focus on differentiating the cognitive search processes used by different individuals: researchers (Ford et al., 2002), engineers and scientists (Ellis & Haugan, 1997; Freund, 2015; Hertzum & Pejtersen, 2000), and new employees (Sias & Wyeres, 2001). These contexts provide some understanding about information exchange behavior, but lack connection to the disaster response literature.

2.1.2 Processes and Mechanisms

The non-disaster literature also provides some understanding about the processes and mechanisms by which people exchange information in steady-state environments. Nonaka and Takeuchi (1995) identify how people exchange tacit and explicit knowledge within

steady-state organizations. This includes enabling tacit exchange through socialization (shared experiences among people), tacit to explicit exchange through externalization (products that convey tacit knowledge in an explicit form), and explicit to tacit exchange through internalization (using explicit knowledge to do something that builds tacit knowledge from intuition and experience). Wilson's (1999) amalgamated model of information behavior further explicates the processes and mechanisms an individual uses to seek information. However, it lacks connection to the disaster response literature, and the organizational and technical intervening variables are noticeably absent despite their ability to influence behavior.

2.1.3 Disaster Context

The small swath of disaster response research that specifically addresses behavioral information exchange is fragmented as it addresses many different information exchange processes and mechanisms across many different dimensions. For example, extant literature finds that expertise and confidence (Drews, Siebeneck, & Cova, 2015; Mishra, Allen, & Pearman, 2014) affect information behavior; social capital improves information exchange in virtual communities (Lu & Yang, 2011); and that pre-incident trust (Longstaff & Yang, 2008) and willingness to share (Altay & Pal, 2014; Day et al., 2009) support faster and more effective information sharing. Additionally, disaster affected people seek out information in particular ways (Austin, Liu, & Jin, 2012; Sommerfeldt, 2015) and disaster decision makers tend to seek out information to justify decisions rather than resolve uncertainty (Mishra et al., 2014). Another study found that responders tend to focus on seeking information needed versus sharing information out to others that may also benefit (Bharosa et al., 2010). Lastly, one recent study identified three types of information sharing

(fact, interpretation, and projection) across three action phases (structuring, information sharing and decision making). A more systematic understanding of the processes and mechanisms responders use to exchange information is needed, especially in relationship to organizational design.

2.2 Organizational Information Exchange

The *organizational* information exchange literature focuses on how the intentional design of an organization, including its information technology systems, can influence or extrinsically motivate information exchange. Information exchange is a significant area of study within the organizational literature. Galbraith (1974) first proposed the information processing view of organizations, which was later supported and extended by Tushman and Nadler (1978). They argue that information processing within the organization can be better supported by designing organizations to embrace rather than eliminate uncertainty. In the 1990s, many of the principles were carried forward in a body of investigation focused on organizational knowledge management. Both streams of literature were an outgrowth of the realization that the intentional design and implementation of an organization can greatly impact its achievements.

The organizational knowledge management literature makes a distinction between the types of information objects being exchanged within organizations. This distinction was based on Polanyi's (1962) description of tacit knowledge as a unique form of knowledge. Since then, many researchers have extended this description of knowledge to encompass two types of knowledge, tacit and explicit (Boisot, 1987; Hedlund, 1994; McAdam & Mccreedy, 1999; Nonaka & Takeuchi, 1995; Polanyi, 1962). Tacit knowledge is generally difficult-to-articulate information based on intuition, experience, or training that is not

readily understood by someone else. Explicit knowledge is defined as readily sharable information that is generally factual in nature and does not need additional explanation for comprehension. Both types of knowledge are generally considered within the literature to be exchangeable "objects" with the implicit assumption that the proper exchange of said objects will result in better achievements for the employee and subsequently the organization (Hedlund, 1994; McAdam & Mccreedy, 1999; Orlikowski, 2002; W.-T. Wang & Belardo, 2009). Within this research, we use "information" to encompass both tacit and explicit knowledge and use the more descriptive terms where appropriate.

However, the ability to accurately define information needs for disaster response remains elusive. In steady-state environments where tasks are often repeatable and predictable within an organization, identifying the needed information objects and then defining the supporting organizational processing mechanisms and activities to facilitate exchange is more straightforward (Zowghi & Coulin, 2005). However, in emergencies and disasters where there are significant amounts of uncertainty regarding the situation and the tasks that need to be performed (Daft & Lengel, 1986), a critical challenge arises that affects the ability to pre-define an appropriate system of information exchange for a response organization: information needs are impossible to comprehensively pre-identify because emergencies and disasters are infrequent high impact events that require an urgent response under extreme uncertainty (Day et al., 2009). Many required tasks, decisions, and, critically, information exchange connections, depend on the exact impacts of the emergency or disaster and the resources available during the response (not necessarily what was planned). Therefore, applying non-crisis organizational design approaches to organizational design for disaster response is inadequate as they are based on significant

amounts of a priori knowledge about information needs and consistent and repeatable processes.

Additionally, while the number and types of management and coordination interdependencies (i.e., relationships) that are needed for information exchange also vary throughout a response, understanding these interdepencies may provide critical information about what methods of communication need to be available and accessible for different responders at different levels of the response organization (e.g., Bharosa et al., 2010; Hedlund & Nonaka, 1993). As a result, organizational design may be able to address the lack of a priori knowledge about information needs by understanding the management and coordination interdependencies that are likely to occur. However, to the best our knowledge, extant disaster research does not address these interdependencies in terms of their impact on information exchange.

Extant literature on organizational information exchange is further divided into two sub-categories of research: 1) organizational design, and 2) information technology design. The former focuses on the conceptual design of the organization, including the various elements, processes and relationships that will help it operate. The latter focuses on the design of technical systems to support organizational objectives and information exchange.

2.2.1 Organizational Design

There has been a significant amount of foundational research on organizational design for information exchange (Daft & Lengel, 1986; Galbraith, 1974; Tushman & Nadler, 1978). For example, Daft and Lengel (1986) argue that the goal of information processing within an organization is to reduce equivocality (ambiguity related to multiple or conflicting interpretations of a situation) and uncertainty (the absence of information).

Bensaou and Venkatraman (1996) further categorize uncertainty as environmental-, partnership- and task-based. They also argue that addressing these uncertainties requires the intentional design of an organization, including focusing on the alignment of the structure, processes, and technology used.

Extant literature outside of the disaster field implicitly assumes information exchange and processing within established firms facing uncertainty (Daft & Lengel, 1986; Galbraith, 1974; Tushman & Nadler, 1978) instead of temporary response organizations (also facing uncertainty) that are commonly utilized today within disaster response (Egelhoff & Sen, 1992). Temporary response organizations are characterized by adaptive teams that quickly flex their structures, processes, personnel and technology as needed to meet the demands of the disaster scenario. The temporary organizations also do not persist beyond the disasters themselves as they remain notional during non-disaster times. This makes it difficult to develop and refine information exchange practices useful in a variety of ambiguous and uncertain situations.

Additionally, there is a lack of clarity or limited agreement on the specific organizational design approaches that enable or constrain information exchange in disaster response and whether the findings solely apply to intra- and/or inter-organizational (e.g., Ley et al., 2014) contexts. For example, one descriptive study defined four prototypical crisis response information network structures and characterized them by information flow intensity and network density (Pan et al., 2012). They included star, pyramid, forest and black-out network structures. Rimstad et al. (2014) explained how response to the 2011 Norwegian terrorist attack resembled both the forest and pyramids network types, which are respectively characterized by low information intensity/low network density and high

information intensity/low network density. They found that interorganizational information exchange was supported because of strong ties between commanders from the different rescue services. However, commanders were still able to receive important information through weak ties to other responders. As a result, it is still unclear in what situations more connections or different relationship structures would better serve information exchange in a disaster response organization.

While other researchers have attempted to identify *how* key features enable or constraint information exchange in disaster response, this knowledge is focused on singular aspects of organizational design. For example, if functional leads act as information hub or an information filter, information is exchanged quicker (Altay & Pal, 2014); boundary spanners help improve interagency communication during emergencies (Kapucu, 2006); a common lexicon helps achieve shared understanding (Bigley & Roberts, 2001); matching information cycles to activity cycles enhances intra-organizational response coordination (Van der Laan, De Brito, Van Fenema, & Vermaesen, 2009); and incentives for sharing information, understanding each other's work-processes, and the usability of information systems have shown positive effects on information sharing and coordination (Bharosa et al., 2010). Lastly, Day et al., (2009) also found eight impediments that reduce the flow of information. They include: inaccessibility, inconsistent data and information formats, inadequate stream of information, low information priority, source identification difficulty, storage media misalignment, unreliability, and unwillingness. While this body of research provides clear findings in their respective areas of focus, their findings do not address the collective impact of different organizational design features on information exchange, and when certain design features should be favored over others.

Based on the review of extant literature, organizational design is clearly important for information exchange. However, organizations are still difficult to design because critical operational and information independencies are not always able to be determined a priori. Some organizational elements can help with information exchange such as certain types of meetings, relationships, roles, network structures, and terminology, but it is still unclear how multiple elements, when considered together, affect information exchange outcomes across the response system.

2.2.2 Information Technology Design

The *technical* information exchange literature explores how information technology can be used to support information exchange during a response. The implicit argument is that information technology, if properly designed, can support and enhance the capabilities of responders by facilitating information exchange and flows. The research also falls into two categories, which to the best of our knowledge, have not been linked to the *organizational* or *behavioral* information exchange literature nor to each other despite their inherent relationships: 1) information delivery and interactivity requirements, and 2) technical information exchange requirements. The former focuses on how technical systems should be designed for human-to-computer interaction while the latter focuses how technical systems communicate with each other.

Extant research on information system requirements focus on the different delivery and interactivity requirements of an information system. In other words, this stream of research focuses on improving the consumption of information by a human from a technical system rather than improving interpersonal exchange. For example, researchers explore requirements such as relevant, timely, and consumable information (Bharosa et al., 2009;

Gonzalez & Bharosa, 2009; Mendonça et al., 2007; Tapia & Moore, 2014; Turoff et al., 2004) while others explore human-computer interaction such as how a system interface can be better designed to support responder activities with different tasks and decisions (Ginige et al., 2014; Netten, Bruinsma, Van Someren, & De Hoog, 2006; Peng, Zhang, Tang, & Li, 2011). Zhang et al. (2002) extended this discussion by articulating a knowledge management framework that outlines specific processes an information system should support for situational awareness and decision making. They include the acquisition, filtering, indexing, categorization, sharing, linking, creation, and maintenance of knowledge.

Research on technical information exchange requirements remains a separate stream of research that focuses on the development and use of ontologies to help facilitate computer-to-computer information exchange (Babitski, Probst, Hoffmann, & Oberle, 2009; Deng et al., 2010; Galton & Worboys, 2011; Keßler & Hendrix, 2009; Liu et al., 2013; Matheus, Kokar, & Baclawski, 2003; W. Xu & Zlatanova, 2007). However, the ability to exchange information among technical systems is only one aspect of information exchange.

2.3 Linking Behavioral and Organizational Information Exchange

Several researchers have attempted to link behavioral and organizational information exchange, but this is still a nascent area of research. Using agent-based modeling, Altay and Pal (2014) investigated how responders with different information roles and a willingness to share and trust impacted information diffusion. Specifically, they found that information hubs, good information quality, and responders' willingness to exchange information resulted in faster information diffusion. Comfort et al. (2004), using a similar modeling approach, investigated the effectiveness of response actions by type of

information strategy, and found that access to core information (critical information needed by responders) resulted in more efficient response actions and increased coordination across the responding organization. Zagorecki et al. (2010) expanded upon this to look at interorganizational information exchange and found that any interorganizational communications among responders is better than none. Similarly, Kapucu (2006) used social network analysis to investigate interorganizational communications among responders. He found that strong communication systems with other organizations before a disaster supports enhanced interagency coordination during a disaster.

However, these models do not capture specific components of organizational design that influence information exchange within a disaster response organization. Altay and Pal (2014) come close, but focus specifically on information roles rather than other components such as meetings and processes that were designed into the system. Zagorecki et al. (2010) come close as well by defining different information exchange structures, but focus on inter-organizational instead of intra-organizational exchanges. Understanding intra-organizational information exchange first, though, is important to improving responder information exchange since it often occurs before external exchange.

2.4 Literature Gap

Extant literature provides limited understanding about responders' information exchange behavior during a disaster response and how organizational design influences this behavior. Information exchange depends on a combination of the seeking, sharing and discussing behavior of the people in the response, the organization enabling the behavior, and the technology supporting it. However, these aspects have been primarily studied

separately with few empirical studies of the exchange behaviors in realistic disaster organizational contexts.

Designing response organizations to better support information exchange requires more knowledge on responders' information exchange behavior. In Section 1.2, we summarize our research approach to address this gap. Addressing this gap will result in a better understanding of how to design future response organizations to better accommodate and support information exchange during a disaster.

Chapter 3: Exchange Behavior in Disaster Response

In Phase I, responders' information exchange behavior was investigated to understand *why and how do responders exchange information in a realistic disaster response organization?* This is a critical first step to understanding how response organizations can be better designed to support information exchange. Specifically, this is because organizational design needs to 1) accommodate the ways humans exchange information during a disaster response, and 2) balance formal and pre-defined exchange modes with features that enable ad-hoc information exchanges, based on how these are actually used by responders.

3.1 Methods

A qualitative case study approach (Eisenhardt, 1989) enabled the research team to observe and record how information is exchanged by responders within a disaster response organization. More specifically, this approach enabled the author of this dissertation to inductively identify key activities, motivations, and processes (Langley, 1999) used by the responders, such as the motivations for exchange and types of information exchanged. Qualitative methods are especially useful when existing theory inadequately described events and behavior (Eisenhardt, 1989), such as the fragmented understanding of individual's disaster information behavior discussed in section 2.1.3.

3.1.1 Research Setting

We selected case studies that used a common organizational structure and a common disaster type. The organizational structure was the Incident Command System (ICS). ICS is an "all-hazards" temporary organizational management system specifically designed for

operating in dynamic and uncertain working environments such as emergency response (Bigley & Roberts, 2001; Boersma et al., 2014; Jensen & Waugh, 2014). It is commonly used in the United States and provides a common, yet flexible set of roles, relationships, and processes for use across different types and sizes of emergencies and disasters such as terrorism, hurricanes, oil spills, public health emergencies, etc. (U.S. Department of Homeland Security, 2008). Observing the use of ICS in response operations enabled the research team to see information exchange in a realistic and standardized organizational context.

Additionally, the observations focused on the use of ICS within maritime oil spill response. Oil spills are known threats that cause significant environmental, health and economic impacts due to shipping accidents like *Exxon Valdez* in 1989 or drilling problems like Deepwater Horizon in the Gulf of Mexico in 2010. Oil spills are also typically no-notice events that require responders to quickly stop the active spilling of oil, clean up the spilled oil, and decide how best to mitigate and recover from the impacts, including managing and coordinating subsequent actions. Oil spill management responses can be small with a core team of just 10-20 people or massive operations that cross numerous jurisdictional boundaries and include hundreds or thousands of personnel such as drill operators, the U.S. Coast Guard, spill clean-up contractors, affected communities, wildlife rescue specialists, etc. Response personnel are generally managed or coordinated by a core ICS team with representatives from many of the key response groups mentioned above, which is similar to many other types of disaster responses in the United States.

Since ICS was used in all the exercises observed and because it is an "all-hazards" system typically used for many different types of disasters, we believe our results regarding

responders' information exchange behavior are plausibly generalizable to a variety of different disaster scenarios in the United States despite only observing maritime oil spill response scenarios. The results, though, may not generalize to responses in other countries or for which the management structure and culture are very different. For example, national public health emergencies that are slower moving may use a different management structure that is less hierarchical to help leverage the expertise of different public health subject matter experts.

3.1.2 Exercise Selection

Observing real-world disasters is difficult because many are no-notice events that would require the rapid approval and deployment of researchers. In addition, by the time the researchers would arrive to observe, many critical information-related behaviors would have already taken place. However, disaster response exercises provide opportunities for relevant data collection because they mimic real-world responses and allow the researchers enough time to obtain appropriate approvals. Additionally, exercises push responders to behave as they would if it was a real disaster response. This includes making critical decisions and coordinating certain actions as the scenario and situation evolves. In fact, exercise designers incorporate special complicating "events" at different points in the exercise to mimic how responders need to respond "on-the-fly" to particular issues or the receipt of certain information (Greenberg, Voevodsky, & Gralla, 2017).

Four disaster response exercises were observed. Each exercise was an operations-based exercise that required a management team to demonstrate their activities as they would in a real-world response (rather than discuss how they would respond). Three exercises were performed out of emergency operations centers (EOCs) that were made up of one large

room or a few connected rooms that included tables/cubes grouped by function (e.g., logistics, operations, finance, etc.) as well as whiteboards and projection displays that contained key information about the situation and the response. The fourth and largest exercise set up an EOC in the ballroom of a hotel and used additional rooms for specialized meetings (e.g., press conference) or functions (e.g., the joint information center that manages the dissemination of public information).

In general, personnel worked from the tables/cubes with their computers and phones and interacted with others as needed to perform their jobs. In the smaller exercises, personnel used their individual offices to perform their roles, but all came back to a central meeting room for key meetings and activities. In all these cases, responders used the same facilities or types of facilities that are used in real responses: smaller responses are typically run by contracted response management teams in their real facilities (contractor or client offices), and larger responses are often run from hotels with a mix of client and contractor response management personnel.

Table 3-1 below provides an overview of the similarities and differences between each exercise; these factors are described in the following paragraphs. Exercises have been labeled Alpha, Bravo, Charlie, Delta to ensure attribution can be maintained while preserving the confidentiality of the exercises. While the response system used was the same, each exercise varied by specific scenario (e.g., spill at a different location with different geographic properties), response team size (number of response personnel participating), and phase of disaster (initial-day 1 vs. sustained-day 4). This variability was important to understanding how response teams handled situations with different complexities and for which procedures and protocols were or were not available. This

included different complexities in the situation as well as resources available to respond. If the same scenarios and dimensions were always used in exercises, responses would be highly prescribed and ultimately insufficient to prepare responders for the unique complexities and uncertainties of each real-world disaster. Because of this variability, we believe the four exercises were sufficient to observe and analyze a wide range of responder information exchange behavior.

Table 3-1: Overview of the Exercises Observed

Exercise	Alpha	Bravo	Charlie	Delta
Response Team Size	Small	Medium	Large	Medium
Phase of Disaster	Initial	Initial	Sustained	Initial
Announced or Surprise	Surprise	Surprise	Announced	Announced

The *size of the response team* is important because large teams generally have more information exchange complexities to deal with that can inhibit information exchange. The small exercise had less than 50 response personnel. The medium exercises had between 50 and 150 response personnel, including a specialized team called source control (SC) that was responsible for how to control and stop the oil spill at the source. The SC team was always located at a different site but worked collaboratively with the core ICS team. The large exercise had over 150 response personnel.

The *phase of disaster* is also important since different tasks occur at different points during a response and require different information exchange. Additionally, information supply, including where information is received, may differ. The scenario for exercises in the initial phase started when the oil spill was first recognized while the scenario for the exercise in the sustained phase started four days after the spill was first recognized.

Whether the exercise is *announced or a surprise* is important since responders could spend more time preparing for an announced exercise. Surprise exercises were initiated by

a government regulatory agency and were more realistic of no-notice disasters such as oil spills, earthquakes, and terrorism. Announced were initiated by private sector oil-related organizations exercises and more closely mimicked disasters such as hurricanes that have some advance notice and allow responders to anticipate some specific response needs despite not knowing specifics of the situation. If an exercise is initiated and led by the government, there were certain regulatory restrictions on what response personnel were required to demonstrate. Therefore, these exercises did not always test the full complement of response actions that would be needed in a real response. If it was initiated by a private sector organization, more response actions could be tested that are not mandated by regulators, but are still important for response (e.g., public information briefings). While we would have preferred all scenarios to exercise the full complement of response actions, these were the exercises that we were invited to observe.

3.1.3 Data Collection and Analysis

Figure 3-1 below provides an overview of the qualitative methods employed to study and analyze the exercises. The first step involved collecting data by observing the four exercises and taking notes, which then served as our data for analysis. The second step involved analyzing the data to iteratively to identify emergent themes or "codes" that described the information exchanges taking place. Lastly, we analyzed the resulting codes, referring to the data as needed, to arrive at a final set of themes and findings. This process is discussed in greater detail in the following sections.

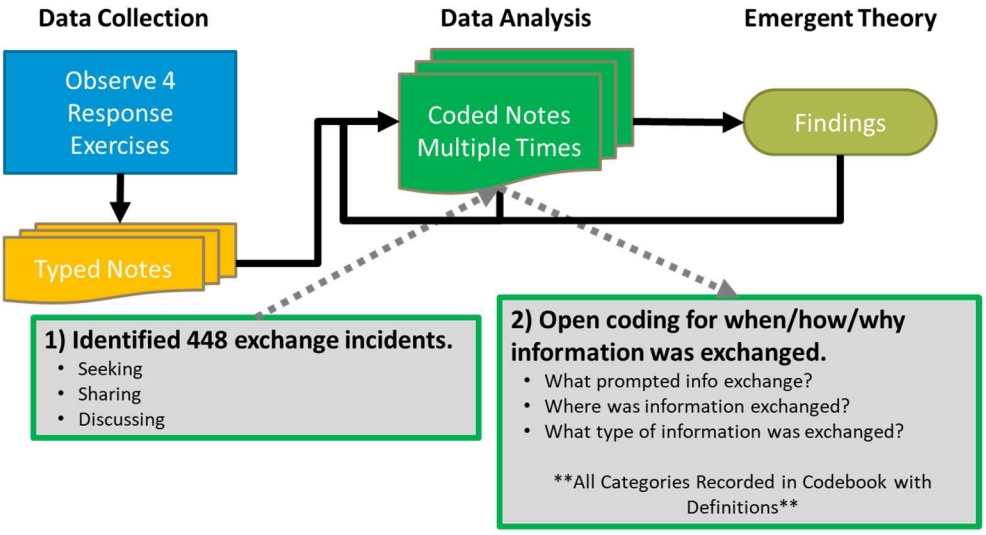

Figure 3-1: Overview of Qualitative Methods Employed

Data Collection. Three researchers[1] observed each exercise except for one where two researchers were present. This allowed the research team to observe many different responder activities simultaneously. Each researcher took handwritten notes that were later updated within 24 hours to ensure details from our memory were also captured (this procedure is suggested by Spradley, 1980). During every exercise, each researcher shadowed a particular group of responders unless a joint meeting was occurring. Researchers captured notes related to what was taking place as well as anything related to the use and exchange of information, occasionally also jotting notes about their interpretation of what was going on. This helped provide important context during the data analysis phase. Finally, all notes were consolidated into a master chronology for each exercise. The final typed notes included descriptions of key response processes, events, actions, and decisions. The team also captured key discussion points between responders.

[1] Observation and data collection were carried out by three researchers, including the author of this dissertation. However, all subsequent data analysis and writing were completed by the author.

Given the relatively small sizes of three of the four exercises, the research team was able to observe nearly all activities taking place at all response locations. However, the size of the larger exercise made it difficult to comprehensively observe all exercise activities. Instead, researchers used their judgement on which groups or meetings would be best to observe at different points in the exercise. For example, one researcher focused on observing the logistics function for the majority of the 2-day exercise, which included both ad hoc and system meetings.

In all cases, though, the research team was only able to observe what was taking place in front of us, which included peer-to-peer interactions and display boards. The team was unable to capture information exchanged through email or other technical systems that were not displayed in the EOC, nor was the team able to capture both sides of a phone conversation (unless it was on speaker phone). While this information was certainly missed, we believe most peer-to-peer exchange occurred in person in three of the four exercises observed and did not greatly affect our results since our research largely focused on human information exchange behavior, such as what prompted their actions and how the exchanges occurred. However, the missed information exchange behavior is considered as appropriate in the analysis and discussion of results.

Data Analysis. The notes from each exercise were inductively analyzed (Glaser & Strauss, 2017) to identify common themes and categories present in the data. A "codebook" of relevant categories and definitions was created to capture and describe these information exchange related themes and relationships. We focused on exchange incidents as the unit of analysis because it provided the lowest unit of analysis in which to understand information exchange behavior. An exchange incident was a single exchange of

information between responders or responders and technical systems or reports that is limited to one topic or theme (e.g., report of safety concerns or discussion about how to cap a well).

The analysis occurred in several steps using qualitative coding techniques. First, the notes were read through to identify exchange incidents and look for key themes. Next, multiple codes were assigned to each exchange incident. These codes were used to describe the information exchange taking place in terms of what prompted the exchange, where it took place, and how.

Second, each exercise was "coded" multiple times and the codebook was updated as needed to reflect new code definitions until new codes were no longer identified in the final set of codes and definitions. Detailed definitions and examples of the all codes are provided in the results section. Each exchange incident could only have one primary behavior (seeking, sharing or discussing). However, multiple codes were used to describe prompts since there were often multiple reasons the exchange incident needed to occur. The number of exchange incidents with multiple prompts is captured in Table 3-2.

To show why multiple prompts might be coded for a single exchange incident, the example below highlights a sharing exchange incident that was prompted by both role responsibilities and formal processes. This coding occurred because the sharing of objectives is expected by the Incident Commander as part of his/her role and is also expected to be shared at the system meeting in which it took place.

The IC then verbally communicated five objectives to start the response and stated that they were in no particular order. (Alpha, 130)

Table 3-2: Co-Occurrence Matrix for Prompts

	Prompts	Role Responsibilities	Formal Processes	Misalignment of Information	Externalities
Prompts	#	213	171	120	70
Role Responsibilities	213		35	42	26
Formal Processes	171			11	18
Misalignment of Information	120				11
Externalities	70				

Third, the codes from each information exchange incident within each exercise were entered into a simple database for further analysis. Several different queries, based on our research questions, were run. We oscillated between querying the database and reviewing the actual data numerous times until theoretical saturation, the point at which continued analysis yields no new insights (Morse, 2004). The findings from these analytic queries are also discussed in the results section.

Lastly, statistical bootstrapping was conducted, using MiniTab Express, to evaluate our hypotheses that key proportions found in our results were statistically different. This technique is a form of resampling that is helpful for making inferences about a population from sample data when the true population is unknown ("Overview of Bootstrapping for 1-Sample Proportion," n.d.). For example, one finding showed that 127 (28%) of 448 exchanges involved seeking. To find a confidence interval for the percent of seeking exchanges, we resampled the 448 exchanges, randomly selecting incidents and computing the percentage of seeking incidents. This resulted in a histogram from which you can obtain

a confidence interval. Each hypothesized proportion (e.g., 127 seeking exchanges out of 448 total exchanges) was resampled 1,000 times to obtain an estimated distribution using 95% confidence intervals (See example of estimated seeking distribution and output in Figure 3-2).

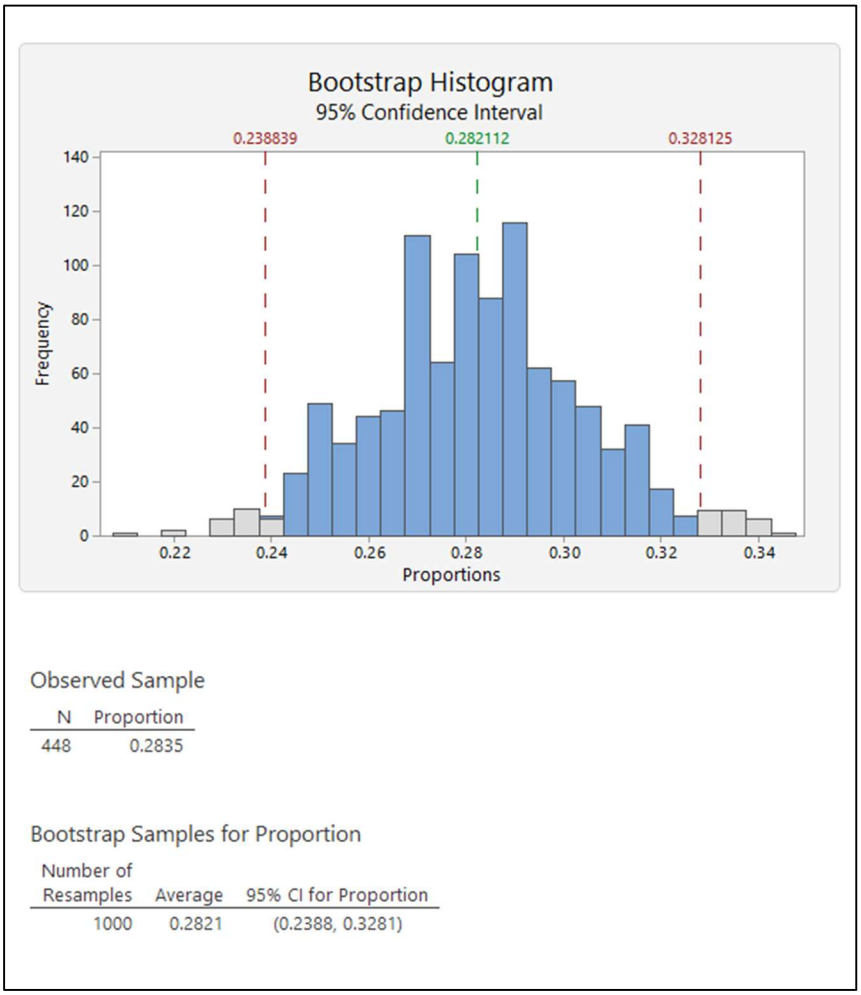

Figure 3-2: Bootstrapping Output for Seeking (Example)

When comparing two proportions, if the confidence intervals did not overlap, then the values were considered different. If they did overlap, then the values were considered similar. Table 3-3 below provides an example comparison of confidence intervals for the three different information exchange behaviors. We conclude, for example, that sharing is the most common information exchange behavior we observed because its proportion is

higher than the others and the confidence interval does not overlap with others. As appropriate, this analysis is discussed in the results section.

Table 3-3: Exchange Incidents by Information Behavior (Example)

Behavior	#/% Incidents		95% Confidence Intervals
Seek	127	28%	23.4 - 32.8%
Share	259	58%	52.5 - 62.5%
Discuss	62	14%	10.7 - 17.0%

3.2 Results and Discussion

The analysis of data yielded several interesting insights regarding information exchange behavior, the motivations for exchange, the settings in which information was exchanged, and the type of information exchanged. In each section, we describe the results and then discuss them in light of the literature and practice implications.

3.2.1 Mix of Information Behaviors

Analysis of the data revealed three distinct information exchange behaviors by responders in a disaster response organization. They included seeking, sharing, and discussing (see Table 3-6 for definitions and examples). Table 3-4 shows the total number and proportions of these behaviors observed across all exercises. Sharing (58%) is the dominant behavior, followed by seeking (28%), then discussing (14%). The Table also includes the estimated confidence intervals (via the Boostrapping method discussed in the previous section). Non-overlapping confidence intervals indicate significant differences between the quantities of behaviors observed. Furthermore, as shown in Table 3-5, these behavior proportions remain largely consistent across the size of a response organization.

Table 3-4: Exchange Incidents by Information Behavior

Behavior	#/% Incidents		95% Confidence Intervals
Seek	127	28%	23.4 - 32.8%
Share	259	58%	52.5 - 62.5%
Discuss	62	14%	10.7 - 17.0%

Table 3-5: Exchange Incidents by Behavior and Disaster Phase/Size of Response Organization

Behavior	*Small (Initial)*		95% Confidence Interval	*Medium (Initial)*		95% Confidence Interval	*Large (Sustained)*		95% Confidence Interval
Seek	33	36%	26.4 - 46.2%	53	26%	20.1 - 32.4%	41	27%	19.6 - 34.0%
Share	48	53%	42.9 - 62.6%	126	62%	54.9 - 68.6%	85	56%	47.1 - 63.4%
Discuss	10	11%	5.5 - 18.7%	25	12%	7.8 - 17.2%	27	18%	11.8 - 24.2%

Table 3-6: Information Exchange Behavior – Definitions and Examples

BEHAVIORS			
Information behavior codes distinguish incidents in which responders are looking for information, providing information to others, or discussing information.			
Information Behavior	**Behavior Definition**	**Example 1**	**Example 2**
Seeking	An information exchange incident is considered ***seeking behavior*** when a responder is requesting or looking for information that already exists from another responder, a technical system, or a document. **NOTE:** The answer or reply to a seeking request is not considered a separate sharing incident.	OBSERVATION (DATA): Someone asks if the sheen is 500 ft or 1000 ft north of the rig. There is some confusion about the numbers, and it starts to appear that someone made a mistake, maybe within the written documentation. Someone tries to clarify that the oil slick is 500 yards north of the location, and the rig was 1000 ft away when it regained power. (Delta, 363-366)	OBSERVATION (DATA): IC-RP asks if there is an unanticipated early impact or just doesn't really count as the expected impact because it's not the heavy oil? (Charlie, 680-681)
		BACKGROUND/INTERPRETATION: A responder tries to clarify an information conflict regarding the location of the oil slick.	BACKGROUND/INTERPRETATION: The Incident Commander from the Responsible Party is seeking information from another responder about the best way to classify the oil sheen in terms of impact.
		JUSTIFICATION: This is seeking because the exchange incident started with a responder requesting information from another responder (to determine whose information was most accurate).	JUSTIFICATION: This is seeking because the Incident Commander asks another responder how he/she would classify the oil sheen in terms of impact without anything related to this topic being shared first.
Sharing	An information exchange incident is considered ***sharing behavior*** when a responder is primarily providing information to another person or group without a request for the information.	OBSERVATION (DATA): The IC then verbally communicated five objectives to start the response and stated that they were in no particular order. They included... (Alpha, 130)	OBSERVATION (DATA): The IC says to move smart teams 2, 2, and 3. Ops says they are already talking about how to get them there. Says he is going to call strike team. (Delta, 502-503)
		BACKGROUND/INTERPRETATION: During a system meeting, the incident commander is communicating the five priorities for the response for the operational period.	BACKGROUND/INTERPRETATION: The incident commander has made a decision about where response teams should be deployed to and is communicating that to another responder who will execute the decision.
		JUSTIFICATION: This is sharing because the incident commander is providing this information to the response team without being requested.	JUSTIFICATION: This is sharing because the incident commander is providing information about a decision he made about where to deploy teams, without being requested to do so.
Discussing	An information exchange incident is considered ***discussing behavior*** when responders talk through a topic or issue to collaboratively produce new information, knowledge, or decisions such as next steps or an action plan. While responders may seek or share information in the process, the behavior is distinguished by the joint talk about an issue or topic using information and perspectives from different responders.	OBSERVATION (DATA): Ops continues to discuss boat availability. He says it's too far offshore for some type of boat [46ers?]. He says something like MSRC you guys have some large offshore barges right? And the blue boats of course. Then the person on the phone says something, and Ops says "it's pretty far offshore so as long as it's seaworthy to go out there..." [then we can use it, presumably?]. (Delta, 132-136)	OBSERVATION (DATA): Legal and LNO-Legal are discussing VOO (vessel of opportunity) program. Agreed with Ops and Logs that 535 vessels enough for now. (Charlie, 724-725).
		BACKGROUND/INTERPRETATION: The Operations Section Chief is working with a person on the phone to jointly understand what boats are available for use in the response (e.g., his available external resources) and jointly decide which ones should be deployed.	BACKGROUND/INTERPRETATION: A responder from legal and another responder (a liaison officer) are discussing whether a disaster response program, called the vessel of opportunity program that leverages volunteers, has enough vessels to meet the current needs of the response.
		JUSTIFICATION: This is discussing because the Operations Section Chief is discussing the deployment strategy, including what resources to deploy, when and where with another party who is part of the decision. They are not just informing each other, but also coming up with a strategy together.	JUSTIFICATION: This is discussing because the responders are jointly making a determination whether the vessel of opportunity program is sufficient to meet the current needs of the response. They each shared information with each other to inform the determination, ultimately deciding together that the program, as it stands, is adequate.

Based on these findings, we posit the following:

> *In a disaster response organization, the proportion of information exchange behavior modes is similar across the phase of disaster and size of the response organization at ~28% seeking/58% sharing/14% discussing.*

Extant literature on individual information behavior aligns with our findings that responders both seek and share information (Bao & Bouthillier, 2007; T.D. Wilson, 1999; Thomas D. Wilson, 2000). Information use behavior (how individuals use information to perform) is also identified as a key information behavior, but was not the focus of this research (Mishra et al., 2014; Thomas D. Wilson, 2000). However, discussing behavior is not explicitly discussed within the information behavior literature; rather, it is typically the object of study for team dynamics and performance (e.g., Siassakos et al., 2011). These findings suggest that discussing is also a critical *information* behavior in disaster response organizations.

Our findings also suggest that the phase of a disaster or size of the response organization has little influence on the mix of responder information ***behavior***. In contrast, the extant disaster literature identifies different information ***needs and challenges*** by phase of disaster (e.g., signal detection, prevention/preparation, containment/damage limitation, pre-crisis, during crisis, post-crisis, etc.) (Pearson & Mitroff, 1993; Ponis & Koronis, 2012), level of analysis (e.g., interpersonal, intra-organizational, inter-organizational, individual, agency, community) (Bharosa et al., 2010; T. M. Yang & Maxwell, 2011), and size of the organization (e.g., agency vs. community, number of employees, multi-organizational networks, etc.) (Bharosa et al., 2010; Kapucu, 2006; Levy & Powell, 2000). Our findings suggest that despite these differences in needs and challenges identified by

extant literature, responders' behavior may not change very much, raising the question of whether there needs to be different information exchange design approaches by disaster response phase or size.

Lastly, our findings suggest that there is a relative mix of information behavior that occurs within a disaster response organization. To the best of our knowledge, existing disaster and non-disaster research does not address the mix or amount of behaviors used by information exchangers. These findings raise crucial questions of whether the observed balance between seeking/sharing/discussing in a response organization is appropriate. More or less of certain behaviors is likely to significantly affect system performance. For example, responders may spend more time seeking information if there are fewer information sharing meetings, which may take up critical time that responders need to perform their duties. We might expect, though, that the appropriate "mix" depends on a combination of factors that include the situation, the organizational design and responder's behavioral tendencies. Understanding this balance is critical to designing response organizations to maximize performance in disasters. These findings provide a baseline proportion to reference in future research and in practice (with the caveat that some exchangers were not observed; see discussion on Data Collection).

3.2.2 Prompts

Table 3-7 and 3-8 provide an overview of the four types of extrinsic motivators that prompted responders to exchange information in a disaster response organization. When motivations where not explicit in our data, we inferred these motivations based on the exchange context, knowledge of the response organizational design, and plausible alignment with one of these prompts. Role responsibilities required the most inferencing

while the others were pretty clear (implicitly). The first two prompts are organizational design features while the latter two are contextual factors.

We analyzed the data to understand which prompts are most common and which prompts lead to the different information exchange behaviors (seeking, sharing, and discussing). Across all information exchange behaviors, role responsibilities (48% of all exchanges) and formal processes (38% of all exchanges) typically prompted information exchange incidents (see Table 3-9). The misalignment of information (27% of all exchanges) and externalities (16% of all exchanges) prompted information exchange incidents less often. In some cases, information exchange incidents were prompted for multiple reasons. For example, as shows in Table 3-2, the misalignment of information and role responsibilities prompts co-occur 42 times within our data.

We also examined the frequency of each information behavior (seeking, sharing or discussing) by prompt (see Table 3-10). Seeking behavior was typically prompted by the misalignment of information (73% of seeking exchanges), sharing behavior was typically prompted by organizational design features such as formal processes (58% of sharing exchanges) and role responsibilities (39% of sharing exchanges), and discussing behavior was typically prompted by role responsibilities (94% of discussing exchanges). Further analysis of the percentages above (using the bootstrapping method discussed in the Section 3.1.3) revealed non-overlapping confidence intervals with the other prompts, suggesting statistically significant differences between the leading prompts for each behavior.

We also examined the frequency of information exchange behavior by the different prompts (see Table 3-9). Sharing was the primary information behavior when an exchange incident was prompted by a role responsibility (48%), formal process (88%), or externality

(76%) However, seeking was the primary behavior when the exchange incident was prompted by the misalignment of information (78%).

Lastly, we examined the proportions of prompts across the size and phase of disaster. The percentages were largely similar (see Table 3-11), suggesting that the motivations for information exchange may not differ by the size of the response organization or the phase of the disaster.

Table 3-7: Information Exchange Prompts – Definitions and Examples (Part I)

PROMPTS			
Prompt codes identify the reason or motivation for the information exchange incident.			
Prompt Category	**Prompt Definition**	**Example 1**	**Example 2**
ORGANIZATIONAL: Role Responsibilities	An information exchange incident is considered to be prompted by ***role responsibilities*** when information exchange clearly aligns with a responder's set of tasks and duties assigned in the response organization. For example, a responder may seek information to inform his or her assigned task. Or, a responder may share information with another responder because the originating responders knows it could inform the other responders' assigned task.	OBSERVATION (DATA): The IC says to move smart teams 2, 2, and 3. Ops says they are already talking about how to get them there. Says he is going to call strike team. (Delta, 502-504)	OBSERVATION (DATA): Ops continues to discuss boat availability. He says it's too far offshore for some type of boat [46ers?]. He says something like MSRC you guys have some large offshore barges right? And the blue boats of course. Then the person on the phone says something, and Ops says "it's pretty far offshore so as long as it's seaworthy to go out there…" [then we can use it, presumably?]. (Delta, 132-136)
		BACKGROUND/INTERPRETATION: The incident commander made a decision about where response teams should be deployed to and is communicating that to another responder who will execute the decision.	BACKGROUND/INTERPRETATION: The Operations Section Chief is trying to ascertain what boats are available for use in the response (e.g., his available external resources) and what should be deployed.
		JUSTIFICATION: This exchange is prompted by a role responsibility because the Incident Commander's (IC's) job is to manage or coordinate overall response efforts. This includes helping direct the assignment of tactical response teams (smart or strike teams).	JUSTIFICATION: This exchange is prompted by a role responsibility because the Operations Section Chief is specifically responsible for managing and coordinating all efforts related to the mitigation of, response to, and recovery from impacts. For oil spills, this includes all the boats that would be responding to the spill to contain or clean up the spill.
ORGANIZATIONAL: Formal Processes	An information exchange incident is considered to be prompted by ***formal processes when it takes place within and aligns with the requirements of*** formal and pre-defined technical systems, documents, processes, or meetings (each with their own information needs or information exchange expectations).	OBSERVATION (DATA): 0849 – [IC] does a quick "201 brief" and asks the [responsible party] what he has done already. (Alpha, 99-100)	OBSERVATION (DATA): [IC Speaking to RP] Need to get your authorization to act as your Qualified Individual to spend money, RESPONSE: Yes, you have it. He then confirms RP is a member in good standing of a specific OSRO. (Delta, 66-67)
		BACKGROUND/INTERPRETATION: During a meeting, the Incident Commander verbally provides the latest information that is typically captured in a specialized briefing document, called the "201". The responsible party is the oil rig operator (private sector organization) that is financially and operationally responsible for response to and recovery from the oil spill.	BACKGROUND/INTERPRETATION: The Incident Commander, who is a contracted responder, is seeking formal authorization to act on behalf of the responsible party (see box to left on explanation of responsible party) during the response, which includes authorization to spend money.
		JUSTIFICATION: This exchange is prompted by a formal process (system meeting) because the incident commander is expected during this meeting to ensure responders have up-to-date information. This includes sharing key information from another information exchange mechanism, the "201" briefing document.	JUSTIFICATION: This exchange is prompted by formal process (procedure) that is part of the responsible party's pre-defined oil spill response plan and requires this formal exchange of information. **This is an example of a quote that is prompted by both a Formal Process and a Role Responsibility.

Table 3-8: Information Exchange Prompts – Definitions and Examples (Part II)

PROMPTS			
Prompt codes identify the reason or motivation for the information exchange incident.			
Prompt Category	**Prompt Definition**	**Example 1**	**Example 2**
CONTEXTUAL: Misalignment of Information	An information exchange incident is considered to be prompted by the ***misalignment of information*** when the language and/or context explicity or implicitly suggest that a lack of information or conflicting information motivates the exchange. For example, responders may notice an information conflict and then seek information to resolve the conflict. The lack of information or conflicting information may result from the situation itself or failures of the organizational to get information where it is needed (these causes are not distinguished in the data). **NOTE:** The Misalignment of Information and Externality prompts differ from each other in that the former prompts exchange because specific information is needed, but is either unavailable or conflicting, while the latter prompts exchange because there is a known problem or change in the situation or response itself (e.g., massive weather change).	OBSERVATION (DATA): Legal w/Finance. There is an injury, but unsure of employer [received via a piece of paper brought by Finance, but finance was unsure who else this was relevant for]. Legal wasn't aware of this. Wants to find out where information came from. (Charlie, 661-667)	OBSERVATION (DATA): Someone asks if the sheen is 500 ft or 1000 ft north of the rig. There is some confusion about the numbers, and it starts to appear that someone made a mistake, maybe within the written documentation. Someone tries to clarify that the oil slick is 500 yards north of the location, and the rig was 1000 ft away when it regained power. (Delta, 363-366)
		BACKGROUND/INTERPRETATION: A finance responder received information about a field injury and is sharing this information with a responder from the legal group to help determine who else needs this information. Additionally, the legal responder also wants additional information to better understand what to do.	BACKGROUND/INTERPRETATION: A responder tries to clarify an information conflict regarding the location of the oil slick.
		JUSTIFICATION: This exchange is prompted by the misalignment of information because both the finance and legal responders did not have enough information with which to properly act on the situation (the field injury). **This exchange would have been considered to be primarily prompted by an externality (the injury itself) had the responder from the finance group simply shared this information with the legal responder. However, in this case, the lack of knowledge about the injured person's employer, who else needs this information, and where this information came from is what really prompted and continued to prompt the exchange.	JUSTIFICATION: This exchange is prompted by the misalignment of information because the responder has conflicting information about the location of the oil spill slick and needs to exchange information with another responder to resolve the information conflict.
CONTEXTUAL: Externalities	An information exchange incident is considered to be prompted by ***externalities*** when the langauge and/or context explicitly or implicity suggests that changes in the disaster situation itself, such as weather, injuries, fires, oil movement, etc. motivates the exchange.	OBSERVATION (DATA): 0916 - Planning talks to BSEE and mentions that the Grand Bay won't be able to cover the GRP based on its draft. They discuss calling Grand Bay back before they spend any more money. However, the OMI MARCO is ok to go to that site. (Alpha, 181-183)	OBSERVATION (DATA): The source caught on fire, cantilever fell over, 6 foot piece of pipe sticking up from [something]. Getting full access to the top of the BOP stack is [something]. Still have a burning condition. The reality will be 5k barrels of oil a day and 14k barrels of water a day. No flow through the drill pipe. (Bravo, 586-588)
		BACKGROUND/INTERPRETATION: The Planning Section Chief is discussing a problem that one of the vessels drafts (amount of boat below water line) they deployed is too deep and will not be able to enter the main area of the oil spill.	BACKGROUND/INTERPRETATION: A responder is communicating new (secondary) series of problems (including some of the details) that the oil rig just experienced and will need to be addressed.
		JUSTIFICATION: This exchange is prompted by an externality because the problem was just discovered and requires information to be exchanged to resolve.	JUSTIFICATION: This exchange is prompted by an externality because the oil rig just experienced a series of secondary catastrophic failures, which required responders to exchange information with each other 1) in case the problems affects their respective role responsibilities and 2) to discuss how best to respond to these new problems.

Table 3-9: Exchange Incidents by Information Behavior and Prompt[2]

Behavior	Prompt	#/% Incidents		95% Confidence Intervals
All Behaviors	**All Prompts**	448		
	Role Responsibilities	213	48%	42.4 - 52.2%
	Formal Processes	171	38%	33.3 - 42.9%
	Misalignment of Information	120	27%	22.5 - 31.0%
	Externalities	70	16%	12.1 - 19.0%
Behavior	**Prompt**	**#/% Incidents**		**95% Confidence Intervals**
Seek	**All Prompts**	127		
	Role Responsibilities	53	42%	33.0 - 50.3%
	Formal Processes	13	10%	5.5 - 15.7%
	Misalignment of Information	93	73%	65.3 - 80.3%
	Externalities	11	9%	3.9 - 14.1%
Behavior	**Prompt**	**#/% Incidents**		**95% Confidence Intervals**
Share	**All Prompts**	259		
	Role Responsibilities	102	39%	33.2 - 45.6%
	Formal Processes	151	58%	52.1 - 64.1%
	Misalignment of Information	19	7%	4.2-10.4%
	Externalities	53	20%	15.4 - 25.5%
Behavior	**Prompt**	**#/% Incidents**		**95% Confidence Intervals**
Discuss	**All Prompts**	62		
	Role Responsibilities	58	94%	87.1 - 98.4%
	Formal Processes	7	11%	3.2 - 19.4%
	Misalignment of Information	8	13%	4.8 - 22.6%
	Externalities	6	10%	3.2 - 17.7%

[2] Some exchange incidents were motivated by multiple prompts. As a result, the percentages for each behavior add up to greater than 100%.

Table 3-10: Exchange Incidents by Prompt and Information Behavior

Prompt	Behavior	#/% Incidents		95% Confidence Intervals
Role Responsibilities	**All Behaviors**	213		
	Seeking	53	25%	19.2 - 31.0%
	Sharing	102	48%	40.8 - 54.9%
	Discussing	58	27%	21.1 - 33.8%
Prompt	**Behavior**	**#/% Incidents**		**95% Confidence Intervals**
Formal Processes	**All Behaviors**	171		
	Seeking	13	8%	4.1 - 11.7%
	Sharing	151	88%	83.0 - 92.4%
	Discussing	7	4%	1.2 - 7.6%
Prompt	**Behavior**	**#/% Incidents**		**95% Confidence Intervals**
Misalignment of Information	**All Behaviors**	120		
	Seeking	93	78%	69.2 - 85.0%
	Sharing	19	16%	9.2 - 22.5%
	Discussing	8	7%	2.5 - 10.8%
Prompt	**Behavior**	**#/% Incidents**		**95% Confidence Intervals**
Externalities	**All Behaviors**	70		
	Seeking	11	16%	7.1 - 24.3%
	Sharing	53	76%	65.7 - 85.7%
	Discussing	6	9%	2.9 - 15.7%

Table 3-11: Exchange Incidents by Information Behavior and Prompts Across Disaster Phase/Size of Response Organization

Behavior	Prompt	*Small (Initial)*		*Medium (Initial)*		*Large (Sustained)*	
Seek	**All Prompts**	33		53		41	
	Role Responsibilities	11	33%	24	45%	18	44%
	Formal Processes	3	9%	8	15%	2	5%
	Misalignment of Information	25	76%	39	74%	29	71%
	Externalities	7	21%	0	0%	4	10%
Behavior	**Prompt**	***Small (Initial)***		***Medium (Initial)***		***Large (Sustained)***	
Share	**All Prompts**	48		126		85	
	Role Responsibilities	20	42%	45	36%	37	44%
	Formal Processes	22	46%	73	58%	56	66%
	Misalignment of Information	5	10%	10	8%	4	5%
	Externalities	15	31%	21	17%	17	20%
Behavior	**Prompt**	***Small (Initial)***		***Medium (Initial)***		***Large (Sustained)***	
Discuss	**All Prompts**	10		25		27	
	Role Responsibilities	9	90%	23	92%	26	96%
	Formal Processes	0	0%	5	20%	2	7%
	Misalignment of Information	1	10%	3	12%	4	15%
	Externalities	3	30%	0	0%	3	11%

Based on these findings, we posit the following:

> *In a disaster response organization, across all organization sizes and phases of disaster, seeking behavior is primarily prompted by the misalignment of information (occasionally in combination with role responsibilities), sharing behavior is primarily prompted by formal processes, then role responsibilities and externalities, and discussing behavior is primarily prompted by role responsibilities.*

The literature provides intrinsic and extrinsic motivations for information exchange. Intrinsic motivations for information exchange include stress/coping, risk/reward, and social learning (Thomas D. Wilson, 2000). Intrinsic motivations were not a focus of this

research and therefore not identified in our research approach. Extant literature on extrinsic motivations, though, corroborate the different types of prompts we identified in this research. For example, role responsibilities and formal processes aligns with existing research on the performance of tasks (Byström & Järvelin, 1995); formal processes align with research on coordination (Comfort et al., 2004; R. A. Gonzalez & Bharosa, 2009; Militello, Patterson, Bowman, & Wears, 2007); the misalignment of information aligns with research on resolving uncertainty (Kuhlthau, 1993; Weary & Jacobson, 1997), the misalignment of information and formal processes align with research on information roles, information accessibility, consistency of data formats, information priority, and trust/willingness to exchange, etc. (Altay & Labonte, 2014; Bharosa et al., 2010; Day et al., 2009).; externalities and misalignment of information aligns with research on situational awareness (Endsley, 1995); and role responsibilities aligns with research on decision making (Mishra et al., 2014). Our findings provide empirical evidence of these motivations framed in context of information exchange within a realistic organization facing a disaster scenario.

Additionally, our findings suggest that certain prompts are associated with particular information exchange behaviors. Seeking is typically prompted by the misalignment of information. This makes sense since a lack of or conflict in information might lead to an immediate need for information which cannot wait for a formal process to obtain. This will likely always be a challenge in disaster response because no formal process can anticipate all information needs. Disasters are complex and dynamic events with many emergent information needs that can't be defined and planned for a priori. As a result, there is an expected misalignment of information due to the conditions that responders face.

In contrast, though, sharing is typically prompted by formal processes. Formal processes help responders develop mental models of the situation (Stanton et al., 2006) and also appear to help ensure that needed information gets to the responders who need it when the needs cannot be pre-identified, emerge dynamically, and/or the information is available in different parts of the organization.

Lastly, discussing is typically prompted by role responsibilities and seem to help responders better understand the situation and make critical response decisions related to their roles by leveraging the input and expertise of other responders. The literature supports these findings by explicating how expertise can be shared (King, 2005; Ley et al., 2014; Majchrzak, Jarvenpaa, & Hollingshead, 2007), built (Smith, Ford, & Kozlowski, 1997), and the role information sharing and discussing plays in decision making and performance (Mishra et al., 2014; Mosier & Fischer, 2011; Weick, 1993).

Overall, extant literature introduces formal processes, roles and other formal organizational features (such as technical systems, databases, displays, and reports) to help mitigate the misalignment of information (Altay & Pal, 2014; Ginige et al., 2014; U.S. Department of Homeland Security, 2008). The literature and our findings support this view that organizational design features play a critical role in supporting information exchange within disaster response organizations.

However, the degree to which organizational design can or should minimize the misalignment of information to improve system performance in disaster response remains an outstanding question. Understanding how key organizational features prompt information exchanges and what types of exchanges must happen outside the formal structure is information that organizational designers can use to reduce or encourage certain

behaviors depending on their design objectives. For example, our findings highlight how formal processes do not typically support much information seeking, and that the misalignment of information leads to seeking outside formal processes. Organizational designers may consider two potential paths based on this knowledge. Either, 1) centralize or aggregate information for easy access, and/or 2) find ways to support ad-hoc seeking. The former approach may discourage seeking information from other responders so they can focus more on performing their duties, but is unlikely to contain all information needed.

3.2.3 Exchange Setting

In the exercises observed, responders exchanged information via two settings: ad hoc and system meetings.[3] Definitions and examples are included in Table 3-12. Responders exchanged information via both system meetings (59% of exchanges) and via ad hoc meetings (41% of exchanges) across all four exercises observed (see Table 3-13). However, the frequency that each setting was selected differed by the type of information exchange behavior used by responders (seeking, sharing or discussing). For example, responders more often *sought* information via ad hoc meetings (63%), *shared* information via system meetings (75%), and *discussed* information via ad hoc meetings (61%).

Additionally, when sharing and discussing behavior was prompted by a formal process, responders primarily shared the information via a system meeting (94% and 71%, respectively). However, if the sharing exchange was prompted by a role responsibility, the

[3] Due to observation constraints, we were not able to effectively observe the many different types of information exchange settings that were present, such as IT systems, status boards, reports, emails, phone calls, etc. Instead, our analysis focused on responders overarching choice of information exchange approach, ad hoc vs formal. In other words, did they choose to exchange information via a formal organizational process or via an ad hoc opportunity.

misalignment of information, or an externality, responders used both ad hoc and system meetings roughly equally to share information (seeTable 3-14). Seeking more often occurred via ad hoc meetings across all prompts.

Table 3-12: Information Exchange Settings – Definitions and Examples

SETTINGS			
Exchange setting codes describe the type of meeting in which the information exchange took place.			
Setting Category	**Setting Definition**	**Example 1**	**Example 2**
Ad Hoc Meeting	An information exchange incident is considered to take place at an ad hoc meeting when the exchange takes place at an meeting of 2 or more people that was not pre-defined by the organizational design.	OBSERVATION (DATA): Ops [speaking directly to another responder outside of a formal meeting] says they got the MSRC [an OSRO] numbers: 4 hours from approval, but they need the full green light. so around 1330 [I assume this means it will take them four hours after they have approval to deploy dispersants]. IC calls the federal on-scene coordinator, asking if approvals are there [for dispersant use]. They decided to note that they got the approval at 1115. (Delta, 493-496)	OBSERVATION (DATA): Someone from Ops is working with the guy running the software to update the IAP. This is not a formal meeting. They're adding a new Area of Operation: "[jurisdiction x] Shoreline Cleanup Group 1 – East". They add what set of boats are there. Now they update the work analysis matrix. They make notes about the work of the new Group. (Charlie, 1212-1215)
		BACKGROUND/INTERPRETATION: The Operations Section Chief is talking with the incident commander about the deployment of oil spill response contractors, including how far off they are from getting approval for the contractors to use dispersants that help break apart the oil on the water.	BACKGROUND/INTERPRETATION: The Operations Section Chief and responder responsible for software that helps aggegrate key information are working together to update the software with the most up-to-date information.
		JUSTIFICATION: This exchange occured at an impromptu meeting between two responders. This quote was part of a larger section of notes that specifically state that responders were working independently and speaking with each other as needed.	JUSTIFICATION: The meeting to update the software occurred because the Ops Section Chief felt this should be updated immediately rather than wait for a formal meeting to communicate the update. As result, the meeting occurred impromptu between the two responders.
System Meeting	An information exchange incident is considered to take place at a system meeting when the exchange takes place at a meeting of 2 or more people that is either pre-defined by the organizational design or is scheduled during the response to address specific purposes and objectives.	OBSERVATION (DATA): [Back at the Command & General Staff Meeting] PI ... notes there's a slight change to the objectives as described earlier: protect more than just environment, continuous evaluation of alternative response technologies, add NEBA tradeoffs messaging [??], adding waterways to the assets. (Charlie, 671-678)	OBSERVATION (DATA): Briefing starts. IC updates everyone that the air monitoring report looks good – there is no need for respiratory protection in the area of the spill. (Bravo, 110-112)
		BACKGROUND/INTERPRETATION: The Incident Commander is updating other responders on some slight changes to the response objectives for that operational period.	BACKGROUND/INTERPRETATION: The Incident Commander is updating other responders on the results of an air monitoring report, which indicates that there is no need for respiratory protection for responders working in the area of the spill.
		JUSTIFICATION: This update took place during a formal system meeting (the Command & General Staff Meeting).	JUSTIFICATION: The update took place during a formal system meeting where this information is expected to be shared.

Table 3-13: Exchange Incidents by Behavior and Setting

Behavior	#/% Incidents		Setting	#/% Incidents	
All Behaviors	448		Ad Hoc	175	41%
			Formal	256	59%
Seek	127	28%	Ad Hoc	76	63%
			Formal	45	37%
Share	259	58%	Ad Hoc	61	25%
			Formal	187	75%
Discuss	62	14%	Ad Hoc	38	61%
			Formal	24	39%

Table 3-14: Exchange Incidents by Behavior, Prompt, and Setting

Behavior	Prompt	#/% Incidents		Setting	#/% Incidents	
All Behaviors	**All Prompts**	448		Ad Hoc	175	41%
				System	256	59%
	Role Responsibilities	213	48%	Ad Hoc	105	51%
				System	100	49%
	Formal Processes	171	38%	Ad Hoc	20	12%
				System	148	88%
	Misalignment of Information	120	27%	Ad Hoc	77	67%
				System	38	33%
	Externalities	70	16%	Ad Hoc	34	53%
				System	30	47%
Behavior	**Prompt**	**#/% Incidents**		**Setting**	**#/% Incidents**	
Seek	**All Prompts**	127		Ad Hoc	76	63%
				System	45	37%
	Role Responsibilities	53	42%	Ad Hoc	30	60%
				System	20	40%
	Formal Processes	13	10%	Ad Hoc	9	69%
				System	4	31%
	Misalignment of Information	93	73%	Ad Hoc	62	69%
				System	28	31%
	Externalities	11	9%	Ad Hoc	7	70%
				System	3	30%
Behavior	**Prompt**	**#/% Incidents**		**Setting**	**#/% Incidents**	
Share	**All Prompts**	259		Ad Hoc	61	25%
				System	187	75%
	Role Responsibilities	102	39%	Ad Hoc	38	40%
				System	58	60%
	Formal Processes	151	58%	Ad Hoc	9	6%
				System	139	94%
	Misalignment of Information	19	7%	Ad Hoc	10	59%
				System	7	41%
	Externalities	53	20%	Ad Hoc	23	48%
				System	25	52%
Behavior	**Prompt**	**#/% Incidents**		**Setting**	**#/% Incidents**	
Discuss	**All Prompts**	62		Ad Hoc	38	61%
				System	24	39%
	Role Responsibilities	58	94%	Ad Hoc	37	63%
				System	22	37%
	Formal Processes	7	11%	Ad Hoc	2	29%
				System	5	71%
	Misalignment of Information	8	13%	Ad Hoc	5	63%
				System	3	38%
	Externalities	6	10%	Ad Hoc	4	67%
				System	2	33%

Based on these findings, we posit the following:

> *In a disaster response organization, the majority of seeking and discussing behavior takes place via ad hoc meetings and secondarily via system meetings. The majority of sharing behavior takes place via system meetings and secondarily via ad hoc meetings.*

While extant literature is more comprehensive about the types of information exchange settings or methods than what we identified, the literature does not address when different settings or methods should be used within a response organization. The literature identifies the following settings or methods for information exchange in a disaster: ad hoc (Ley et al., 2014); documents, reports and meetings (U.S. Department of Homeland Security, 2008); technology solutions (Ginige et al., 2014; Ley et al., 2014; Turoff et al., 2004); key processes such as socialization (continuous social interaction), externalization (developing formal bodies of knowledge), and internalization (providing opportunities for conceptual learning) (Hedlund, 1994; McAdam & Mccreedy, 1999; Nonaka & Takeuchi, 1995); and individuals that act as information intermediaries such as facilitators, hubs, brokers or boundary spanners (Altay & Pal, 2014; Kapucu, 2006). Extant literature includes many more settings and methods for information exchange than identified in our research but lacks insight on the relative value or usage of the different settings and methods.

Our findings suggest that responders rely heavily on both ad hoc and system meetings to exchange information, which highlights the need to understand the most appropriate balance between two types of information exchange settings: 1) organizationally *enabled* information exchange settings and 2) organizationally *prescribed* information exchange settings. The former focuses on how the organization is designed to accommodate ad hoc/as needed information exchange. Examples include co-location of personnel and

access to other responders via phone or radio, etc. The latter focuses on the key organizational features that specifically call for certain types of information to be exchanged at different times. These include standardized meetings and reports. In practice, enabled and prescribed information exchanges are typically part of the organizational design (U.S. Department of Homeland Security, 2008). However, the best balance between these two types of information exchange is poorly understood within practice as well as the literature.

3.2.4 Type of Information Exchanged

There were two types of information exchanged in a disaster response: explicit and tacit. Definitions and examples are included in Table 3-15 and align with definitions from extant literature (Nonaka & Takeuchi, 1995; Polanyi, 1962). Most of the information exchanged in the observed exchange incidents was explicit (89% of all exchanges) (see Table 3-16). However, the amount of tacit vs. explicit exchanges differed by behavior. In seeking and sharing exchanges, nearly all information was explicit (>90%). In discussions, both explicit and tacit information were exchanged in equal proportions. Furthermore, 66% of all tacit exchanges occurred in a discussion (see Table 3-17).

Table 3-15: Types of Information Exchanged – Definitions and Examples

INFORMATION TYPE			
Information Type codes describe the type of information transferred during an information exchange incident.			
Information Type	**Information Type Definition**	**Example 1**	**Example 2**
Explicit	An information exchange incident is considered to have exchanged ***explicit*** information when factual or objective information about a topic is exchanged between people and systems. For example, the boats are at xyz coordinates.	OBSERVATION (DATA): The IC then verbally communicated five objectives to start the response and stated that they were in no particular order. They included... (Alpha, 130)	OBSERVATION (DATA): The [Incident Commander] says they notified the marine mammal standby network, and simulated a call to [several states]. (Delta, 558-559)
		BACKGROUND/INTERPRETATION: During a system meeting, the incident commander is communicating the five priorities for the response for the operational period.	BACKGROUND/INTERPRETATION: The Incident Commander is telling other responders, in a meeting, that the notifications to activate a mammal response network have been made.
		JUSTIFICATION: The five priorities are factual pieces of information that are being exchanged with other responders. There is no opinion about their merits or how they were selected.	JUSTIFICATION: An update on which notifications have been made is a factual piece of information that is being communicated to other responders.
Tacit	An information exchange incident is considered to have exchanged ***tacit*** information when contextual or experiential expertise about a specific situation or topic (including opinions and interpretations) is exchanged or new information is dynamically created. For example, the best way to deploy a fleet of boats.	OBSERVATION (DATA): [Two responders] are discussing how to set up an [Incident Command Post] with the hotel/IT...[another responder] is saying they want neutral ground....Sometimes the [Coast Guard] wants the ICP near them and we will look there first. (Bravo, 364-367)	OBSERVATION (DATA): The IC then walks in and wants to consider what will "suffice" between [different plans] for a burn or do we need [to know] how to match them. Planning says this is first step either way. In theory, plans should match. (Alpha, 424-426)
		BACKGROUND/INTERPRETATION: Three responders are discussing how/where to set up an incident command post at a hotel to manage operations longer term. The third responders adds that key responders generally want to operate on neutral ground, but some senior responders like the post near them.	BACKGROUND/INTERPRETATION: The Incident Commander is asking another responder his/her opinion about whether different response plans need to be matched/deconflicted to conduct oil slick burn operations (burning the oil on the surface of the water). Planning says they need to check the plans first regardless.
		JUSTIFICATION: The third responder injects his historical expertise about different stakeholders' desires when selecting where and how to setup the hotel/ICP.	JUSTIFICATION: The Incident Commander is asking for an expert-based opinion from a responder whose expertise is related to response planning and who is familiar with the different response plans that apply to this situation.

Table 3-16: Types of Information Exchanged by Exchange Behavior

Behavior	# Incidents	Info Type	#/% Incidents		95% Confidene Intervals
All Behaviors	448	Tacit	50	11%	8.4 - 14.1%
		Explicit	398	89%	85.5 - 91.7%
Seek	127	Tacit	10	8%	3.1 - 12.6%
		Explicit	117	92%	86.6 - 96.1%
Share	259	Tacit	7	3%	0.8 - 5.0%
		Explicit	252	97%	95.0 - 99.2%
Discuss	62	Tacit	33	53%	40.3 - 64.5%
		Explicit	29	47%	33.9 - 58.1%

Table 3-17: Exchange Incidents with Tacit Information by Exchange Behavior

Behavior	# Tacit	% Tacit	95% Confidene Intervals
All	50	100%	
Seek	10	20%	10.0 - 32.0%
Share	7	14%	4.0 - 24.0%
Discuss	33	66%	52.0% - 78.0%

Based on these findings, we posit the following:

1) *In a disaster response organization, only 11% of the exchanges include tacit information.*

2) *During seeking and sharing, explicit information is most frequently exchanged.*

3) *Two-thirds of tacit information exchanges occur in discussions.*

4) *Nearly half of all discussions exchange explicit information.*

Our findings suggest that the vast majority of information exchanged during a disaster response is explicit (89%), especially when responders engaged in seeking and sharing behavior. This suggests that responders primarily need and use explicit information about the current situation to inform their own decision-making and action-taking processes rather than needing outside expertise and knowledge to inform their duties. This further supports the rationale that ICS is designed as a "specialist" or "functional" organization (Bigley & Roberts, 2001; Jensen & Thompson, 2015) in which responders seek and share factual or explicit information to fulfill their individual responsibilities and tasks as the subject matter expert for a particular role. However, to the best of our knowledge, extant literature (e.g., Boisot, 1987; Hedlund & Nonaka, 1993; Nonaka & Takeuchi, 1995; Polanyi, 1962) does not address the relative amount of explicit vs. tacit information exchange within a disaster response organization.

Because explicit knowledge is easier to codify into reports, technical systems and other information products, our findings beg the question of why more the observed exchanges could not be avoided using faster (i.e., technical) exchange approaches. When expertise is required or new knowledge must be created, technical exchange systems will not be able to replace face-to-face or virtual meetings. However, we found that most meetings

exchanged explicit information, which could indeed be placed in a database or other technical system. Future research should seek to understand whether meetings fill some other need, such as providing context for explicit information, creating shared mental models, etc. If not, future organizational designs should consider making more explicit information available and accessible in technical and non-technical repositories (e.g., reports, technical systems, displays, etc.) to enable rapid ad hoc access and reduce the number of time-consuming meetings (ad hoc and prescribed).

The findings in this section provide an initial understanding of responder information exchange behavior in a disaster response organization. This behavior plays a key role in effectively modeling socio-technical systems such as disaster response organizations. As a result, we used these findings to inform our next stream of research, notably the development of an agent-based model, to understand the impact of different organizational design features on information exchange performance.

Chapter 4: Organizational Design and Information Exchange Model

Phase II of this research builds upon findings from Phase I by modeling the impact of individual information exchange behavior and key organizational features on system (information exchange) performance within a response organization. The findings from this investigation can inform improved design for response organizations. Figure 4-1 below provides an overview of the phenomena being investigated.

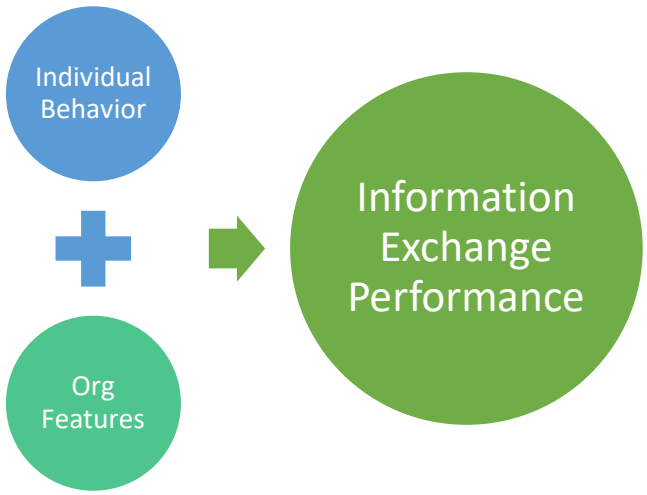

Figure 4-1: Overview of Phenomena Investigated

We attempt to answer the following question in this phase of research: *How do different organizational design features impact information exchange in a disaster response organization?* The following sections provide an overview of the research approach, findings, and discussion.

4.1 Methods

We utilize agent-based modeling (ABM) to investigate the phenomenon described above. This approach is well-suited to this investigation for a couple reasons: First, simulation models, such as ABMs, help explore phenomena in a controlled environment

that would otherwise be hard to investigate. For example, experimenting with different organizational designs during real-world operations may negatively impact those operations and is practically difficult, as is isolating the effects of each feature on information exchange performance.

Second, ABM allows you to define rules that mimic key aspects of real-world behavior and systems. Agent-based models account for individual behavior within a system to show emergent system-wide patterns. In a disaster response, individual behavior and organizational design features interact to produce combined impact on information exchange performance. ABM has been shown to be an effective "bottom-up" investigative approach that accounts for both the effects of organizational design and individual behavior at the same time (Altay & Labonte, 2014; Aros & Gibbons, 2018; Comfort et al., 2004; Hashemipour, Stuban, & Dever, 2018). Therefore, we use ABM to test the impact of key organizational design elements, given some assumptions about individual behavior drawn from insights in Phase I, that may affect information exchange performance.

4.1.1 Model Setup

To mimic key dynamics observed in real-world behavior, we model a functionally-based response organization. The organization has 12 functions, each with 13 responders. There is also one commander for a total of 157 responders. These responders are typically a group of personnel co-located at one emergency operations center and are responsible for managing and coordinating the overall response to a disaster. Each responder requires 12 unique pieces of information (6 typically managed by their own function, 6 typically managed by other functions) to fulfill their respective roles. In addition, the Lead of each function takes on all the information needs of the responders in their respective function.

There were ~2500 information needs total in the response organization. Within the model, responders' behavior is governed by a set of rules that specify when and how to exchange information.

The size of the response organization was selected for several reasons. First, one of the four response exercises observed in Phase I were close to this size. According to our discussions with response professionals, this size is representative of many real-world response organizations. Second, we believe this size is large enough to observe the phenomena being investigated. Third, maintaining one size of an organization helps normalize the results for analysis. Additionally, in initial versions of the model, we tested several different sizes and the results were similar.

Each responder is assigned a notional role within one of 12 different functions to help capture the different formal working relationships that are typically present in a response and form the "structure" of an organization. Different structures (i.e., relationships to other responders) are tested in this model and are explained in further detail in the sections that follow. However, in every simulation, there are always twelve operational functions intended to represent the many different groupings of responders during a response (e.g., operations, logistics, firefighting, public information, hazardous materials, etc.). Additionally, within each function, there is always one lead, four followers, and two partners per follower (13 responders in total), representing different roles within a function (see Figure 4-2).

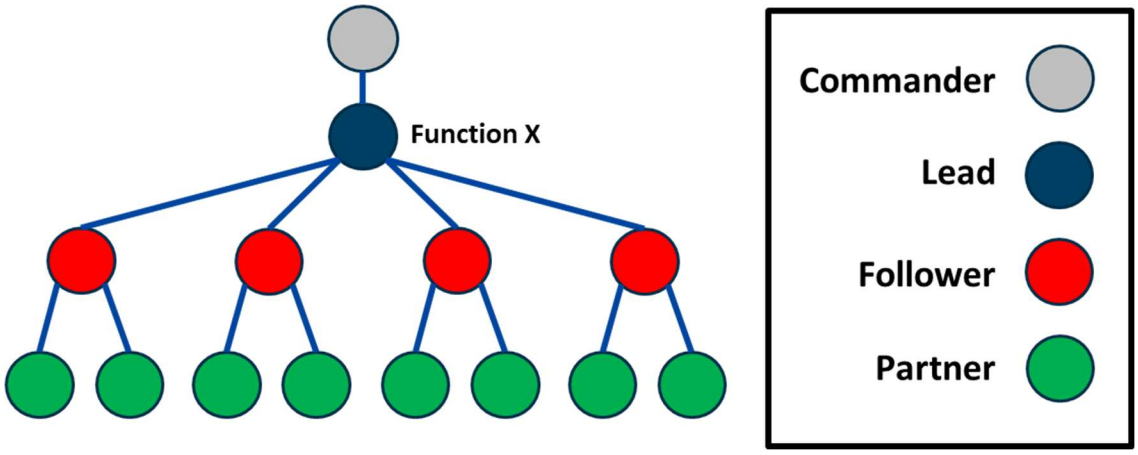

Figure 4-2: Example Organizational Structure for One Function

4.1.2 Simulation Rules

Our findings from Phase I suggest that responders typically obtain information they know they need by directly seeking information from another responder, a report, a display, or a software system. However, they are not always able to find the information they need, even if it is available within the organization, due to factors such as the information being difficult to access (e.g., 100-page PDF with no table of contents or not having login credentials for a software system), not knowing who to ask for the information, or not having a working relationship with the person who possesses the information.

Responders also attend meetings to obtain new or updated information about the situation. The information shared at the meetings may or may not be relevant to participating responders, but they attend in case some of the information shared is relevant or if they can provide additional information that would benefit others or a specific team decision. While meetings can provide some important information to groups of responders more efficiently and support group decision making, they also occupy significant amounts of responders' time that could otherwise be spent performing their duties.

The rules of the simulation model are intended to mimic these real-world dynamics. Within the model, responders can seek information from another responder or a central database or obtain information by attending a meeting. Each round of the simulation represents roughly one information exchange cycle between responders. As soon as a responder acquires information that matches one of their needs, whether from seeking or during a meeting, that *need* is considered satisfied. Once each responder obtains all twelve pieces of information needed, the *responder* is considered satisfied. The simulation stops when diminishing returns are experienced (defined as less than 0.50% increase in information needs satisfied for 500 rounds). Very few runs stopped due to this requirement. The paragraphs below describe the information exchange rules in greater detail.

Each round the simulation runs, up to eight responders who are not in a meeting and have at least one outstanding information need, are randomly selected to seek information. Each selected responder seeks up to two pieces of information per round. The responder first checks the database for the information. If the responder has already checked the database for this information, the responder will not check the database again. If the database has the information needed, then the responder is done seeking for that round. If not, the responder seeks information from one of his/her connections. Depending on the responder's source knowledge (a parameter varied in our experiments), the responder will either ask a specific connection (targeted request) that the requesting responder knows has the information needed (if such a connection exists) or will ask a randomly chosen connection who may or may not have the information needed. If the responder that was asked has the information needed, then it is counted as a successful exchange. Otherwise, it is counted as an unsuccessful exchange. During a targeted request, though, if there are

no connections that have the information needed, no information exchange attempt will occur and no "unsuccessful" seeking exchange will be counted. When this happens, the responder must wait until another round to seek the specific piece of information needed.

During meetings, responders cannot seek information or have information sought from them. When the meeting is over, all attendees then possess the information shared in that meeting, whether needed or not. Table 4-1 below describes the three types of meetings and their associated rules.

Table 4-1. Overview of Meeting Types

Meeting Type	Attendees	Sharers	Amount Shared	Meeting Length
Functional (1 Per Function)	All Members of the Function (~13 Responders)	All Attendees	Up to 10 Pieces of Information	10 Rounds
All-Hands	80% of all Responders (~126 Responders)	Commander and Leads in Attendance	Up to 20 Pieces of Information	20 Rounds
Leadership	Commander and All Leads (~13 Responders)	All Attendees	Up to 20 Pieces of Information	20 Rounds

Within this model, though, we do not include the behavior of a requestee taking on the information need that is being sought, including collecting the information in case the requestor asks for it again or to share directly with requestor once possessed. Instead, meetings provide all shared information to all participants. Therefore, responders leave the meetings with additional information that other responders may need, which more realistically mimics information diffusion. Additionally, we only simulate the exchange of information that is needed by responders and that other responders possess. We do not include dis-information (malicious information intended to confuse responders), mis-information (needed information that is wrong) or un-obtainable information in the simulation.

4.1.3 Simulation Implementation

Each scenario experiment included 50 simulation runs using NetLogo 6.0.4, a programmable agent-based modeling software application. The results from one scenario with 1000 simulations was compared with the data from only 50 simulations to ensure that 50 runs provided similar results with less computational expense. We analyzed the resulting data using MiniTab 19. We used four dependent variables (discussed in the next section) to assess the impact of different design features on information exchange performance. For each independent variable, we used one-way ANOVA to compare the variances of means across the independent variable values. Additionally, we tested the interaction effects of two independent variables and their associated values (or levels) at one time using full factorial experiments. Table 4-2 below summarizes the factorial experiments conducted and analyzed.

Table 4-2: Pair-Wise Interaction Effects Tested Using Full Factorial Experiments

Y = Yes, Analyzed N = Not Analyzed	Network Type	Supply Type	Central DB	Source Knowledge	Meeting Frequency	Meeting Type Proportions
Network Type		Y	Y	Y	Y	Y
Supply Type			Y	Y	Y	Y
Central DB				N	Y	Y
Source Knowledge					N	N
Meeting Frequency						Y
Meeting Type Proportions						

4.1.4 Dependent Variables

Many measures and methods have been proposed to test the performance of information systems. These include the specific information or types of information needed

to first understand what constitutes a successful information exchange (Comfort et al., 2004; Endsley, 2000; Uitdewilligen & Waller, 2018) and the timeliness, accuracy and relevancy of acquired information to measure the variability of success (Bao & Bouthillier, 2007; Bharosa et al., 2009; DeLone & McLean, 1992; R. A. Gonzalez & Bharosa, 2009; Pitt, Watson, & Kavan, 2016). Table 4-3 below provides an overview of the dependent variables we used to measure information exchange performance. They are based on extant literature and our research question(s). The first two variables help understand information exchange performance within a response organization while the latter two variables help understand the impact on responder performance, such as the ability to complete their role responsibilities.

Table 4-3: Overview of Dependent Variables

Variable	Description
Incompleteness	The total percentage of information needs not satisfied within the organization before diminishing returns.
Time to Satisfy	The average amount of time (in rounds) it takes for 50% of information needs to be satisfied within the organization. (Proxy for diffusion speed)
Time Away from Duties	The average percentage of time each responder spends *exchanging* information (seeking and attending meetings) before 50% of the organization's information needs are satisfied.
Wasted Effort	The average percentage of information seeking requests each responder makes that are unsuccessful before 50% of the organization's information needs are satisfied. *(Used only if above variable indicates further investigation)*

Incompleteness helps understand the totality of information that can be realistically exchanged given the design feature. Information needs may not be able to be satisfied because responders can be located too far from the information source, not have access to the information source, or because other responders do not gather information on behalf of another. This variable is important, though, because responders often require as much information as possible to inform their decisions and act. *Time to satisfy* helps understand

the speed at which information is obtained within an organization. This variable is important because responders typically need information as quickly as possible to understand the situation and to choose the best way to respond. *Time away from duties* helps understand how much time responders are spending exchanging information rather than performing the duties of their response roles. *Wasted effort* helps understand how often responders are asking unable to obtain the information they need. This variable is important because responders can often waste precious time and effort trying to find information if it is not available or provided by an organizational design feature. For example, the amount of information available in a central database can greatly influence the amount of wasted effort.

For each variable, we first tested *incompleteness,* the percentage of information needs (~2500 total) that could be satisfied, using the baseline values. They are highlighted in Table 4-5 below. Then we tested performance (*time to satisfy*, *time away from duties*, and *wasted effort*) for the organization to satisfy 50% of information needs, again using the baseline values as constants. This satisfaction threshold was informed by the results from above 1) to ensure simulations testing information exchange performance were solvable and comparable, and 2) because 50% represents a realistic and attainable number of information needs that can be satisfied in a disaster response. Therefore, our results related to information exchange performance focus on the organization's ability to satisfy 50% of its information needs. Finally, based on the results from the prior two tests, we investigated the interaction effects between different variables using the baseline values as appropriate.

4.1.5 Independent Variables

Table 4-4 below provides an overview of the six independent variables tested. The paragraphs that follow provide more information on each of these.

Table 4-4: Overview of Independent Variables

Design Features (IVs)	Feature Description	Levels
Network Structure	Type of notional network structure, including relationships among responders.	Hierarchy, XFunc-H, XFunc-HD, XFunc-HD+, Team (See Table 4-6 and Figure 4-3)
Source Knowledge	How often responders know which connections have the information they need (so they can ask for the information directly). (x% of the time)	0.0, 0.25, 0.50, 0.75, 1.0
Amount of Information Available in a Central Database	The amount of information available in a central database. (x% of all unique information)	0.0, 0.25, 0.50, 0.75, 1.0
Information Supply Type	Where information is initially located in an organization.	Top Down, Functional-Specialist, Functional-Spread, Random-Centered, Random-Spread (See Table 4-7)
Meeting Frequency	How often a meeting occurs within a response organization. (every x rounds)	(Frequent Mtgs) 30, 60, 90, 120, 150, 180, 210, 240, 270 100000 (No Mtgs)
Meeting Type Proportions	The proportion of meeting types within a response organization. (See Table 4-1)	(No Fx Mtgs) 0, 3, 6, 9, 12, 15, 18, 21, 24, 100000 (All Fx Mtgs)

The baseline scenario and values in Table 4-5 below were decided upon by testing the effects of mid-range vs. extreme values. Extreme values were chosen for the baseline simulations because the effects were similar, but more pronounced, thereby enabling to better isolate and assess the impact of different variables.

Table 4-5: Summary Table of Baseline Scenario and Variable Values Tested

Design Features (IVs)	Baseline Values	Value Description
Network Structure	Hierarchy	In each function, partners are connected to their parent followers, who are then connected to their parent leads. The commander is connected to all leads and all leads are connected to each other.
Source Knowledge	None	When seeking information, responders never know which connections have the information they need (so they always ask a random connection for the information).
Availability of Information in a Central Database	None	No information is available in a central database.
Information Supply Type	Top Down	The lead of a function starts with all the information typically managed by the function.
Meeting Frequency	None	*When meeting frequency and meeting type proportions are run, they include a constant since they are dependent on each other.*
Meeting Type Proportions	None	For meeting frequency, meeting type proportions was held constant at 12. For meeting type proportions, meeting frequency was held constant at 75.

Network Structure. One of the primary network structures for disaster response, ICS, is well-documented (U.S. Department of Homeland Security, 2008). However, it describes the formal reporting structure rather than the information relationship structures (between seeker and source) that are also present in a disaster response organization. These relationship structures have been studied within disaster response to a limited degree in relation to the role of boundary spanners (Kapucu, 2006), information flow structure (Pan et al., 2012), and connections to central hubs of information (technical or interpersonal) (Altay & Pal, 2014).

We developed five hypothetical network structures to represent different information relationship configurations within a disaster response organization that can support information exchange. They include: 1) Hierarchy, 2) XFunc-H, 3) XFunc-HD, 4) XFunc-HD+, and 5) Team. Hierarchy and Team structures are extreme (i.e., unrealistic) examples meant to help understand key dynamics. Hierarchy structures most closely mimic the ICS

reporting structure. The XFunc-H, XFunc-HD, and XFunc-HD+ structures are intended to represent a spectrum of more realistic organizational structures that have different types of cross-functional relationships among responders and information sources. All these structures include horizontal connections (Galbraith, 1974) to other responders at the same level (H). Additional diagonal connections are added from followers to other responders at different levels of the organization (HD). Finally, additional diagonal connections are made (HD+). Table 4-6 and Figure 4-3 below provide key details about the network structures.

Table 4-6. Network Structures

Design Feature	Levels	Level Descriptions
Network Structure Type of notional network structure, including relationships among responders.	Hierarchy	In each function, partners are connected to their parent followers, who are then connected to their parent leads. The commander is connected to all leads and all leads are connected to each other.
	XFunc-H	Same as hierarchy, except responders at each level of the organization are also connected horizontally.
	XFunc-HD	Same as XFunc-H, except each follower is also connected with 1 lead from another function and 1 partner from another function.
	XFunc-HD+	Same as XFunc-HD, except each follower is also connected with 4 random leads from others functions and 4 random partners from other functions.
	Team	All responders in organization is connected to each other.

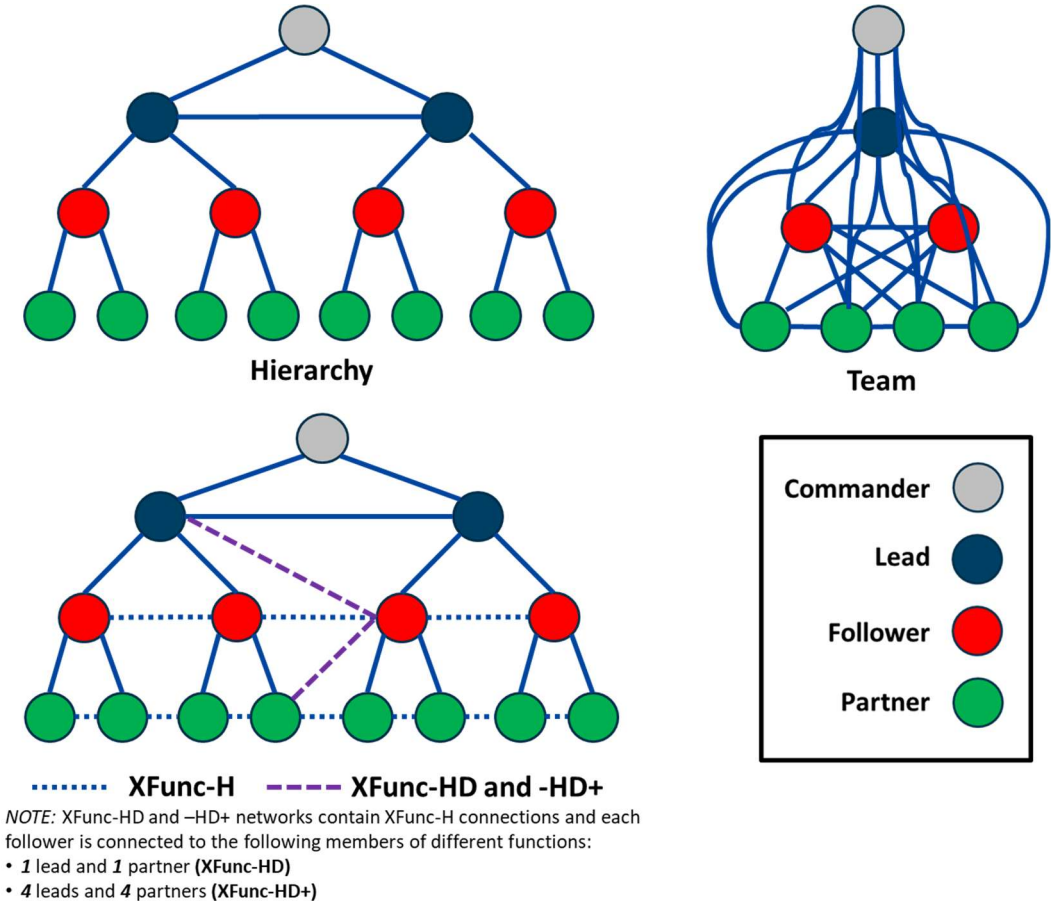

Figure 4-3: Overview of Network Structures

Source Knowledge. In disaster response organizations (Bigley & Roberts, 2001), difficulty identifying information sources can impede critical information flow (Day et al., 2009). Responders assume temporary roles that differ from their steady-state responsibilities and align with objectives of the disaster response organization. When this shift occurs, responders have varying degrees of familiarity with who has the information they need (i.e., knowledge of the information source) as they familiarize themselves with the new roles and responders in the organization and the disaster situation being faced.

To investigate the impact of source knowledge (familiarity with who has needed information), we varied how often a responder knows who to ask for the information they

seek. This ranges from always having to ask a random connection ("0") to always knowing exactly which connection has the information needed ("1").

Information Available in a Central Database. Organizational designers define and include different information products in disasters to support emergent information needs. These products include reports, technical systems, and display boards that responders can easily reference to obtain needed information (U.S. Department of Homeland Security, 2008), including central databases and systems (Ley et al., 2014). They can reduce the amount of time responders spend exchanging information, including how often responders are asked for information. In turn, this can improve coordination (Ancona, Kochan, Scully, Van Maanen, & Westney, 2004) and decision making (Galbraith, 1974),

To understand the impact of having information readily available and accessible to all responders, we introduced a central database that has varying amounts of information. This ranges from 0 to 100% of the 144 unique pieces of information needed in the organization.

Supply Type. Organizational designs also include assumptions or features about how and where information is supplied and made available in the organization (Altay & Pal, 2014; Bao & Bouthillier, 2007; Kapucu, 2006; Ley et al., 2014; Pan et al., 2012). For example, information can come in randomly to any responder or be directed to specific nodes across the organization so it is easier to access by other responders. While our research attempts to understand the diffusion of information within an organization once the information is there, where the information is first supplied can have a big impact on the diffusion of information and ultimately system performance. To investigate this, we developed five notional information supply scenarios intended to represent a spectrum of information supply possibilities (see Table 4-7).

Table 4-7: Overview of Information Supply Types

Design Feature	Levels	Level Descriptions
Information Supply Type Where information is initially located in an organization.	Top Down	The lead of a function starts with all 12 pieces of information typically managed by the function.
	Functional	A random person within each function starts with all 12 pieces of information typically managed by the function.
	Functional-Spread	4 random responders within each function start with 3 (25%) of the 12 pieces information typically managed by their function.
	Random-Centered	12 random responders within the organization start with 12 (~8.3%) of the 144 unique pieces of information in the organization. Information is randomly assigned.
	Random-Spread	24 random personnel within the organization start with 6 (~4.2%) of the 144 unique pieces of information in the organization. Information is randomly assigned.

As described earlier, each of the 12 functions is associated with 12 unique pieces of information that is typically managed by that function. There are 144 different pieces of information in total within the model. Additionally, during simulation, the objective of each responder is to obtain all 12 pieces of information he/she needs (6 typically managed by function, 6 typically managed by other functions). This is because responders typically need information related to their functional responsibility (e.g., firefighting) as well as information from another functional area (e.g., logistics) to inform their decision making. For example, the firefighting lead may need to know from logistics how many unassigned fire trucks are available from the staging area. Because of this cross-functional demand for information, it is not enough to assume that information should simply be aggregated and supplied by function. Additional understanding about where within a function is also important, especially when other cross-functional connections exist as well.

Meeting Frequency. Organizational designers also include different formal processes for information exchange (U.S. Department of Homeland Security, 2008). These processes

include procedures and meetings that enable information diffusion. However, these processes take up significant amounts of responders' time. Additionally, their impact on information exchange behavior and ultimately system performance is not well understood. For example, is having more meetings better than allowing responders to seek information on their own?

To understand this, we vary the frequency of meetings by decreasing and increasing the time (number of rounds) between meetings. We use meetings as a proxy for different formal exchange processes. Meetings range from very frequent (every 30 rounds) to no meetings at all. As discussed earlier, there are three types of meetings that differ by length and based on which responders are participating (see Table 4-1). To isolate the effects of this variable, we keep the proportion of meeting types constant with the sequence of: functional, all-hands, then leadership meetings. Each time a meeting is called for, a functional meeting is selected first until all functional meetings have been cycled through (12 functional, 1 all-hands, and 1 leadership). Then then the sequence repeats.

Meeting Type Proportions. Within a response organization, there are also different types of meetings that take place (U.S. Department of Homeland Security, 2008). They differ by who is in attendance, how long they run, and their purpose. Future organizational designs can be more specific about the optimal meeting type proportions to support information exchange and system performance.

We test the impact of different proportions by holding one all-hands and one leadership meeting every "x" functional meetings (vs. the baseline value of 12 functional meetings to 1 all-hands and 1 leadership meeting). Each functional meeting is associated with one function and is held sequentially without duplication, even if an all-hands or leadership

meeting occurs before all 12 functional meetings are completed. These values range from having no functional meetings at all to having twice as many functional meetings as there are functions, meaning each function has two meetings before the next all-hands and leadership meeting. Meeting frequency is held constant at one every 30 rounds to test this variable.

4.2 Results and Discussion

The results are discussed in detail below. The findings for each variable are described, including any relevant interaction effects. Then the findings are discussed in relation to extant literature and the implications for practice.

4.2.1 Network Structure

We identified three primary findings when analyzing network structures using the baseline values previously discussed in Table 4-5, which did not include any meetings. First, regarding *incompleteness*, more information needs can be satisfied when there are more connections to other responders. Table 4-8 and Figure 4-4 below show the amount of information needs satisfied by each network structure. Figure 4-4 also shows the mean value line. The gradual increase in completeness occurs as more connections are added because there is a much greater likelihood that a requesting responder will be connected to another responder with the information needed. However, sometimes not all needs can be satisfied because of the distance and location between responders and where the information is located. Information has a difficult time diffusing depending on the which responders need and request the information. While they may ultimately obtain the information needed, this will likely not occur without significant time or effort since the model stopped when there were diminishing returns.

Table 4-8: Network Structure – Results Summary (Baseline Scenario + IV Levels)

Network Structure						
	Baseline	Hierarchy	XFunc-H	XFunc-HD	XFunc-HD+	Team
Incompleteness	***28.9%***	***28.7%***	***21.2%***	***19.7%***	***16.4%***	***0.0%***
Delta		0.2%	7.7%	9.2%	12.5%	28.9%
% Change		-0.5%	-26.6%	-31.9%	-43.3%	-100.0%
Time to Satisfy	***3048.0***	***2632.9***	***2145.2***	***2136.2***	***2122.3***	***3506.1***
Delta		-415.1	-902.8	-911.8	-925.7	458.1
% Change		-13.6%	-29.6%	-29.9%	-30.4%	15.0%
Time Away from Duties	***20.2%***	***20.1%***	***20.2%***	***20.1%***	***20.0%***	***20.1%***
Delta		-0.1%	-0.1%	-0.1%	-0.2%	-0.1%
% Change		-0.4%	-0.3%	-0.5%	-1.0%	-0.5%
Wasted Effort	***97.5%***	***97.1%***	***96.5%***	***96.5%***	***96.4%***	***97.9%***
Delta		-0.4%	-1.0%	-1.1%	-1.1%	0.3%
% Change		-0.4%	-1.1%	-1.1%	-1.1%	0.3%

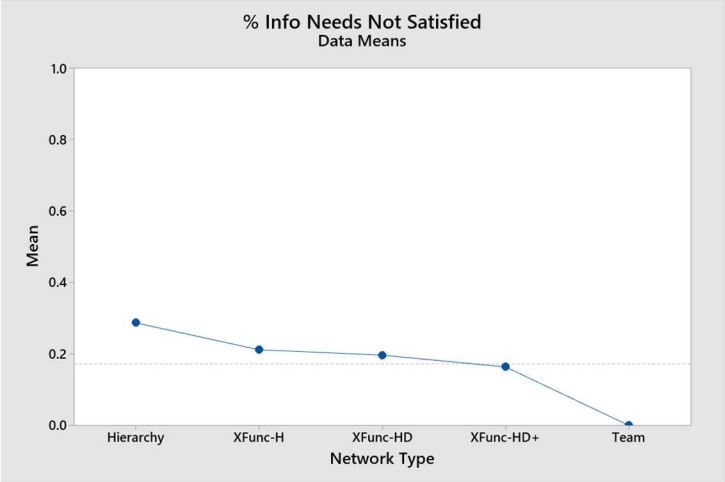

Figure 4-4. Completeness (Network Type)

Second, regarding the *time to satisfy,* more connections to other responders decrease the time to satisfaction unless all responders are connected to each other. Figure 4-5 below shows the results for all network structures. For the hierarchy structure, information satisfaction took longer because information wasn't easily accessible by responders across different functions in the organization. For the team structure, information satisfaction took longer because responders spent a lot of time asking other responders for information they didn't have. In other words, the wrong responders were asked for information more often, thereby increasing the time to obtain needed information.

Interestingly, the team structure took notably longer to satisfy information needs than the hierarchy structure, indicating that too many connections to information sources can be more detrimental than when the only horizontal connections in the network are between leaders. However, there were no significant differences between the cross-functional network structures. This indicates that the horizontal connections to equivalent responders in different functions may be the primary drivers of satisfaction speed. If diagonal connections were also impactful, we might have seen progressive increases in the

speed of satisfaction from XFunc-H through the XFunc-HD+ network structures. This can be validated in the future by testing an equivalent number of diagonal connections among responders and by removing all horizontal connections to help isolate the effects.

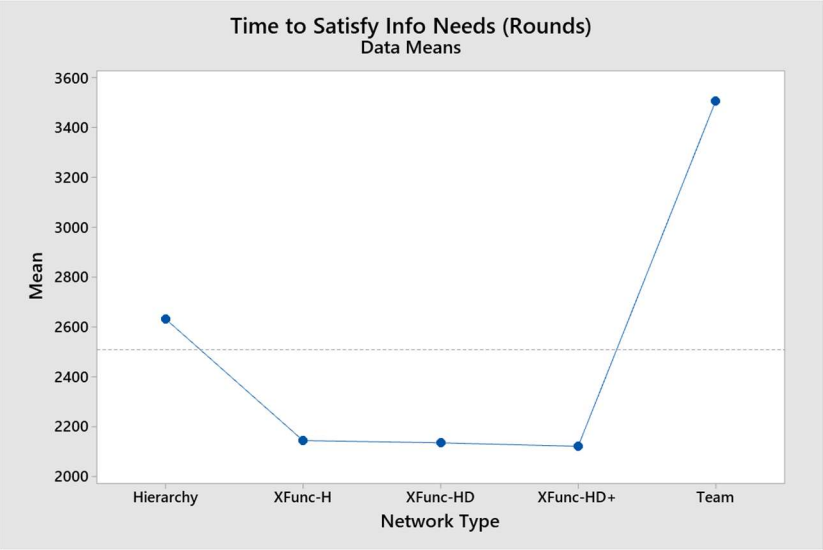

Figure 4-5. Time to Satisfy (Network Type)

Finally, when responders' *time away from duties* and *wasted effort* was examined (see Table 4-8), there were no notable differences between network structures. This is because responders spent the same relative amount of time exchanging information and wasting time seeking information despite the changes in speed of satisfaction.

Discussion

Our findings suggest that information exchange performance, namely *time to satisfy* and *incompleteness*, is improved with increased cross-functional (horizontal and/or diagonal) relationships. This aligns with Galbraith's (1974) findings that lateral relationships are critical for achieving goals in uncertain conditions. Additionally, Pan et. al (2012) find that hierarchical information network structures (information pyramid structure) actually support high amounts and speed of information flow, but encounter

difficulty with cross-functional information diffusion. Overall, the literature supports our findings that limited or no horizontal connections is detrimental to both the completeness of information needs satisfied and the speed of satisfaction.

Our findings also show that too many connections can negate the benefits of these horizontal connections. These findings validate extant literature across several domains that recognize the need to avoid information overload (R. A. Gonzalez, 2010; Klijn & Koppenjan, 2012; Staw, Sandelands, & Dutton, 1981) and the need for the "right" connections (Altay & Pal, 2014; Ancona et al., 2004; Kapucu, 2006). Specifically, we find that an excessive number of connections creates too many opportunities for unsuccessful searches. However, we did not investigate the impact of boundary spanners, liaisons and other specialized information management roles for exchanging cross-functional information (Altay & Pal, 2014; Kapucu, 2006; U.S. Department of Homeland Security, 2008), which can potentially mediate the negative impacts of too many connections.

These findings have several implications for practice. If the goal is to improve *incompleteness*, the organizational design should ensure as many people as possible are connected to each other. As you move from a strict hierarchy (baseline) to more connected network structures, there is a 41% decrease in *incompleteness*. However, if the goal is to improve timeliness of information exchange, organizational design should ensure there are enough, but not too many connections between responders. As you move from a strict hierarchy (baseline) to more connected network structures (excluding Teams), there is a ~30% increase in *time to satisfy*. If the goal is to balance both *incompleteness* and *time to satisfy*, then an XFunc-HD+ network structure appears to be the best network structure. This network structure is characterized by a significant number of horizontal *and* diagonal

connections across functions that improve the accessibility of needed information while not providing too many ways to access information. This balance of information accessibility should be investigated in future research to provide more precise understanding of this phenomenon (e.g., x methods of information access is optimal).

4.2.2 Source Knowledge

We identified three primary findings when testing source knowledge. First, regarding *incompleteness* and *time to satisfy*, source knowledge does not impact the amount of information needs that can be satisfied or the speed of information satisfaction in a response organization (see Table 4-9). This is because source knowledge only helps when a responder (1) is connected to another responder, and (2) the other responder already has the needed information. This was unexpected as it is reasonable to conclude source knowledge would enable responders to find information more quickly. However, this was not the case because if information is not yet well-diffused, responders, regardless of the source knowledge, will still take roughly the same amount of time to obtain needed information. In other words, while they may know who of their connections may ultimately have the information needed, those connections do not yet have said information. If information was better diffused to start with (e.g., see supply type), it is possible that source knowledge would increase the speed of satisfaction.

Table 4-9: Source Knowledge – Results Summary (Baseline Scenario + IV Levels)

Source Knowledge						
	Baseline	**0**	**0.25**	**0.5**	**0.75**	**1**
Incompleteness	***28.9%***	***28.8%***	***28.9%***	***28.9%***	***28.8%***	***28.9%***
Delta		0.1%	0.0%	0.0%	0.1%	0.0%
% Change		-0.3%	-0.2%	0.1%	-0.2%	-0.2%
Time to Satisfy	***3048.0***	***2603.1***	***2616.2***	***2579.2***	***2603.9***	***2643.7***
Delta		444.9	431.8	468.8	444.1	404.3
% Change		-14.6%	-14.2%	-15.4%	-14.6%	-13.3%
Time Away from Duties	***20.2%***	***20.1%***	***15.2%***	***10.2%***	***5.3%***	***0.0%***
Delta		0.1%	5.0%	10.0%	14.9%	20.2%
% Change		-0.4%	-24.9%	-49.4%	-73.7%	-100.0%
Wasted Effort	***97.5%***	***97.1%***	***96.2%***	***94.3%***	***89.0%***	***0.0%***
Delta		0.4%	1.4%	3.3%	8.5%	97.5%
% Change		-0.4%	-1.4%	-3.3%	-8.7%	-100.0%

Second, regarding *time away from duties*, more source knowledge helps responders spend less time exchanging information, thereby allowing them to focus on required tasks rather than information management (See Figure 4-6). For every 25% increase in source knowledge, there is an approximate 5% decrease in responders' time away from duties. This occurs because requesting responders do not ask for information as much since they know which, if any, connected responder have the information needed. As a result, the average amount of time a responder spends seeking information reduces greatly as there are significantly less unsuccessful seeking requests.

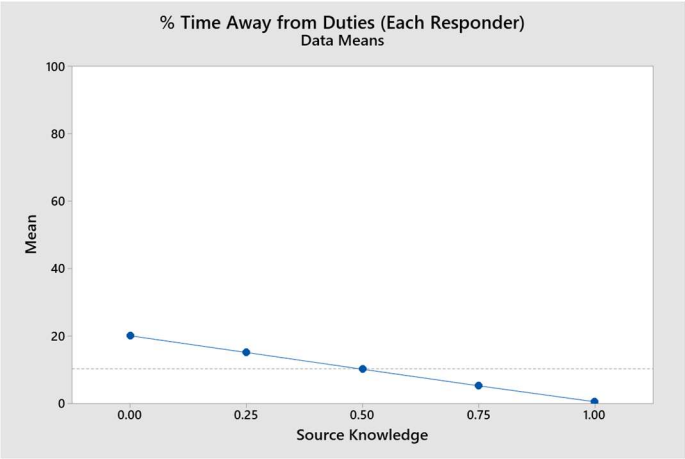

Figure 4-6: Time Away from Duties (Source Knowledge)

Third, regarding *wasted effort*, while the amount of time exchanging information decreases with more source knowledge (finding above), *wasted effort* for the exchanges that did occur only improves significantly when source knowledge is greater than 90% (see Table 4-10 and Figure 4-7). This is because information diffusion is slow (in a hierarchy, which is the baseline value) and not dictated by source knowledge. In other words, when source knowledge is less than 90%, responders are still continuously asking other responders for information who don't have the information needed. Source knowledge appears to only matter when information is already well-diffused within an organization, which should be further validated in future research.

Table 4-10: Wasted Effort (Source Knowledge - Baseline Scenario + IV Levels)

	Source Knowledge											
	Baseline	**0.5**	**0.55**	**0.6**	**0.65**	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**	**0.95**	**1**
Wasted Effort	***97.5%***	***94.3%***	***93.7%***	***93.1%***	***92.1%***	***90.8%***	***89.0%***	***86.7%***	***82.5%***	***75.3%***	***57.9%***	***0.0%***
Delta		3.2%	3.9%	4.4%	5.5%	6.7%	8.6%	10.9%	15.0%	22.2%	39.6%	97.5%
% Change		-3.3%	-3.9%	-4.5%	-5.6%	-6.9%	-8.8%	-11.1%	-15.4%	-22.8%	-40.6%	-100.0%

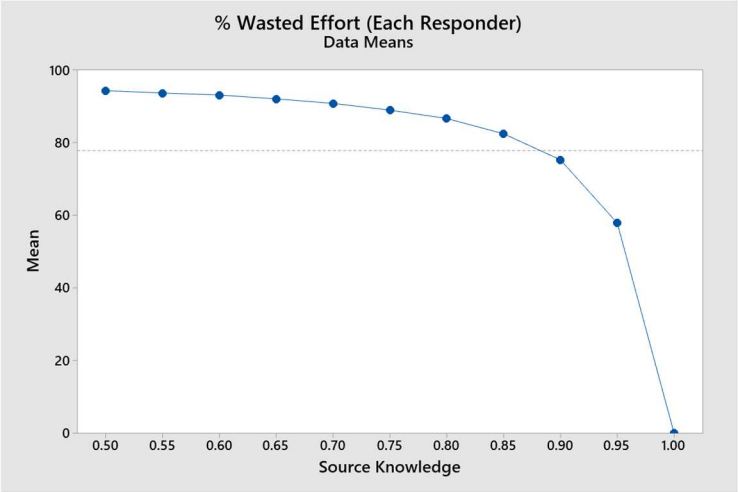

Figure 4-7: Wasted Effort (Source Knowledge)

Discussion

Extant literature discusses the importance of knowing who to ask (Borgatti & Cross, 2003) and overcoming source identification impediments (Day et al., 2009) to obtain needed information. Our research extends existing theory to understand the impact of source knowledge on information exchange performance. Specifically, we find that source knowledge incrementally decreases *time away from duties* (by ~5% for every 25% increase in source knowledge) because they have a better sense of who to ask for information and when. However, a significant amount of source knowledge is required to greatly improve wasted effort because information is not yet well-diffused in the organization and responders must still ask a substantial number of random responders for information, resulting in similar amounts of *wasted effort*. Interestingly, though, source knowledge does not impact *incompleteness* or *time to satisfy*.

These findings indicate that there are more impactful organizational design features than source knowledge that help responders find the information they need. There appears to be only a marginal benefit from investment in source knowledge for improving information exchange performance, unless source knowledge is greater than 90%. However, achieving 90% source knowledge may be practically unrealistic in dynamic, uncertain, and complex operations. In other words, investment in source knowledge by itself may only make marginal improvement in overall performance. For organizational designers, these findings suggest that knowing who to ask *and* ensuring the information is available near the person in need may improve information exchange performance. This is because knowing who to ask is insufficient by itself to improve *incompleteness* and *time to satisfy*.

4.2.3 Amount of Information Available in a Central Database

If a central database of information is available to all responders, *incompleteness* decreases, *time to satisfy* improves, and responders experience the least amount of *time away from duties* and *wasted effort* (see Table 4-11, Figure 4-8, Figure 4-9, and Figure 4-10). This is because responders have access to more of the information they need before they ask other responders for information. Also, the responder from which information was being sought does not have to spend time providing information to the requesting responder. As a result, the more information available in a central database and accessible by all responders, the more likely information will diffuse quicker and that responders will be able to obtain the information they need.

Table 4-11: Info Available in a Central Database – Results Summary (Baseline Scenario + IV Levels)

Info Available in a Central DB						
	Baseline	**0**	**0.25**	**0.5**	**0.75**	**1**
Incompleteness	***28.9%***	***28.8%***	***21.5%***	***14.3%***	***7.1%***	***0.0%***
Delta		0.1%	7.4%	14.6%	21.8%	28.9%
% Change		-0.3%	-25.6%	-50.6%	-75.4%	-100.0%
Time to Satisfy	***3048.0***	***2577.4***	***1009.7***	***277.6***	***128.0***	***74.8***
Delta		470.6	2038.3	2770.4	2920.0	2973.2
% Change		-15.4%	-66.9%	-90.9%	-95.8%	-97.5%
Time Away from Duties	***20.2%***	***20.1%***	***20.9%***	***20.1%***	***16.3%***	***10.2%***
Delta		0.1%	-0.7%	0.1%	4.0%	10.0%
% Change		-0.4%	3.4%	-0.6%	-19.6%	-49.6%
Wasted Effort	***97.5%***	***97.1%***	***93.3%***	***77.7%***	***50.0%***	***0.0%***
Delta		0.5%	4.3%	19.8%	47.5%	97.5%
% Change		-0.5%	-4.4%	-20.3%	-48.7%	-100.0%

Interestingly, though, the biggest improvements in *time to satisfy* occurs when there is between 0 and 50% of information available (see Figure 4-8, Figure 4-9, and Figure 4-10). When between 50% to 100% of information is available, wasted effort experiences significant improvements. This indicates that, when more information is initially available

in a central database, the *time to satisfy* will improve first, and as more information is available in the central database, *wasted effort* will then also be significantly reduced.[4]

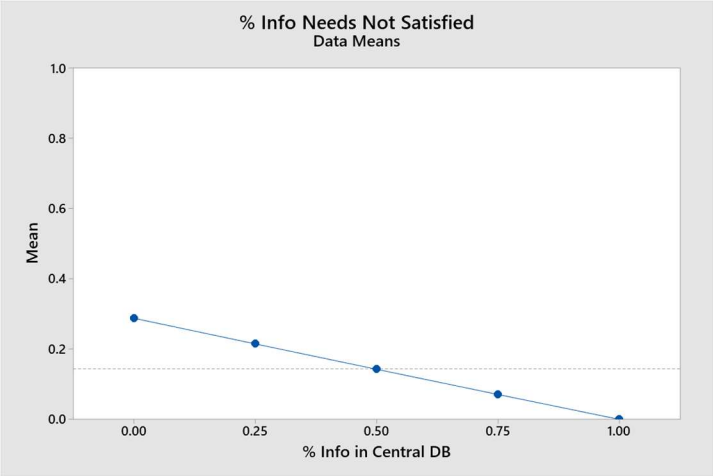

Figure 4-8: Incompleteness (Information Available in a Central Database)

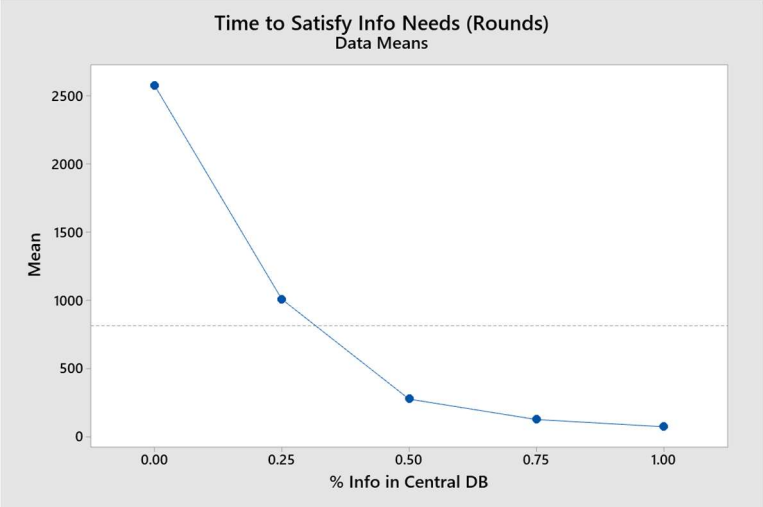

Figure 4-9: Time to Satisfy (Information Available in a Central Database)

[4] We do not argue that 50% is *the* key breakpoint in which wasted effort will begin to significantly improve. The 50% breakpoint is due to our model simulation being forced to stop when 50% of the organization's information needs are satisfied. We simply argue that there *is* a breakpoint and that additional research is required to explicate.

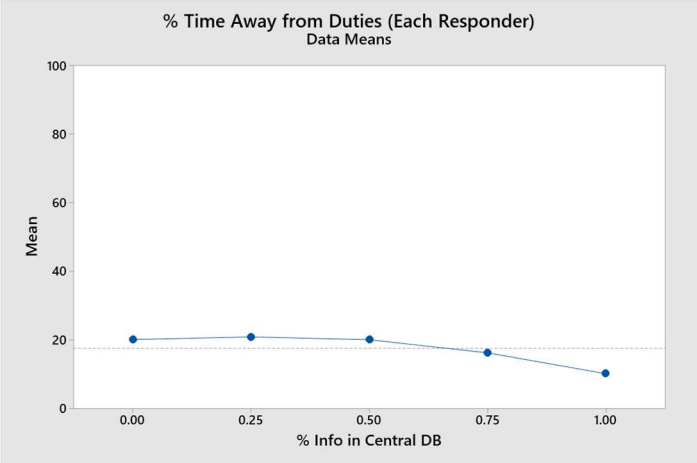

Figure 4-10: Time Away from Duties (Info Available in a Central Database)

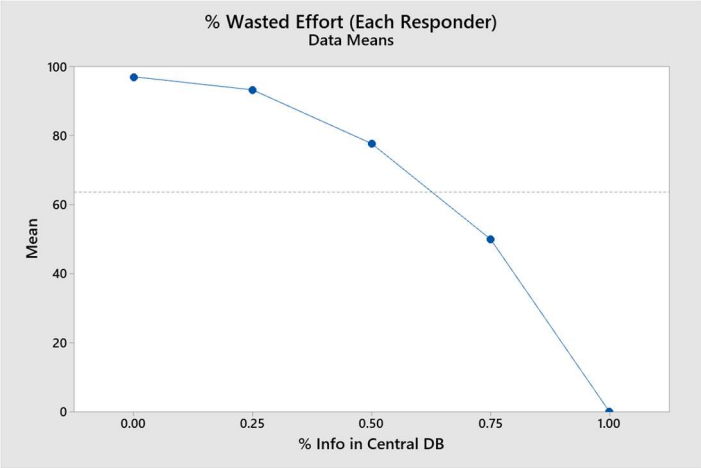

Figure 4-11: Wasted Effort (Information Available in a Central Database)

The dramatic improvements to information exchange performance raises the question of how much information exchange performance would improve (or not) when used in combination with other features. This is especially important because in practice the likelihood of a central database containing all information needed by responders or providing all available information in the right format is low. Therefore, we tested the interaction effects between the amount of information in a central database and the

following design features: meeting frequency (see Figure 4-12), meeting type proportions (see Figure 4-13), network structure (see Figure 4-14), and supply type (see Figure 4-15).

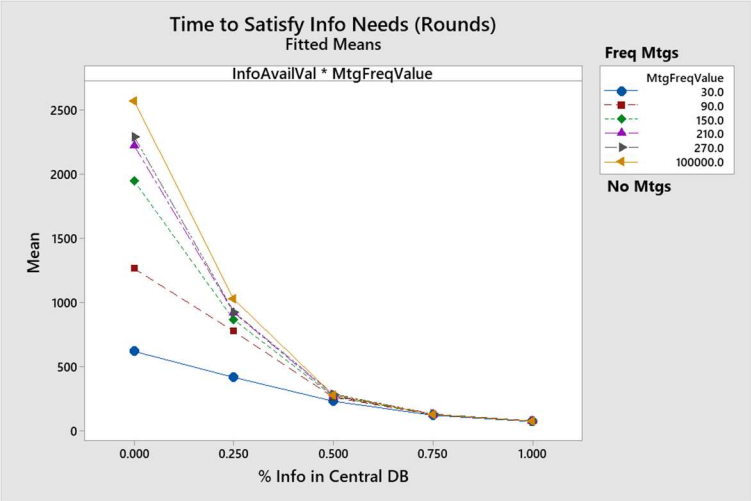

Figure 4-12: Time to Satisfy (Central Database vs. Meeting Frequency)

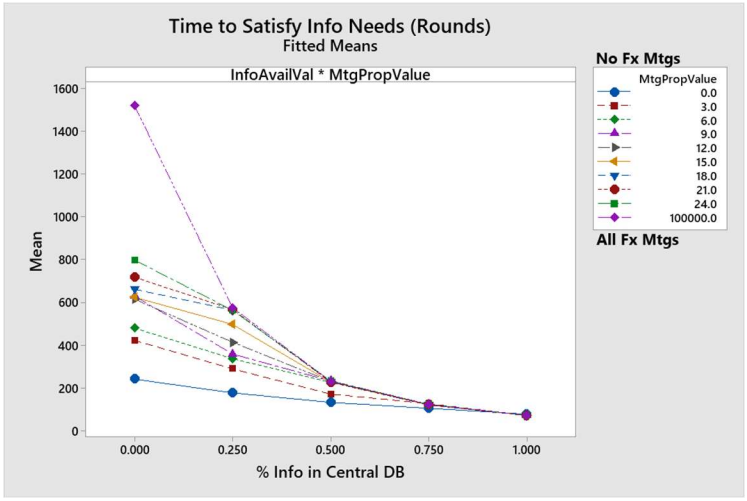

Figure 4-13: Time to Satisfy (Central Database vs. Meeting Type Proportions)

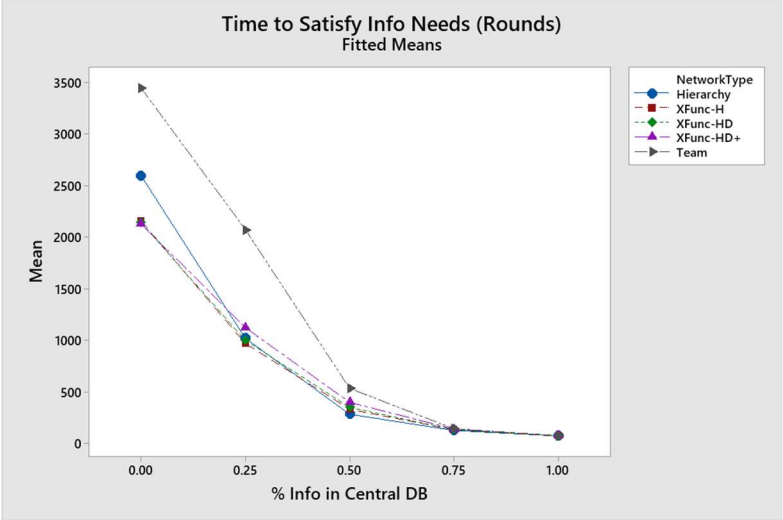

Figure 4-14: Time to Satisfy (Central Database vs. Network Structure)

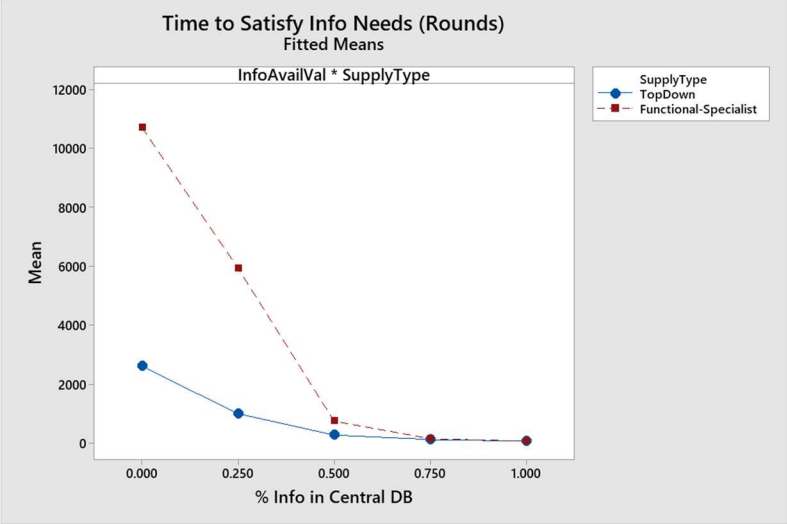

Figure 4-15: Time to Satisfy (Central Database vs. Supply Type)

Across all tests, *time to satisfy* was most impacted by the combination of information in a central database and other design features. Specifically, as the amount of information in a central database increases and reaches a certain threshold of the information needed, the need for and benefits of other design features decrease. Our results suggest the threshold

to be 50%, but this number is artificial because the simulations were structured to stop when 50% of information needs were satisfied.[5]

However, when the amount of needed information available in a central database is less than the threshold, using certain design features in combination is advantageous to how quickly information is exchanged. For example, more frequent meetings are very helpful when the database contains less information needed by responders. Interestingly, though, network structure (see Figure 4-14) appears to have the least amount of interaction effects, indicating that a central database may supplant the need for network structure as an information exchange design feature.

Overall, these findings suggest that when the amount of information in a central database contains a certain threshold of the information needed by responders, other design features are not needed or provide minimal added benefit. However, if the amount of information is less than the threshold, incorporating other design features such as meeting frequency (frequent meetings) or supply type (TopDown) is important for information exchange performance.

Discussion

Our findings corroborate existing theory that information systems improve information exchange performance. Shared information repositories facilitate exchange (Ley et al., 2014), IT systems improve coordination (Ancona et al., 2004) and decision making (Galbraith, 1974), and the timely and low cost access to information (in whatever form) also facilitate exchange (Borgatti & Cross, 2003). As the amount of needed information

[5] See previous note. We can only argue that this threshold exists and cannot suggest a specific threshold at which other design features are not needed.

available in a central information database increases, information exchange performance also increases.

However, the finding that *time to satisfy* is most improved first, then *wasted effort* is improved appears to be a novel finding about how organizational design features can have sequential vs. concurrent or distinctive impacts on performance. If a central database is designed into a disaster response system, information exchange performance will primarily improve the *time to satisfy*. However, we cannot determine from this research the exact point in which marginal benefits are experienced for *time to satisfy* while significant benefits to *wasted effort* increases. We can only argue that 1) this phenomenon exists and 2) that it occurs because responders can initially find a greater number of their information needs in the central database, thereby decreasing the effort to seek information directly from other responders that may or may not have the information they need.

For organizational designers, our findings indicate that a central database is very helpful and providing as much information as possible within the database is very beneficial to information exchange performance, notably for increasing the *time to satisfy*. However, we tested this design feature in a model-based environment that did not account for other operational issues such as information accessibility (Day et al., 2009; R. A. Gonzalez & Bharosa, 2009; O'Reilly III, 1982; Tsai & Yau, 2012) and externalities, such as the dynamism, uncertainty, and complexity of disaster. These issues make it unlikely the database will ever provide ***all*** or even significant amounts of needed information unless information processing capabilities are significantly increased (Galbraith, 1974). Some information won't be created or available yet, or responders will continue to experience emergent information needs that are impossible to predict. In addition, peer-to-peer

interactions may provide additional contextual information that would other be hard to capture in a central database. Therefore, organizational designers should consider a central database as one key feature, especially because explicit information is easy to put into a database, to be used in combination with other features.

4.2.4 Information Supply Type

We identified two primary findings when testing information supply types. First, regarding *incompleteness*, as information supply becomes more random, fewer information needs can be satisfied. The Functional-Spread supply type reaches approximately 24% of needs satisfied while the Random-Centered and Random-Spread supply types result in less than 6% of needs satisfied (see Table 4-12 and Figure 4-16). This is because information is either randomly available within the organization or spread across responders in a such a way that responders are unlikely to have a connection with the information needed (and there is no mechanism for responders to seek information on behalf of other responders in this model). In other words, when the location of available information has no or limited association to the location of need, the ability for information to diffuse and satisfy information needs is exceptionally bad. Based on these findings, Functional-Spread, Random-Centered, and Random-Spread were dropped from subsequent analyses. Only Top Down and Functional-Specialist supply types were analyzed.

Table 4-12: Supply Type – Results Summary (Baseline Scenario + IV Levels)

Supply Type						
	Baseline	TopDown	Functional-Specialist	Functional-Spread	Random-Centered	Random-Spread
Incompleteness	***28.9%***	***28.8%***	***28.9%***	***76.0%***	***94.1%***	***94.5%***
Delta		0.1%	0.0%	-47.1%	-65.2%	-65.6%
% Change		-0.4%	-0.1%	163.2%	225.8%	227.2%
Time to Satisfy	***3048.0***	***2581.4***	***11198.7***			
Delta		466.6	-8150.7			
% Change		-15.3%	267.4%			
Time Away from Duties	***20.2%***	***20.1%***	***20.2%***			
Delta		0.1%	0.1%			
% Change		-0.4%	-0.4%			
Wasted Effort	***97.5%***	***97.1%***	***99.3%***			
Delta		0.5%	-1.8%			
% Change		-0.5%	1.8%			

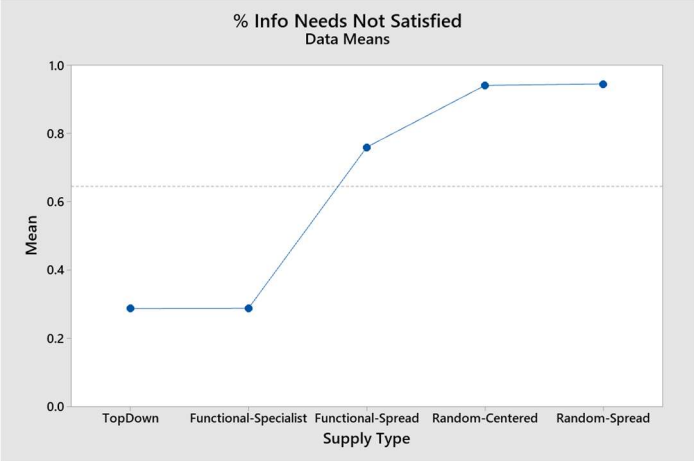

Figure 4-16: Incompleteness (Supply Type)

Second, when information is supplied within a function rather than to the leadership of that function, the *time to satisfy* gets worse (see Figure 4-17). This is because, in our baseline scenario, the functional leads are all connected to each other (and there are no other cross-functional connections in the hierarchy). Therefore, having the information with the lead enables responders in a particular function to obtain needed information from another function that typically manages the information. As a result, the cross-functional diffusion of information improves, followed by the within-function diffusion of information. When more connections are added, though, the type of information supply

becomes less important in decreasing the *time to satisfy* (see Figure 4-18). With more cross-functional connections, the performance delta (speed of satisfaction) between supply types decreases significantly. This is because responders are able to obtain more information from other functions due to more cross-functional connections. As a result, network design structure (connections) needs to be considered in tandem with the information supply approach.

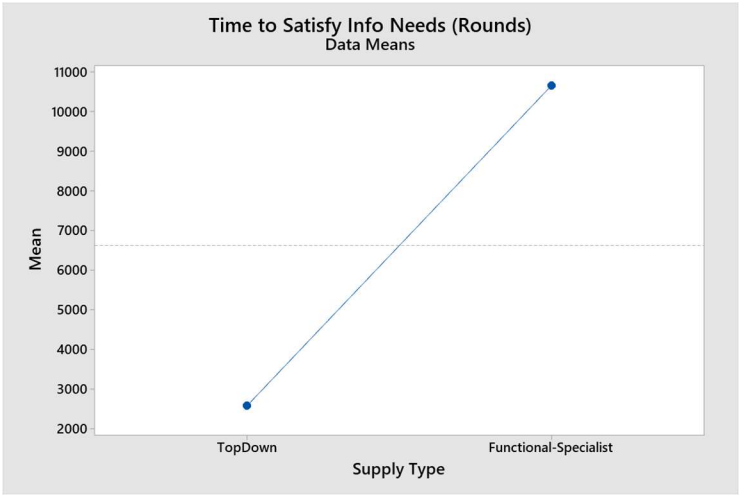

Figure 4-17: Time to Satisfy (Supply Type)

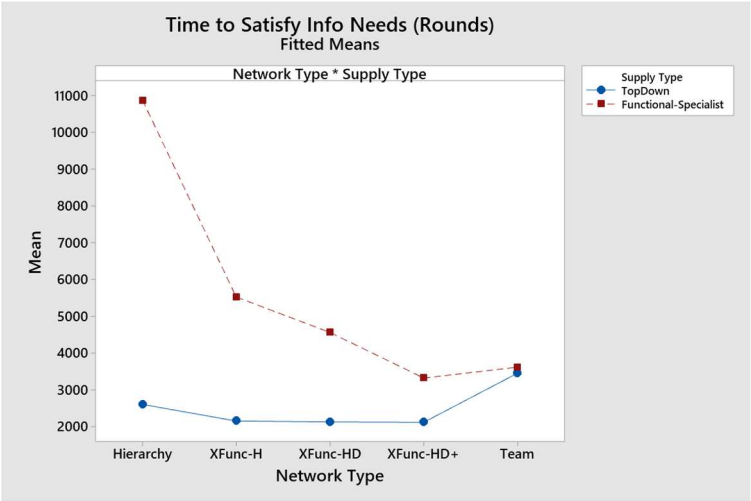

Figure 4-18: Time to Satisfy (Network Structure vs. Supply Type)

Discussion

The importance of information supply type (information location) within an organizational structure is well supported in the literature (Altay & Pal, 2014; Borgatti & Cross, 2003; Day et al., 2009; Kapucu, 2006). However, we differentiate supply location from information processing roles (Altay & Pal, 2014; Galbraith, 1974; Kapucu, 2006). While the two can overlap, our results focus solely on where needed and available information is aggregated and available within the organizational structure. We do not address additional information roles for processing information, either for analysis or facilitated information exchange (e.g., collecting and sharing information on behalf of another). While extant literature focuses on central repositories, the impact of IT systems, and information processing roles, our findings extend existing theory to specifically address the location of available/aggregated information, which can also improve information exchange performance.[6]

For organizational designers, these findings have several implications. First, it is important that there is an intentional information management strategy that addresses how to aggregate and make information available *within* the organizational structure rather than for the entire organization. Second, it is better to supply information with people that have cross-functional responsibilities or engage in significant cross-functional activities. Third, supply type strategies should be used to complement rather than replace other design features such as a central database, IT system, status board, or report.

[6] We did not test a functional-specialist design with all members of a function connected to each other. This may have provided additional insights related to information supply and should be a topic for future research.

4.2.5 Meetings (Frequencies and Proportions)

When testing the **frequency of meetings**, we found that a higher frequency of meetings improves the amount of information needs that can be satisfied (i.e., *incompleteness*) and the *time to satisfy* (see Table 4-13, Figure 4-19, and Figure 4-20). Interestingly, though, the higher frequency of meetings does not significantly increase responders' *time away from duties* or *wasted effort*. In Figure 4-21, we only see marginal increases in the amount of time responders spend exchanging information unless there is an extremely high number of meetings (greater than 50% of the time). This means that, in general, more frequent meetings improve *incompleteness* and *time to satisfy* without significantly impacting *time away from duties,* assuming there is a constant rate of seeking behavior (an assumption in our model).

Table 4-13: Meeting Frequency – Results Summary (Baseline Scenario + IV Levels)

Meeting Frequency						
	Baseline	**No Mtgs**	**210**	**150**	**90**	**Many Mtgs (30)**
Incompleteness	***28.9%***	***28.8%***	***18.5%***	***14.8%***	***11.6%***	***2.2%***
Delta		0.1%	10.4%	14.1%	17.3%	26.7%
% Change		-0.3%	-35.9%	-48.8%	-59.8%	-92.6%
Time to Satisfy	***3048.0***	***2613.6***	***2213.4***	***1954.0***	***1261.0***	***605.8***
Delta		-5661.6	-5261.4	-5002.0	-4309.0	-3653.8
% Change		-14.3%	-27.4%	-35.9%	-58.6%	-80.1%
Time Away from Duties	***20.2%***	***20.2%***	***20.6%***	***21.3%***	***22.3%***	***25.5%***
Delta		0.1%	-0.3%	-1.1%	-2.1%	-5.3%
% Change		-0.4%	1.6%	5.5%	10.3%	26.2%
Wasted Effort	***97.5%***	***97.1%***	***97.2%***	***97.1%***	***96.6%***	***95.9%***
Delta		0.4%	0.4%	0.4%	0.9%	1.6%
% Change		-0.4%	-0.4%	-0.5%	-1.0%	-1.7%

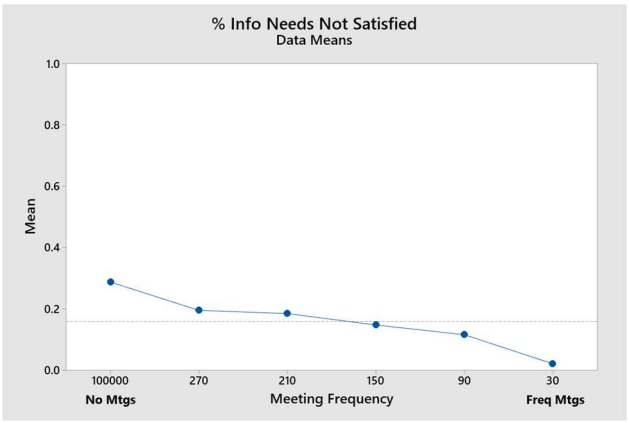

Figure 4-19: Incompleteness (Meeting Frequency)

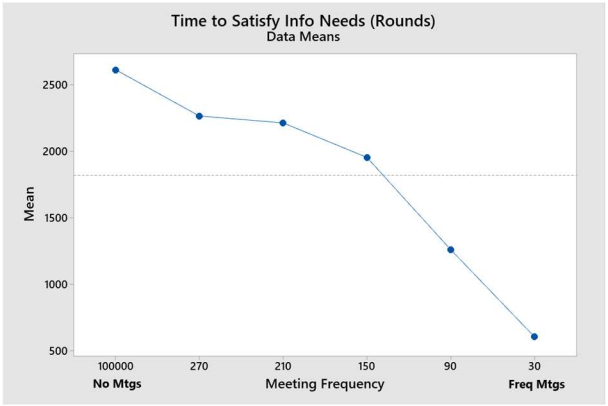

Figure 4-20: Time to Satisfy (Meeting Frequency)

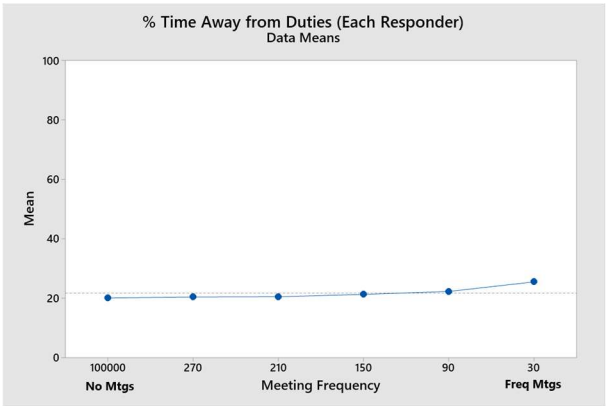

Figure 4-21: Time Away from Duties (Meeting Frequency)

When testing the **meeting type proportions**, we found that *incompleteness*, or the amount of information needs that can be satisfied, decreases greatly as the number of functional meetings between all-hands and leadership meetings decreases (see Table 4-14). This indicates that having any proportion of meetings is helpful. However, more functional meetings between all-hands and leadership meetings results in only marginal increases in the completeness of information. Second, the *time to satisfy* increases as there are more functional meetings between all-hands and leadership meetings (see Figure 4-22). This is because while functional meetings support some cross-functional diffusion of information, they do so at a slower pace and with the increased likelihood that some information will not diffuse sufficiently *across* the organization and other functions like it would if there were more all-hands and leadership meetings with representatives from other functions.

Table 4-14: Meeting Type Proportions – Results Summary (Baseline Scenario + IV Levels)

Meeting Type Proportions								
	Baseline	**All Fx**	**24**	**12**	**9**	**6**	**3**	**No Fx**
Incompleteness	***28.9%***	***4.0%***	***4.9%***	***2.4%***	***2.2%***	***0.3%***	***0.8%***	***0.2%***
Delta		24.9%	24.0%	26.5%	26.7%	28.6%	28.1%	28.7%
% Change		-86.0%	-83.0%	-91.7%	-92.4%	-98.8%	-97.2%	-99.2%
Time to Satisfy	***3048.0***	***1528.9***	***799.6***	***605.9***	***624.3***	***482.5***	***420.1***	***245.3***
Delta		1519.1	2248.4	2442.1	2423.7	2565.5	2627.9	2802.7
% Change		-49.8%	-73.8%	-80.1%	-79.5%	-84.2%	-86.2%	-92.0%
Time Away from Duties	***20.2%***	***22.9%***	***24.9%***	***25.6%***	***26.9%***	***29.3%***	***32.4%***	***49.2%***
Delta		-2.7%	-4.6%	-5.3%	-6.6%	-9.1%	-12.2%	-28.9%
% Change		13.3%	22.9%	26.3%	32.8%	45.0%	60.4%	143.0%
Wasted Effort	***97.5%***	***97.9%***	***97.0%***	***95.9%***	***95.8%***	***94.9%***	***94.0%***	***94.3%***
Delta		-0.3%	0.6%	1.6%	1.8%	2.7%	3.5%	3.2%
% Change		0.3%	-0.6%	-1.6%	-1.8%	-2.7%	-3.6%	-3.3%

However, having more all-hands and leadership meetings are costly in terms of responders' *time away from* duties because of the amount of time spent exchanging information in meetings (see Figure 4-23). All-hands meetings require 80% of all responders and last the longest. Additionally, if there are only all-hands and leadership meetings, responders spend nearly 50% of their time in meetings. When functional meetings are added, the *time away from duties* immediately drops to ~32% with only

marginal decreases as more functional meetings are added between all-hands and leadership meetings. This indicates that have at least some functional meetings between all-hands and leadership meetings are helpful for decreasing responders' *time away from duties*.

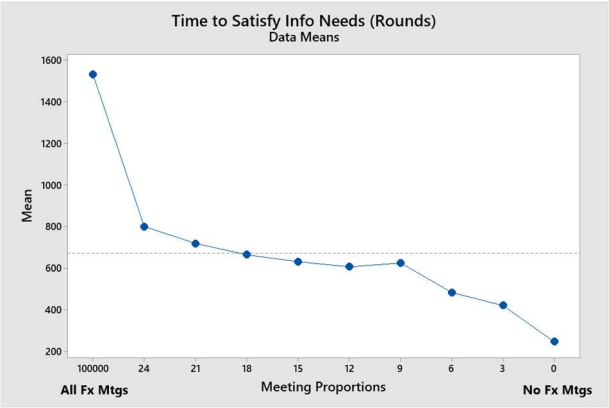

Figure 4-22: Time to Satisfy (Meeting Type Proportions)[7]

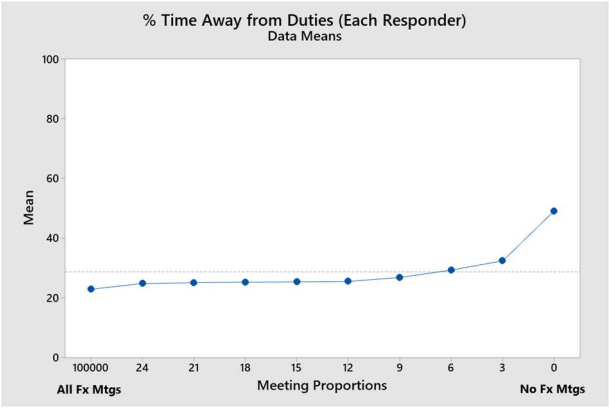

Figure 4-23: Time Away from Duties (Meeting Type Proportions)

[7] When there are nine functional meetings per each all-hands and leadership meetings, there is an artifact of the model. This artifact is due to the relatively low number of rounds where there was not an extra set of all-hands and leadership meetings that would speed up information diffusion. We re-ran the experiment but stopped it at 90% of information needs satisfied rather than 50%. The anomaly was no longer present.

Interaction Effects of Meetings

Analysis of our results suggest that meetings are the primary drivers of interaction effects, namely as it relates to network structure and supply type. Additionally, there are some nuanced effects between **meeting frequency** and **meeting type proportions**. These are discussed below.

Network Structure Effects. In terms of **meeting frequency**, when there are more frequent meetings, the network structures make no difference in the *time to satisfy* information needs (see Figure 4-24). This is because meetings assist with cross-functional information exchange, which was the key differentiating issue among network structures). In contrast, where there are no meetings, the *time to satisfy* differs across some network structures. Again, this is because meetings play a vital role in the initial cross-functional diffusion of information. As a result, less meetings result in more time needed for information to diffuse, and therefore more time for responders to obtain needed information.

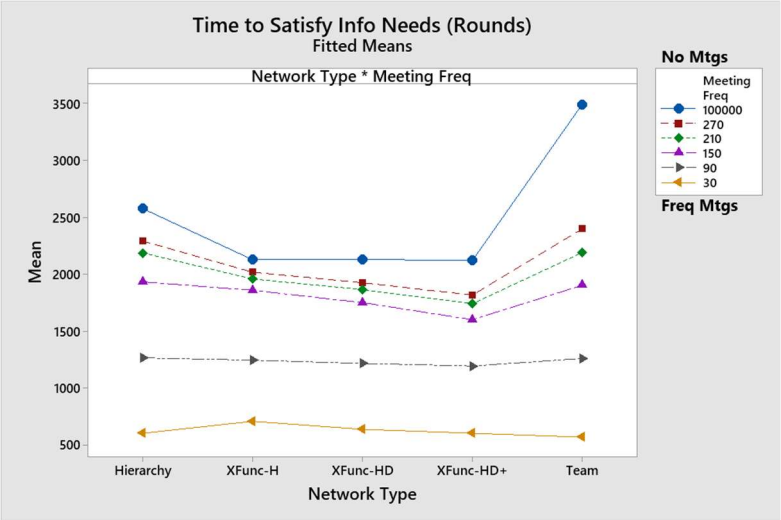

Figure 4-24: Time to Satisfy (Meeting Frequency vs. Network Type)

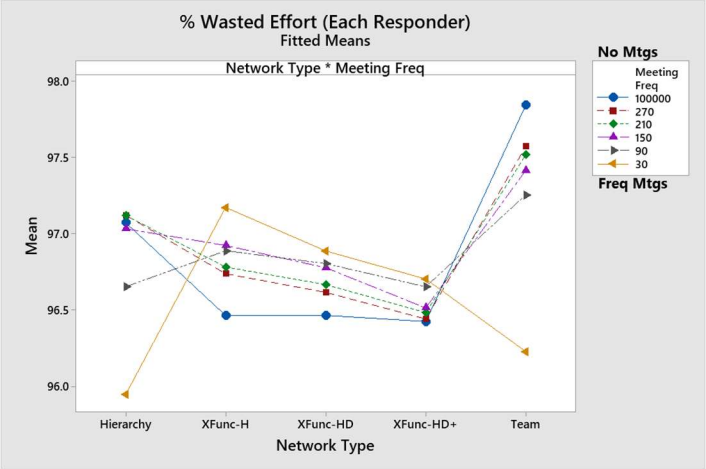

Figure 4-25: Wasted Effort (Meeting Frequency vs. Network Type)

A high frequency of meetings in hierarchy or team network structures, though, greatly reduces responders' *wasted effort* (see Figure 4-25). In a hierarchy, meetings (primarily all-hands and leadership meetings) greatly improve *wasted effort* because they support critical cross-functional information exchange across typically vertical and siloed information flows. This, in turn, enables more rapid diffusion of information across the network and increases the likelihood that responders will obtain needed information with fewer attempts. In a team, responders are also more likely to obtain needed information in fewer attempts because they are closer to the location of the information to begin with since all responders are connected. However, in cross-functional network structures, responders are more likely to *waste effort* because they are not close to the information needed and have a significant number of connections to ask for information, resulting in more unsuccessful seeking attempts. In summary, more meetings in hierarchy and team network structures are important for reducing responders' *wasted effort*.

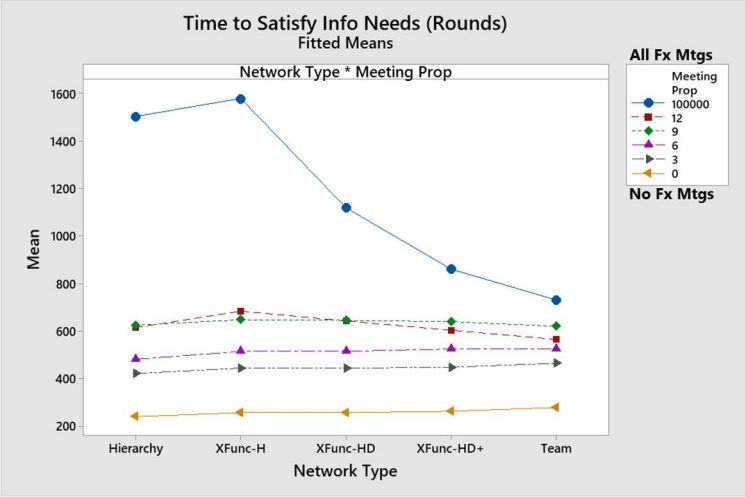

Figure 4-26: Time to Satisfy (Meeting Type Proportions vs. Network Type)

Lastly, in terms of **meeting type proportions** when there are only functional meetings (no other meeting types), the hierarchy and XFunc-H networks take significantly longer *time to satisfy* responders' information needs (see Figure 4-26). This is also because meetings, notably all-hands and leadership meetings, play a vital role in the cross-functional diffusion of information, and these network don't have cross-functional links.

Supply Type Effects. As shown in Section 4.2.4 for the baseline scenario, when there are no meetings, Top Down supply results in the fastest *time to satisfy* information needs (see Figure 4-27). This is because in a hierarchy (the baseline value), the leaders of each function are connected to each other and more likely to obtain information needed by members of their function. However, when there are meetings, this advantage disappears and similar satisfaction times can be achieved regardless of supply type.

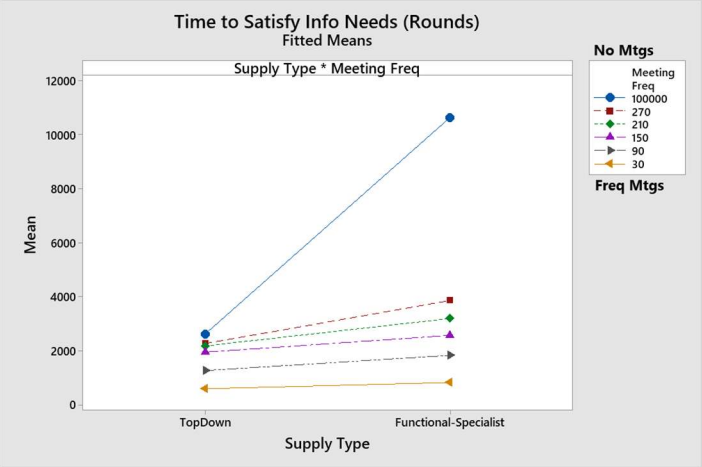

Figure 4-27: Time to Satisfy (Meeting Frequency vs. Supply Type)

Meeting type proportion is also relevant in relationship to information supply type. When there are only all-hands and leadership meetings, the functional-specialist type greatly increases the *time to satisfy* information needs (see Figure 4-28). This is because while members of the functions attend the all-hands meetings, they are not the sharers. Therefore, it is difficult for cross-functional information to diffuse. In a Top Down supply type, though, leaders hold much of the information needed by others and are also the sharers.

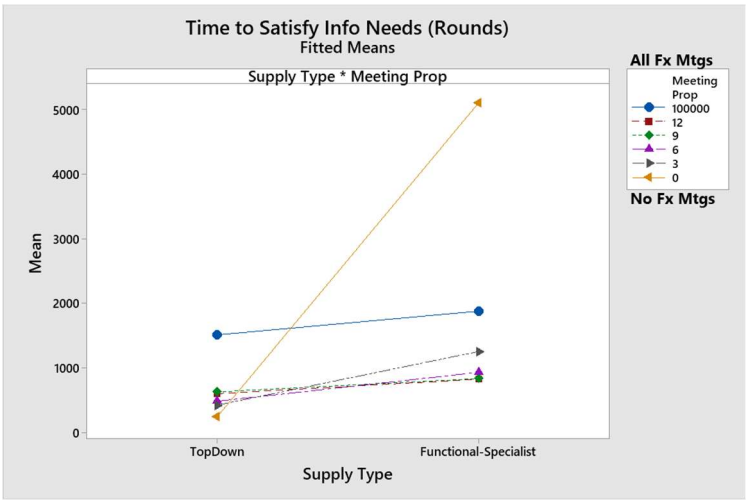

Figure 4-28: Time to Satisfy (Meeting Type Proportions vs. Supply Type)

In summary, when there are no meetings or only all-hands/leadership meetings, the *time to satisfy* increases greatly when information is not held at the lead level (i.e., functional-specialist supply type). This indicates that 1) meetings are key for cross-functional information exchange/diffusion, and 2) it is important to "bubble up" information to those who are sharing in the cross-functional meetings (i.e., all-hands and leadership meetings). The latter enables effective cross-functional information exchange/diffusion when supply is located within a function rather than at the top.

Meeting Effects. As there are fewer meetings, responders' *time to satisfy* and *wasted effort* increases when there are only all-hands and leadership meetings and regardless of meeting type proportions (see Figure 4-29 and Figure 4-30). However, responders' *time away from duties* decreases (see Figure 4-31). This indicates a need for balance between the frequency of meetings and the number of functional meetings between all-hands and leadership meetings. Determining this balance is an area of future research. Meeting frequencies in this model are relative/arbitrary.

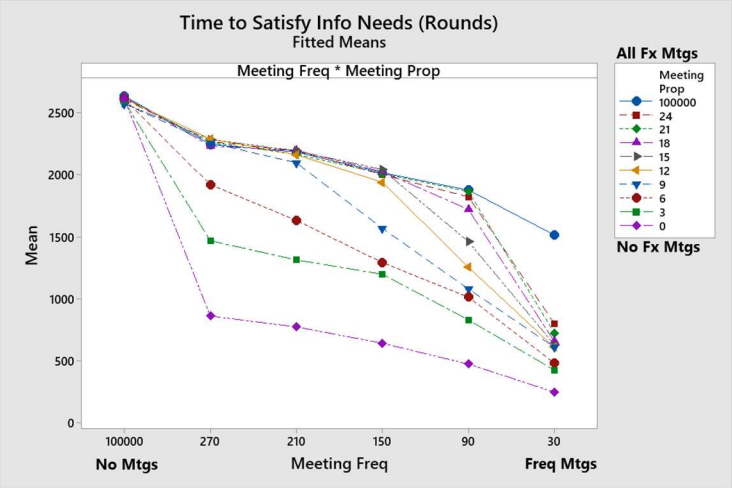

Figure 4-29: Time to Satisfy (Meeting Frequency vs. Proportions)

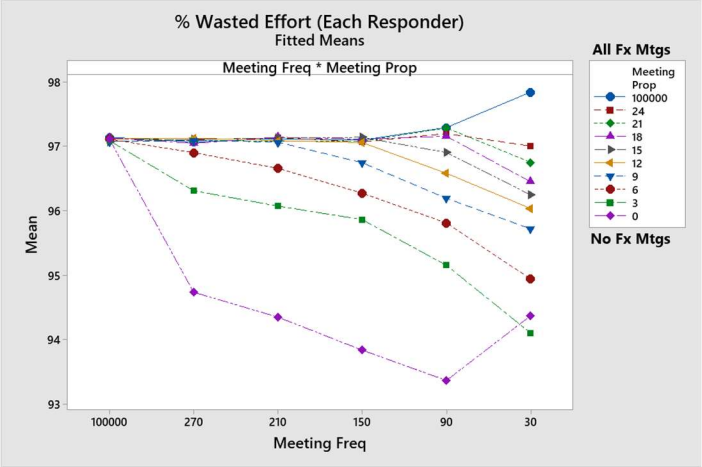

Figure 4-30: Wasted Effort (Meeting Frequency vs. Proportions)

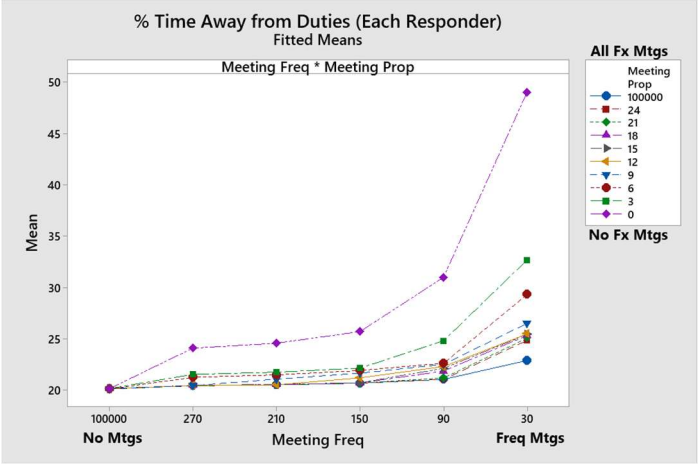

Figure 4-31: Time Away from Duties (Meeting Frequency vs. Proportions)

Discussion

In our first phase of research, we identified the presence of different meeting types within a response organizational design. This finding is corroborated by the multitude of research streams on meetings that include team performance (Kauffeld & Lehmann-Willenbrock, 2012), collaborative decision making (Christiansen & Varnes, 2007; Halvorsen & Sarangi, 2015), and communications (Wittenberg-Lyles, 2005). Additionally, our findings from both phases of research also validate extant literature that meetings serve

a cross-functional information processing role in disasters (Altay & Pal, 2014; Dolinskaya, Shi, Smilowitz, & Ross, 2011; U.S. Department of Homeland Security, 2008).

To the best of our knowledge, though, 1) the trade-off between the frequency of meetings and information exchange performance, or 2) the impact of different meeting type proportions on information exchange performance has not been addressed in extant disaster literature. Rather extant literature focuses on the impact of *meeting frequency* on employee well-being (Luong & Rogelberg, 2005), turnover (Braeunig, 2007), innovation (Drach-Zahavy & Somech, 2001) and overall firm performance (Kauffeld & Lehmann-Willenbrock, 2012; Vafeas, 1999). Additionally, to the best of our knowledge, the *interaction between meeting frequency or meeting type proportion in disasters ha*s not been studied in relation to network structures or information supply types. As a result, we believe our findings extend existing theory on meetings within organizational design, specifically the impact of meeting frequencies and proportions on information exchange performance in response organizations.

For organizational designers, our findings indicate that having more meetings is better because it leads to improved *incompleteness* of information and *time to satisfy* without compromising responders *time away from duties*, primarily by enabling important cross-functional information sharing. These findings require additional research to validate as we would have expected a more significant positive correlation in which more meetings greatly increase responders' *time away from duties*. We suspect that more frequent meetings enable significant information diffusion early in a disaster response. This, in turn, results in responders spending relatively less time trying to obtain information, especially seeking information directly from other responders. These findings could indicate a long

tail effect in which less meetings result in less initial information diffusion earlier in a disaster response, which causes responders to spend more time trying to obtain information from other responders. Testing the number of meetings within a specific time frame (e.g., 12 hours) may provide additional insights on this finding, such as explicating the optimal number or frequency of meetings relative to ad hoc information exchange

However, future testing should keep several practical considerations in mind. First, information needs and supply typically evolve over time in a disaster response, so information diffusion is continuous. Second, for urgent situations, organizational designers may want to emphasize ad hoc seeking features to better support faster information exchange rather than more complete information exchange. Third, meetings are more likely to help information diffuse in organizations where information supply is siloed, decentralized or distributed rather than centralized. Lastly, this model assumed that all information needed in a disaster response organization would be exchanged across the meetings that take place, which may not be the case in reality. Some information may only be exchanged 1-on-1 or require discussions between responders.

4.2.6 Approaches to Organizational Design for Response

The results discussed earlier in this chapter provide insights on the relative trade-offs between different organizational design features that support information exchange in disaster response. The following more clearly summarizes how potential features should be considered when designing future response organizations.

1. **When a network structure mimics a hierarchy or a team, and/or when information may enter the organization at random locations (rather than the locations of need in the organization), cross-functional design features are very important (e.g., cross-functional meetings or a central database).** In the case of random supply or a hierarchical structure, information needed by other functions is spread across the organization or siloed in the originating function, requiring cross-functional design features to ensure diffusion across the organization. In the team structure (highly connected), responders have the option to obtain information from many responders, which results in many unsuccessful information exchange attempts as a responder attempts to determine who has the information needed. Therefore, cross-functional design features are essential to helping focus information exchange efforts in a productive way.
2. **Designing specific cross-functional connections based on potential responder information needs is likely to be more effective than connecting all responders to each other.** Too many connections, especially when it is not clear who may possess the information needed, will significantly slow the ability of responders to obtain needed information quickly. However, due to a lack of a priori knowledge about information supply and demand, response organizational designers will not know (with high degrees of certainty) which responders must be connected to each other during a response. Therefore, considering which cross-functional connections *might* be needed and designing a network structure to support those connections appears to be more advantageous than ensuring all responders are connected to each other.
3. **When relatively low amounts of needed information are available in a central database, the use of other design features helps improve information**

exchange performance. In particular, more frequent meetings and ensuring information supply is located with responders who liaise between different functions help improve information exchange performance when combined with a central database. However, there are minimal to no benefits of incorporating additional design features when the amount of needed information available in a central database is relatively high.

4. **Supplying information to responders who typically liaise between different functions helps ensure good information exchange performance.** The ability to diffuse information across functions helps improve information exchange performance by ensuring responders have close access to information from other functions. This form of information supply also appears to work well when other design features cannot be controlled. For example, network structures with cross-functional connections may not be able to be controlled depending on the environmental conditions being faced. In addition, there appears to be no downside to supplying information in this manner. Therefore, if possible, this feature should be incorporated in most response organizational designs.
5. **Having a mix of meeting types at different levels helps "bubble-up" and diffuse information across functions.** This includes having intra-functional meetings and cross-functional meetings to help cover bases. The former helps diffuse information within a function while the cross-functional meetings become less reliant on who is sharing at the meetings. The combination of meetings helps information diffuse to other functions or areas of the organization that may need it, which in turn, increases the proximity of information supply to demand and results in improved information exchange performance.

Chapter 5: Conclusions

Effective information exchange can improve decision making and minimize responders' costs (time and effort) to find information. Organizational designs try to enable responders to obtain as much needed information as possible without negatively affecting the responders' ability to fulfill their goals and objectives. Designing organizations to support information exchange in uncertain, dynamic, urgent and complex situations differs from designing organizations to support information exchange for repeating tasks, processes, behaviors and goals when there is a priori knowledge of what information is needed, where it will be needed, and where it will come from. Organizational designs for disaster response need to accommodate unpredictable information supply and demand, human information behavior, omni-directional information flows, and urgent, time-sensitive information needs.

To understand how to accommodate these factors in organizational design for disaster response, this research focused on 1) investigating information exchange behaviors by observing disaster response simulation within a realistic disaster response organization (Phase I), and examining the impact of different response organizational design features on information exchange performance using and agent-based model (Phase II).

5.1 Summary of Findings

In the first phase of research, we investigated the information exchange behavior of disaster responders by observing a realistic simulated response using a real organizational design. We found that: 1) the balance of information exchange behaviors is similar across the phases of a disaster, 2) information exchange is prompted by either organizational

design features or contextual factors, 3) responders choose to exchange information via both ad hoc and formal settings, and 4) explicit rather than tacit information is typically exchanged.

In the second phase of research, we investigated the impact of different organizational design features on information exchange performance, given individuals' information behavior. Using an agent-based model, we found that: 1) information exchange performance (completeness, speed, and time away from duties) is negatively affected by network structures with too few or too many connections to other responders, 2) the location of information supply (where information enters the organization) is important, especially in organizations with few cross-functional connections (such as hierarchies with few meetings), and 3) more meetings, including more all-hands and leadership type meetings, can improve cross-functional information diffusion and information exchange performance while potentially minimizing impact to other performance measures.

Table 5-1 below summarizes the research's key results and limitations. Overall, our findings suggest that there is a need to balance formal processes (pre-defined meetings or reports with their own information needs) with opportunities for ad hoc exchange, and that the balance can be influenced with organizational design features. We discuss the key contributions and the theoretical and/or practical implications in the sections that follow.

Table 5-1: Summary of Recommendations and Challenges Across Research Phases

Design Feature	Recommendations	Challenges
Central Database	Put as much information as possible into central DB.	Supply and demand in constant flux, making 100% (or close to it) unrealistic.
Meetings	Have more cross-functional meetings with the right sharers.	Baseline scenario included extreme network structure (hierarchy) where meetings critical.
Network Structure	Modify network structure to ensure responders can easily access responders from other functions.	Too many connections can overload responders.
Supply Type	Make sure information enters the organization in the right location (e.g., cross-functional locaitons).	Unpredictable and emergent information flows from other organizations or responders.

5.2 Contributions

Extant literature contains a significant amount of research on designing organizations to enhance operations, improve coordination and support decision making, including for emergency or disaster contexts (e.g., Bigley & Roberts, 2001; Jensen & Thompson, 2015; Lagadec, 1997; Mitroff, Shrivastava, & Udwadia, 1987; Moynihan, 2008; Quarantelli, 1988). This literature, both explicitly and implicitly, argues that the information processing system (IPS) employed is a key design component and implicitly assumes that individuals' information behavior is also accounted for within the design. While researchers have offered many definitions for an IPS, they all center around the notion that an IPS is a structured approach to collecting, managing, and sharing information to support organizational activities and decision making (Egelhoff & Sen, 1992; Galbraith, 1974; Lin et al., 2006; Lord & Maher, 1990; Premkumar, Ramamurthy, & Saunders, 2005; Tushman & Nadler, 1978). There are two primary approaches to designing an IPS within an organizational context:

1. **Design to meet requirements.** The goal of this approach to elicit sufficient information requirements or information processing requirements to inform organizational design. The approach is based on the premise that more a priori knowledge of information supply and demand enables designers to maximize benefit by aligning specific design features to the organization's precise information requirements. There is extensive research in this area (Bolstad, Riley, Jones, & Endsley, 2002; Endsley, Farley, Jones, Midkiff, & Hansman, 1998; Stroh, Winter, & Wortmann, 2011; L. Yang, Prasanna, & King, 2015; Zowghi & Coulin, 2005).
2. **Design to accommodate uncertainty.** The goal of this approach is to design an organization with enough information processing flexibility to accommodate uncertainty. The approach is based on the premise that comprehensive a priori knowledge of information supply and demand is unrealistic. As such,

> organizational designs need to incorporate the right design features to accommodate emergent information supply and demand. There is also extensive research in this area (Galbraith, 1974; Lord & Maher, 1990; Premkumar et al., 2005; Tushman & Nadler, 1978).

Disasters are extreme cases in which there is a very high degree of uncertainty about information supply and demand. This is due the lack of predictability and precision around how a threat or hazard will impact an organization or community such as the emergent and cascading impacts and the complex interaction effects of the response. However, there is a minimal amount of research that holistically addresses IPS design in this extreme context (e.g., Egelhoff & Sen, 1992; R. Gonzalez, Verbraeck, & Dahanayake, 2010; Lin et al., 2006). Rather, the bulk of extant disaster literature focuses on specific aspects of an IPS such as the impediments to flow (Day et al., 2009), technologies employed (Ginige et al., 2014; Marincioni, 2007; L. Yang et al., 2009), technical requirements (Deng et al., 2010; R. A. Gonzalez & Bharosa, 2009; Keßler & Hendrix, 2009; Liu et al., 2013), and network structure, including specific information roles (Altay & Pal, 2014; Kapucu, 2006; Pan et al., 2012).

Since disaster response organizations deal with situations of extreme uncertainty, it was unclear to what extent the existing IPS organizational design literature would apply. For example, do organizational members behave very differently in disaster response, and/or are the usual organizational information exchange mechanisms insufficient for their goals or needs? Therefore, we 1) investigated responders' information behavior in this context, and then 2) built a model to understand potential differences between cases with more certainty and cases with extreme uncertainty, such as disasters.

Our findings largely validate extant theory on IPS design to accommodate uncertainty (e.g., Ancona et al., 2004; Borgatti & Cross, 2003; Galbraith, 1974; Lord & Maher, 1990; Premkumar et al., 2005; Tushman & Nadler, 1978). This indicates that extant theory is indeed applicable to the extreme case of disaster response in two primary ways: First, common design features such as network structures, databases or technical systems, and meetings are sufficient to support effective information exchange in disaster response organizations. Second, organizations require the right mix of information exchange features (formal and ad hoc) to accommodate various levels of uncertainty for different contexts, of which disaster response is one type.

However, we have four key findings that highlight important considerations for IPS design in the disaster response context. First, we found the mix of information exchange behaviors (seeking, sharing, discussing) to be similar across disaster response phases even as the uncertainty of information processing needs is gradually reduced. As a result, organizational designers can likely introduce consistent information exchange features across all phases rather than having to design different features for different phases. However, this creates an additional question of whether consistent behavior or organizational designs across phases is desirable or even optimal? Perhaps organizational designs should more explicitly account for different response phases to improve information exchange performance. Our results suggest that as the response progresses and information needs and flows can be better predicted and more easily directed to where they are needed, fewer formal processes such as meetings may be needed. This is an important question as extant *disaster* literature (theory and practice) embraces a singular organizational reporting and operations structure that is flexible enough to support mission

objectives across any phase of disaster (e.g., Bigley & Roberts, 2001; *NIMS*, 2008) without explicitly considering the design features that should (or should not) remain consistent across different the phases.

Second, we found that most information exchanged in seeking and sharing behavior is explicit. Therefore, disaster response information can be easily codified to store in technical databases, reports or other information products, which can subsequently reduce the time needed by responders to exchange information. We demonstrated this in Phase II by employing a central database accessible by all disaster responders within the organization. However, this raises a larger question about why in practice, if most information is explicit, is so much information still exchanged through more time-consuming interpersonal exchanges (either ad hoc or via meetings)? We suspect that poor information accessibility is a contributing factor (e.g., Day et al., 2009) and that interpersonal exchanges may provide additional value, which we discuss in the following paragraph.

Third, we found that most information sharing behavior occurs in meetings. This indicates that formal processes such as meetings play critical roles in information exchange by bringing together responders from across the organization who possess different information. However, given that most information shared in meetings was explicit and could have been stored in technical databases or other information products, we suspect meetings have additional value for responders beyond the simple exchange of explicit information. Based on our findings, we suggest:

1. Meetings enable problem-solving and decision-making, which requires the real-time exchange of information for double loop learning (Bakacsi, 2010; Carroll, Rudolph, & Hatakenaka, 2002; Moynihan, 2009). This was supported by the prevalence of discussing in Phase I as a distinct information behavior.
2. Meetings enable the rapid diffusion of information across functions and responders, thereby improving the proximity of available information to demand. This is particularly important when there is limited knowledge of what will be needed, where information will come from, and/or where it will be needed.

Based on our practical knowledge of disaster response, we believe information exchange meetings serve two additional purposes that explain this finding but were not specifically identified in this research.

3. Meetings, in urgent and dynamic conditions, help push needed information to the people in need of it, thereby helping to ensure completeness of information that may be otherwise missed despite being available within the response organization, even in a database.
4. Meetings enable discovery of latent/non-explicit information needs for the participant or the participant's connections, thereby also enabling faster diffusion of needed information and improving completeness of information obtained.

Lastly, we found that the "right" mix of organizational design features to improve information diffusion depends on the "proximity" (or degrees of separation) of available information to need. Overall, there needs to be sufficient cross-functional linkages via network structure, supply type, use of a central database, and/or meetings to adequately support information exchange between responders. In siloed organizational designs with few cross-functional connections (e.g., hierarchies), information supply needs to be located where there are the most cross-functional connections to improve the proximity of

available information. In organizational designs with many cross-functional connections, information supply location is less important. Organizational designers need to consider the constraints (such as whether information supply location can be controlled) and features together based on their information exchange performance objectives.

The above findings validate the applicability of extant literature regarding the important components for organizational design (e.g., Ancona et al., 2004) to disaster response, despite the distinction between design for steady-steady and for disaster response. In steady-state organizations, the number and types of cross-functional linkages are optimized due to a much higher degree of a priori knowledge about information supply and demand (Bolstad et al., 2002; L. Yang et al., 2015). However, in disaster response where there is more uncertainty and dynamism regarding the conditions being faced, especially where information will enter the organization and where it will be needed, more and multiple types of cross-functional linkages are likely needed to ensure the best information exchange performance. In other words, with less a priori knowledge, build more information exchange capacity and capability through multiple organizational design features. Still, there is no need for dramatically different organizational designs for information exchange in disaster response—rather an appropriate mix of existing strategies is needed. This research begins to explicate which design features are most helpful for disaster response organizations, including the feasibility of and trade-offs between different features.

5.3 Limitations

There are several methodological and generalizability limitations worth discussing.

Disaster Information Exchange Behavior. First, in terms of methodological limitations and as discussed in Section 3.1, our findings were based on what we could see and hear, then capture in our notes. As a result, our findings may be limited to information exchange behavior between individuals only, whether directly with another responder or in a meeting. They may not be generalizable to all information exchange behaviors such as those via phone, databases, technical systems or other information products such as reports.

Second, the exercises observed focused on organized responses to either the initial or sustained phase of a disaster. We were not able to observe a response from start to finish, including changes in information exchange behavior over time. However, we were able to analyze the data by phase of disaster to partially overcome this limitation.

Lastly, our research context focused on maritime oil spill disasters. However, we believe our focus on the response system employed, an all-hazards incident management system called ICS, rather than the nature of the hazard or scenario, extends the plausible generalizability of the results beyond the oil spill context.

Response Organizational Design. First, this agent-based model mimicked select information exchange dynamics rather than the full complement of dynamics and exchanges that would normally occur in a disaster response. For example, we do not include the role of trust in information exchange (Altay & Pal, 2014; Day et al., 2009), or responders taking on other responders' information needs when asked for information they don't have.

Second, this research focuses on organizational design for intra-organizational rather than inter-organizational information exchange. In a disaster response, though, organizational design affects both information exchange types. We believe some findings, namely those around responders' connections, can be generalizable to organizational design for inter-organizational information exchange. These include our findings regarding the need for more formal processes with fewer connections.

Third, our model supplied information to pre-determined locations. In disaster response, though, information supply is continuous or periodic. Additionally, different information needs also emerge over time depending on the situation being faced. However, we believe the findings are still generalizable as the overall model design can be viewed as a single supply event with a new demand for information that is part of an overall response.

5.4 Implications for Policy and Practice

Due to extreme uncertainties, response organizations are difficult to design with reliable approaches to information exchange that satisfy responders' information needs. This is because comprehensive (or close to it) a priori knowledge of information supply and demand is impossible to attain, which typically informs how steady-state organization are designed and for which there is a significant body of knowledge. Therefore, design approaches to information exchange within response organizations need to accommodate the inherent uncertainty rather than exclusively focusing efforts on reducing information requirements uncertainty by attempting to define all information needs a priori.

Galbraith (1974) and researchers since have discussed many approaches to accommodate information requirements uncertainty, which this research builds upon. We discuss some notable implications for policy and practice, which center around

organizational features that facilitate information aggregation (e.g., central database or information supply types), information flow (e.g., meeting frequency and types), and information sourcing (e.g., network structure). These implications enable policy makers and organizational designers to incorporate reliable approaches to information exchange in the absence of a priori knowledge about information supply and demand, or when features such as the ones investigated in this research cannot be controlled during a response.

5.4.1 Information Aggregation Features

These features help collect, manage, and make available potentially needed information to 1) improve the proximity of supply to demand within the response organization and 2) make as much information as possible easily discoverable and consumable. A loose understanding of what information or types of information *might* be needed or could be helpful (should it become available) is required. In addition, these features require dynamic management and should not be considered static repositories of aggregated information. Therefore, a combination of technical and human resources will be needed to design the feature(s) before a disaster and implement during a disaster.

Based on this research, one approach to making data more discoverable and consumable is to **aggregate information into a central repository such as a database**. The database can help pull together available information from technical systems inside and outside the organization and make information available "at-the-ready" for responders to discover and consume. However, employing a database like this requires a dedicated group of responders and the appropriate technical tools to design and dynamically manage. This includes the resources to identify, ingest, index, and organize information to ensure it is accessible to potential responders in the appropriate consumable ways they might need

it, which includes the ability to read, visualize, analyze, link to, and combine information for new or specific insights. In addition, the database is likely to contain variable quality information. Additional concerns and details (e.g., metadata) about the information will need to be provided so responders can better assess the information's relevance, timeliness, and/or representativeness.

5.4.2 Information Flow Features

These features *force* (vs. enable) the flow of information across an organization to help *actively* diffuse information possessed by some responders that *might* be needed by other responders. These features require a loose understanding of the organizational structures that may be encountered to design features that force information flow across the most relevant areas of the organization. In addition, these features require clear objectives to ensure they accomplish the intended information exchange goals. For example, one feature's objective may be to help information flow from one function to another while another feature's objective may be to ensure information flows from tactical responders at an incident to operational coordinators in an emergency operations center.

Based on this research, one approach to ensuring information flows across the organization is to **incorporate different types of information exchange meetings**. For example, formally incorporating the three different meeting types contained in this research (all-hands, leadership, and functional) can help diffuse information from one part of the organization to another. For example, attendees in a functional meeting also attend other meetings with responders from different functions or with different responsibilities. In addition, meetings force responders to get together to exchange information they possess. They also increase the likelihood of responders discovering information they weren't

specifically seeking, but is important, such as recent information about the spread of norovirus in a local shelter that impacts existing efforts by the logistics, sheltering, and healthcare functions. The different meetings have some overlap in attendees, which can also provide additional value for problem-solving and decision making. Finding the best balance of different meeting types, their objectives, and the attendees to ensure good information diffusion across the organization may require some experimentation in practice. Too much overlap might take up too much of responders' time and too little overlap may hinder the feature's benefit.

5.4.3 Information Sourcing Features

These features minimize the degrees of separation between a responder in need of information and the source of that information in order to facilitate *ad hoc* information exchange. These features act as safety nets for when the prior two feature types do not provide the information needed or an impromptu information exchange is needed. While such exchanges can also occur via information flow features, information sourcing features *enable* (vs. force) responders to exchange information.

Based on this research, one approach to ensuring responders can exchange information when needed is to **develop and employ some method for responders to discover who is most likely to have particular kinds of information,** such as response relationship management (RRM) software system. An RRM would combine the most relevant features from a social networking platform and customer relationship management software to support ad hoc information exchanges. For example, rather than schedule notifications to follow-up with prospective clients at a later date or track sales opportunities across the different stages of a sales pipeline, the RRM would help a responder quickly find the person

most likely to have the information being sought and facilitate an exchange by either providing key contact details (including current operational role) and/or providing a secure method to exchange the information. While there are variations of this currently being used in practice, they are secondary features of incident management software rather than key features. An RRM as envisioned, though, would be a standalone technology with its own feature set that can be integrated with other systems as needed. However, developing and implementing an RRM would require additional research to 1) understand the most valuable features, 2) define data type requirements to facilitate responders' searches for the right people (to leverage advanced search techniques), and 3) develop methods for ensuring responders' profile information remains up-to-date in a dynamic fast-moving disaster response.

There are several notable points regarding the implications discussed above. First, the types of features mentioned above complement rather than supplant the need for information requirements gathering. Designers need to recognize when they have reached maximum ability to define (with reasonable certainty) information requirements a priori (e.g., financial processes that are consistent from disaster to disaster), and then assess what other features will be needed to accommodate the remaining less-certain information requirements. Second, organizational designers need to consider what the balance of features should look like as this is not well understood within the literature and because this research only addresses this issue to a limited extent. Third, designers should attempt to find synergies among features employed for more-certain *and* less-certain information requirements to avoid duplication of effort and impact to responders' time away from duties. Fourth, organizational designers should consider how effectively features are

implemented, which can have a great impact on their success or failure to support and improve information exchange performance. Lastly, organizational designers should observe the effects of their changes and experiment with different combinations of features to understand the impact on their organization.

5.5 Future Research

By linking information behavior and organizational design, our research provides a foundation for future research. Based on our findings, we outline several areas of future research that may benefit both academia and practice:

- **Expand information exchange model for *inter-organizational* information exchange in disasters.** Our findings are based on the study of organizational design features for the exchange of available information among responders operating in one organization. In disaster response, though, there are often many response organizations working together that also require information exchange between organizations or responders from different organizations. However, despite a significant amount of extant literature on inter-organizational information and knowledge exchange (e.g., Bharosa et al., 2010; Huesemann, 2006; Kapucu, 2006a; Stephenson Jr. & Schnitzer, n.d.), their links to human information exchange behavior and disaster response are nascent. The approach to this research should be expanded to include inter-organizational contexts and consider information exchange among teams-of-teams.
- **Define common information flow patterns within and across organizations.** This research identified key behaviors and methods for information exchange within a disaster response organization. While these behaviors and methods provide insights for organizational design, how information typically flows through an organization can extend our findings by providing more specificity on where, when and how organizational design features should be introduced. For example, knowing common information flow archetypes, such as how information flows from entry into the organization to demand locations, can

inform specific information supply locations and preferred information exchange features in particular situations. However, this research did not trace information flows from supply to demand location and the model assumed information flows were dictated by behavior or organizational design features rather than other contextual factors. There are significant amounts of data available, though, from emails and technical systems in a disaster response or response exercise that can help expand findings from this nascent area of disaster research (e.g., Baber, Stanton, Atkinson, Mcmaster, & Houghton, 2013).

- **Investigate how information technologies can be integrated into response organizational designs to support emergent information exchange behavior within and across organizations.** The focus of U.S. policy on response organizational design has been on establishing effective mechanisms to support collaboration, coordination, and decision making among responders. However, within the U.S. policy framework (U.S. Department of Homeland Security, 2008), existing best practices for information exchange are based on extant theory that embraces technology as a supporting rather than integrated design feature. In other words, like non-crisis organizational design, information technology is used to support defined organizational processes (e.g., assignment of resources) rather than more realistic emergent information exchange behavior.
- **Test additional responder information roles or expertise.** In our model, we tested the aggregation of information at certain locations. However, responders did not take on additional processing roles such as the direct sharing of information to another responder that needs it or taking on the information needs of another responder (e.g., playing the role of information wrangler or allowing proxy information needs for a fellow responder). Directed sharing or information seeking by proxy can affect information diffusion, including the speed and costs (time & effort) incurred.

  This research also investigated the impact of one type of expertise, source knowledge, on information exchange performance. However, other types of

expertise, such as expertise in one's own information needs, can affect a responder's ability to obtain needed information. Understanding the type of expertise needed would support training programs and standards for response personnel.

Incorporating these roles and expertise in future models will likely provide additional details regarding our findings and contributions useful to organizational designers.

- **Consider how information accessibility issues impact information exchange.** Our findings indicate that the location(s) of available information (information supply) play critical roles in improving information exchange performance within response organizations. However, just because information is available to a responder, does not mean it is adequately accessible (e.g., available via PDF vs. spreadsheet, which better enables responders to analyze data for specific needs). Extant literature identifies both technical and cognitive accessibility issues that range from formatting inconsistencies to cognitive overload that affect information exchange (e.g., Day et al., 2009; Eppler & Mengis, 2004; Gonzalez & Bharosa, 2009). While many of these are well-documented, they also need to be incorporated into future socio-technical models to better understand their nuanced impacts on information exchange performance within a response organization.

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