A MULTIFACETED APPROACH TO UNDERSTANDING RESILIENCE OF INCIDENT MANAGEMENT TEAMS

A Dissertation

by

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ABSTRACT

At the onset of the disasters, incident management teams (IMTs) are established to direct and support on-scene tactical activities in the field. IMTs cope with challenges of disasters such as constantly changing situations, limited resources, and inaccurate information. Therefore, resilience, an ability to adjust performance to such challenges, has emerged as an essential attribute of IMTs. As a narrated collection of journal articles, this dissertation aims to answer two general research questions: 'What are characteristics of resilience of IMTs?' and 'How can we analyze the characteristics of resilience of IMTs?'

To answer these questions, this dissertation consists of six journal articles (five peer-reviewed publications [Articles #1 - #5] and one journal manuscript in preparation [Article #6]). Articles #1, #2, and #3 address the first research question regarding the characteristics of resilience of IMTs and Articles #4, #5, and #6 address the second research question regarding the analysis of resilience of IMTs. Specifically, the analysis of resilience of IMTs is conducted through two essential lenses of organizational resilience: work-as-done (WAD) and work-as-imagined (WAI).

With respect to the traits of IMT resilience, Article #1 documents an integrative review of 55 articles and presents findings about definitions, characteristics of IMT resilience, and common tools used to support resilience of IMTs. Regarding resilience of real-world IMTs, Articles #2 and #3 provide characteristics of resilience of government

and hospital IMTs that responded to Hurricane Harvey in 2017 based on semi-structured interviews.

With respect to the analysis of the characteristics of IMT resilience, Article #4 develops a cognitive system model of an IMT and develops a novel Interaction Episode Analysis (IEA) method that incorporates interactions between three cognitive system elements (i.e., humans, technical tools, and tasks) in IMTs to enable granular analyses of WAI and WAD. Next, by applying the IEA to data collected from naturalistic observations of two high-fidelity IMT exercises at Emergency Operations Training Center (EOTC), Article #5 presents six WAD episodes regarding the IMT's information management tasks and reveals qualitative and quantitative differences between the WAD episodes and between the two IMTs. Article #6 elicits WAI episodes corresponding to the WAD episodes and investigates the reasons behind the differences between the two IMTs. Based on semi-structured interviews with seven IMT training course designers and instructors, the WAI episodes were generated. Quantitative analyses revealed of notable differences between the two IMTs and subsequent qualitative analyses have revealed possible reasons why the differences between the two IMTs have taken place. Such reasons include the non-occurrence of critical interactions that were anticipated to occur in the WAI episodes and the occurrence of unexpected interactions in the WAD episodes. Findings regarding the characteristics of IMT resilience and the IEA method to identify gaps between WAI and WAD in IMTs presented in this dissertation serve as a basis for future research to better examine and enhance IMT's resilient actions in future disasters.

DEDICATION

First and foremost, I would like to dedicate this dissertation to my family. This work would have not been possible without their unyielding love and support.

To Soyun: I cannot find appropriate words to accurately describe your devotion and patience. You have always encouraged me whenever I underwent difficulties. You have sacrificed many things for my success. During the remainder of my life, I will support you to the best of my ability. Let's continue to fill the next chapters of our lives with beautiful and pleasant memories as we have done until this moment.

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NOMENCLATURE

CAID	Cross-agent Interaction Diversity
COP	Common Operating Picture
COVID-19	Coronavirus Disease 2019
CSE	Cognitive Systems Engineering
CSIR	Cross-sectional Interaction Ratio
DHS	Department of Homeland Security
ED	Emergency Department
EL	Episode Length
EM	Emergency Management
EOC	Emergency Operations Center
EOTC	Emergency Operations Training Center
FEMA	Federal Emergency Management Agency
FI	Frequency of Interactions
FRAM	Functional Resonance Analysis Method
IAP	Incident Action Plan
ICP	Incident Command Post
ICS	Incident Command System
IEA	Interactive Episode Analysis
IMT	Incident Management Team
JCS	Joint Cognitive System

JIC	Joint Information Center
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
RAG	Resilience Analysis Grid
RE	Resilience Engineering
SIIL	Sum of Individual Interactions' Length
SOP	Standard Operating Procedure
TEEX	Texas A&M Engineering Extension Service
UNDRR	United Nations Office for Disaster Risk Reduction
UNGCRP	United States Global Change Research Program
WAD	Work-as-done
WAI	Work-as-imagined
WTC	World Trade Center

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CHAPTER 1 INTRODUCTION

1.1. Increasing threats from disasters

Disasters occurring as natural events, technical incidents, and public health crises continue to pose escalating risks to humanity. Impacts of natural disasters have increased significantly over the years. Annual global economic losses due to natural disasters have increased from $14 billion in 1985 (adjusted for inflation) to over $300 billion in 2017 (UNDRR, 2019). In the US, there were 263 weather-related disasters with at least one billion dollars in damages between 1980 to 2019 (NOAA, 2020). In particular, Hurricanes Harvey, Irma, and Maria, all of which occurred in 2017, resulted in the total cost of $265 billion, equivalent to 1.4% of the annual US GDP in that year (UNDRR, 2019).

Industrial disasters also revealed unforeseen risks of hazardous processes in industries. For example, fire and explosion in the Deepwater Horizon drilling rig in 2010 caused 11 fatalities and approximately 4 million barrels of oil spill in the Gulf of Mexico, making itself the worst marine disaster in this history (Ramseur, 2010). The total cost incurred by the event is estimated to be $145 billion required for oil spill recovery, settlement, and liabilities (Lee, Garza-Gomez, & Lee, 2018).

At the time of this writing, the world has been experiencing an unprecedented public health crisis caused by Coronavirus Disease 2019 (COVID-19) since November, 2019. According to Coronavirus Resource Center at Johns Hopkins University (Dong, Du, & Gardner, 2020), the total confirmed cases worldwide exceed 120 million and the total number of deaths surpasses 2.6 million as of March 17, 2021. In the US, over 29 million people were confirmed positive and over 530,000 died of COVID-19 as of the same date. The global GDP losses due to the current COVID-19 pandemic are projected to reach $82.4 trillion over the next five years based on the worst case scenario (The Centre for Risk Studies, 2020).

1.2. Roles of incident management teams

At the onset of such large-scale disasters, incident management teams (IMTs) are established to direct and support on-scene tactical activities in the field. An IMT is a multidisciplinary team that comprises members with different expertise such as firefighting, law enforcement, and emergency medical service (FEMA, 2017b). When an incident is sufficiently large enough in scale that exceeds one jurisdiction's capacity, IMTs play crucial roles by commanding and coordinating multiple entities (e.g., fire and police departments, search and rescue task forces, and public health officials) that are operated upon different procedures, equipment, and facilities (Crichton, Lauche, & Flin, 2005). Another key role of the IMTs is to continuously adjust their actions and decisions by identifying and addressing emerging risks for a prolonged incident period (Buck, Trainor, & Aguirre, 2006). Importance of the roles of the IMTs has long been emphasized in previous disasters such as 9/11 World Trade Center attack (Kendra & Wachtendorf, 2003; Mendonça, 2007), Hurricane Katrina (Carwile, 2005; Hayes, 2012), Deepwater Horizon disaster (Harrald, 2012), and the current COVID-19 pandemic (Cook, 2020; Farcas et al., 2020).

1.3. Organizational structure and core functions of IMTs

As a multidisciplinary organization to deal with diverse and complex disasters, an IMT is generally composed of five sections: Command, Operations, Planning, Logistics, and Finance & Administration [F&A] (Figure 1.1). The Command Section is responsible for organizing the IMT and defining incident objectives and priorities. Command staff, who support incident commanders, are designated to provide incident information to the public and media; to ensure the safety of emergency personnel; and to liaise with other agencies. The Operations Section supervises on-scene tactical activities (e.g., fire suppression, search and rescue, emergency medical treatment) to fulfill the incident objectives established by the incident commanders. The Planning Section manages incident information including the status of incident situations (e.g., casualty, damage) and resources. Also, the Planning Section is responsible for steering the incident action planning process used to sustain extended emergency operations. The Logistics Section provides support and services including resources (e.g., food, facilities, supplies) to IMT personnel and field responders. Lastly, the F&A Section handles financial matters such as cost, compensation, and procurement (FEMA, 2017b). Each Section consists of multiple units, divisions, or groups that work collaboratively to accomplish specific functions of the Section.

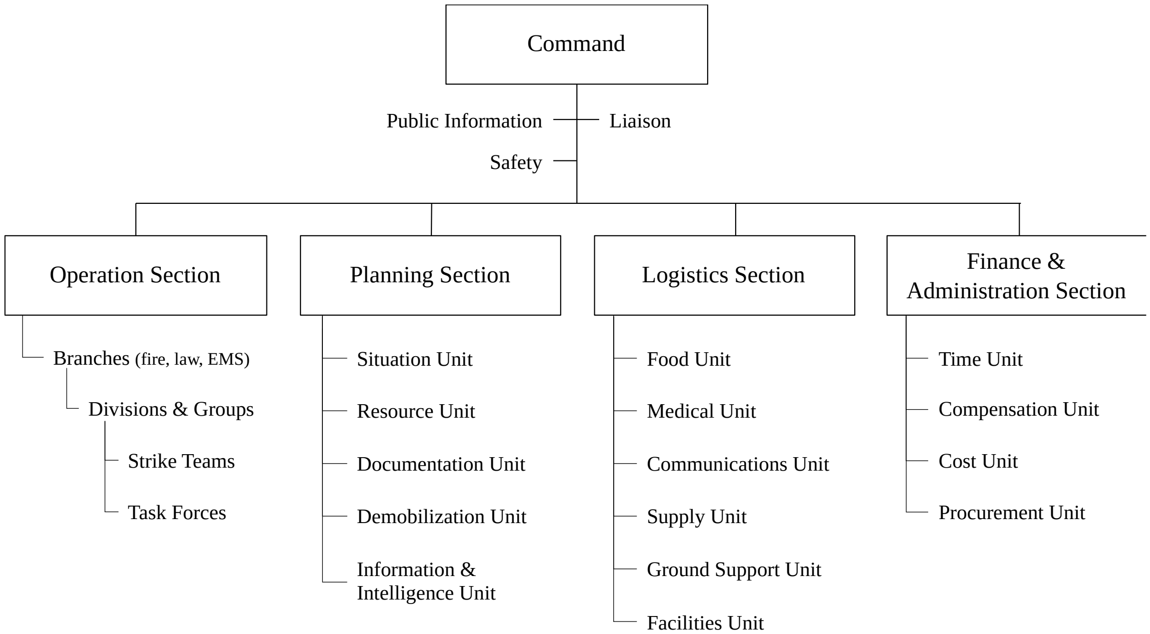

Figure 1.1 Generic organizational structure of an IMT

Once a large-scale emergency occurs, IMTs are structured in an ad hoc and flexible manner. In other words, members of an IMT may work together only while responding to a particular incident and may not work together in future incidents. Also, the roles of the IMT are initially filled by personnel who are available at the time of the incident and further complemented as additional individuals join the IMT (Bigley & Roberts, 2001). For instance, the captain of a local emergency response organization (e.g., a fire chief) that first arrives to the scene serves as an initial Incident Commander. The initial Incident Commander then converts part of individuals in his/her organization into essential roles for the IMT such as Command Staff (e.g., Public Information Officer, Safety Officer, and Liaison Officer) and four section chiefs (i.e., Operations, Planning, Logistics, and F&A) based on their credentials and experience (FEMA, 2017b). As the situation escalates, the initial Incident Commander can be replaced with ones with higher ranks or positions, forming a Unified Command. As the incident begins to subside and the activated roles are deemed no longer necessary, the individuals assigned to the roles return to their original organizations.

The size of an IMT varies depending on the scope and severity of the event being dealt with. The minimum number of personnel for IMTs that deal with less severe incidents ranges from 12 to 15, mostly filling key staff and Section Chiefs (FEMA, 2017a). For high-consequence events, a typical configuration of large IMTs (Figure 1.1) involves over 40 personnel to incorporate more organizational elements (FEMA, 2018). Also, depending on the magnitude of the incident, multiple IMTs can be established at various locations and different hierarchical levels of government, ranging from a municipal to the national level (FEMA, 2017b). Members of an IMT are collocated at a facility such as an incident command post (ICP) or emergency operations center (EOC).

In real-world incidents, IMTs are established with varying team sizes at multiple locations. During the Deepwater Horizon incident in 2010, for instance, one unified area command post and five ICPs were set up near the Gulf Coast to coordinate on-scene oil spill response operations (US Coast Guard, 2011). The largest IMT established at Houma, Louisiana had approximately 1,200 people at its peak, involving representatives from multiple federal, state, and local agencies (Briggs, Lundgren, Parker, & McMullin, 2011).

IMTs provide three major functions to direct and support emergency operations in the field: information management, resource management, and command and coordination (FEMA, 2017b). First, IMTs manage incident information by collecting, evaluating, integrating, disseminating, and updating incident data. Second, IMTs manage human and physical resources by procuring, allocating, tracking, and demobilizing the resources. Third, IMTs command and coordinate participating agencies to meet the incident objectives using available resources and identified information. Among the three major functions, the information management is deemed critical since IMTs' decisions related to the resources, and actions regarding command and coordination are based on the information processed in the IMTs (FEMA, 2015). Figure 1.2 illustrates a cyclic process of information management expected to occur in IMTs.

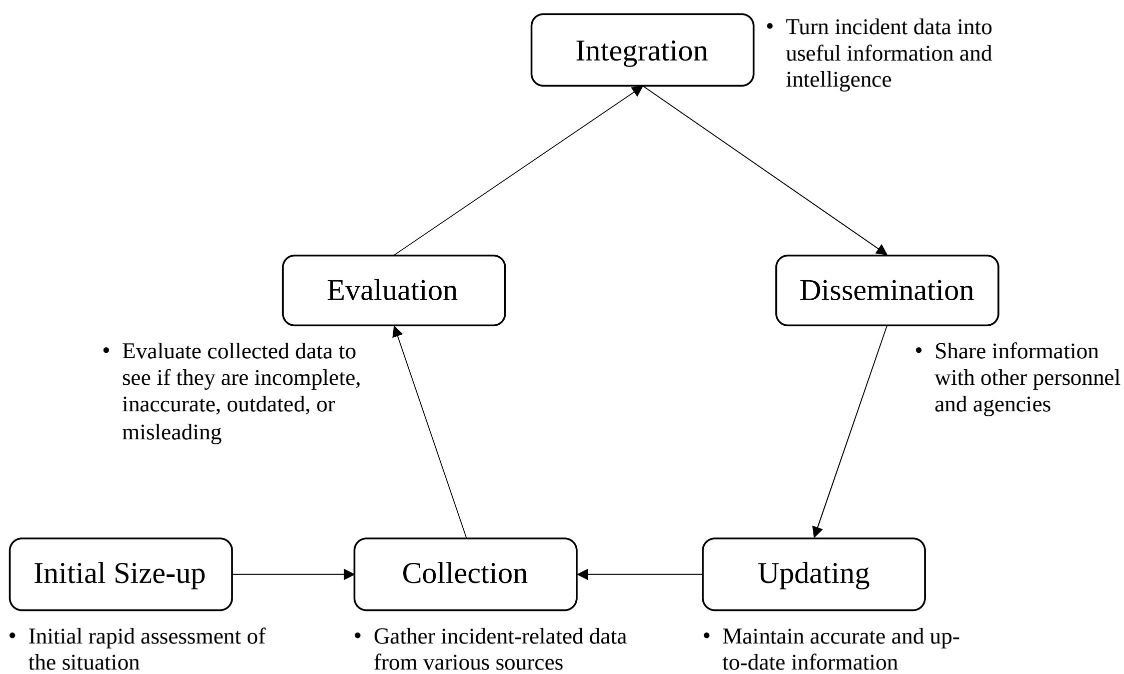

Figure 1.2 A cyclic process of information management in an IMT

1.4. Challenges to IMTs

There are external and internal challenges that make it difficult for IMTs to carry out their functions. External challenges to IMTs originate from the high level of uncertainty associated with disasters. Generally, a disaster starts from local events that occur suddenly without notice. For instance, the 2020 El Dorado wildfire in California was caused by a firework set off at a small gathering and ended up burning over 22,000 acres. In addition, new hazards emerge constantly and unexpectedly during the course of a disaster. In the 2010 Deepwater Horizon incident, the sinking of the drilling rig and the failure of a blowout preventer (BOP) was hardly expected and thus the incident resulted in an unprecedented amount of oil spills despite repeated efforts to cap the oil well (Kim, 2017). Also, a disaster brings severe disruptions to physical, social, and economic infrastructure as well as potential harms to the public and emergency responders (Perry, 2018). As an aftermath of the 9/11 World Trade Center disaster, critical infrastructure such as water, electricity, and telecommunications was heavily destroyed and nearly 3,000 people were killed, including 412 emergency workers (Comfort & Kapucu, 2006). In addition to the external challenges, IMTs encounter difficulties in executing their own functions. Usually, resources (e.g., staff, supplies, space) required to meet the demands of an incident are not fully available. In response to Hurricane Katrina in 2005, there was a severe shortage of transportation for over 100,000 evacuees (Litman, 2006). IMTs also have to rely on inaccurate and incomplete information during the course of the incident. For example, it was found that information of the number and condition of evacuated people and status of shelters during Hurricane Katrina was highly unreliable (Mattox, 2005). With such constraints on the resources and information, IMTs need to make high-stake decisions under time pressure and continuously adapt their actions to cope with variable risks and meet changing incident objectives (Kapucu & Garayev, 2011; Perry & Lindell, 2003).

1.5. Needs for resilience of IMTs

To cope with increasing and unpredictable threats from disasters, resilience—an ability to adjust performance to expected and unexpected disturbances—has emerged as an essential attribute of effective responses to incidents (Boin, Comfort, & Demchak, 2010; Hollnagel, 2011). Previous research on resilience in incident management has highlighted different levels of the incident management hierarchy. Research at a macro-level of the incident management hierarchy has focused on overarching incident management frameworks such as the National Incident Management System (NIMS) and the Incident Command System (ICS). Previous studies examined how the incident management frameworks support IMT resilience in organizing their structure and adapting their operations in a flexible manner. For example, Bigley and Roberts (2001) highlighted the flexibility of the ICS in terms of organizing mechanism, adaptations of roles and work processes, and development of shared understanding of incident responses. Similarly, Harrald (2006) emphasized the advantages of the NIMS that guides IMTs' formal processes as well as allows for IMTs' adaptive performance during an incident. Research on a micro-level of the incident management hierarchy was focused on field responders' resilient behavior. Previous research at this level examined individual field responders' improvised actions with respect to roles, procedures, tools, and spaces (Mendonça, Webb, Butts, & Brooks, 2014; Webb, 2004; Webb & Chevreau, 2006). Compared to the macro- and micro-level research on disaster resilience, the current knowledge of resilience of IMTs, that is, the meso-level of the incident management hierarchy has been quite limited. Some early work regarding the resilience of IMTs was focused on stressing the needs for resilience of IMTs and narratively describing partial attributes of resilient IMTs. For example, Weick (1993) in his scrutiny of smokejumpers' response to a wildland fire in Mann Gulch, claimed the needs of resilience in the team that could have saved lives of 12 crew members. Kendra and Wachtendorf (2003) identified a few traits of IMT resilience exhibited in the aftermath of 9/11 World Trade Center attack. Such traits included adaptations in the organizational structure and improvised use of human and physical resources in IMTs. Nevertheless, a holistic understanding of characteristics of resilient IMTs is still lacking in the literature and previous approaches to analyze such characteristics were largely based on individual researchers' subjective and narrative interpretations of an event being investigated.

1.6. General research questions and overall research approach

Despite the overwhelming challenges of disasters and crucial roles of IMTs, previous research has provided limited knowledge regarding resilience of IMTs (refer to Chapter 2 for a detailed description of the limitations). Therefore, integrated research efforts are necessary to understand the characteristics of resilience of IMTs both from the literature and from the field of practice. In addition, the existing literature on the resilience of IMTs largely depends on narrative approaches (e.g., analysts' subjective experience and interpretation of an incident) to describe resilience of IMTs or lack thereof. Thus, there is a persistent need to develop a novel approach to analyze the resilience of IMTs. More specifically, it is necessary to examine how and why IMTs adjust their performance during an incident since such findings are essential to understand specific challenges to IMTs and adaptive actions that IMTs have taken to cope with such challenges. With this knowledge, developing future interventions (e.g., emergency training, technical solutions) to better support IMT resilience can be facilitated.

To address these research gaps (refer to Chapter 2 for more detail), my dissertation is aimed at addressing two general research questions as follows:

- What are characteristics of resilience of IMTs?
- How can we analyze the characteristics of resilience of IMTs?

1.7. Organization of dissertation

To answer these questions, my dissertation presents six articles as shown in Figure 1.3. Chapters 2, 3, and 4 (Articles #1, #2, and #3) address the first question by identifying characteristics of resilience of IMTs from an integrative literature review (Chapter 2) and from interviews with actual IMT personnel who responded to Hurricane Harvey in 2017 (Chapter 3 for government IMTs and Chapter 4 for hospital IMTs). Next, Chapters 5, 6, and 7 (Articles #4, #5, and #6) address the second question by modeling an IMT as a cognitive system in which humans and tools interact to deal with given tasks, proposing ways to analyze the traits of resilience of IMTs such as team interactions (Chapter 5), and analyzing work-as-imagined (WAI) and work-as-done (WAD) of IMTs, two essential concepts of system resilience, based on team interactions (Chapter 6 and Chapter 7).

In what follows, I introduce these chapters in more detail.

- Chapter 2 (Article #1) presents findings from an integrative literature review of resilience in incident management. By following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework (Moher, Liberati, Tetzlaff, & Altman, 2009), a total of 55 articles were reviewed. An iterative thematic analysis has identified four key traits of resilient IMTs: collective sensemaking, team decision making, harmonizing WAI and WAD, and interaction and coordination. The literature review has also identified commonalities and differences among definitions of resilience, adaptation, and improvisation, the terms that are interchangeably used in the field of incident management. In addition, five types of technical tools commonly used to support resilience of IMTs were identified: geospatial mapping, event history logs, mobile communication applications, integrated information management system, and decision support tools. Finally, two design factors of emergency simulations to train for IMT resilience were highlighted: design of incident scenarios and design of IMT members' roles.

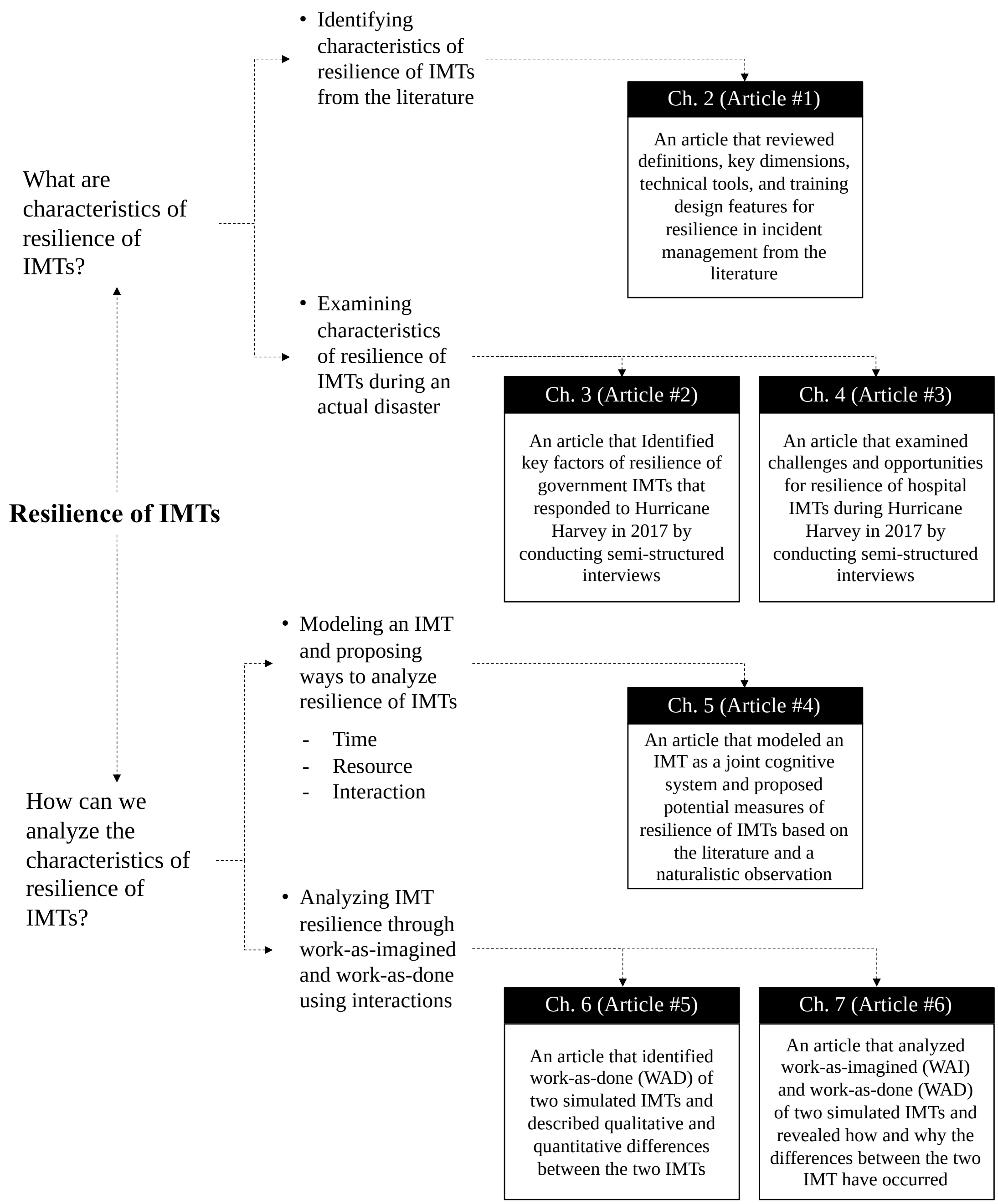

Figure 1.3 An overview of research conducted for this dissertation

- Chapter 3 (Article #2) provides six characteristics of resilience of government IMTs that responded to Hurricane Harvey in 2017. Semi-structured interviews with 10 IMT managers and supervisors in affected counties and municipalities were conducted, followed by a qualitative thematic analysis to identify emerging themes of real-world IMTs' resilience. Results indicate that the IMTs exhibited traits of resilience such as establishing a common operating picture, adopting and adapting plans and protocols, making proactive, reprioritizing, and unconventional decisions, increasing resourcefulness and redundancy, learning for improved anticipation and response readiness from past experience, and promoting inter-organizational relationships between IMTs.

- Chapter 4 (Article #3) presents challenges imposed on hospital IMTs and characteristics of the hospital IMTs' resilience during Hurricane Harvey in 2017. By conducting semi-structured interviews with six hospital IMT personnel in a regional hospital in Texas, this article describes the hospital IMTs' resilience in terms of organizational structure and individual roles of the IMT, communication and situational awareness within the hospital, operating plans and protocols, human and physical resources, lessons learned from previous incidents, and leadership and high-level decision-making in the hospital IMTs.
- Chapter 5 (Article #4) documents the modeling of an IMT as a cognitive system to illustrate the characteristics of resilience of the IMT such as adaptive team processes based on interplays between humans, technical tools, and tasks in the IMT. The cognitive system model illustrates a cyclic process

through which the IMT establishes shared awareness of ongoing situations, makes team decisions for strategic and tactical actions, and continuously adapt its functioning to emerging conditions. Based on the cognitive system model, this chapter provides three possible ways of analyzing traits of resilience of the IMT: time-, resource-, and interaction-based approaches. Particularly, this chapter proposes an Interaction Episode Analysis (IEA), a novel method developed to capture a series of complex interactions between humans, technical tools, and tasks within the IMT.

- Chapter 6 (Article #5) provides findings from an application of the IEA to high-fidelity IMT emergency exercises. Using audio and video recordings collected from naturalistic observations of the two simulated IMTs at Emergency Operations Training Center (EOTC), this article presents six WAD episodes that consist of a series of interactions that occurred to handle different information management tasks (e.g., updating injury and damage information) in the IMTs. For a quantitative analysis of the WAD episodes, this chapter develops three quantitative measures related to the rapidity of the IMT's team process such as Frequency of Interactions (FI), Episode Length (EL), and Sum of Individual Interactions' Length (SIIL). Results show qualitative and quantitative differences between the two IMTs in processing the same information management tasks.
- Chapter 7 (Article #6) presents WAI episodes elicited from IMT training course designers and instructors and analyzes both WAI and WAD episodes

of the same IMT exercises at EOTC. Quantitative analyses with three previously-developed measures of rapidity and two additional developed measures of team interactions (Cross-sectional Interaction Ratio [CSIR] and Cross-agent Interaction Diversity [CAID]) have been conducted to detect differences of the WAD episodes between the two IMTs. Next, qualitative analyses have been carried out to investigate possible reasons behind the differences between the two IMTs by examining gaps between WAI and WAD episodes. Results indicate that non-occurrence of critical interactions that were anticipated in the WAI episodes and the occurrence of unexpected interactions between IMT members in the WAD episodes have contributed to the differences between the two IMTs in handling the same task.

- Chapter 8 provides a summary of key findings from the articles, relationships between the findings, contributions to the existing knowledge and practice, limitations, and recommendations for future research.

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CHAPTER 2 ARTICLE #1

INVESTIGATING RESILIENCE IN EMERGENCY MANAGEMENT: AN INTEGRATIVE REVIEW OF LITERATURE[1]

2.1. Overview

As disasters become more challenging to prepare for and respond to, there is a growing need for resilience in dealing with unexpected events. Thus, the purpose of this review was to summarize and synthesize findings of the literature that examined resilience in the context of emergency management (EM). Using a systematic literature search method, a total of 55 documents from five journal databases (Compendex, PsycINFO, JSTOR, MEDLINE, and CINAHL), proceedings of resilience engineering symposia, and resilience engineering book chapters were included in this review. Analysis of the literature generated four groups of findings regarding resilience in EM: definitions, key dimensions, technical tools, and research settings employed in the research. First, definitions of resilience, improvisation, and adaptation were summarized and critically evaluated. Second, four key dimensions of EM resilience were identified: collective sensemaking, team decision making, harmonizing work-as-imagined and work-as-done, and interaction and coordination. Third, this review identified five prevalent technical tools used to enhance resilience in EM: mapmaking, event history

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logging, mobile communication applications, integrated information management system, and decision support tools. Fourth, two major design features of emergency simulations, incident scenarios and participant roles, are evaluated. For each finding, directions for future research efforts to improve resilience in EM are proposed.

2.2. Introduction

Recent disasters such as catastrophic hurricanes and wildfires have consistently demonstrated the need for emergency management (EM) systems to adapt their performance to both expected and unexpected disruptions – a property often referred to as *resilience* (Boin, Comfort, & Demchak, 2010; Shakou, Wybo, Reniers, & Boustras, 2019). Disasters pose severe challenges to affected communities and individuals in preparing for, making sense of, and responding to adverse events: disasters are unpredictable, usually propagate severe consequences, entail risks and time pressure, and deplete available resources, all of which render established emergency plans ineffective (Perry, 2007). The 9/11 World Trade Center attack was an archetypal event for which the need for resilience in managing unanticipated events was clearly recognized. For example, exploitation of civilian airplanes for mass destruction was neither expected nor prepared for (Comfort & Kapucu, 2006); emergency operation plans did not work as intended, and responses among emergency operation teams were not communicated or coordinated as planned (Kendra & Wachtendorf, 2003). A similar call for resilience during disasters has been identified even in expected events. Hurricane Katrina, though anticipated through advanced forecasting, showed how emergency personnel and organizations could fail to adjust, improvise, and innovate their decisions and actions to situations that cascade into a catastrophic event (Boin & McConnell, 2007; Waugh & Streib, 2006).

Recognizing such apparent needs, researchers have studied resilience in EM from multidisciplinary viewpoints. For instance, crisis and disaster studies have examined why resilience is needed and have critically examined emergency management policy and administration (Boin et al., 2010). These studies were primarily concerned with understanding the etiology of incidents and influencing policy makers and public administrators towards more resilient approaches (Boin & McConnell, 2007; Wise, 2006). One of the primary efforts in this area was to highlight factors that hinder or promote resilience of incident management protocols such as the Incident Command System [ICS] and the National Incident Management System [NIMS] (Bigley & Roberts, 2001; Buck, Trainor, & Aguirre, 2006). However, such an approach has lacked efforts to aid in evaluating system's resilience or engineering resilient in the EM domain (Boin et al., 2010).

To address this gap, a discipline called resilience engineering (RE) has emerged to enhance knowledge regarding resilience of socio-technical systems in which human operators and technical tools jointly adapt to and cope with complexity of unanticipated events (Hollnagel & Woods, 2005; Hollnagel, Woods, & Leveson, 2006). Various definitions of resilience have been proposed in the RE literature. Woods (2006) defined resilience as a system's capability to handle disruptions that fall outside a designed performance envelope, emphasizing adaptations to unanticipated situations (2006, p. 21).

Later, Hollnagel (2011b) proposed a refined definition of resilience as the system's inherent ability to adjust its functioning before, during, and after changes and disturbances (2011b, p. xxxvi). Several characterizations of resilience have focused on identifying factors that contribute to resilient performance. For example, Hollnagel (2011a) suggested four main capabilities of resilience (i.e., ability to anticipate, monitor, respond, and learn) and these factors were used to assess resilience of socio-technical systems such as healthcare organizations (Chuang, Ou, & Ma, 2020; Patriarca, Di Gravio, Costantino, Falegnami, & Bilotta, 2018). Woods (2006) described underpinning properties of resilience such as buffering capacity, flexibility, margin, tolerance, and cross-scale interactions. These attributes were evaluated to assess resilience of other complex systems such as chemical processing plants (Shirali, Motamedzade, Mohammadfam, Ebrahimipour, & Moghimbeigi, 2016), emergency departments (Son, Sasangohar, Rao, Larsen, & Neville, 2019b), and disaster response organizations (Mendonça, 2008). Finally, research efforts have focused on engineering resilience into systems, in other words, making a system more resilient. For example, scenario-based training was designed and implemented to nurture resilience skills needed to build a shared understanding of situations-at-hand and to plan response strategies ahead (Saurin, Wachs, Righi, & Henriqson, 2014). Another study proposed a novel design of healthcare information technology (e.g., infusion pump) that monitors current dosage and anticipates future states, which are essential pre-conditions for adaptive response to unpredicted adversaries (Nemeth & Cook, 2007).

While RE has hitherto contributed to addressing emerging challenges and identifying new capabilities in complex socio-technical systems (Woods, 2017), commensurate efforts to examine resilience in EM, compared to other domains, are still limited. Several existing literature reviews aimed at providing an extensive overview of resilience literature (Bergström, van Winsen, & Henriqson, 2015; Righi, Saurin, & Wachs, 2015), a summary of definitions (Hosseini, Barker, & Ramirez-Marquez, 2016), and a focused evaluation of healthcare resilience (Patriarca et al., 2017). However, none of these reviews explored resilience in the EM domain, which requires greater attention due to increasing catastrophic disasters. In addition, Hosseini et al. (2016) concluded that there is lack of a universal definition across application domains. While previous reviews were largely based on RE literature since its initial advent (e.g., Hollnagel et al., 2006), resilience, in conjunction with other notions such as adaptation and improvisation which are crucial concepts in emergency and disaster management research (Alexander, 2013; Kendra & Wachtendorf, 2003) has not been explored. Moreover, existing reviews focused mostly on summarizing various definitions ('what is resilience?') and application areas ('how is resilience used?') with limited attention to documenting constituent dimensions of resilience ('what makes a system resilient?'). Finally, none of the previous reviews investigated technical tools used to support individuals and organizations in achieving resilient performance. Such tools enable interactions between social (e.g., individual responders and organizations) and technical factors and contribute to system resilience (Salmon et al., 2014). To address these gaps, the current research, by reviewing a broad range of resilience literature in EM, aims to examine definitions of resilience and other related constructs, contributors to resilient performance in EM, and technical tools to achieve resilient performance in EM. Based on our synthesis, we propose directions for future research efforts.

2.3. Method

2.3.1. Search protocol

A systematic review librarian was consulted for the development of literature search and review strategies and techniques, including search database selection. Two coders applied a systematic review protocol to search documents from published between January 1990 and December 2019. The five databases were chosen to cover relevant literature in various fields of study: Compendex for engineering literature, PsycINFO for psychology literature, JSTOR for social science literature, and MEDLINE and CINAHL for healthcare literature. Non-indexed sources such as proceedings from Resilience Engineering Association symposia and chapters of RE books (Resilience Engineering: Concepts and Precepts, Resilience Engineering Perspective Vol. 1 and 2, Resilience Engineering in Practice Vol. 1 and 2, Resilient Health Care Vol. 1, 2, and 3, and Delivering Resilient Health Care) were searched using the established protocol.

In order to retrieve relevant publication archives, two search strategies similar to Jenuwine and Floyd (2004) were employed. In the subject search strategy, a list of controlled terms was developed (Table 2.1) for each database and a search was carried out to locate documents concerning subjects of interest. Subjects such as cognitive system, human-machine system, and decision making were considered to be significant in this search since these concepts are major topics in resilience engineering (Woods & Hollnagel, 2006). In addition, disaster- and emergency-related idioms were also deemed as necessary subjects to be searched. Due to the differences in subject vocabulary between the databases, a respective set of controlled terms for each database was developed and applied to the literature search. A second strategy then applied non-indexed or free-text terms to extract the target literature. Three keywords were used in this strategy: *emergency*, *management*, *resilience* and their relata (Table 2.2). Two additional terms, *adaptation* and *improvisation*, were included as these concepts and *resilience* are often used interchangeably (Grøtan, Størseth, Rø, & Skjerve, 2008; Righi et al., 2015).

Table 2.1. Controlled search terms used for different databases

Database	Controlled terms	Database	Controlled terms
PsycINFO	Decision making Decision support systems Disaster Emergency preparedness Emergency Management Human machine systems design Human machine system Group decision making Natural Disaster	CINAHL	Decision making Decision support systems Decision support techniques Disaster planning Disasters Emergency service Information systems Natural disasters
JSTOR	Cognitive systems Decision making Decision support systems Human machine systems	MEDLINE (Ovid)	Cognitive science Decision making Decision support systems Decision support technique Emergencies
Compendex	Cognitive systems Command and control systems Decision making Decision support systems Disaster Emergency services		

Table 2.2. Free-text search terms

Keyword	Emergency	Management	Resilience
Relata	$emergency $disaster $incident $crisis	$manage $control $respond $operate	resilien* adapt* improvis* improviz*

Note: $ for auto-stemming and * for truncation.

2.3.2. Inclusion and exclusion criteria

The initial search was limited to documents published between 1990 and 2019 in order to embrace early literature on resilience and improvisation in emergency response such as Weick (1993) and Mendonça, Beroggi, and Wallace (2001) while the major attention was raised around 2006, following Hollnagel et al. (2006) seminal work. The initial search results were then screened using Rayyan (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). Documents were excluded if (a) the abstract covered domains other than emergency and disaster management, (b) the type of the publication was review article, dissertation, technical report, or white paper, or (c) the document was not written in English. Duplicate records were eliminated using a duplicate-handling feature of Rayyan. Two authors independently coded approximately 12% (n=480) of the initial search results by screening the abstracts. The intercoder reliability with Cohen's kappa (κ=.76) was interpreted as substantial (McHugh, 2012). A full-text screening was then conducted to exclude documents that (a) discuss less relevant constructs such as environmental, psychological, architectural, or financial resilience or (b) do not treat resilience as a core subject. The same authors individually screened the full documents for eligibility. The intercoder reliability for the full-text screening was also shown substantial (κ=.79). Discrepancies that occurred at each round of screening were resolved through clarification on inclusion criteria and consensus-building.

2.3.3. Data extraction and analysis

First, relevant information such as bibliographic data (e.g., authors, published year, journal/conference proceeding) and major findings (e.g., research focus, study design and methods, type of events considered, technical tools examined, study location) were extracted from the selected literature and entered into a spreadsheet. Next, in line with Alias and Suradi (2008) and Rowley and Slack (2004)'s recommendation, a concept mapping tool called CmapTools (Institute for Human & Machine Cognition, 2017; cf. also Cañas et al., 2004) was used for thematic analysis (Braun & Clarke, 2006). Concept maps are deemed suitable to elicit various concepts (nodes) and relationships between them (arcs) using visualization features (Braun & Clarke, 2006; Wheeldon & Faubert, 2009). In CmapTools, individual documents were represented as a high-level (parent) node and specific findings from each document as low-level (child) nodes. As the review progressed, the nodes were continuously regrouped and the arcs between the nodes were iteratively adjusted to code main themes. Figure 2.1 presents an example of the concept map developed to elicit themes and sub-themes regarding the harmonization of work-as-imagined (WAI) and work-as-done (WAD).

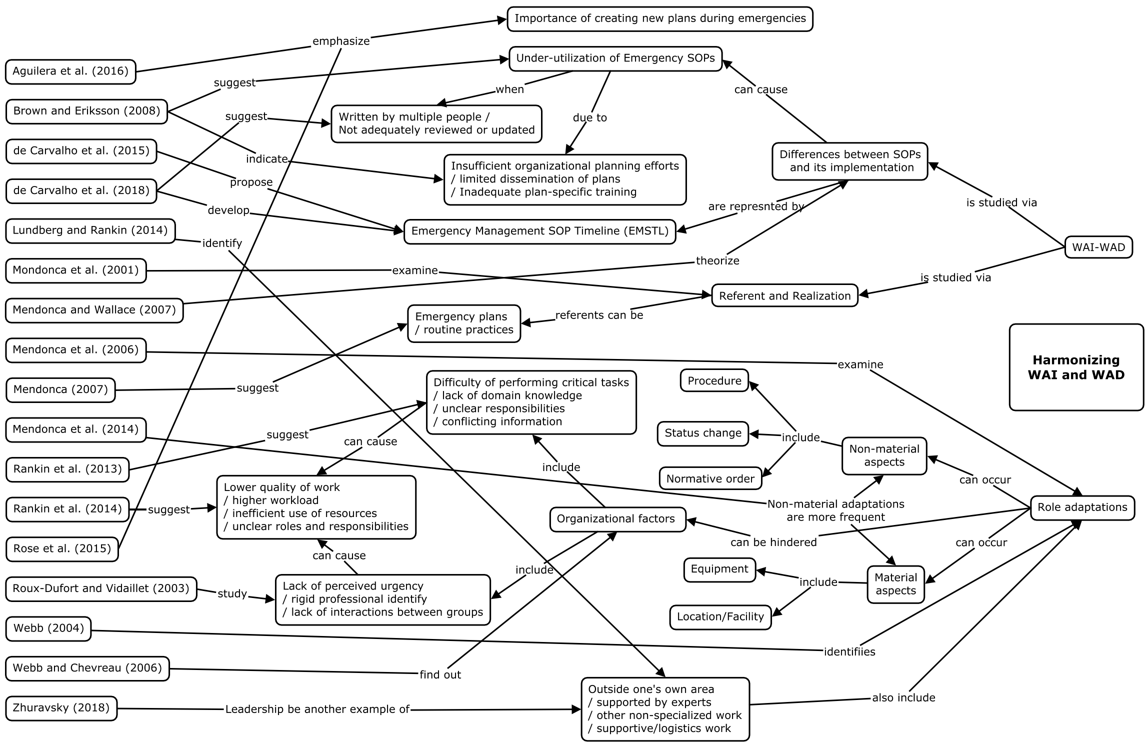

Figure 2.1 An example of the concept map developed to code findings from the literature

2.3.4. Search and screening results

The initial search yielded 4,158 documents from which 55 were finally selected for review after abstract and full-text screening based on the inclusion and exclusion criteria. Figure 2.2 shows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) diagram (Moher, Liberati, Tetzlaff, & Altman, 2009) of the current review, depicting the literature search and selection process in more details.

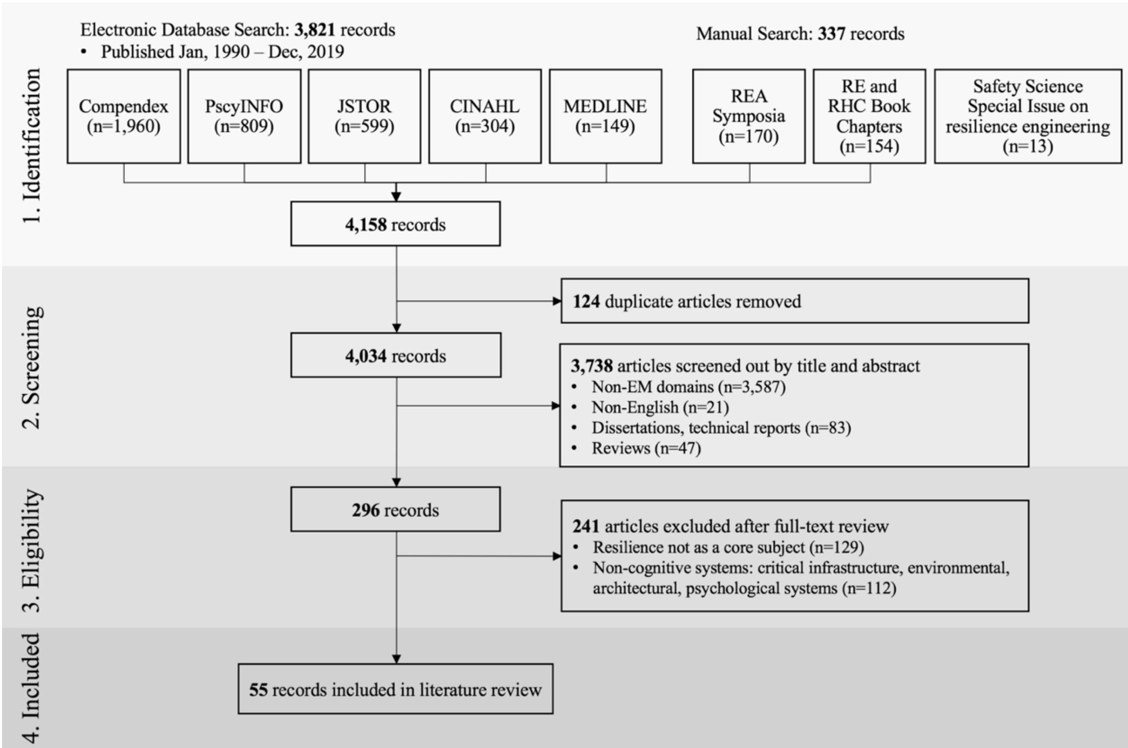

Figure 2.2 PRISMA flow chart of literature search and inclusion/exclusion process

2.4. Results

2.4.1. Overview of research characteristics

Findings from the current review indicate that there is variability in research efforts for resilience in EM (see Appendix B for details). With respect to publication types, over half (n=32) were journal articles, 15 conference papers, and eight book chapters. For study designs, a majority of the research (n=46) employed empirical techniques rather than theoretical approaches. Of those 46 documents, a large portion (n=37) were based on qualitative methods such as observation, interview, group discussion, or audio-video recording. While many studies adopted mixed methods, observation (n=19) and interview (n=19) were two primary ways to collect research data.

Only eight documents reported quantitative results by adopting controlled experimentation, document analysis, or survey analysis. Various types of emergency events were examined in the literature. From 43 documents that specified incident types, 17 covered natural disasters (e.g., wildfire, storm, earthquake, landslide), 16 addressed technical incidents (e.g., chemical spill, maritime incident, hazardous material), and 10 examined civil events (e.g., terrorism, riot, sports events). Regarding the geographical location of research, 20 were conducted in North America, 17 in Europe, five in South America, and three in Oceania. The annual trend of included documents was also assessed as illustrated in Figure 2.3. The graph shows a continued interest in studying resilience in EM during the past three decades.

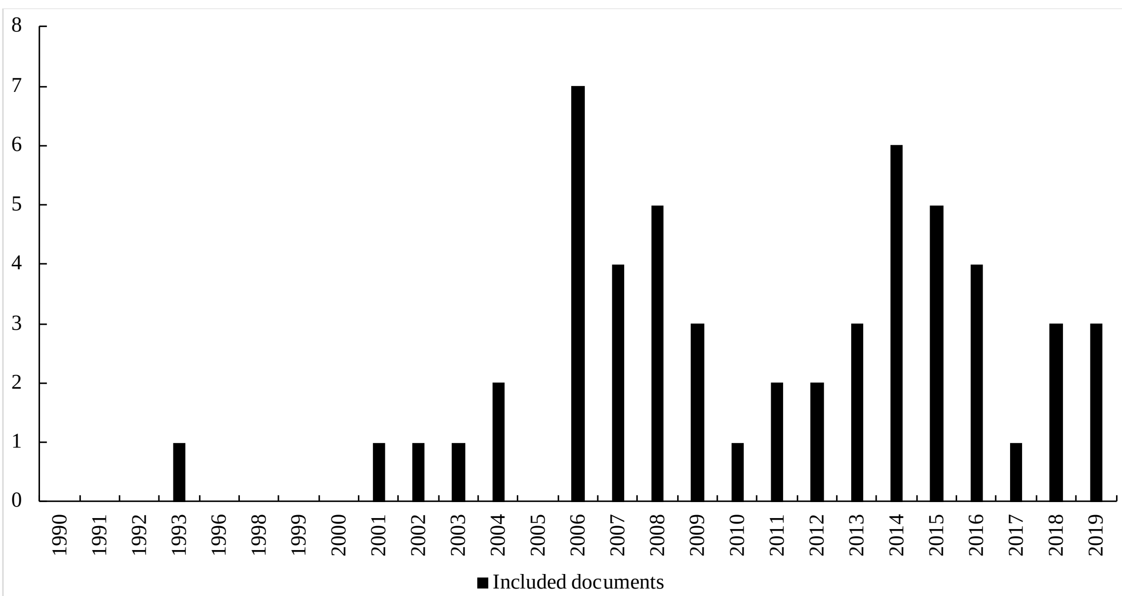

Figure 2.3 Annual number of included documents in the present review

2.4.2. Definitions of resilience in EM

The findings from this review show large variability in how resilience, adaptation, and improvisation in EM have been defined in the literature (Table 2.3). In line with Righi et al. (2015), the current review confirms a high degree of cross-reference between these terms in the EM context. For instance, resilience is generally defined as a system's adaptive capacity or adaptation to variable conditions in and around the system (Lundberg, Tornqvist, & Nadjm-Tehrani, 2012; Woods & Branlat, 2011). Similarly, definitions of improvisation include adaptation to changing situations where new responses need to be planned and executed in a timely manner (Mendonça & Wallace, 2002; Trnka, Lundberg, & Jungert, 2016).

In general, three distinct aspects have emerged from the definitions: a temporal aspect, expectancy of disruption, and means for achieving resilience, adaptation and improvisation. The first aspect identified from the definitions is an EM system's temporal behavior along different phases of emergency management (i.e., prevention, preparation, response, and recovery). Some definitions use a *reactive* framing to highlight the capacity to respond to and recover from a disruption *after* its occurrence (Abbasi, Hossain, Hamra, & Owen, 2010; Caldwell, 2014; Hollnagel & Sundström, 2006). Other definitions stress a *proactive* behavior such as prevention and preparation *before* an adverse event in addition to response and recovery (Longstaff & Yang, 2008; Righi, Huber, Gomes, & de Carvalho, 2016; Westrum, 2006; Woltjer, Trnka, Lundberg, & Johansson, 2006).

The second emerging aspect in the definitions is the expectancy of disruption. In particular, the ability to deal with *unexpected* events is highlighted as an essential attribute of resilience (Aguilera, Fonseca, Ferris, Vidal, & de Carvalho, 2016; Gomes, Borges, Huber, & de Carvalho, 2014; Righi et al., 2016). However, others (e.g., Comfort, 2002 and Hollnagel & Sundström, 2006) posit that any changes, either expected or unexpected, in the system require the capacity for resilience, adaptation, or improvisation. In addition to expectancy, resource limitation (Lundberg et al., 2012) and time pressure (Mendonça & Wallace, 2002; Wybo, Jacques, & Poumadere, 2006) are addressed as other challenging traits of the disruption to EM systems.

Table 2.3 Definitions of resilience, adaptation, and improvisation

Author(s)	Definition
Abbasi et al. (2010, p. 821)	"[Being **adaptive** means being] able to recover quickly and effectively reallocate roles as the situation changes…in a variety of situations, in time and in space."
Aguilera et al. (2016, p. 20)	"[**Resilience** is] the adaptive capacity, or the ability of the system to identify and to adapt to handle unanticipated perturbations in order to keep the system under control."
Bharosa and Janssen (2009, p. 1)	"**Adaptivity** refers to collective system property different from concepts such as agility and flexibility, which indicate the possibilities for adapting from the one state to the other. More specifically, we define adaptivity as the degree to which a decision-making unit has a variety of dynamic capabilities and the speed at which they can be activated, to match information demand and supply."
Caldwell (2014, p. 320)	"[**Resilience** considers] how quickly and completely can one recover after the event prevents reasonable operations."
Comfort (2002, p. 34)	"[**Adaptation** is] the ability to reallocate resources and action to meet changing demands from the environment."
Franco, Zumel, Holman, Blau, and Beutler (2009, p. 2)	"[T]he context of **improvisation** ... would describe the balance of procedural versus management tasks anchored, for example, by first responders adjusting procedures to fit a given situation at one end, and the organizational flexibility of an Emergency Operations Center at the other."

Table 2.3 Continued

Author(s)	Definition
Gomes et al. (2014, p. 782)	"**Resilience** can be very widely defined as the capacity of the system/organization to successfully handle disturbances, including the surprising ones."
Hollnagel and Sundström (2006, p. 339)	"A **resilient** system, or organization is able to withstand the effect of stress and strain and to recover from adverse conditions over long time periods."
Longstaff and Yang (2008, p. 1)	"[**Resilience** is defined as] capacity of a system to absorb disturbance, undergo change, and still retain essentially the same function, structure, identity, and feedbacks. In other words, the system has the ability to bounce back after a surprise."
Lundberg et al. (2012, p. 101)	"[**R**]**esilience** … [is] adaptation to the changes in the situation, for instance an unusually high demand for limited resources, often together with breakdown of communications technology and other technical systems."
Mendonça and Wallace (2002, p. 1)	"To **improvise** is to rework knowledge to produce a novel action in time to meet the requirements of a given situation."
Righi et al. (2016, p. 119)	"[**Resilience**] can be defined as the ability of a system to adjust its operation, before, during or after disruption in order to maintain the necessary operations under both expected and unexpected conditions."
Trnka et al. (2016, p. 253)	"**Improvisation** … [is] an intentional process of thinking and doing through which individuals and team (organizations) continuously adapt to changing needs and conditions in order to generate novel responses."
Voshell, Trent, Prue, and Fern (2008, p. 423)	"A **resilient** organization must have the adaptive capacity and resource management capability to cope with complexity and surprise."
Webb and Chevreau (2006, p. 67)	"[**I**]**mprovisation** refers to social activities that are carried out in non-routine, atypical, or unexpected ways."
Westrum (2006, p. 59)	"**Resilience** is the ability to prevent something bad from happening, [o]r the ability to prevent something bad from becoming worse, [o]r the ability to recover from something bad once it has happened."
Woltjer et al. (2006, p. 72)	"**Resilience** is … defined as the ability to anticipate, prevent, detect, and recover from harmful events."
Woods and Branlat (2011, p. 129)	"**Resilience**, as a form of adaptive capacity, is a system's potential for adaptive action in the future when information varies, conditions change, or when new kinds of events occur…"
Wybo et al. (2006, p. 2)	"[**R**]**esilience** is the ability of the organization (at any level) to remain under control when faced to hazardous situations, uncertainty, time pressure and threats, from outside and inside."

The third aspect is the means for achieving resilience, adaptation and improvisation. In the field of EM, commonly employed means to cope with varying demands of an emergency include allocating roles and resources (Abbasi et al., 2010; Comfort, 2002; Voshell et al., 2008), handling incident information (Bharosa & Janssen, 2009) or adjusting emergency procedures (Franco et al., 2009).

While resilience, adaptation, and improvisation have common attributes, nuanced differences also exist. First, *adaptation* is defined in a more generic manner that highlights changes in the EM system's performance of allocating roles and resources (Abbasi et al., 2010; Caldwell, 2014), not addressing the temporal nature of the response (proactive vs. reactive), nor the severity of the demands that is common in the definitions of resilience and improvisation. Second, definitions of *improvisation* tend to stress the capability of creating and implementing novel or non-routine actions shortly or immediately after recognizing the need to depart from established plans or procedures (Franco et al., 2009; Mendonça & Wallace, 2002; Trnka et al., 2016; Webb & Chevreau, 2006). Hence, improvisation can be seen as quick, creative adaptation and one of the possible behavioral markers of EM resilience in the response phase.

Unlike the other two constructs, definitions of *resilience* point to an overarching systems concept that encompasses all the EM phases (Righi et al., 2016; Westrum, 2006). Also, resilience is concerned with coping with both expected and unexpected disruptions in order to maintain EM system functions (Aguilera et al., 2016). Indeed, this inclusive framing incorporates both adaptation and improvisation into the conception of resilience (Lundberg et al., 2012; Trnka et al., 2016; Woods & Branlat, 2011).

2.4.3. Key dimensions of resilience in EM

Utilizing a thematic analysis approach, this review has identified the following four key dimensions of EM resilience: (a) collective sensemaking, (b) team decision making, (c) harmonizing work-as-imagined (WAI) and work-as-done (WAD), and (d) interaction and coordination. Table 2.4 presents a list of the literature that addresses any of the four dimensions. While findings regarding each dimension are presented in subsequent subsections respectively, these dimensions are largely interrelated and complementary, serving as constituent attributes of resilience in EM.

Table 2.4 Four key themes identified from the literature

Reference	Collective sensemaking (n=14)	Team decision making (n=15)	Harmonizing WAI and WAD (n=18)	Interaction & coordination (n=15)
Abbasi et al. (2010)				✓
Aguilera et al. (2016)	✓		✓	
Bergström, Petersen, and Dahlström (2008)		✓		
Bharosa and Janssen (2009)	✓			
Brown and Eriksson (2008)			✓	
Caldwell (2014)		✓		
Comfort (2002)		✓		
Comfort (2007)	✓	✓		
Comfort, Dunn, Johnson, Skertich, and Zagorecki (2004a)	✓	✓		
de Carvalho et al. (2015)			✓	
de Carvalho et al. (2018)			✓	

Table 2.4 Continued

Reference	Collective sensemaking (n=14)	Team decision making (n=15)	Harmonizing WAI and WAD (n=18)	Interaction & coordination (n=15)
Domeneghetti, Benamrane, and Wybo (2018)	✓	✓		
Franco et al. (2009)				✓
Frye and Wearing (2016)	✓			
Gomes et al. (2014)	✓			✓
Harrald (2006)				✓
Hollnagel and Sundström (2006)	✓			
Hunte (2017)	✓			
Klimek, Varga, Jovanovic, and Székely (2019)	✓			✓
Longstaff and Yang (2008)				✓
Lundberg and Rankin (2014)			✓	
Lundberg et al. (2012)	✓			
Mendonça (2007)		✓	✓	✓
Mendonça, Beroggi, van Gent, and Wallace (2006)		✓	✓	
Mendonça et al. (2001)			✓	
Mendonça and Hu (2007)		✓		
Mendonça and Wallace (2007)			✓	
Mendonça, Webb, Butts, and Brooks (2014)		✓	✓	
Pramanik, Ekman, Hassel, and Tehler (2015)				✓
Rankin, Dahlbäck, and Lundberg (2013a)	✓		✓	
Rankin, Lundberg, and Woltjer (2014)			✓	
Reuter, Ludwig, and Pipek (2014)		✓		
Righi et al. (2016)	✓		✓	
Rose, Seater, and Norige (2015)		✓	✓	

Table 2.4 Continued

Reference	Collective sensemaking (n=14)	Team decision making (n=15)	Harmonizing WAI and WAD (n=18)	Interaction & coordination (n=15)
Roux-Dufort and Vidaillet (2003)			✓	
Stachowski, Kaplan, and Waller (2009)				✓
Son et al. (2018)		✓		✓
Trnka et al. (2016)				✓
Voshell et al. (2008)				✓
Webb (2004)			✓	
Webb and Chevreau (2006)			✓	
Weick (1993)	✓	✓		✓
Westrum (2006)				✓
Woods and Branlat (2011)				✓
Zhuravsky (2018)		✓	✓	

2.4.3.1. Collective sensemaking

Comfort (2007) posits that the 'cognition' of emerging and evolving risks is a crucial element of emergency response. In RE theory, monitoring what happens in a system, which is an essential element of resilience, depends on the system's cognitive processing of information (Hollnagel, 2011b). In EM practice, this cognitive process is described as creating a 'common operating picture (COP)' which serves as collective awareness of incident status shared among emergency responders (Wolbers & Boersma, 2013). This review has identified several factors associated with collective sensemaking during an emergency. For example, in Weick (1993) study, the death of a firefighting crew was ascribed to the crew's failure to quickly and accurately establish common understanding of evolving bushfire conditions. Then, four sources of resilience that foster collective sensemaking were suggested: improvisation or bricolage (creative reconfiguration of existing resources at hand), virtual role systems (imagining what others would do even when they are lost), attitude of wisdom (avoiding overconfidence and overcautiousness), and respectful interaction (honestly reporting to others and respecting others' report). Later in the Sumatra tsunami, the failure of a foreign government to make initial sense of the disaster was ascribed to a delayed deployment of overseas rescue operations for its citizens (Hollnagel & Sundström, 2006). Researchers further examined the relationship between collective sensemaking and resilience in EM. For instance, Lundberg et al. (2012) found that an EM team's collective sensemaking is associated with essential factors of resilience such as buffering capacity, flexibility/stiffness, tolerance, margin, and cross-scale interactions (Woods, 2006). Particularly, Hunte (2017) indicated that similar experience in the past helps increase the buffering capacity (e.g., human and physical resources) in the face of a large civil disorder that occurred after a major ice hockey play-off. Aguilera et al. (2016) emphasized collective efforts across multiple response organizations to keep chemical spill assessment up to date.

While collective sensemaking is a key to EM resilience, its maintenance during emergency situations may come at the cost of cognitive overload due to excess influx of incident data (Gomes et al., 2014). To relieve such overload, emergency personnel take advantage of standard operating procedures (SOPs) as they prescribe what actions need to be implemented and they promote routine behaviors (Righi et al., 2016). SOPs, nonetheless, may increase the cognitive load when a situation unfolds in unplanned ways. As an alternative approach to SOPs, Frye and Wearing (2016) emphasize two metacognitive skills of emergency responders: self-awareness (an ability to maintain situation awareness by reconciling a ‘big picture’ and ‘ground truth’) and self-regulating (a skill to prioritize one decision over another and to regulate decision making tempo).

In addition to cognitive skills of individuals working in the EM area, collective sensemaking requires clear organizational processes for information management. For example, Comfort et al. (2004a) emphasize the importance of designing an adaptive information communication process in inter-organizational incident management. The study found that failure of inter-organizational adaptation had largely resulted from ineffective search, processing and integration of information. As a way to facilitate collective sensemaking during an emergency, Bharosa and Janssen (2009) proposed four types of capabilities: preemptive (i.e., extending organizational boundaries), protective (i.e., loosening coupling of and diversifying information resources), exploitative (i.e., forecasting information needs), and corrective (i.e., accommodating new pieces of information when they arrive). On the other hand, Rankin et al. (2013a) investigated information and communication flow of a crisis response team and identified three factors that contribute to reduced adaptive performance: i) lack of linguistic skills, ii) lack of domain-specific knowledge, and iii) inadequate organizational structure for disseminating, updating and validating information. With respect to the communication pattern, Klimek et al. (2019) found out that horizontal communication was prevalent when facing unanticipated situations while vertical communication took place more frequently for expected events. Domeneghetti et al. (2018) observed more frequent information communication (e.g., face-to-face) to expediate collective situation awareness in EM organizations.

2.4.3.2. Team decision making

The second key dimension of resilience in EM is team decision making in order to adapt to challenging and changing conditions. Decision making during an extreme event has typical traits such as rarity, uncertainty and high consequences of the event, complexity among infrastructure systems, time pressure, and multiple decision makers (Mendonça, 2007; Mendonça & Hu, 2007). Under these constraints, common decisions for the EM team to make during an emergency include how to allocate limited resources, how to circulate information within EM teams as well as to the affected population, and how to keep responders from hazards (Mendonça et al., 2006; Rose et al., 2015). In order to cope with rare, unpredictable, and high-stake situations, EM teams generally adopt an analytical and coordinated decision making protocol such as the Incident Command System [ICS] (Mendonça et al., 2014; Son et al., 2018). Also, training on generic decision making protocols, thus not specific to a certain scenario, was helpful in promoting proactive decision making (Bergström et al., 2008)

Decision making of EM teams goes hand in hand with collective sensemaking following a cyclic process of information search, information exchange, comprehending emergency situations, establishing action plans, implementing or adapting the plans, and organizational learning (Comfort, 2007). The negative effect of lack of collective sensemaking on team decision making was actually noticed in previous incidents such as terrorist attack (Comfort, 2002) and wildfire (Weick, 1993). More recently, Domeneghetti et al. (2018) observed that decision makers at a local command center relied on pre-established decisions (e.g., evacuation perimeter and shelter-in-place), and leveraged information being fed into the center to determine if the original plan requires adaptation. In this regard, Caldwell (2014) theorizes *boundary resilience framing* to explain decision makers' approach towards situations that exceed the boundary of designed capabilities. Domeneghetti et al. (2018) also found that delayed information feed made it more difficult for decision makers to adapt their decisions, and that expertise on subject matter (e.g., nuclear radiation) was crucial to deal with specific hazardous scenarios.

There are also temporal and spatial differences between organizational decision makers and implementers of such decisions, which make coordination between EM personnel difficult (Reuter et al., 2014). Hence, researchers claim that EM teams should accommodate distributed and coordinated decision making as well as centralized processes in order to more readily adapt to unexpected events and to reduce pressure on central decision makers (Bergström et al., 2008; Zhuravsky, 2018). To support the distributed decision making, system-wide information sharing is needed as it facilitates mutual adaptation among multiple decision makers and prevents locally, as opposed to globally, adaptive decisions (Comfort et al., 2004a).

2.4.3.3. Harmonizing WAI and WAD

Another key dimension of EM resilience identified in this review is the relationship between WAI and WAD. WAI stipulates how work should be done and WAD refers to how such work is actually done under varying circumstances (Wreathall, 2006). Researchers viewed SOPs for emergency response as an instance of WAI and examined which steps of the SOPs were actually implemented or omitted for WAD (de Carvalho et al., 2015; Righi et al., 2016). Further, de Carvalho et al. (2018) found that only about one third of steps of emergency SOPs were carried out as prescribed. To compare and contrast between WAI and WAD in emergency operations, event timeline analysis methods such as 'Emergency Management SOP TimeLine [EMSTL]' (de Carvalho et al., 2018) were developed and applied.

Possible reasons for the gaps between WAI and WAD can be found in the way the SOPs were developed. SOPs may be written by those with different ranks and expertise or not adequately reviewed and updated. It may be due to lack of alignment between specific circumstances of situations at hand and the abstraction level of the SOPs (de Carvalho et al., 2018). Brown and Eriksson (2008) suggest that misapplication or under-utilization of emergency SOPs may occur due to insufficient organizational planning processes, limited dissemination of plans, inadequate plan-specific training, inaccurate hazard and vulnerability assessment, and issues with design and usability of the plans. Therefore, the ability of the EM organizations to adapt plans and to create new solutions is considered essential to mitigate the limitations of emergency plans and procedures (Aguilera et al., 2016; Rose et al., 2015).

From improvisation theory, implementation of WAI into WAD can occur in two stages. The first stage is to recognize either that no appropriate plan is available or that an appropriate plan cannot be implemented due to lack of resources needed. The second stage is to create and execute a new plan spontaneously (Mendonça & Wallace, 2007). The dichotomy between WAI and WAD is similarly found between a *referent* and its *realization*. A referent is an abstract direction that guides one's cognition or behavior and is then realized into a specific course of action given situational constraints (Mendonça et al., 2001). One such realization is generating an alternative resource when a standard resource cannot be mobilized, for example, using a gravel truck to block a road in lieu of a police vehicle (Mendonça et al., 2006). Other referents in emergency response may include routines formed from past experience (Mendonça, 2007), pre-defined roles and responsibilities, and highly-skilled individuals (Rankin et al., 2013a).

WAD has been studied in the context of emergency personnel's role changing behavior. For example, Rankin et al. (2013a) highlighted that behavioral changes occur within the same role or by taking a different role. Webb (2004) identified five types of role changes of emergency personnel: procedure change (altering ways of performing a role), status change (assuming additional or broader scope of the role), normative order change (laying unusual restrictions on public access, acquiring private assets without consent), and equipment and location/facility change. Such role adaptation in practice was similarly assessed in the 1995 Oklahoma City bombing and the 9/11 attack (Mendonça et al., 2014). These studies found that changes in the intangible norms (e.g., procedural, status) were more frequent than changes related to tangible materials (e.g., equipment, facility). With respect to role change, Lundberg and Rankin (2014) identified four categories: performing specialized work outside one's own expertise, conducting the same specialized work supported by a highly skilled expert, practicing non-specialized work, and performing works otherwise handled at an organizational level (e.g., logistics). Moreover, Zhuravsky (2018) observed that even the leadership was shared among multiple members of the organization in response to a catastrophic earthquake incident.

While WAD represents a common practice of adaptation in the emergency context, there are some organizational traits that hinder WAD from being laid out: over-reliance on documented rules and standard procedures, excessive specialization of tasks, focusing on a 'plan' instead of 'planning,' failure to learn from near-misses, strong dependence on centralized command and control, and an attitude to replace emergency personnel with technology (Webb & Chevreau, 2006). In a similar vein, Roux-Dufort and Vidaillet (2003) postulated conditions in which EM personnel's adaptive behaviors may not occur, such as an absence of shared perception of urgency, an extreme level of urgency and surprise, rigid professional identity, and a lack of interaction across different response groups. In addition, adaptations realized in WAD may accompany some negative impacts such as lower quality of work, higher workload, inefficient use of resources, and unclear roles and responsibilities of EM personnel (Lundberg & Rankin, 2014; Rankin et al., 2014). To mitigate such shortcomings, the following recommendations are given: providing training on non-routine roles, defining roles and responsibilities for tasks more formally, sharing updated information to relevant roles in a timely fashion, and allowing personnel to observe various emergency cases (Lundberg & Rankin, 2014; Rankin et al., 2013a).

2.4.3.4. Interaction and coordination

The fourth dimension that emerged from the literature is that interaction and coordination among individuals facilitate EM resilience by promoting exchange and synthesis of knowledge for problem-solving and mutual adaptation to emerging risks (Weick, 1993). For example, an EM team coordinator's effort to brief and debrief on incident information is instrumental for a common understanding across different organizations (Domeneghetti et al., 2018; Gomes et al., 2014). Moreover, coordination is required among distributed multiple decision makers to adapt to changing or unexpected conditions (Harrald, 2006). In reality, standard EM protocols such as the ICS tend to place incident commanders in the center of organizational decision making, such that the protocol may not work between different organizations (Mendonça, 2007). Issues associated with the lack of coordination and collaboration between multiple disciplines and jurisdictions were clearly identified in the 9/11 attack (Westrum, 2006). Also, interaction and coordination is necessary to reconcile WAI and WAD. Gomes et al. (2014) also found that ad hoc sub-teams were formulated to deal with specific incident scenarios. Thus, the study proposes that diversity of team members would be a source of resilience in coordination and problem-solving. Along with this claim, Franco et al. (2009)'s experimental work suggests that team heterogeneity (a degree to which team members were not trained together) would enhance the adaptive performance of ad hoc

EM teams. As another example of adaptation through coordinating team members, Trnka et al. (2016) observed that EM teams coordinated different expertise and skills as responders arrived at the scene and resolved the mismatch between initial plans and actual needs. Stachowski et al. (2009) indicated that effective EM teams tend to circumvent routine interaction patterns to adapt to non-routine events.

Coordination across multiple EM operators and organizations, however, is subject to at least five challenges. First, inter-linked EM functions need to be assigned to the same role to facilitate coordination between such functions. Second, a change in one organization's tempo that is faster or slower than that of others along evolving situations may cause coordination loop asynchrony. Third, disparity in levels of support between one's own team and other organizations may result in support asymmetry (Voshell et al., 2008; Woods & Branlat, 2011). Fourth, the lack of familiarity and expectancy of using external resources may hinder the actual resource utilization. Indeed, Pramanik et al. (2015) found that when familiarity with other organizations' capabilities and expectation of future collaboration was increased, the EM personnel were more likely to work with other units and utilize their resources. Finally, lack of trust among members is found to increase the need to consult with additional members, stifling coordination among them (Longstaff & Yang, 2008).

Methods such as social network analysis have been used to understand social interaction and coordination among members of EM systems. Gomes et al. (2014) performed a brief analysis on number and direction of interactions, proposing further efforts to identify critical roles in communication and decision making and to understand routine or non-routine patterns of interaction. Abbasi et al. (2010) conducted a survey with fire and emergency service personnel and identified that social network measures such as individual and team tie strength (e.g., perceived amount of time spent together, emotional connectivity and intimacy) were positively associated with team coordination. Results of a recent quantitative study (Klimek et al., 2019) indicate that when encountering unexpected situations, vulnerability and redundancy of EM organization network increased and efficiency of the network decreased due to the addition of new responders and bottlenecks. To represent the interactions in a temporal dimension, Son et al. (2018) developed the 'Interaction Episode Analysis' method and examined how a large-scale team handles incident information through interactions between EM personnel and technical tools.

2.4.4. Technical tools supporting human operators for resilience in EM systems

Our review has identified five common technical tools used to support tasks and processes of individual operators and EM organizations for improved EM resilience: (a) geospatial mapping, (b) event history logs, (c) mobile communication applications, (d) integrated information management systems, and (e) decision support tools.

2.4.4.1. Geospatial mapping

Mapping or map-making tools are widely employed in emergency operations. For example, Petersen (2015) viewed map-making as collective generation of risk knowledge through collaborations among multiple operators. The study compared two mapping approaches: centralized vs. distributed map-making. While the centralized mapping was suitable for maintaining authority and security, the ad hoc mapping strategy that enabled distributed public engagement was more capable of providing up-to-date information and helping make sense of changing conditions. Bharosa and Janssen (2009) investigated roles of a plotter or a mapper in assisting decision making units. Such roles were responsible for visualizing and integrating incident information into figures and maps, and sharing them with information managers of decision-making units. Also, it was suggested that integrating other data such as weather and potentially hazardous areas would enrich the 'common operating picture' (Bharosa & Janssen, 2009; Reuter et al., 2014).

2.4.4.2. Event history log

Event history log is another common tool used in the EM field that provides a chronological repository of situations reported and actions taken during an emergency (Comfort et al., 2004a). The event history log is also an important artifact that facilitates coordination and information sharing by serving as a common source of updated incident information (Rankin et al., 2013a; Tveiten, Albrechtsen, Waero, & Wahl, 2012). However, the updates in the log are often not communicated well with other emergency personnel, so it may also cultivate incorrect information (Rankin et al., 2013a). Tveiten et al. (2012) supported this finding and stressed the need to protect event history log managers from receiving an excess amount of information and requests for information.

2.4.4.3. Mobile communication applications

Due to advanced mobile information technology, mobile communication applications have become a common tool in EM (Robinson, Maddock, & Starbird, 2015). Although standardized communication systems are required to ensure technical interoperability among different organizations, emergency operators frequently utilize off-the-shelf consumer applications such as social media and cloud workspace for informal and improvised communication. Usage of instant messaging mobile applications has been documented for inter-agency communication in real-world emergencies such as civil disorders (de Carvalho et al., 2015). To facilitate the informal and ad hoc communication, Reuter et al. (2014) demonstrated a mobile application called ‘Mobile Collaboration (MoCo)’. This application was conceived to allow for improvised, multilateral communication across both designated and unplanned participants while addressing the limitation of one-to-one cellphone communication. The study claims that participating agencies and stakeholders in the emergency response would receive benefits from the informal yet informative mobile communication systems for better sensemaking of changing situations and coordination among different response efforts.

2.4.4.4. Integrated information management system

An integrated information management system is also found to be necessary for adaptive inter-organizational decision making during an emergency. For instance, Comfort et al. (2004a) designed and implemented a prototype of ‘Interactive, Intelligent, Spatial Information System (IISIS)' to improve collaboration among multiple organizations across different jurisdictions. To support the EM organizations in adapting to emerging and evolving hazardous conditions, IISIS features real-time communication between different organizations, real-time access to a distributed database (e.g., geographic information) and rapid risk assessment. Neville, Doyle, Sugrue, and Muller (2013) provided an overview of commercial incident information management systems including functional requirements such as multi-agency collaboration mandated by the NIMS.

2.4.4.5. Decision support tools

For adaptive decision making in EM systems, decision support tools have been developed. Mendonça et al. (2001) and Mendonça et al. (2006) created a group decision support system (GDSS) named 'emergency management improviser (EMPROV)' and conducted an experiment to examine whether the GDSS influences planning and execution of team decisions regarding resource allocation during an emergency. To generate alternative resources when a standard resource becomes unavailable, EMPROV incorporated cognitive processes for improvisation: determining whether an event can be handled by existing resources, searching for a pertinent referent for such resources, and generating alternatives. The results of the experiment showed that supported groups spent relatively less time on planning for the allocation of alternative resources and reported a lower level of perceived improvisation than unsupported groups.

2.4.5. Use of simulation to investigate resilience in EM

The current review found out that emergency simulation exercise is predominantly used as a study setting. Due to the inherent risks involved in observation and collection of data from real emergencies, of 39 studies that involved data collection, 22 (56%) were conducted in simulated exercises. Among these, a few studies discussed design factors including exercise scenarios, roles, and techniques for increasing the realism of the simulation as well as for cultivating resilience skills. For example, Trnka et al. (2016) proposed six design variables for stimulating adaptive behaviors in emergency response: risk (likelihood and consequence of an adverse event in the simulation), dynamism (magnitude of a situation change), tempo (how rapidly or slowly such change occurs), stress (a gap between work demands and available resources in the response operations), information structure (distribution of information across multiple participants), and feedback (provision of the state of the simulated occurrences to the participants). In addition, Trnka et al. (2016) suggest that providing information inputs or 'injects' to the participants in real-time further increases the realism of the exercise. Furthermore, Field, Rankin, van der Pal, Eriksson, and Wong (2011) suggested three ways to manipulate the realism of the simulated emergency: number of events (increasing or decreasing may affect the risk and tempo of the design variables above), randomness of events (degree of expectation of a situation occurring), and situational complexity (configuration of contextual factors of an incident scenario).

While the scenario design is concerned with creating a stage for emergency response, the design of roles is an important step for assigning tasks to actors on that stage. Indeed, a role-play exercise is considered an effective approach to understand how actors in the exercise perform in a fluid and complex conditions (Woltjer et al., 2006). Indeed, Trnka et al. (2016) observed how the roles of participants in emergency exercises were adapted over time. Such adaptation occurred when the team was initially charged with an emergency situation and when new tasks were identified along the course of the exercise. In both instances of adaptation, similar functions were merged into one role (e.g., information management and media relations) and a team member assumed another role outside of that member's specialized area. The role-play exercise can be devised with a different level of fidelity. Hermelin et al. (2019) indicate that the exercise may take place from a simple table-top setting to a full-scale facility. Regardless of the fidelity, however, after-action review of the exercise is recommended as an effective way to self-reflect about which adaptations were successful and to mitigate similar issues in the future (Hermelin et al., 2019; Woltjer et al., 2006).

2.5. Discussion

By recognizing escalating threats from recent disasters as well as lack of focused attention on resilience in the context of emergency management, we conducted a systematic literature review and provided a summary and synthesis of resilience in EM research. While a majority of the research efforts have taken an empirical approach and thus provided actual evidence for EM resilience, the predominant use of qualitative methods may reduce the generalization of findings and make comparison between the findings difficult (Gelo, Braakmann, & Benetka, 2008). Given sufficient contextual knowledge of resilience in EM, future studies are recommended to employ quantitative approaches (e.g., controlled experiments and hypothesis testing) to infer generalizable knowledge and predict resilient performance of an EM system. In what follows, we discuss the defining elements of resilience in EM, key factors and technical tools to achieve resilience in EM, and the value of simulation studies in future research to further enlighten knowledge of resilience in EM.

2.5.1. Three aspects of definitions of resilience in EM

Unlike previous reviews (Hosseini et al., 2016; Righi et al., 2015) that were mostly focused on resilience, the current review evaluated definitions across three cognate concepts in EM—resilience, adaptation and improvisation—and provided distinctions between these constructs along three aspects (i.e., temporality, expectancy of adverse events, and means for achieving resilience). Specifically, in line with Patriarca, Bergström, Di Gravio, and Costantino (2018), our evaluation of the definitions further supports that improvisation is an essential phenomenon for resilience in EM where quick actions are required under time pressure. By highlighting each of the three aspects, future work should focus on i) investigating what the EM system does to prepare for and respond to an adverse event, ii) measuring the effects of unexpectedness of an emergency situation on the EM system's performance adjustment, and iii) developing and testing means (e.g., training programs, work processes, and technical tools) that support adaptation under changing and challenging conditions.

2.5.2. Four key factors to achieve resilience in EM

The current review elicited four key dimensions that contribute to resilience in EM: collective sensemaking, team decision making, harmonizing WAI and WAD, and interaction and coordination. While some of these factors were partially claimed in the previous RE literature (Hollnagel, 2011b; Woods, 2006), our research provides a collection of interlinked factors needed to achieve resilience in the context of EM. Therefore, our findings may facilitate future investigations on individual dimensions of EM resilience as well as interdependencies among them as suggested in the following research agenda.

First, creating a common understanding of incident situations or collective sensemaking has been considered a foundation of EM resilience. However, only a few studies (Bharosa & Janssen, 2009; Petersen, 2015; Rankin et al., 2013a) have focused on specific tools to improve the collective sensemaking in EM. For example, the role of information management tools used in EM (e.g., incident mapping, event history logging) needs further investigation. Based on the current review, promising research topics for future investigations include: studying differences between centralized control and distributed participation; incorporating multiple incident data into a visually informative form for decision makers (e.g., hazardous conditions); and improving designs suitable for updating information in a timely manner. Widespread commercial collective sensemaking tools such as WebEOC can also benefit from similar improvements (Robinson et al., 2015; Scholl, Ballard, Carnes, Herman, & Parker, 2017). Such collective sensemaking tools should be designed to support knowledge-based reasoning commonly required during an emergency (Vicente, 2002) in addition to the current utilization as an information repository (Comfort et al., 2004a).

Second, this review has identified that team decisions during an emergency involve coordination among distributed decision-makers. Particularly, team decision making in EM is often driven by government protocols such as ICS and NIMS (Son et al., 2018). Consequently, future research should investigate how temporally or spatially distributed decision makers are coordinated to adapt decisions while following such principles in a fluid emergency condition. While a few team decision support systems have been developed and documented (Mendonça et al., 2001; Mendonça & Wallace, 2002), findings pertaining to the effects of such support systems on the EM team's resilient performance are somewhat inconclusive (Mendonça et al., 2006). Future efforts should, therefore, focus on developing more effective support systems that help EM teams quickly recognize adverse events and adapt to changing or unexpected conditions. These systems should also support perception and integration of incident information, as well as complex problem-solving under time-pressure.

Third, bridging the gap between WAI (e.g., pre-emergency plans) and WAD (e.g., implemented actions) has long been a challenging quest in response to emergency events (Buck et al., 2006). The fact that emergency procedures cannot cover all the possible scenarios and that such procedures may not be implemented exactly as imagined (Hollnagel, 2017) should be acknowledged in the first place. Specifically, the current review provided different dimensions where such discrepancies could occur such as roles of emergency responders (Mendonça et al., 2014; Webb, 2004). Hence, it is imperative to develop emergency operators' ability to devise and implement adaptive actions to changing conditions while meeting the overall goals during an incident (de Carvalho et al., 2018). As indicated by Son et al. (2019b), it would be necessary to incorporate such temporary improvisational actions into formal emergency training programs or emergency operations plans. To that end, the gaps between emergency operating procedures and their actual implementation would be reduced.

Fourth, our review has found that *interaction and coordination* among EM personnel is an essential factor that renders other aspects of EM resilience possible. In reality, it has been a recurring challenge to create supportive and value-added interaction and coordination among distributed EM personnel (Comfort, Ko, & Zagorecki, 2004b). Considering the prevalence of a team-oriented environments in emergency operations, future studies along the interaction and coordination dimension can take two approaches. One approach is to investigate actions that EM team members carry out, for example, temporary assembly of sub-teams to reach a decision for specific problems (Domeneghetti et al., 2018; Gomes et al., 2014) to identify what type of interactive and coordinative actions occur in the EM team setting and how such actions contribute to collective sensemaking or team decision making. Another approach can be taken from a team composition perspective. Given the common practice of ad hoc teaming and role changing patterns in EM (Pramanik et al., 2015; Trnka et al., 2016), additional attention should be paid to the formation of EM teams when necessary roles are not filled (Rankin, Lundberg, Woltjer, Rollenhagen, & Hollnagel, 2013b), or when expertise of team members is disparate (Franco et al., 2009). From a methodological standpoint, many studies have sought to descriptively explain how the interaction and coordination occurs in EM; nonetheless, complex interaction patterns of the EM personnel have rarely been analyzed, and quantitative assessment methods are largely absent. Hence, future studies may benefit from analytical methods suitable for complex and dynamic interactions such as social network analysis (Roberts, Stanton, Fay, & Pope, 2019), recurrence quantitative analysis (Demir, McNeese, & Cooke, 2019), and interaction episode analysis (Son, Sasangohar, Neville, Peres, & Moon, 2020).

2.5.3. Developing technical tools to support resilience in EM

This article presents a summary of five common technical tools used to support individual operators and organizational processes during emergencies. While advanced technologies often provide better opportunities to increase resilience of socio-technical systems, they may also result in brittleness, as opposed to resilience, when poorly designed (e.g., clumsy automation; see Patriarca et al., 2017; Woods, 2017). Several opportunities and challenges associated with each of the common technical tools, in terms of the four key factors of resilience in EM need to be discussed (Table 2.5).

First, the mapping tools offer a rich geospatial overview of incident operations regarding what events are occurring where. Such representation shows how planned tasks occur in real life which may contribute to informed decisions. Also, multiple mapmakers can use the mapping tool as a joint platform for collaboration. However, it may be challenging to integrate multiple geospatial data entered at different times and from different locations.

Table 2.5 Opportunities and challenges of technical tools for resilience in EM

	Opportunities				Challenges
	Collective Sensemaking	Team Decision Making	Harmonizing WAI and WAD	Interaction and Coordination	
Mapping tool (Bharosa & Janssen, 2009; Petersen, 2015)	Providing rich and current geographical information.	Informing decision makers of up-to-date overview of status.	Understanding how planned tasks are currently happening.	Allowing for collaborative efforts from multiple mapmakers.	Multiple data may be entered at different times from multiple sites.
Event history log (Comfort et al., 2004a; Rankin et al., 2013a; Tveiten et al., 2012)	Storing notable events and actions in a sequential order.	Providing a track of past events to identify patterns of occurrence.	Showing how actual events occurred regarding expected scenarios.	Serving as a common warehouse for individuals to retrieve past records.	Difficulty of locating a specific entry as the list gets longer.
Mobile communication application (de Carvalho et al., 2015; Reuter et al., 2014; Robinson et al., 2015)	Enabling multilateral communication (i.e., many-to-many).	Reducing variability of decisions made at different sites.	Accommodating ad hoc participation of unplanned individuals.	Providing enhanced interoperability among different organizations.	Extra efforts to control access and ensure the validity of data.
Integrated information management system (Comfort et al., 2004a; Neville et al., 2013)	Supporting information management cycle and providing COP.	Suggesting potential risks to inform future actions to be taken.	Re-assigning roles of participating members.	Reducing discrepancies of knowledge shared among multiple organizations.	Different entities may require customized type and level of information.
Decision support tool (Mendonça et al., 2006; Mendonça et al., 2001)	Feeding the same information basis to multiple decision makers.	Generating alternative decisions to achieve incident objectives.	Complementing formal, analytical planning process.	Facilitating negotiation among multiple decision makers.	Over-reliance on suggested alternative decisions and over-creativity of the decisions.

An event history log provides notable events and actions in a chronological order. Although the event history log is mostly based on text that conveys less information compared to maps, the logs can better trace what has occurred in the past, which helps identify patterns of event occurrence. Since the log lists such individual events as a separate input, it may be difficult and time-consuming to pinpoint a specific entry. Mobile communication applications are promising as they enable multilateral and simultaneous communication even with unplanned users and can support other functions such as visual mapping. By expediting the sharing of common incident information, mobile communication applications may reduce the discrepancies between decisions made at different sites or different organizational levels. However, additional care should be taken to control the ad hoc access and to validate data entered by unplanned users. Integrated information management systems are emerging in the field of EM (Neville et al., 2013). These systems support the information management cycle of EM systems–that is, searching, processing, and disseminating incident information–and thus provide a common operating picture (COP). Moreover, additional advanced functions such as potential risk estimation and role assignment may be provided. Nevertheless, it should be also noted that participating organizations may require customized scope and type of information rather than a single, big picture (Son, Sasangohar, Peres, & Moon, 2019a). Lastly, decision support tools (DSTs) can be useful when the need for generation of alternative decisions emerges. Therefore, DSTs can complement a formal and analytical, and often lengthy, planning process usually taking place in the EM field. In addition, ensuring the same information is available in DSTs may facilitate negotiation among multiple decision makers. However, over-reliance on DSTs or over-creativity of the alternative decisions should be eschewed.

2.5.4. Emergency simulation to facilitate future research efforts

Despite the widespread use of emergency simulation exercises as a study setting, extant knowledge regarding the effect of scenario design factors and role-playing conditions on resilience of EM organizations is quite limited. Thus, future studies should place more efforts on devising emergency simulations, being not only realistic but also amenable to the investigation of resilience. First, such simulations need to reflect the dynamic and uncertain nature of an emergency incident. This can be achieved by varying tempo (slow vs fast progression), intensity (low vs high consequence), and uncertainty (expected vs. unexpected events) of simulated events (Field et al., 2011). Second, actual operating processes of EM organizations should be incorporated into the simulation settings. For instance, the simulation needs to consider multiple, different roles (e.g., incident data collector, mapper, event logger) involved in the information management and decision-making process. In addition, providing real-time feedback about the status of the incident and the EM organizations via 'injects' (Trnka et al., 2016) can be used to increase the fidelity of simulated exercises.

2.6. Summary

The current review was focused on summarizing and integrating findings from the literature on resilience in EM. The evaluation of definitions indicated that resilience is intertwined with two other concepts, namely adaptation and improvisation, but also showed differences across three categories: temporality (proactive vs. reactive performance), expectancy (expected vs. unexpected disruptions), and means for managing disruptions. This article also documented four essential and interrelated factors of resilience in EM: collective sensemaking, team decision making, harmonizing WAI and WAD, and interaction and coordination. Regarding the key factors, future research areas were suggested to address associated limitations identified in this review. Considering the EM system as a socio-technical system, five types of technology used to support EM resilience were identified. Further, possible opportunities and challenges that such technology might bring were also discussed. Lastly, our review indicated that simulation exercises can be an effective way to investigate EM resilience and thus provided guidelines for designing emergency simulations.

Given the complexity of emergency management in recent disasters, resilience in emergency management has emerged as a core agenda both in research and practice. However, addressing challenges that impede resilience in EM remain a critical research gap. By integrating diverse theoretical and empirical findings, this review would serve as a foundation for further efforts to engineer resilience into EM systems from various perspectives, such as supporting collective sensemaking, reconciling WAI and WAD, and adaptive team decision making through interaction and coordination between EM systems.

2.6.1. Limitations of the present review

First, the scope of the present review was confined to the domain of emergency and disaster research. Thus, the findings and discussions may not be directly applicable to resilience of other socio-technical domains. However, previous reviews were largely focused on resilience engineering literature rather than a broad scholarly work of resilience in a disaster context. Hence, the current review may fill the gap that exists in such comprehensive RE reviews. Second, while the current review utilized established systematic review methodologies under the supervision of a librarian at a tier-one research-intensive university and with an advanced screening support tool (i.e., Rayyan), we acknowledge that developing sets of exhaustive search terms (e.g., controlled terms, free-text terms) was a difficult undertaking and it is possible that several relevant papers might have been missed. Third, to mitigate the coders' biases in eliciting emergent factors of resilience, future research is required to develop a set of criteria for which agreement between multiple coders can be assessed. Fourth, although we summarized study designs (e.g., theoretical, qualitative, quantitative) of the included literature, we did not appraise the quality of evidence, which may offer further value of the review and thus is recommended as future inquiry.

2.7. References

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CHAPTER 3 ARTICLE #2

MUDDLING THROUGH TROUBLED WATER: RESILIENT PERFORMANCE OF INCIDENT MANAGEMENT TEAMS DURING HURRICANE HARVEY[2]

3.1. Overview

Resilience of incident management teams (IMTs) during adverse events becomes crucial to protect lives and physical systems. However, prior studies have only partially highlighted factors related to IMT resilience. To provide a holistic understanding of resilience of the IMTs, this study conducted semi-structured interviews with 10 experienced IMT personnel during Hurricane Harvey. Thematic analysis revealed six characteristics of resilient IMTs during a hurricane event: i) establishing common operating picture, ii) adopting and adapting plans and protocols, iii) proactive, re-prioritizing, and unconventional decision-making, iv) enhancing resourcefulness and redundancy, v) learning for improved anticipation and response readiness, and vi) inter-organizational relationship to promote IMT functions. As an empirical investigation of resilience of the IMTs, the findings inform future endeavors for developing incident information technologies and strategies to harmonize pre-established plans with adaptive actions in the field, and fostering capabilities to learn from incidents.

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3.2. Introduction

Disasters caused by natural hazards continue to pose increasing risks to humanity. Yearly global economic losses due to natural disasters have escalated from $14 billion in 1985 (adjusted for inflation) to over $300 billion in 2017 (UNDRR, 2019). In the US, there were 250 weather-related disasters with at least one billion dollars in damages between 1980 to 2019, among which tropical cyclones, including hurricanes were the costliest hazard accounting for 54% of total costs (National Oceanic and Atmospheric Administration, 2019). In particular, Hurricanes Harvey, Irma, and Maria, all of which occurred in 2017, resulted in a total loss of $265 billion, equivalent to 1.4% of the annual US GDP (UNDRR, 2019).

At the onset of a large-scale disaster, incident management teams (IMTs) are assembled with the aim of responding to and recovering from adverse impacts of the incident. An IMT is an ad hoc multidisciplinary team with complementary expertise (e.g., firefighting, law enforcement, emergency medical service), operating in a collocated facility such as an incident command post (ICP) or emergency operations center (EOC). Depending on the size of an incident and the areas of jurisdictions, IMTs can be activated at different hierarchical levels of government from municipal to national level (FEMA, 2017).

IMTs have to cope with both external and internal challenges that typically arise during a disaster. External challenges to IMTs emanate from the unpredictable nature of disasters: sudden onset of emergency events, constantly and unexpectedly evolving conditions, severe disruptions to physical, social, and economic functions, and potential harms to the public and emergency responders (Perry, 2018). IMTs also face internal difficulties: limited resources (e.g., staff, supplies), inaccurate and incomplete incident information, high-stake decisions to be made under time pressure, and discrepancies between pre-established emergency management plans and their implementation (Kapucu & Garayev, 2011; Perry & Lindell, 2003).

Resilience, defined as a system's capability to adapt its functions to expected and unexpected disturbances, has emerged as a crucial concept of academic and practical inquiry to describe coping mechanisms during complex disaster management (Boin, Comfort, & Demchak, 2010; Hollnagel, Paries, Woods, & Wreathall, 2011). Research efforts for disaster resilience often pertain to a specific level of the incident management system hierarchy. First, research at a macro-level of the government hierarchy has highlighted issues associated with overarching incident management frameworks such as the National Incident Management System (NIMS) and the Incident Command System (ICS), and emphasized the scalability and adaptability of the frameworks (Bigley & Roberts, 2001; Chen, Sharman, Rao, & Upadhyaya, 2008; Harrald, 2006). Second, studies focusing on a micro-level of the hierarchy investigated individual responders' cognitive and behavioral traits such as improvisation with respect to roles, plans, tools, and facilities (Mendonça, Webb, Butts, & Brooks, 2014; Webb, 2004; Webb & Chevreau, 2006). Third, at a meso-level where a group of emergency personnel (formed as an IMT) becomes a primary unit of analysis, intra- and inter-team aspects of resilience in dealing with adverse incidents were examined in some studies. For example, collective sensemaking or common operating picture (COP), a shared understanding of ongoing situations among different organizations (Comfort, 2007), was identified as a key to maintaining resilience in the face of unexpected circumstances, not only within a team (Schraagen & van de Ven, 2011; Weick, 1993) but also across organizations (Wolbers & Boersma, 2013). Other highlighted aspects of resilience at the meso-level include coordinated decision-making within and across IMTs (Militello, Patterson, Bowman, & Wears, 2007; Smith & Dowell, 2000), role adaptation of team members and its trade-offs (Lundberg & Rankin, 2014), anticipatory and proactive actions (Furniss, Back, Blandford, Hildebrandt, & Broberg, 2011; Tveiten, Albrechtsen, Waero, & Wahl, 2012), and resourcefulness and rapidity in stabilizing disruptions (Kendra & Wachtendorf, 2003).

Despite the crucial role of the IMTs during a disaster, not much attention has been given to investigating meso-level IMTs compared to the micro- and macro-level incident management. More importantly, existing literature regarding IMTs tends to spotlight partial dimensions or enumerate related constructs associated with resilience (e.g., collective sensemaking, coordinated decision-making) in isolation without understanding the relationship between such constructs or using a holistic systems approach to account for different layers of such a complex system.

Joint cognitive system (JCS) theory is one such approach that views resilience as one of the defining patterns of a cognitive system in which humans and technology function as a whole (Norros & Salo, 2009; Woods & Hollnagel, 2006). A JCS exhibits goal-oriented functions by planning and modifying its performance based on knowledge of itself and surrounding environments (Hollnagel & Woods, 1983)—a characterization that resembles the functioning of IMTs. While the JCS theory was applied to some complex system domains such as healthcare and process control, (Hegde et al., 2015; Inagaki, 2010; Lay, Branlat, & Woods, 2015; Thraen, Bair, Mullin, & Weir, 2012), little has been studied in the realm of incident management. Our previous work conceived a JCS model of the IMT (Son et al., 2018), reflecting the cyclic, adaptive process consisting of major cognitive phases of perceiving the situations, coordinated decision-making, adaptive control actions, and continuous feedback. The model represents the IMT's continual performance adjustment to bridge the gap between challenges rising from an incident and goals to be accomplished. Efforts to apply the JCS model of the IMT to describe a real-world incident, however, have so far been limited. From a methodological standpoint, many of the previous studies focusing on the IMT resilience (e.g., Gomes, Borges, Huber, & Carvalho, 2014; Lundberg & Rankin, 2014) were based on simulated environments (e.g., emergency exercise). To this end, the objective of this study was to address this gap by garnering practical insight of the JCS functions of an IMT—how it perceives conditions of itself and environments, adapts its decisions and actions to achieve high-level goals, and utilizes resources to realize the actions in the context of a recent disaster: Hurricane Harvey.

3.3. Background

3.3.1. Incident management teams

When demands from an incident exceed a local jurisdiction's capacity, IMTs comprising staff from multiple agencies and organizations are established to supervise and support tactical activities in the field. The primary purpose of an IMT includes handling imminent hazardous situations and providing coordinated support to incident commanders, field responders, and other organizations. Generic functions of the IMT are defined by the US Federal Emergency Management Agency (FEMA) to include: collecting, analyzing, and consolidating incident information; meeting resource needs by allocating and tracking them; and coordinating plans based on current status and future goals (FEMA, 2017).

Activities of the IMTs are guided by a coordinated and iterative *incident action planning* process that results in an Incident Action Plan (IAP). The incident action planning process is aimed at ensuring that day-to-day operations are aligned with incident objectives and conducted within available resources and financial capability (FEMA, 2015). To cover various facets of such activities, an IMT is generally composed of five sections: Command, Operations, Planning, Logistics, and Finance & Administration [F&A] (refer to Chapter 1 for more details of the organizational structure and core functions of the IMT).

3.3.2. Hurricane Harvey

Hurricane Harvey was a Category 4 tropical storm that made landfall over south-central Texas on August 25, 2017. The estimated total cost incurred by Harvey was $125 billion, second only to Hurricane Katrina, which caused an approximate cost of $161 billion (National Hurricane Center, 2018). Harvey did not follow typical patterns of a hurricane, which tends to weaken or dissipate in one to two days after landfall due the loss of heat and humidity (Sampson, Jeffries, Chu, & Neumann, 1995). Unlike a traditional hurricane, Harvey moved extremely slowly after striking inland and re-emerged as a tropical storm while stalling over the Texas Gulf coast, all of which resulted in tremendous amounts of rainfall (National Weather Service, 2018). Until it became a tropical depression, Harvey dropped record-setting rainfalls of more than 60 inches and caused an unprecedented flooding, affecting over 100,000 residential properties. The flood damage in the Greater Houston area was extremely serious with all 22 watersheds and many creeks and bayous in that area flooded. Although this region is accustomed to dealing with floods, given that the entire region (around 1,800 square miles) was experiencing severe flooding, emergency responders were soon overwhelmed with the large number of residents who had to leave their homes with little preparation or warning. Further, the temporary shelters that needed to be set up in the middle of the hurricane to accommodate the increased number of people who voluntarily evacuated or got rescued, were not reliably established (The Governor's Commission to Rebuild Texas, 2018). Such anomalous impacts of Harvey were dissimilar to previous flooding events in Texas such as 2015 Memorial Day Flood and 2016 Tax Day Flood, which left localized damage for several hours, and thus allowed recovery operations to start swiftly (Harris County Office of Homeland Security and Emergency Management, 2016).

No large-scale mandatory or voluntary evacuation order was issued from the city of Houston. However, citizens in some limited surrounding areas were recommended to evacuate voluntarily. In several surrounding cities and counties, however, mandatory evacuations were ordered (Sebstian et al., 2017). As a result, nearly 780,000 residents evacuated their homes and more than 42,000 were accommodated in 692 shelters temporarily. First responders from local, state, and federal agencies rescued over 122,000 people and over 5,000 pets (Texas Commission on Environmental Quality, 2018). Over time, Harvey caused 68 direct fatalities, the largest number from a tropical storm since 1919 (Zelinsky & Blake, 2018). Due to the unanticipated impacts from Harvey, recovery activities (e.g., removing debris, insuring health) were initiated and sustained while the immediate response (e.g., search and rescue) was being operative (The Governor's Commission to Rebuild Texas, 2018). In response to and recovery from Hurricane Harvey, several IMTs were formed to manage and coordinate the response and recovery efforts at the municipal, county, or state level.

3.4. Method

3.4.1. Research sites

Six IMTs at state, county, or municipal levels in Texas that served a primary role during Hurricane Harvey were chosen as the sites for the current research (Table 3.1). The jurisdictions covered by the IMTs experienced high emergency response demands that resulted from Harvey. The size of the IMTs varied, ranging from about 10 to over 700 members when fully utilized. City-level IMTs had only essential roles such as the Incident Commander and Command Staff with multiple roles being covered by the same personnel. County-level IMTs fully incorporated the ICS structure as they involved representatives from individual municipalities, state agencies, and non-profit organizations (e.g., Red Cross). IMTs at the state-level covered specialized areas of operations (e.g., search and rescue, mass care and human services) across the state, and thus activated the largest number of personnel. While most of the IMTs' capacity was utilized during Hurricane Harvey, such large IMTs generally deal with other types of public safety events, sometimes in parallel, such as large-scale fire and explosion, mass shooting, and incidents during major sports (e.g., Super Bowl, World Series).

Table 3.1 Research sites involved in this study

Site No.	IMT level	Approximate No. of staff if activated	Primary emergency functions
S01	County	100	All-purpose
S02	State	720	Search and rescue
S03	State	500	Mass care and human services
S04	County	50	All-purpose
S05	City	15	All-purpose
S06	City	10	All-purpose

3.4.2. Data collection

In order to elicit a comprehensive understanding of resilient performance of the IMTs, semi-structured interviews were conducted with 10 government emergency personnel (nine male) who were deployed to the IMTs during Harvey. The average age of the interviewees was 51.6 years (SD=9.5), and the average overall length of their career in emergency services was 20.8 years (SD=6.9). Interviews took place in the interviewee's office or their preferred location between February and July of 2018. No one refused to participate or dropped out during the interview. To account for multifaceted aspects of the IMTs, the interviewees were recruited from different organizations and areas of specialization by utilizing purposive and snowballing sampling strategies (Creswell & Poth, 2017), based on the initial email contact by a collaborator who was a subject matter expert in the emergency management field. Criteria used to choose an interviewee were: i) whether the person worked as an incident commander or key staff at IMTs, not as a field responder, and ii) whether the person was deployed in immediate response to Hurricane Harvey, not in the long-term recovery phase. The interviewees' areas of expertise based on their past experience and roles during Harvey are presented in Table 3.2. Interviewers had no previous familiarity with the participants and participants were not familiar with the specific goals of the research project.

Table 3.2 Government IMT interviewees' areas of expertise

Interviewee No.	Site No.	Command	Operations	Planning	Logistics	F&A
H01	S01	✓	✓	✓	✓	✓
H02	S02		✓	✓		
H03	S01				✓	✓
H04	S01		✓	✓		
H05	S02	✓	✓			
H06	S03		✓	✓	✓	
H07	S04	✓	✓			
H08	S04	✓		✓	✓	✓
H09	S05	✓		✓		
H10	S06	✓		✓	✓	✓

Two faculty members at a large public university and a postdoctoral fellow knowledgeable in the incident management domain and qualitative study methods served as the primary interviewers during each interview and were supported by two PhD students for note-taking, audio-recoding, and probing questions when further clarification was needed. Interviewers discussed saturation during post-interview briefings.

The interviews were guided by a set of questions concerning the constituent aspects of the JCS framework of resilience. Table 3.3 presents major aspects of the JCS framework and some examples of the associated questions used in the interviews. In some cases, new questions were asked based on emergent findings as the conversation progressed.

Table 3.3 Questions used in semi-structured interviews with government IMT personnel

Aspect	Related questions
Personal and organizational context	• What was your role in response to Harvey? • Can you describe organizational structure and composition of the IMT you worked at?
Challenges and successes during the incident	• What were the major challenges of Harvey that you had not expected or experienced from previous incidents? • How did you overcome such challenges?
Goals of IMTs	• What were the major goals that you tried to achieve during Harvey and how did you accomplish those goals?
Functions of IMTs	• How did you make sense of evolving situations during Harvey? • What key decisions did you make to solve problems in Harvey and how? • Can you tell us about procedures, plans, or guidelines you used in response to Harvey? • How did you utilize resources to perform response actions?

Interviews took on average 1.2 hours. After acquiring informed consent, the interviewer first asked for a brief professional career history and roles that the interviewee carried out during Harvey. Based on the interviewee’s initial answer, the interviewer asked the next questions deemed relevant. The audio-recordings were first transcribed by an artificial intelligence-based transcription service (Temi, 2018), and then manually corrected by the first author. The study followed a research protocol approved by the Institutional Review Board.

3.4.3. Data analysis

A thematic analysis method (Braun & Clarke, 2006) was used to identify patterns or themes relevant to resilience of the IMTs during Harvey. While some *a priori* themes were reflected on the interview questions, coding of the data was conducted in different inductive and deductive phases (Creswell & Poth, 2017). Initial coding was done by the first author focusing on what the data evinced, minimizing theoretical preconceptions. The initial inductive codes were then presented to other authors and the codes were revised, discarded, and regrouped into themes based on existing theories of resilience via multiple discussions. Also, the codes and the themes were continuously adjusted based on the constant comparative method with which data of a similar concept were grouped together during the course of analysis (Corbin & Strauss, 2015). Several themes emerged deductively that represent core aspects of resilience of IMTs. To facilitate the qualitative analysis, MAXQDA® (Version 18.0.7; VERBI Software, 2018), was used.

3.5. Results

The identified themes and subthemes are presented in Table 3.4. First, analysis of the data identified general themes regarding challenges the IMTs encountered and goals the IMTs strove to achieve during Harvey. Second, in the course of filling the gap between the challenges and the goals, the IMTs were found to exhibit six resilient behaviors: i) establishing common operating picture, ii) adopting and adapting plans and protocols, iii) proactive, re-prioritizing, and unconventional decision-making, iv) enhancing resourcefulness and redundancy, v) learning for improved anticipation and resource preparedness, and vi) the inter-organizational relationship, which emerged as an important factor that facilitated the resilience functions of the IMTs as multiple organizations and other agencies coordinated and collaborated during Harvey.

Table 3.4 Categories and themes of resilience of the IMTs

Categories	Themes	Sub-themes
Challenges and goals of IMTs	Challenges during the incident	Unexpected patterns of Harvey Massive demands for response activities
	Incident response goals	Life safety Incident stabilization
Traits of IMT resilience	Establishing common operating picture (COP)	COP as an integrated snapshot of evolving situations
		COP as distributed awareness among IMTs
		COP established via joint information platform
		COP as a basis for decision-making in IMTs
		Trustworthiness of inputs to COP
	Adopting and adapting plans and protocols	Adapting to ad hoc plans under changing situations
		Flexibility of operating protocols
		Advantages and disadvantages of following plans and protocols
	Proactive, re-prioritizing, and unconventional decision-making	Proactive decisions
		Dynamic re-prioritizing decisions
		Unconventional decisions
		Trade-off of decision-making
	Enhancing resourcefulness and redundancy	Strengthening resourcefulness
		Increasing technical redundancy
	Learning for improved anticipation and resource preparedness	Learning for informed anticipation
		Lessons reflected on resource preparedness
	Inter-organizational relationship to promote IMT functions	Facilitating COP of IMTs
		Promoting pre-incident planning among IMTs
		Coordinating decision-making between IMTs
		Enabling resourcefulness of IMTs

3.5.1. Challenges and goals of IMTs during Hurricane Harvey

3.5.1.1. Unexpected impact of Harvey and massive response demands

Unlike other tropical storms that affected the US, response to Harvey faced unique challenges. Interviewees (9/10) indicated that Harvey had an unusual movement pattern as hurricanes affecting south-central Texas typically make landfall and dissipate or head northward, but Harvey reconstituted while staying along the Gulf Coast, and as a result it dropped an unprecedented amount of rainfall. Due to the unusually severe consequences, the IMTs confronted massive demands for response activities such as evacuation, search and rescue, and mutual aids for additional resources.

> *"[A similar] one that happened was the 9-1-1. It got to the point where calls were going on hold and then it went out over the radio waves that 9-1-1 crashed and everybody was panicking with what we did."*
>
> *"[Search and rescue demands were so high that an adjacent city] actually asked for help. [The adjacent city] never wanted help from us. We have literally been on the outskirts of [the adjacent city] multiple times for flooding and there's been no request for assistance from our resources."*

3.5.1.2. Goals in the incident response

In the face of unanticipated challenges from Harvey, IMTs set goals that guided their operational and tactical activities. Major goals of IMTs that the majority of interviewees (8/10) stated include *LIPS*, or Life safety, Incident stabilization, Property protection, and Societal restoration. However, not all the goals of the IMTs carried the same weight. Among others, the highest priority was given to life safety such as preventing loss of life and addressing immediate threats to the safety of the public and emergency responders. During Harvey, evacuating vulnerable populations such as residents in nursing homes and treating dialysis patients were notable examples of context-specific objectives. The second priority was placed on incident stabilization aimed at keeping the incident from expanding and getting affected populations back into a new normal state of living, albeit in a diminished state. Additionally, the interviewees emphasized the time-sensitivity of attaining such goals.

> *"Our priority is LIPS, right? Life safety, incident stabilization, property protection, and societal restoration. So, 'L' is first. 'L' is always first. And that's how we drive our priorities. […] Again, going back to the life safety, time is a key."*
>
> *"In emergency management, our goal is to get back to a new state of normal. How do I get on my community back to where it was as a whole?"*

3.5.2. Establishing common operating picture (COP)

Interviewees commonly claimed that COP was the *sine qua non* in sustaining incident management, serving as the basis for decision making and other several critical purposes in the IMTs. We identified three major interpretations of COP: an integrated understanding of changing situations; distributed awareness depending on IMT's scope of work; and a joint information platform.

3.5.2.1. COP as an integrated snapshot of evolving situations

Most participants (8/10) stressed the importance of establishing and updating COP since situations surrounding Harvey changed relentlessly and a multitude of emergency operations occurred simultaneously. As a *common* picture of the evolving and complex situations, the COP served as an integrated snapshot of multiple facets of incident management such as on-scene tactical activities, weather forecast, status of infrastructure and allocated resources. In particular, the interviewees emphasized that the COP should be a real-time reflection of the evolving situation rather than an information repository.

> *"So, the way I see common operating picture is not really stating like information warehouse, but I guess it is constantly updated [or] should be updated. And how do you manage that? How do you deal with discontinuity of this common operating picture? That's the thing. It's a different snapshot every two minutes."*

> *"All of the partners in the room enter information into our portal, which goes to the situation unit. […] Here's what we have. Here's what we're doing. Here's what we know. What we call a SWEAT report, which is Security, Water, Energy, Accessibility, Telecommunications. So, that gives me a snapshot. […] Now I can have a snapshot of a jurisdiction and know now who's in trouble."*

3.5.2.2. COP as distributed awareness among IMTs

In contrast to the commonality of the COP, some (5/10) expressed an opposing view that the COP was distributed and diverged among the IMTs depending on jurisdictional boundaries or organizational responsibilities. In other words, the COP meant an *uncommon* operating picture that spotlighted an individual IMT's scope of interest.

> *"There's no such thing as a common operating picture. They're uncommon operate pictures, right? So, I have my own common operating picture that I use for my team. Somebody else has their own common operating picture. Those two are not common!"*

> *"[EMS] also wants to know the common operating picture of the hospitals, which are working with the EMS so that they know where to take patients. Military doesn't care. My county attorney doesn't care. Right? […] They're looking at that snapshot on that dashboard that's important to them."*

3.5.2.3. COP as a joint information platform

Given the concept of COP as a shared but distributed awareness of changing situations, all the interviewees treated joint information platforms as the COP itself. The IMTs utilized different platforms to incorporate inputs from multiple sources into the COP via the IAPs or computer-aided applications (e.g., WebEOC, GeoSuite). However, some of the interviewees commented on limitations of the computerized application interface designs which often suffer from low usability and traceability.

> *"That incident action plan is your common operating picture. […] it actually had an assignment list where everybody was, the communications plan or a medical plan, hazmat plan, […], the safety message, our air operations summary, what air frames do we have out there? Who do they belong to? Where were they stationed?"*

> *"[A computerized application] is intended to be a common operating picture here. If ten of us were having the same conversation via text messaging and I needed you to recall some bit of data, it would require you to physically read through each one of those until you find the information. That's what [the application] is. And what we're trying to transition to is a picture worth a thousand words."*

3.5.2.4. COP serving as a basis for decision-making in IMTs

While the COP was largely responsible for the IMT's common understanding of ongoing situations, half of the interviewees (5/10) also implied that the COP informed decisions for operational and tactical actions made in the IMTs. Specifically, the COP helped the IMTs make decisions regarding evacuation route, location of shelters, and allocation of necessary resources.

> *"Here's the downstream application. We're going to flood 2,000 homes. It's going to happen within the next two hours. Alright. Call [a neighboring city].*

> *Talk to them. 'Hey guys, flood control says we've got a huge problem. You want to keep them in place? Do you want to evacuate anybody?', 'Got any functional and access needs of population that might be in that area?"*

3.5.2.5. Trustworthiness of inputs to COP

Many (8/10) questioned the trustworthiness of information put into the COP. According to the participants, information to establish the COP often comes from multiple sources in parallel, and during Harvey, those inputs were often based on rumors (e.g., breached levee, dead bodies), inflated through social media, or on suppositions not validated against ground truth via field responders or trusted informants from federal agencies and private partners.

> *"Nothing you hear is right. Everything that comes in has got a little bit of a thread on it and you got to figure out what 'right' looks like."*

> *"I would have to bed more people. I have to feed over more people and then it wouldn't happen. In three hours, 150 people would show up but you get like ten. Right? And I mean that happened pretty consistently."*

3.5.3. Adopting and adapting plans and protocols

3.5.3.1. Adapting to ad hoc plans under changing situations

Due to volatile conditions surrounding Harvey, incident objectives had to be updated accordingly. This dynamic shift in demands required the IMTs to not only *adopt* pre-established emergency operations plans and protocols but also *adapt* the plans to the new situation. In other words, according to the interviewees, the IMTs espoused a formal incident action planning process put in place to promote continuous adjustment of high-level objectives and associated strategies. Nonetheless, the IMTs claimed being successful in adapting to *ad hoc* tactical plans when situations at hand were inimical to the execution of the original plans. One noteworthy example was a change in one of the IMTs' food distribution plan that shifted points of distribution from fixed locations to first responders on the move, accounting for civilians' limited mobility during Harvey.

> *"I made a decision that we weren't going to do that [referring to the distribution plan]. We had to change it after the event. We changed it to the first contact. […] So, we called the first contact and I gave food and water to every first responder. […] I wanted them to be able to hand them [citizens] food and water. So, we created a new process within the point of distribution plan that we had not done before, but we adapted."*

3.5.3.2. Flexibility of operating protocols

Recognizing the needs for adaptation due to unpredictable environments, some (4/10) highlighted the flexibility of the incident management protocols to be a convenient factor. For example, the flexible nature of the Incident Command System (ICS) and National Incident Management System (NIMS) was praised for being adaptable to different hazards and sizes of an incident.

> *"The best part about the ICS is [the ease of] changing plans … [are there] two people at that desk or is there 12 today? It doesn't matter. It's expandable and contractible based on the incident."*

3.5.3.3. Advantages and disadvantages of following plans and protocols

Most of the interviewees (9/10) pointed out tension between complying with and departing from plans and protocols. On one hand, advantages of following plans and protocols include synchronizing operational tempo, maintaining unified knowledge among the IMT personnel, and minimizing surprising actions. On the other hand, the interviewees commented that they had to depart from the plans or protocols to deal with imminent threats, deficient resources, and situations in the field that did not correspond to the plans.

> *"They follow the normal planning 'P'. We go through the [same] cycle each day. We have our meetings. We go through the briefings in all the next operational periods. They were 12-hour operational periods. They followed it exactly. They would write it out so everybody knew that they were on the same page."*

> *"I can plan ahead for the next day, but I am flooded. I can't get any more resources. So, what's the point of having 215 [an ICS form for planning resources]? I mean, what's the point of doing some of that planning if you can't get those resources to fulfill that plan."*

3.5.4. Proactive, re-prioritizing, and unconventional decision-making

3.5.4.1. Proactive decisions

According to the interviewees, the tracking of future impacts of a hurricane is relatively easier than other abrupt disasters such as earthquakes. Based on previous operations for tropical storms and hurricanes, the IMTs were able to make proactive decisions before Harvey caused actual impacts. One proactive decision commonly made in the IMTs was to pre-position necessary resources to anticipated areas even when such actions were not requested.

> *"I'm sitting here looking and going, 'Okay. We're getting all this rain over here. I need to start. I know you have fire chief. You haven't asked for resources.' Let me send you resources because I know what the water's about to do. So, let me pre-position them before I can't get them to you."*

3.5.4.2. Dynamic re-prioritizing decisions

In a broad sense, impacts from Harvey (e.g., its path, wind, and precipitation) were forecasted by responsible agencies in the US (e.g., National Weather Service). Nevertheless, unpredicted situations that arose from local levels required the IMTs to allocate limited resources to those impacted with the highest priority. This meant making difficult calls to delay responses to lower priority entities. Such dynamic re-prioritization decisions were especially evident in search and rescue operations where limited resources had to be allocated to those under more critical states such as nursing home residents and patients with life-threatening conditions.

> *"We got somebody with heart conditions. So that's where you really had to make that hard decision and as painful as it was…we had to prioritize who has high, medium and low risk. And those are the ones having to prioritize."*

3.5.4.3. Unconventional decisions

In cases where pre-established operating plans were rendered inoperable due to overwhelming demands, innovative decisions were attempted in the IMTs. Although response activities were largely driven by the incident action planning process, the IMTs took advantage of unconventional decisions. The one that many interviewees (7/10) highlighted was a decision to allow civilians including Cajun Navy to engage in search and rescue using their own assets (e.g., boats, high-water vehicles). Other unconventional practices identified from our study include using food trucks to feed members of the IMTs, conducting aerial evacuation from an isolated island to another big city, and launching civilians' boats at flooded highways.

> *"I think Harvey took thinking outside the box to a totally new level […] [A jurisdiction's chief official] made the decision to basically say, 'We can't handle this. We need to ask for citizens to bring in their boats.' I think that was probably the number one decision that saved more lives than anything else, to speak openly. It's not in the book. It's not in the ICS program. We need to do something. And it worked out. There were no known injuries or fatalities [of citizens rescuing others], which is unbelievable."*

> *"We had sought to do air evacuation where we can push people to Galveston from the shelters that could then be flown to Dallas. That was the first time that's ever been done because they couldn't go north by bus."*

3.5.4.4. Trade-offs in decision-making

Notwithstanding the benefits of re-prioritized and unconventional decisions, decisions that forgo one value over others entail trade-offs. For instance, by involving civil resources in the government-led search and rescue activities, the IMTs had to lower the rigor of command and control and sought to mediate the coordination among civilian helpers. One interview also mentioned that civilians' involvement in the search and rescue, in fact, resulted in duplicate efforts of the IMT personnel and field responders.

> *"It wasn't command and control. […] Inevitably, those civilians were going to go out and try to help their neighbors. […] We're trying to manage that, just coordinate it, right? Very loosely."*

3.5.5. Enhancing resourcefulness and redundancy

3.5.5.1. Strengthening resourcefulness

Given the quantity and quality of resources not commensurate with demands brought by Harvey, the IMTs had to strengthen their resourcefulness, an ability to promptly devise means for sustaining their operations. A common resourceful action that the IMTs practiced was mobilizing resources in an unusual fashion. For example, the IMTs designated local schools as a shelter, utilized web-based documentation application (e.g., Google Docs, SharePoint) for information sharing, used a commercial real estate website (e.g., Zillow) for locating those who needed be rescued, and took advantages of local restaurants (e.g., Waffle House) and recreational merchandise retailers (e.g., Bass Pro Shop) to meet the needs of feeding and rescue activities. Such resourceful activities were epitomized in the establishment of the largest shelter at a football stadium in a short amount of time.

> *"We added the ISD [independent school district] onto [the planning process] because the schools ended up being a big part of the sheltering by itself. […] It became an impromptu shelter or a refuge."*

> *"We're just getting the whole thing set up and it was unbelievable to see the logistics. When I got down there, there were already tractor trailers coming in with water and food, and COTS [commercial-off-the-shelf products]. And there were literally a thousand youths from this organization setting stuff up. […] I've never seen it. It was unbelievable at 10:00 that evening, they took their first person, then it was 18 hours after the request went out and we had a full-blown shelter."*

3.5.5.2. Increasing technical redundancy

In addition to the resourceful actions, some interviewees (6/10) stressed technical redundancy when a primary resource or an operating system had malfunctioned and thus needed to be substituted readily. The interviewees also expressed their doubt on the reliability of modern technologies (e.g., telecommunication, computer-aided software) and emphasized the importance of sustaining operational activities under deteriorated conditions. Indeed, one IMT during Harvey leaned on sticky notes to maintain resource status that was usually kept via standard forms (e.g., ICS 219 T-Card). The redundancy among technical resources were also found in the use of telecommunication methods such as text message, cell phone call, email, and radio since each provided distinct advantages and disadvantages. Interviewees especially preferred emails and text messages to convey much richer information (e.g., photos) to multiple recipients in a prompt manner.

> *"We are as redundant as possible. But what happens if we're the target of a bomb and we can't operate in this facility. […] Do I have electricity? Do I have the resources in order to boot it all up? Maybe, maybe not. But if we don't, can you do your job with a chief tablet and pencil because that's what you have to be able to fall back to? If we don't train to that level, we will fail."*

3.5.6. Learning for improved anticipation and response readiness

A majority of interviewees (7/10) emphasized that lessons learned from previous incidents played a key role in increasing the knowledge base for anticipatory actions and resource preparedness pertaining to the IMTs' response to Harvey. The interviewees also implied the importance of learning lessons not only from rarely occurring catastrophic disasters, but also recurrent local incidents.

3.5.6.1. Learning for improved anticipation

The IMTs took advantage of past experience and lessons learned in order to recognize their vulnerabilities and to more accurately anticipate ensuing situations. For example, the IMTs were able to predict which areas would be likely to be flooded and what types of resources (e.g., rescue boats) would be needed based on their knowledge regarding geography around the area and historical flooding patterns. Furthermore, one interviewee stated that such lessons were utilized in choosing the location of the IMT facility such that it had a minimal impact from floods.

> *"It's easy to say when this part floods, I know how many resources I need. […] When the Sabine river floods, we know exactly what it's gonna do. You gotta get a boat load of people out there quickly because you're going to need that many resources out there. So as soon as we saw what the storm started to do, we realized you're going to get cut off."*

3.5.6.2. Lessons reflected on resource preparedness

Another area in which the IMTs utilized lessons from past incidents was their resource preparedness and technological capabilities. For example, the quantity of water rescue assets was increased and a county-wide resource management system was initiated in the aftermath of two consecutive large-scale flooding events in southeastern Texas. Also, lessons used to enhance the resource readiness in the IMTs were not only derived from local incidents but also other incidents. As an example, the IMTs took benefits from mobile cell towers on wheels during Harvey based on lessons from cellular network disruptions during Hurricane Sandy in 2012.

> *"So, what we did following the 2015 and 2016 floods was we actually created a database of all of the county-based water rescue assets. […] On Wednesday [a week before landfall], we started making phone calls. 'Is the piece of equipment operational and is it staffed and will you respond if we need it? Okay. So, if a department over here needed more boats, could I reach over to this department here to go there?' So, we had outlined all that data out."*

> *"So, we had two buses brought in. Two mobile networks were brought in. Both parked trucks right next to us. So, this time we took care of that. When I was in Sandy, [it] was a different ball of wax. We couldn't text. We couldn't use radios.*

We had to do face-to-face because the tower has originally got knocked out by the storm."

3.5.7. Inter-organizational relationship to promote IMT functions

Most of the interviewees (8/10) indicated the importance of the inter-organizational relationship among the IMTs since it supported different aspects of resilient functions of the IMTs. As Harvey imposed demands that exceeded one jurisdiction's response capacity, coordination among multiple agencies including the IMTs was found to be essential to attaining their goals.

> *"[Our jurisdiction] is unique because we have 34 cities, 57 fire departments, over 125 law enforcement partners that have jurisdictional authority within [the jurisdiction]. So, we try to build those relationships, build those partnerships in order to meet the mission of getting to a new state of normal, based on the risk and the threat that has occurred as quickly and effectively as possible." (H01)*

3.5.7.1. Facilitating COP of IMTs

The relationship between IMTs and other organizations was considered a basis for the establishment of accurate and updated COP because it depended upon external partners as well as internal sources. In particular, interviewees (5/10) claimed the important role the Liaison Officer plays in the inter-agency communication.

> *"Once I had a liaison officer in [a jurisdiction's IMT], I started getting good information from [the jurisdiction]. But remember we don't work on a direct dial. […] I just happened to get a call from the emergency manager for [another jurisdiction] that got my number from probably one of my guys."*

3.5.7.2. Promoting pre-incident planning among IMTs

The partnership between neighboring jurisdictions was important in pre-incident planning. Some interviewees (3/10) stressed the benefits of collaborative planning before Harvey such as reduced stress and opportunities to initiate mutual agreement and to discuss strategic matters in a preemptive manner. Especially, one of the interviewees addressed that a face-to-face visit to a nursing home helped build the relationship and establish the emergency plans for the nursing home, a high-priority facility during Harvey.

> *"I've been having to build all those relationships, to get people in the room to have those conversations, and to work on the plans so that we can go forward and not have to make those decisions during periods of stress instead of being able to do them during a blue sky day when there's no stress or less stress. And the strategic stuff that we can do ahead of time."*

3.5.7.3. Coordinating decision-making between IMTs

The relationship between the IMTs played a crucial role in making decisions that affected neighboring jurisdictions during Harvey. Decisions regarding the issuance of ground and aerial evacuation, among others, were predicated upon the pre-established relationship among response agencies. As seen in the establishment of COP, the Liaison Officer facilitated decision-making that took place between the IMTs in terms of reallocation of ambulances from one jurisdiction to another, for instance.

> *"We have a handshake agreement. […] Typically, if we're going to call for evacuation, we need to let them [other adjacent jurisdictions] know and they'll give us time to get the county clear before they call for an evacuation because we're closest to the dangers."*

"We had one liaison that worked for a bunch of weeks. She was really good. She's been out there a lot so she was the one that made decisions or suggested the ambulance trade-off. […] They speak for us because they know our capabilities."

3.5.7.4. Enabling resourcefulness of IMTs

We also found that multi-agency coordination was a critical factor to boost resourcefulness of the IMTs. Some interviewees (6/10) pointed out formal mutual aid systems such as FEMA Emergency Management Assistant Compact (EMAC) and Interstate Emergency Response Support Plan (IERSP) designed to legalize state-to-state assistance. Nevertheless, the IMTs that responded to Harvey also counted upon relationships with local and community partners in satisfying the needs for resources (e.g., volunteers, food, water, and fuel).

"During Hurricane Harvey, we made sure that there were no boundaries. You know, jurisdiction lines pretty much got washed away. Community effort is a lesson learned. The FEMA model calls to have to be community-oriented. And it's very true because we were not able to get the State resources."

"The kind of frugal innovation comes in whether it be human resources or food resources or water resources, relationships are very important. Our logistics section chief has the keys to pretty much three of the supermarkets here. So, we would never have an issue."

3.6. Discussion

3.6.1. Resilient behaviors of IMTs during Harvey

The main purpose of this study was to draw a holistic picture of resilience of IMTs during a catastrophic incident. As illustrated in Figure 3.1, the findings presented in this article show what challenges the IMTs faced, what goals they sought to accomplish and how the IMTs muddled through unprecedented situations by exerting essential functions of a JCS: establishing and updating COP, balancing between adopting and adapting plans and protocols, making proactive, re-prioritizing, and unconventional decisions to remain functional, fostering resourcefulness and redundancy with limited resources, and learning for anticipatory knowledge and improving resource readiness. Moreover, our study suggests that the relationship between IMTs and other organizations promoted some aspects of the resilient functions.

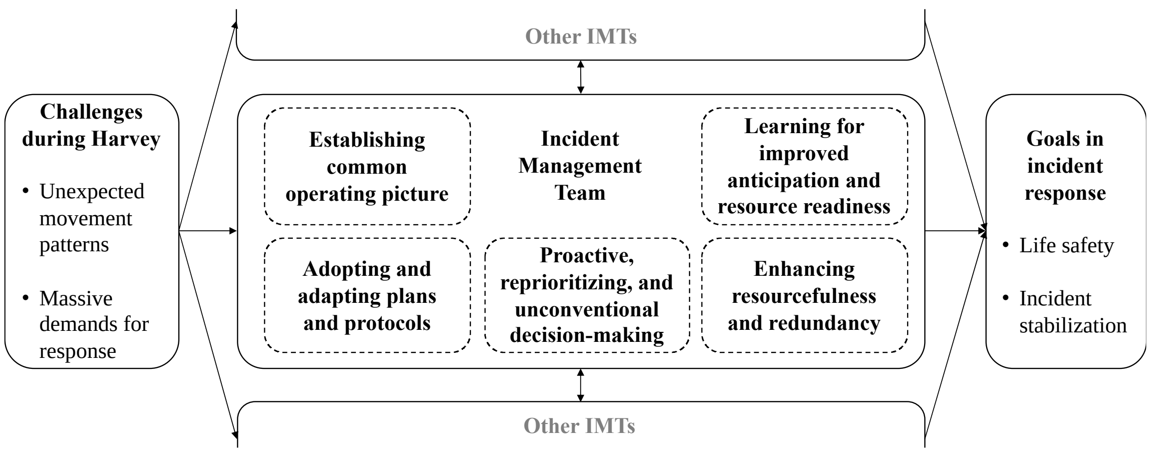

Figure 3.1 A thematic map of resilient IMTs during a disaster. To overcome the challenges imposed by Harvey and achieve the goals in incident response, the characteristics of a resilient IMT are necessary.

First, our findings support three major characteristics of COP in the context of incident management: i) an integrated operating picture, ii) a distributed awareness, and iii) a joint information platform. In line with a general meaning of the term, *common*, the COP for the IMTs during Harvey meant a global, consolidated awareness of the ongoing operations (McMaster & Baber, 2012). From shared mental model theory (Cannon-Bowers, Salas, & Converse, 1993), the COP of the IMTs can be regarded as a team's shared understanding of what response activities to carry out, how team members function as a team, and what information (e.g., resource status) to collect and disseminate. As a complementary concept, the COP also existed as multiple divergent, thus *uncommon*, representations depending on the responsible areas of individual IMTs (Luokkala & Virrantaus, 2014). The concept of uncommon COP supports the idea of transactive memory system (Lewis, 2003) in that the overall picture of an emergency operation can be better established through communication between members or IMTs with specialized and credible knowledge of their respective roles and responsibilities. To facilitate *shared yet distributed* awareness of the IMT operations, the COP served as a joint platform or a trading zone where incident information is exchanged (Baber, Stanton, Atkinson, McMaster, & Houghton, 2013; Comfort, 2007; Wolbers & Boersma, 2013). However, recurrent challenges in integrating different components of the information and problems associated with information integration technologies (Militello et al., 2007; Scholl, Ballard, Carnes, Herman, & Parker, 2017) also emerged during Harvey, which warrant future endeavors to improve the design of COP applications.

Second, an attitude towards balancing between adopting formal plans and adapting from them appears to be a key to remaining functional under unpredictable conditions during a disaster. While acknowledging the advantages of a formal incident action planning process such as the Incident Command System, our findings on the benefits of adjusting the plans support viewing plans and protocols as resources for situated actions rather than as prescriptive, ‘one-and-done’ rules (Wears & Hunte, 2017). In this regard, future studies should focus on harmonizing two seemingly conflicting perspectives (e.g., developing directive but flexible emergency management plans). In a similar sense, our study captured the advantages of proactive and unconventional decisions that helped the IMTs better respond to the overwhelming challenges. Particularly, such decisions exemplify transformative adaptations commonly seen in extreme conditions (Son, Sasangohar, Rao, Larsen, & Neville, 2019). Nonetheless, ways to address the trade-offs resulting from the unconventional decisions in incident management should be further examined in future research.

Third, the current study proposes that resilience of the IMTs also depends on how the IMT becomes resourceful and the technical systems redundant. As highlighted in other studies (Kendra & Wachtendorf, 2003; Zobel, 2011), the IMT’s attempts to promptly devise resources and operate under substitutive, degraded environments during Harvey are noteworthy. Considering that such endeavors were impromptu rather than planned, a question to be answered is how to incorporate ideas from the improvised actions (e.g., the use of web-based information sharing applications) during Harvey into pre-incident planning and existing emergency operation protocols.

Fourth, our study recognizes the importance of learning from past incidents in promoting different resilient functions (Hollnagel, 2011). We found that learning facilitates other aspects of the IMTs’ behaviors, playing an especially crucial role in the anticipation of adverse event scenarios and in improving resource readiness. It is noteworthy that the lessons that benefitted the IMTs were learned from not only large-scale crises but also small- to mid-scale local incidents, the latter being more frequent than the former. Such finding indicates that resilient performance of the IMTs can be nurtured via continuous cycles of learning from both few-and-far-between catastrophes and routine successful emergency operations. In that vein, to our knowledge, this article is the first attempt at documenting the resilient behavior exhibited by IMTs during the response to a major disaster and can inform proactive anticipatory efforts to mitigate the impact of future incidents.

Lastly, our findings indicate that resilience in the IMTs is exhibited at both the macro- and micro-level of the incident management system as well as coordinated efforts between the two. In relation to the macro-level (e.g., federal), the flexibility and adaptability of incident management policies such as NIMS and ICS (Bigley & Roberts, 2001; Harrald, 2006) has been substantiated through the very users (e.g., emergency managers)' recent implementation during Harvey. With respect to the micro-level (e.g., on-scene activities), team efforts to adapt the use of incident resources further suggest that the adaptive and improvisational behaviors of individual responders (Mendonça et al., 2014; Webb & Chevreau, 2006) could be extended to a team setting.

3.6.2. Contextual meaning of JCS in the IMT environment

In addition to investigating resilience of an IMT from a holistic viewpoint, this study elicits anecdotal insights for better understanding of the JCS model of the IMT in a real-world disaster context. In line with the cognitive systems theory (Hollnagel &

Woods, 1983, 2005), this article describes how the IMT plans and changes its actions to reach goals based on a current understanding of surrounding situations, supporting the proposition that the IMT acts as a JCS (Son et al., 2018). More importantly, basic elements of the JCS model (i.e., collective perception of information, coordinated decision-making, taking adaptive actions) were further embodied into context-specific instances applicable to a hurricane event. Our study suggests that maintaining the COP is considered as the IMT's effortful action as a JCS to have a shared understanding of changing situations. Based on the COP, the IMT's operational and tactical decisions were made in an ad hoc manner in addition to a formal incident action planning process. This article highlights the impromptu decisions such as involving citizens in search and rescue operations. This article also presents multiple examples of the IMT's adaptive actions in implementing decisions made in the midst of Harvey. For instance, the IMTs utilized commercial facilities and services, and civilian resources in order to support search and rescue, and sheltering operations.

The essential functions of the IMTs during Harvey identified in our study are in agreement with fundamental abilities of the JCS to monitor, anticipate, respond, and learn (Hollnagel, 2011). For instance, maintaining the COP in the IMT may be equated with the JCS's ability to monitor. Furthermore, several themes pertaining to the IMT's anticipatory behavior (e.g., pre-positioning resources), adaptive and resourceful actions, and an attitude of learning to improve its response capacity may resemble the JCS's abilities to anticipate, respond, and learn. In a similar sense, the characteristics of resilient IMTs during Harvey are in line with adaptive team performance processes

(Burke, Stagl, Salas, Pierce, & Kendall, 2006; Zajac, Gregory, Bedwell, Kramer, & Salas, 2014), in that the IMTs adjusted their operations by assessing evolving situations and operational status (i.e., COP), formulating and executing incident action plans, and reflecting lessons from past storm and flood events on their current capabilities. While it is worthwhile to investigate interdependent relationships between resilience functions and between team adaptation processes, such investigation exceeds the scope of the current study. Therefore, future endeavors to examine how the essential functions and processes of the IMTs influence each other are greatly recommended. Furthermore, as indicated in the team adaptation literature (Maynard, Kennedy, & Sommer, 2015), we also recommend future studies to examine how the functions and processes of resilient IMTs influence the team performance outcomes (e.g., populations and areas affected, team members' affective reaction) and are influenced by team inputs (e.g., similarity of member's skills and knowledge, organizational structure).

3.6.3. Limitations of the current study

Several limitations of our study need to be stated. First, a relatively small number of interviewees were recruited in the study. While involving more participants in the interview was desirable, it was difficult to gain access to a larger number of IMT personnel due to the ad hoc nature of the organizations. In addition, there was a limited pool of emergency personnel who were deployed to the IMTs compared to the populous field responders, given the hierarchical structure of the incident management system. Despite the small sample, interviewees had broad and lengthy experience in the IMT operations, and the analysis of themes was considered to reach a point of saturation. Second, findings of this study are predicated on settings in the US, for example, a hurricane that hit south-central US and incident management protocols (e.g., NIMS, ICS) commonly mandated across the US. Therefore, results specific to this context may not be generalizable to other countries or states having dissimilar disaster management frameworks, although the advocacy for such protocols is growing worldwide (Jensen & Thompson, 2016).

3.7. Summary

This article presents a holistic view towards resilience of IMTs during a large-scale incident through a thematic analysis informed by theories of resilience engineering and joint cognitive system. Based on subject matter experts' recent experience during Hurricane Harvey, this article documents characteristic functions that make the IMTs able to plan and modify their activities to remain resilient when confronted with unforeseen challenges. While Harvey offered an opportunity to inspect 'markers of resilience' of a system (Woods & Cook, 2005), our investigation of the IMTs leaves several areas of vulnerability to remediate in future studies: developing information management technologies that better maintain common operating picture, reconciling formal incident management planning with goal-seeking, adaptive actions in the field, and capturing opportunities to learn from routine emergency operations before waiting for a catastrophic disaster to occur.

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CHAPTER 4 ARTICLE #3

OPPORTUNITIES AND CHALLENGES FOR RESILIENT HOSPITAL INCIDENT MANAGEMENT: CASE STUDY OF A HOSPITAL'S RESPONSE TO HURRICANE HARVEY[3]

4.1. Overview

As disasters grow more intense and critical infrastructure increases in complexity, resilience has emerged as an essential attribute of incident management systems. Despite concerted efforts to examine government organizations and their associated policies, understanding resilience traits exhibited by hospitals and healthcare systems during disasters is limited. We employ two fundamental viewpoints of safety to assess what went wrong (Safety-I) and right (Safety-II) during Hurricane Harvey in a large regional hospital. Through qualitative analysis of semi-structured interviews with hospital emergency management and operators, we examine both opportunities and challenges in six aspects of hospital incident management: organizational structure and functions; situational awareness; operating plans; human and physical resources; lessons learned from previous incidents and leadership; and high-level decision making. The benefits of incorporating both the Safety-I and Safety-II frameworks in evaluating

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hospital incident response and the implications of this approach for disaster management policies are discussed.

4.2. Introduction

Over the years, communities have experienced increasing threats from natural and human-caused disasters such as hurricanes, wildfires, volcanic eruptions, and industrial incidents. Between 1998 and 2017, global economic losses incurred by disasters amounted to nearly $3 trillion, of which the United States recorded the largest loss of $945 billion (United Nations Office for Disaster Risk Reduction, 2018). Particularly troubling is the approximately 20-fold increase in the frequency and intensity of such extreme events in the past two decades (Coronese, Lamperti, Keller, Chiaromonte, & Roventini, 2019).

Major challenges posed by these disasters include disruptions and damages to critical infrastructure functions that are highly coupled and complex. This results in increased difficulties with planning for and mitigating adverse impacts on social and environmental systems. For instance, the 9/11 World Trade Center (WTC) disaster clearly demonstrated the unprecedented challenges of a disaster to the critical functions of a society. Prior to the event, no public agencies or jurisdictions anticipated or prepared for such an act of terrorism in their emergency planning (Comfort & Kapucu, 2006; Cruz, Burger, & Keim, 2007). During the response to the incident, significant weaknesses were discovered from multiple interdependent critical infrastructure elements such as electric power, water supply, transportation, and telecommunication

(Kendra & Wachtendorf, 2003; Mendonça, 2007). When the twin towers collapsed, underground water pipelines were ruptured and flooded train tunnels and telecommunication cable vaults, exacerbating the problems being addressed (O'Rourke, 2007).

In order to protect critical infrastructures from disasters, and thereby sustain public welfare and economic prosperity, there have been continuous efforts in the United States to provide a standardized incident management framework for all-hazard scenarios. The primary example of this is the National Incident Management System (NIMS), first launched in 2004 in the aftermath of the 9/11 WTC disaster (Perry, 2003). The NIMS requires all government agencies and jurisdictional organizations (e.g., firefighting, law enforcement, emergency medical service) to adopt the Incident Command System (ICS), a core protocol that guides organizational structure and operating processes in response to local emergencies to catastrophic disasters regardless of their type and size (FEMA, 2017).

The ICS has been advocated by policy makers and practitioners due to its standardization approach that provides common terminology, formal planning process, and unified resource typing and documentation (Anderson, Compton, & Mason, 2004). Nevertheless, concomitant concerns were also raised regarding its hierarchical and centralized authority, difficulty of establishing accurate information and intelligence, and lack of flexibility under rapidly changing environments during incidents (Buck, Trainor, & Aguirre, 2006; Jensen & Thompson, 2016; Tierney, Lindell, & Perry, 2001; Waugh Jr, 2009).

With increased scholarly attention to *resilience*, a system's ability to absorb, mitigate, and recover from disturbances (Boin, Comfort, & Demchak, 2010; Paton, Smith, & Violanti, 2000); disaster management policies such as the NIMS and the ICS have been assessed for their efficacy in supporting adaptive performance of emergency response organizations. For instance, Bigley and Roberts (2001) argued that the ICS, a primary component of the NIMS, supports emergency managers and responders to be adaptive in terms of organizational structure and transfer of authority and responsibility. Further, Harrald (2006), through a comprehensive document review of Hurricane Katrina response, claimed that both the principles of the NIMS and other factors not covered by the NIMS such as improvisation, creativity and adaptation were necessary to successfully cope with challenging situations during disasters.

While general understanding on the role of incident management policies (e.g., the ICS, the NIMS) has deepened in the literature, the applicability of these frameworks to the healthcare sector has been limited due to distinct characteristics of hospital operations in the face of disasters (Boin & McConnell, 2007; Bulson & Bulson, 2018). Hospitals and healthcare systems that receive any type of US Federal preparedness funding are required to operate in accordance with the NIMS (FEMA, 2006). In addition, as they receive injured or ill patients from public emergency services (e.g., search and rescue, emergency medical service), hospitals and their emergency departments (EDs) become an interface with public agencies governed by the NIMS principles (Farmer & Carlton, 2006). Despite the importance of regional hospitals as critical infrastructure for communities experiencing the hazards of a disaster, issues associated with the adoption of the ICS in the healthcare domain need resolution. For example, researchers argue that the ICS may not cover hospital-specific needs such as mass casualty management, patient evacuation, and the mental health of hospital staff (Jenkins, Kelen, Sauer, Fredericksen, & McCarthy, 2009). Other areas for further consideration in hospital incident management policy include protecting critical care capabilities, maintaining surge capacity, planning staff assignments, and hospital-specific incident command system and training programs (Lynn, Gurr, Memon, & Kaliff, 2006; Meyer et al., 2018; Rodríguez & Aguirre, 2006).

In order to better inform incident management policies that nurture resilient healthcare systems, it is crucial to understand the challenges and opportunities that exist with regard to resilient hospital incident management. However, such knowledge has been markedly limited to date. To address this gap, the present article aims to investigate resilient traits of a large regional hospital's recent response to a catastrophic disaster, Hurricane Harvey (2017). Our study employs two major safety perspectives: *Safety-I* or analysis of what went wrong to identify challenges, and *Safety*-II, the analysis of what went right to document opportunities for safety improvement (Hollnagel, 2014).

4.3. Background

Responses to large-scale wildfires that frequently occurred in California during the 1970s revealed many issues such as differences in organizing mechanism, communication protocols, and multi-agency coordination (Dague & Hirami, 2015). Addressing these recurring problems led to a cooperative program called Firefighting

Resources of California organized for Potential Emergencies (FIRESCOPE). One outcome of this was the Incident Command System (ICS) widely adopted in forest fire incidents since the early 1980s (Buck et al., 2006).

As a standardized guideline for on-scene incident command to all types of incidents and hazards, the ICS enables different response organizations to adopt a common organizational structure, to coordinate between multiple jurisdictions and agencies, and to follow organized processes for continuous incident action planning (Chang, 2017; Son et al., 2018). The incident management organization is generally established in the incident command post (ICP) or emergency operations center (EOC). ICS consists of five major sections: command; operations; planning; logistics; and finance and administration, as shown in Figure 4.1. The incident commanders work with command staff and general staff of each section to plan and manage emergency situations, including, of course, major hurricanes.

Hurricane Harvey officially made landfall in Texas on August 25, 2017, striking Aransas County as a Category 4 hurricane and travelled inland in a northwest direction before winds halted and pushed the storm southeast towards the Gulf. Harvey was a particularly slow-moving storm, in addition to its backtracking path which kept City of Houston inundated with rain for far longer than normally anticipated. While staggering over the Texas coast, Harvey dropped record-setting rainwater of more than 60 inches and caused unforeseen flooding, resulting in nearly 800,000 evacuees (Texas Commission on Environmental Quality, 2018). The estimated total cost incurred by Harvey was $125 billion, second only to Hurricane Katrina among costly natural disasters (National Hurricane Center, 2018). To examine the characteristics of a resilient hospital in a real-world disaster, Hurricane Harvey was selected due to its recency and accessibility to the authors of the present study.

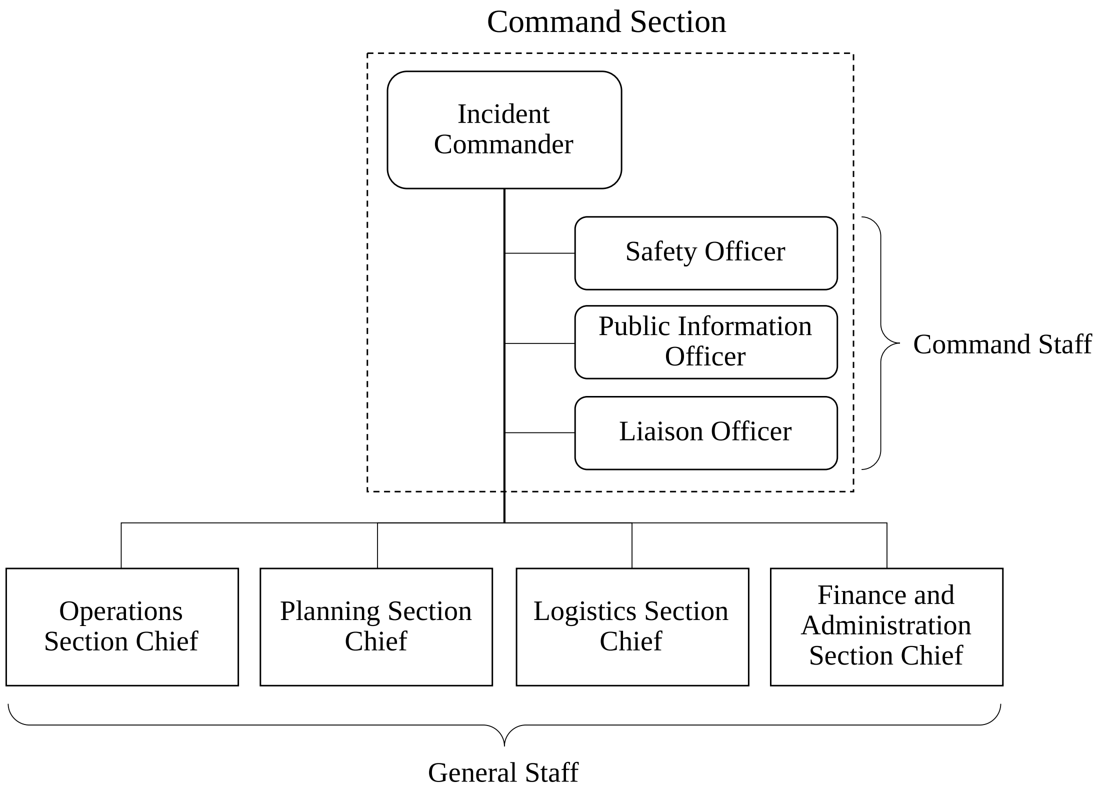

Figure 4.1 Core members of an incident management organization. Command and general staff include section chiefs, safety officer, public information officer, and liaison officer who provide assistance to the incident commander.

Given the current threat landscape, the importance of resilient hospital incident management is clear. As an emerging concept for increasingly complex social and technical systems, resilience has been defined, operationalized, and measured in various scientific disciplines (Hosseini, Barker, & Ramirez-Marquez, 2016). From a disaster risk management perspective, resilience is generally defined as an ability of a social and physical system to prepare for, respond to, and recover from the effects of a disaster incident in a timely and efficient manner (Alexander, 2013; United Nations International Strategy for Disaster Reduction, 2009).

As an abstract construct, an examination of resilience or resilient performance of systems often requires two safety viewpoints. *Safety-I*, a traditional and dominant view of safety, focuses on system failures and instances where things went wrong during an incident, and stresses corrective actions to fix such issues (Hollnagel, 2014). The application of the Safety-I approach hospital disaster response has been effective in revealing problems experienced by hospitals such as staff shortages, loss of utilities, insufficient supplies, and lack of regional communication (Downey, Andress, & Schultz, 2013; Klein, Rosenthal, & Klausner, 2005; Milsten, 2000). Recently, the safety paradigm has shifted towards *Safety-II* to highlight positive adaptations or workarounds in daily operations or instances of where things go right, in addition to what goes wrong (Hollnagel, 2014). Safety-II treats human operator flexibility as an indispensable attribute of a resilient system (Sujan, Huang, & Braithwaite, 2017). While the Safety-I framework is typically applied in the area of hospital disaster management, the Safety-II approach is not often used. In order to best inform effective hospital disaster planning, both approaches should be employed in order to produce a more holistic and balanced investigation.

4.4. Method

To elicit both challenges and successes experienced by hospital incident management in Hurricane Harvey, semi-structured interviews were conducted with personnel who were involved in the incident command center of a large regional hospital located in southeastern Texas.

A pool of potential participants who were involved in the hospital's incident response to Harvey was first identified by the hospital safety office. The potential participants were individually contacted by one of the authors via email to ask for their voluntary participation in a semi-structured interview focused on the hospital's response to the hurricane. Of the 20 potential participants initially contacted, eight responded and six agreed to participate in the study. After the first round of interviews, non-responsive candidates were contacted again; no additional participants were recruited. Participants had all received training in response management and their roles covered the entire command structure of the hospital - from the executives (e.g., vice presidents) who served as an incident commander, to the staff responsible for operations, health and safety, and facilities management (Table 4.1). The research protocol of the current study was approved by the hospital's institutional review board (IRB No.: Pro00018680).

Semi-structured interviews were conducted with the participants during the normal working day in the hospital in September 2018. One faculty member and one postdoctoral researcher at the hospital knowledgeable in the incident management domain and qualitative research methods served as the primary interviewers and were supported by one graduate student for note taking and audio-recording of interviews.

Table 4.1 Hospital IMT interviewees' position, experience, and certification

Participant No.	Position	Experience	Certification
P01	VP, Quality and Safety	25 years	ICS-300†
P02	VP, Operations	2 years	ICS-300
P03	Operations Admin, Health Supervisor	6 years	ICS-300
P04	Operations Admin, Safety Officer	27 years	ICS-300
P05	Supervisor, Compliance and Environment, Health, and Safety	1 year	None
P06	Manager, Environment, Health, and Safety	11 years	ICS-300

† ICS-300, Intermediate ICS for Expanding Incidents, is an advanced emergency management training program required for an incident of a mid to high level of complexity (FEMA, 2007).

The interviewers used a set of questions focused on the major aspects of disaster resilience (i.e., functions to overcome challenges and achieve organizational goals) as a guide for the interview. Table 4.2 represents the interview themes and associated questions asked in the interviews. Where applicable, new questions were introduced based on emerging topics as the interview progressed.

Table 4.2 Questions used in semi-structured interviews to hospital IMT personnel

Aspect	Related questions
Personal and organizational context	• What was your role in response to Harvey? • Can you describe the structure and composition of the response organization you worked for?
Challenges and successes during the incident	• What were the major challenges of Harvey that you had not expected or experienced from previous incidents? • How did you overcome such challenges?
Goals of IMTs	• What were the major goals that you tried to achieve during Harvey and how did you accomplish those goals?
Functions of IMTs	• How did you make sense of evolving situations during Harvey? • What key decisions did you make to solve problems in Harvey and how? • Can you tell us about procedures, plans, or guidelines you used in response to Harvey? • How did you utilize resources to perform response actions?

The interviews took approximately 40 minutes on average. After informed consent was obtained from participants, the interviewers first requested a brief overview of each respondent's professional career and specific roles that were assumed during Harvey. Interviewers then followed the semi-structured interview protocol. Not all questions were asked during all interviews. The audio-recordings of the interviews were transcribed by an external professional service.

To capture emerging topics regarding characteristics of resilient hospital incident management, a thematic analysis method was adopted (Braun & Clarke, 2006). The codebook used was derived from a larger project studying the regional response of government-led emergency operations centers in the southeast Texas region during Harvey (Son, Sasangohar, Peres, & Moon, 2019). Since hospitals are a subset of regional emergency operations, the codebook used in the present study was streamlined based on its relevance to the hospital context. The transcripts were coded in an iterative manner by two study authors, who were also responsible for reducing the codebook. After individual coding was completed, the coders discussed disagreements and revisited the coding results to clarify discrepancies. A kappa statistic was calculated using MAXQDA 2018 (VERBI Software, 2018) to evaluate concurrence between the coders on individual transcripts. The kappa value between the two coders was 0.623, indicating a moderate to significant level of agreement in coding of the transcripts. Finally, the coding of the first author was used to report the results in this article.

4.5. Results

The analysis yielded two sets of findings regarding resilient hospital incident management during Harvey. The first set consists of demanding situations and major events that occurred, and hospital goals under such conditions (Table 4.3). The second set of findings contains specific challenges (i.e., Safety-I) and opportunities (i.e., Safety-II) that existed in hospital incident management in relation to six aspects of disaster resilience (Table 4.4). In the interest of highlighting the context and consequences of incident command decisions during a major event, we selectively include some of the transcribed respondent comments.

Table 4.3 Situations faced and goals pursued by the hospital staff during Harvey

Noticeable events during Harvey	Goals of the hospital
• Massive rainfall and flooding • Severely limited access to hospital • Shutdown of local clinics for a longer period • Patient surge (e.g., dialysis) in the ED • Loss of electric power in some areas • Contamination of sterile supplies and patient samples • Inundation of the basement	• Patient health and safety • Stabilization of hospital operations • Maintaining hospital structural integrity

Table 4.4 Opportunities and challenges of the hospital response to Harvey

Aspect	Opportunities / Strengths	Challenges
Organizational structure and functions, and individual roles	• Establishing multiple incident command centers for respective accountability • Functional flexibility of turning into an outpatient-centered operation • A smooth role transition from normal duties to incident	• Excess endeavors to coordinate multiple incident command centers • Concentration of resources on specific areas of care (e.g., dialysis)

Table 4.4 Continued

Aspect	Opportunities / Strengths	Challenges
Communication and situational awareness	• Availability of various formal and informal communication channels. • Regular conference calls and briefings as a vehicle to transfer knowledge across shifts.	• Need for a hospital-wide notification system. • Lack of direct communication between medical facilities. • Incompatibility between different hospital information management systems.
Operating plans and protocols	• Skipping administrative operating procedures for urgent work requests • Accepting food donation from private and non-government organizations • Maintaining a critical patient reporting protocol	• Difficulty of following a formal planning process (e.g., the NIMS) • Overly specific requirements for reimbursement from federal funding
Human and physical resources (staff, space, and supplies)	• Sufficient staffing capacity • Flexible utilization of spatial resources for patient care and staff welfare • Mobilizing back-up supplies and equipment to sustain hospital operations	• Increased fatigue and anxiety of hospital staff • Issues with the ad hoc use of spatial resources (e.g. helipad, sleeping space) • Hazards from back-up equipment (e.g., emergency generator) and limitations in the stock of supplies (e.g., fuel)
Lessons learned from previous incidents	• Reflecting lessons into current preventative and protective measures • Regular inspections and drills for disaster preparedness	• Lack of a community-wide effort to incorporate lessons into the community infrastructure
Leadership and high-level decision making	• Walk-arounds and hands-on interaction with front-line staff to get more accurate operational needs and to make relevant decisions	• Delayed declaration of emergency within the hospital • Lack of incident command leadership amongst neighboring hospitals

4.5.1. Difficulties faced and goals pursued during Harvey

Harvey resulted in a massive rainfall and subsequent flooding in the affected areas. An unprecedented amount of rainfall and flooding created difficult situations both outside and inside the hospital. With respect to external factors, interviewees stated that the general public’s access to medical facilities (e.g., local and regional healthcare providers) was severely limited due to road closure, and that most local clinics (e.g., dialysis providers) were closed for an extended period of time even after Harvey dissipated. As a result, the study hospital experienced a patient surge including those who had to receive dialysis, especially in the emergency department (ED). Inside the hospital, some areas lost electric power and the sterile supplies department was contaminated due to ruptured pipes. In addition, the hospital's basement was inundated with rainwater.

Under these adverse situations, the hospital incident command staff pursued common goals. These included ensuring the health and safety of patients, stabilizing hospital operations, and maintaining the hospital's structural integrity. In particular, the interviewees were highly attuned to the possibility of water seepage as it might cause critical problems in the hospital's internal infrastructure (e.g., sanitation and power supply systems).

4.5.2. Opportunities for and challenges to the hospital during Harvey

Six aspects of resilient response to a large-scale disaster emerged: i) organizational structure and functions, and individual roles, ii) communication and situational awareness, iii) operating plans and protocols, iv) human and physical resources, v) lessons learned from incidents, and vi) leadership and high-level decision-making.

4.5.2.1. Organizational structure and functions, and individual roles

The hospital made adaptations in organizational structure and functions as in well as staff roles that contributed to its resilience. First, while public agencies and jurisdictions manage their response generally at one central emergency operations center, the study hospital established two incident command centers during Harvey for the first time; one for overall operations and the other for facility management. Across participants, there was ambivalence regarding the benefits and disadvantages of this approach. According to the respondents, this distributed model resulted in a more efficient response, but some participants cited problems with communication and coordination.

The respondents indicated that the hospital was flexible in turning its operational focus from inpatient care to outpatient service to accommodate the increased ambulatory patient flow. The emergency department initially provided continuous dialysis service, but as the hurricane progressed, the dialysis patients had to be referred to other facilities in order to maintain the hospital's patient care resource balance.

Another resilience trait was hospital staff's perception that their role did not change during the disaster. However, the interviewees offered some examples of role adjustment such as executive personnel on call assuming the incident commander role, and a public relations staff who served as a public information officer.

> *"[The incident commander] was able to have the people do the things that they normally do. We didn't have to take a job that we were not comfortable with."*
>
> *"I didn't feel any difference from other normal days, truthfully."*

4.5.2.2. Communication and situational awareness

Study respondents emphasized the importance of timely and accurate communication and situational awareness within the hospital as well as between healthcare organizations and government agencies. Factors that contributed to effective and efficient information management included the availability of various means of communication and regular conference calls and briefings for knowledge transfer within the hospital.

Varied communication channels (e.g., direct phone call, in-person conversation, text messages, email) were used to understand what was occurring within the facility and issues needing resolution. However, a respondent pointed to a major need for a mass notification system capable of communicating incident information and alerts through multiple channels for timely, unified situational awareness.

Additionally, there were multiple shifts involving various disciplines in the hospital's main incident command center, interviewees viewed regular conference calls and briefings as a primary vehicle to transfer situational knowledge throughout the event. In order to accommodate this, the hospital incident command center held campus-wide conference calls to integrate and disseminate updated information regarding response needs and operating status.

> *"I think the common operating picture was pretty well-formed because we had multiple opportunities. For instance, [our hospital] had every day at 11:10 a.m. a daily briefing with all the leads around the hospital, both our patient care leads and our ancillary leads, and we talked about all the needs in the house."*

While communication inside the hospital was active during the disaster, there were insufficient interactions between the hospital incident command center and the jurisdictional (e.g., municipal) emergency operations center. In particular, when the hospital needed to understand the operational status and capacity (e.g., bed availability) of other hospitals, such communication was mediated by the jurisdictional emergency operations center, which hindered hospital-to-hospital interaction.

> *"If our incident commander or one of us had an issue, we would have called it into the central EOC. If a patient was going to be needed to be transferred, transfers were handled through [the jurisdiction's] central command."*

As part of jurisdictional emergency operations in a large-scale event, hospitals are required to use a government-based platform (e.g., *WebEOC*). Notwithstanding its intent to centralize incident information, the government-centered program was not compatible with hospital-based information systems. For instance, the hospital was using hospital-based emergency information systems such as *EMResource* and *EMTrack* to monitor hospital status and to track patients across medical facilities. An interviewee, however, indicated that these systems were not compatible or harmonized with the government-adopted system. In addition to the government-hospital information system interface problem, a similar incompatibility issue regarding the interface between the hospital emergency information systems and an electronic health record (EMR) system commonly used for everyday clinical operations.

> *"If I'm in WebEOC, I literally have to leave WebEOC go to EMResource to see what the status is. There is no page on WebEOC where I can look and say what is the status. […] The interface between those two databases, in my humble opinion, is not as robust as it could be in this type of event."*

> *"There is no easy interface between Epic (an EHR application) and EMTrack, or whatever patient tracking. So what that leads to is either redundancy or delay."*

4.5.2.3. Operating plans and protocols

Although the hospital adopted formal incident management guidelines such as NIMS, some interviewees claimed that they did not follow the planning process and forms specified in the NIMS. Rather, their response to emerging needs were carried out pragmatically and in an informal and opportunistic manner to find and fix emerging problems. Importantly, one respondent stated that documentation requirements for federal fund reimbursement were too difficult to adapt.

> *"There was an informal type of a planning session. They did not follow the formal process. They were supposed to have the [designated form] as far as planning for the next operational cycle but we did not use that form down here."*
>
> *"I don't think there was an exact, specific book that was being followed 100 percent, to be honest. We were just making a general assessment and really figuring out what we're able to do and where we might have deficits in supplies, food, and all those things."*
>
> *"I was very shocked to see the specific need for FEMA funding for damage. We found out that it was kind of a headache post-recovery. There was a lot of very specific documentation or specific things within the documentation that the federal government wanted that we couldn't necessarily provide."*

Several instances were mentioned where hospital staff found that departure from required operating procedures were advantageous. In dealing with work requests, for example, interviewees said they often skipped the *P-C-R (Problem-Cause-Resolution)* procedure, a formal trouble-shooting system for hospital day-to-day operations. Similarly, the hospital accepted food donations from external private and non-governmental organizations, which they were not normally allowed to do.

"There was a P-C-R procedure of the work ticket. […] And staff should be filling that out as part of the work order ticket closure process. We didn't do any of that. We didn't have the staff to sit down and type this stuff out."

"There were a lot of restaurants that started donating to us, and then we gave away free. [A fast food franchise] came over and gave us 2,000 sandwiches one day, and we went and handed those out, but we don't normally do that."

In contrast to deviating from operating procedures, continued compliance was sustained with mandatory protocols despite a deferral declaration. For example, the Centers for Medicare and Medicaid Services (CMS) granted the impacted region a moratorium on the federally mandated reporting of infections and other adverse events. Nonetheless, the hospital elected to report all events to the CMS, demonstrating an ability to maintain normal operations and compliance under pressure.

4.5.2.4. Human and physical resources

The interviews captured adaptive use of hospital resources: *staff*, *space*, and *supplies* (three S's). First, the hospital maintained a sufficient staff pool before and during Harvey. To do so, the hospital called in staff, who were originally responsible for post-incident recovery efforts, for assist in immediate response activities. In addition, staff worked a double shift for high-demand areas such as dialysis care. Also, there was additional support from non-clinical personnel and staff who worked beyond their job specifications.

"We had a stable labor pool. In fact, the labor pool was so packed at one point that they were about to send people away, but then we said, 'No, no' because the need is going to happen later."

"There was a very generous staffing pool of people that were not in clinical side that I think helped relieve some of the stress. And there were some of the other duties that were utilized from other areas."

"We were always thinking about next 24 to 48 hours. Where are we going to get staff? How are you going to give some people some rest? In cases where we had some departments that were really critically short or in critical mood issues, where could we get them some relief?"

Second, the hospital was flexible in utilizing physical space. A temporary clinic was organized to deal with excess influx of patients. A sterile supplies room was created ad hoc, since the original location was contaminated by ruptured pipes. For sleeping arrangements, hospital staff used waiting areas and unlocked offices to accommodate increased staff volume. Commenting on sleeping arrangements for future disaster responses, an interviewee highlighted a need to pre-designate locations for rest and sleep. In addition, interviewees noted that some helicopter pilots were using a decommissioned helicopter pad instead of a newly-built yet remote landing space for faster patient transport in spite of associated risks.

A third type of resource adaptation concerned the use of supplies and equipment. For instance, the hospital experienced a loss of power in one of its buildings that housed patient sampling laboratories. To sustain the laboratories and thus preserve the patient samples, the hospital mobilized emergency diesel generators. However, issues arose such as generator exhaust emissions and an insufficient supply of diesel fuel. With the exception of power loss in some areas, one respondent stressed the strength of the hospital's cross-connected utility infrastructure (e.g., water, electricity) which prepared the system for major disruptions.

> *"We had generators stand by and fuel for 96 hours. But with the city being the mess, we would have lost power if there has been a delay before we got fuel"*
>
> *"We're set up to adapt. Every building has the ability to power another building and to send water to another building. And it's a matter of just going out there and hooking it up. I don't think we ever had to rig anything."*

4.5.2.5. Lessons learned from previous incidents

The interviewees highlighted the benefit of applying experience gained from previous incidents regarding preventative and protective measures for hospital incident management systems. One successful adaptation was the prior installation of flood gates. Based lessons learned from Tropical Storm Allison in 2001 (that inundated multiple large medical centers in the impacted region), the hospital had installed flood gates sealing off entryways from flood water. Critical emergency equipment (e.g., generators) was also moved from the basement. Furthermore, interviewees emphasized regular inspections and drills aimed at verifying readiness (e.g., fuel stock, flood gate) for potential flood risks.

> *"I was very happy to see the flood gates basically pay for themselves after they were installed after Tropical Storm Allison. Getting the flood doors closed and maintaining them went really smoothly. […] We train on doors at [the hospital] at least every year. We make sure that the equipment is up and running."*

While the hospital had benefitted from past disaster experience, the respondents raised the need for a broader community-wide effort to apply lessons learned about community infrastructure beyond individual hospitals. They were especially concerned about managing elevated demands for patient care during a large-scale incident.

4.5.2.6. Leadership and high-level decision making

While participants acknowledged that the response and recovery were a collective task, hospital leadership was seen as having played a paramount role in coping with difficulties. It is noteworthy that hospital incident command center leaders were focused on staying in close interaction with public emergency responders. Such actions were helpful in assessing current needs, allocating resources in a pragmatic fashion and in facilitating situational awareness.

Nevertheless, our study also identified decision-making challenges for hospital leadership during Harvey. First, the incident commanders' delayed activation of the hospital's emergency operations plan prevented a portion of "ride-out staff", who were responsible for immediate response, from returning to the hospital as hurricane conditions intensified. Second, interviewees opined that collaborative incident leadership among neighboring hospitals was lacking, which might be necessary for sharing required resources and maintaining close communication among them.

> *"A window was extremely small for people to do that (activate the emergency plan) and I think it caught people off guard. The only major vulnerability I could see from [the hospital] was that we didn't have a clear process for the release of staff before landfall."*

> *"[An adjacent medical center] was calling a whole lot because they were trying to get some supplies or some activities in but it wasn't successful. […] We went through a number of meetings during and after actions to talk about some of the challenges. […] But formal processes for communication can be a challenge."*

4.6. Discussion

4.6.1. Safety-I and Safety-II evaluation of a hospital incident management

The findings of the current study highlight the importance of using both safety viewpoints (Safety I and II) in evaluating hospital operations during a large-scale incident. From a Safety-I perspective, our study identified some recurrent issues experienced by hospitals during disasters. For example, excess volume of dialysis patients, loss of electric power, and staff shortages, have been repeatedly cited (Downey et al., 2013; Klein et al., 2005; Kopp et al., 2007; Murakami, Siktel, Lucido, Winchester, & Harbord, 2015). The response to such challenges, however, appeared to be unduly reactive. The subject hospital and its local counterparts appeared to lack a sufficiently proactive and coordinative posture, as argued in the literature (Farmer & Carlton, 2006; Timmins, Bone, & Hiller, 2014).

Our findings also suggest a need to address interoperability between advanced emergency and healthcare information technologies. In particular, incompatibility between multiple emergency information systems (e.g., *WebEOC*, *EMTrack*) deserves further investigation due to its importance in cross-sectional communication and collaboration during disasters. Additional attention is also warranted to address the interface between the EHR applications and the emergency information systems given the increased EHR adoption and its recognized advantages (Abir, Mostashari, Atwal, & Lurie, 2012).

This study also showed that Safety-II approach could shed light on the resilience of hospital incident management teams. In terms of organizational structure, the study hospital stood up two incident command centers to handle matters specific to facilities, a critical component of the hospital operations. Although decentralized decision making process enabled the facility's command center to quickly address rising needs, the discontinuity in incident command created an additional communications hurdle. This finding is consistent with research findings that adaptations of a normal practice entail a trade-off between multiple goals across different levels of an organization (Hollnagel, 2009; Woods & Branlat, 2011) as well as findings regarding resilience in the use of operating procedures (Furniss, Back, Blandford, Hildebrandt, & Broberg, 2011; Wachs & Saurin, 2018).

The hospital exhibited adaptive behavior by deviating from a formal work order procedure to quickly address urgent issues. However, the hospital continued to abide by its CMS reporting policy although it was exempted, showing robustness in implementing required protocols.

Consistent with previous studies (Autrey & Moss, 2006; Son, Sasangohar, Neville, Peres, & Moon, 2020; Wolbers & Boersma, 2013), our research found that maintaining collective situational awareness was an essential element of a resilient system that understands and rapidly responds to changing needs during disturbances. In particular, frequent rounding of the facilities incident commanders to increase situational awareness and to boost staff morale is recommended as a practice for hospital leadership. The study also confirmed a need for a hospital-wide notification system operating in real time to create unified internal awareness of conditions in addition to external situation awareness.

The adaptive use of hospital resources in terms of three S’s (i.e., staff, space, and supplies) observed in our study is consistent with the characteristics of a resilient healthcare organization documented in the literature (Hick, Hanfling, & Cantrill, 2012; Son, Sasangohar, Rao, Larsen, & Neville, 2019). Since adaptive or improvisational behaviors (e.g., staff sleeping in unlocked offices) during an adverse event may not reoccur and may lead to undesirable outcomes (Hollnagel, 2008), best practices need to be institutionalized into formal operating procedures to increase benefits and reduce associated risks.

Finally, it is important to note that, by and large, lessons from previous flooding events were helpful in improving the level of disaster preparedness in the study hospital. However, our research provides presumptive evidence for the need to increase community-wide disaster planning efforts (Burkle et al., 2007). It is particularly important that professionals across healthcare systems and jurisdictional emergency services work in tandem to effectively deal with chronically vulnerable populations (e.g., dialysis patients) and emerging public health threats (e.g., pandemic disease) from disasters.

4.6.2. Implications for disaster management policies

Integrating findings from the two safety perspectives, we propose two areas of incident management policy warranting attention. First, we found that the ICS incident action planning process was not adequately implemented by hospital incident operations. Reasons for this may include the hospital’s internal planning and communication processes (e.g., reliance on a pre-scheduled morning conference call) that serves the purpose of understanding ongoing situations and deciding what actions to take. Hospitals should consider how the ICS can be incorporated into their existing planning policies and practices under disaster conditions.

Second, the utilization of government incident management organizations for inter-hospital communication should be assessed by individual communities. In the present case, communication among multiple hospital incident command centers was mediated by the jurisdiction's Emergency Operations Center, hindering direct coordination and collaboration between hospitals. Given the relatively hierarchical and vertical nature of NIMS (Jensen & Thompson, 2016), and the relatively more collaborative hospital environment (Christian, Kollek, & Schwartz, 2005), developing ways to promote horizontal communication among healthcare organizations during a disaster should be sought.

4.6.3. Limitations of the current study

Our study examined the response to Harvey almost a year after the hurricane struck, which may have contributed to recall bias. In addition, the responses were self-reported narratives of staff who worked in a single hospital throughout the event. Research is warranted to compare resilient response among multiple hospitals and healthcare systems to understand patterns, variabilities, and context-specific strategies. Another study limitation was the small number of respondents (n=6). However, it should be noted that most common government and healthcare emergency operations centers are small (fewer than 10 people). We included in the sample, personnel from almost every level of the study hospital's incident command. To address these limitations, future research might employ complementary methods such as direct observation or the video-recording of response management processes following a major disaster.

4.7. Summary

This article incorporates two resilience viewpoints (i.e., Safety-I and Safety-II) in assessing hospital incident management during a large-scale disaster. Based on healthcare emergency professionals' experience during Hurricane Harvey, the case study attempted to identify what "went right" and what "went wrong" in hospital incident management from six perspectives: organizational structure and individual roles; communication and situational awareness; operating plans and protocols; hospital resources; lessons learned; and leadership and high-level decision making. The study confirmed that chronic challenges to hospital disaster planning and management should be addressed with both a hospital and an incident management policy perspective. The opportunities and practice improvements identified in our case study require further exploration for their incorporation into hospital disaster preparedness programs in order to make hospitals and healthcare systems more resilient in large-scale disaster events.

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CHAPTER 5 ARTICLE #4

MODELING AN INCIDENT MANAGEMENT TEAM AS A JOINT COGNITIVE SYSTEM[4]

5.1. Overview

Resilience is considered an essential capability of an Incident Management Team (IMT) in planning for and responding to disasters and catastrophes. While IMTs have been studied as a decision-making unit, few attempts were made to view them from a Joint Cognitive System (JCS) perspective that highlights the interplay among humans and technical agents and demands imposed by the incident. To that end, this article presents a JCS model of the IMT grounded in findings from the existing literature and naturalistic observations of simulated IMT's incident action planning, which functions in a cyclic manner across multiple scales. Using this model, three measures for resilience of the IMT, recovery time, resource status, and interactions, are discussed. To effectively represent the resilient performance incorporating these measures, Interactive Episode Analysis is developed. By providing a few examples of the analysis method, this study provides proof-of-concept for objective assessment of the resilience characteristics of the IMT. The proposed JCS-based IMT model can be used for descriptive modeling of

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similar systems to investigate resilient performance during a disaster in coping with time and resource constraints and complexity in human and technical interactions.

5.2. Introduction

Disasters have persistently challenged societal capabilities of managing risks from technical, natural or civil threats (Jain, Pasman, Waldram, Rogers, & Mannan, 2017; Mendonça, 2007). This challenge has been repeatedly observed through extreme loss events, for example, Hurricane Harvey (Harris County Fire Marshal's Office, 2017), Great East Japan earthquake and tsunami in 2011 (Yu et al., 2017), Macondo well explosion (Birkland & DeYoung, 2011; Skogdalen, Khorsandi, & Vinnem, 2012; Sylves & Comfort, 2012), Hurricane Katrina (Comfort, Birkland, Cigler, & Nance, 2010; Cruz & Krausmann, 2009; Wise, 2006), and 9/11 World Trade Center attack (Comfort, 2002a, 2002b). In order to address this persistent challenge, the US Department of Homeland Security has launched the National Incident Management System (NIMS) in 2004, to provide a standardized and integrated incident management template for all hazards and for all levels/types of organizations (Anderson, Compton, & Mason, 2004; FEMA, 2004).

Prior to NIMS, the Incident Command System (ICS), based on the provision of fire services, was the predominate system used for cross-jurisdictional operations (Perry, 2003). While ICS worked well for organizations with similar functionalities, its efficacy for inter-organizational coordination and collaboration was limited. Moreover, its functioning has been shown to hinder under unplanned conditions (Bigley & Roberts, 2001). To rectify these issues, NIMS was developed to incorporate a comprehensive, interoperable and adaptable incident management framework. In addition, NIMS was designed to manage high-consequence events that necessarily involve multiple agencies, jurisdictions, organizations, and disciplines. Such events can span from local emergencies and planned events (such as sports) to larger natural and man-made disasters. Moreover, a life cycle of incident management in NIMS includes all the mission phases such as prevention, protection, mitigation, response and recovery (Keybl, Fandozzi, Graves, Taylor, & Yost, 2012).

NIMS is characterized by joint operations among multiple actors who are temporally and spatially distributed across different organizational levels. A core component of NIMS is the Incident Command Post (ICP), a temporary on-site facility in which an Incident Management Team (IMT), formed ad hoc of multiple operators with different expertise, supervises and supports tactical operations (Vidal & Roberts, 2014). Organizationally, an IMT is positioned between Emergency Operations Center (EOC) that coordinates support among multiple ICPs and field responders.

While NIMS was devised to improve coordination and collaboration among different organizations, its fundamental structure followed that of the ICS. An IMT in the ICS structure typically consists of five functional sections: Command, Operations, Planning, Logistics and Finance & Administration (refer to Chapter 1 for more details of organizational structure and major functions of the IMT).

Previous research has examined the limitations of such centralized, hierarchical ICS structure. Buck, Trainor, and Aguirre (2006) claimed that the ICS functions well for like organizations having clear goals but suffers when these goals are ill-defined and conflicted due to multiple hazards and among heterogeneous organizations in large-scale disasters. Similarly, Lutz and Lindell (2008) pointed out the weakness of the ICS for non-fire incidents which require more functions (e.g., evacuation, mass care) than simply controlling hazard sources (e.g., fire). In recognition of these limitations, Bigley and Roberts (2001) stressed the ICS's flexibility and proposed three factors that enhance such flexibility: structuring mechanism, constrained improvisation, and cognition management. Structuring mechanism indicates how rapidly an incident management organization changes its structure. This is facilitated by structure elaboration, a prompt construction or alteration of the organizational structure as incident evolves. This structure-elaborating process is also facilitated by authority transfer and role switching. Constrained improvisation is denoted as developing and applying creative tactical activities to local, unexpected situations in order to achieve given tasks from higher authority. Finally, cognition management of ICS requires a cognitive structure that helps establish 'common operational representation' as the two preceding factors largely rely on this. The cognition points to both what happens within the organization and in its environment. While individual emergency responders' cognitive processes have been emphasized and investigated (Comfort, 2007), investigating incident command teams from the perspective of a Joint Cognitive System (JCS) remains as a general gap.

A JCS is a system in which human practitioners (e.g., incident managers and operators) work with technological tools and modify what the system does to maintain control (Hollnagel & Woods, 2005). Resilience is a unique property of a JCS (Woods &

Hollnagel, 2006) and as implied above, the need for resilience in incident/emergency management is evident (Comfort, Boin, & Demchak, 2010; Harrald, 2006). To that end, this study aims to model an IMT as a JCS using theoretical grounds and to propose potential measures for resilient performance with some examples as a proof of concept. In what follows, we describe theories of JCS, Resilience Engineering and JCS modeling, present methods used for the modeling and understanding of resilient behaviors of the IMT and propose three metrics for resilience of the IMT.

5.2.1. Joint cognitive systems

JCS theory emphasizes 'co-agency' or 'ensemble' of a human and a machine and seeks to define a boundary that surrounds the co-agency (Hollnagel & Woods, 2005). Using the JCS framework the Cognitive Systems Engineering (CSE) research has focused on helping practitioners' problem-solving in complex real-world systems (Woods & Roth, 1988) by taking into consideration three inter-relational components termed 'JCS triad': (i) cognitive agents (e.g., human and machine), (ii) demands from the world on cognitive work, and (iii) artifacts that represent or manipulate the world (Hollnagel & Woods, 2005; Roth, Patterson, & Mumaw, 2002; Woods, 2003). Observations of coping with complex works in natural settings have revealed that the interplay among this JCS triad has led to adaptations to changes and anomalies in the world (Sanderson, 2017; Woods, 2003). In this vein, Hollnagel and Woods (2005, p. 22) define a JCS as "a system that can *modify* its behavior on the basis of experience so as to achieve specific anti-entropic ends". Furthermore, Woods and Hollnagel (2006) propose three relational properties of a JCS: affordance (fit among the triad), coordination (joint functioning over distributed, multiple agents and artifacts) and *resilience* (dealing with challenges and changes that go beyond designed competence).

Among the three properties, resilience is emphasized since it is a whole-of-system's ability to meet the work demands based on affordance that the artifacts possess and coordination among the cognitive agents (Woods & Hollnagel, 2006). As the work demands in modern systems become more complex and thus require adaptation, the CSE's focus on resilience has given rise to an area of research called Resilience Engineering (Woods, 2017).

5.2.2. Resilience engineering

Due to variability of a system's internal sources or external environment, it is inevitable and necessary for the systems to be resilient in order to cope with complexity of the real world (Hollnagel, Woods, & Leveson, 2006). In that sense, resilience is defined as "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances…" (Hollnagel, 2011, p. xxxvi). Resilience is difficult to measure as it is a tacit property of the system (Mendonça, 2008). As such, factors that contribute to resilience are often measured. Such measures include buffering capacity, flexibility (vs. stiffness), margin & tolerance, and cross-scale interactions (Woods, 2006). Buffering capacity indicates the degree to which a system can withstand impact without collapsing its fundamental structure. Flexibility refers to the system's ability to alter its structure to match work demands. Margin and tolerance are concerned with how the system is operating near its capacity boundary over which the system breaks down or gracefully degrades (Woods, 2015). Cross-scale interaction highlights reciprocal influence between sharp end and blunt end of the system; local adaptations affect managerial policies or strategies, and vice versa.

The factors of resilience are also explained by four abilities of a resilient system, namely: monitoring, anticipating, responding and learning – or *MARL'ing* (Hollnagel, 2011). Monitoring consists of making sense of what is happening in the environment as well as in the system itself. Anticipating represents forecasting what challenges and opportunities to emerge. Responding indicates knowing what actions to take and how to execute such actions. Finally, learning refers to gaining lessons both from failures and successes. The ability to learn lessons from what went wrong as well as what went right characterizes 'Safety-II' approach that views failure and success as two different outcomes of the same adaptive process (Hollnagel, 2014).

Resilience Engineering research has investigated the aforementioned factors and abilities in safety critical domains such as oil and gas industry (Aguilera, Fonseca, Ferris, Vidal, & de Carvalho, 2016; Azadeh, Salehi, Ashjari, & Saberi, 2014; Dinh, Pasman, Gao, & Mannan, 2012; Jain, Pasman, Waldram, Pistikopoulos, & Mannan, 2017; Shirali, Motamedzade, Mohammadfam, Ebrahimipour, & Moghimbeigi, 2012), nuclear power generation (de Carvalho, dos Santos, Gomes, & Borges, 2008; Gomes, Borges, Huber, & de Carvalho, 2014; Vidal, Carvalho, Santos, & dos Santos, 2009), and maritime (Tveiten, Albrechtsen, Waero, & Wahl, 2012). While few previous efforts have attempted to create a cognitive system model of nuclear power plant control (de

Carvalho et al., 2008; Vidal et al., 2009) and oil and gas (Aguilera et al., 2016), these studies addressed emergency management as a component of the system under investigation. To my knowledge, no model for the IMT as a JCS has been developed to date.

A main purposes of JCS modeling is to represent functional, not structural (e.g., Figure 5.1), relationships and adaptive processes between JCSs that seek to maintain its control (Hollnagel, 2002). With regard to measuring resilience, a number of measurement methods have hitherto been developed (Hosseini, Barker, & Ramirez-Marquez, 2016). However, none of them rendered quantitative measurement that can be applied to a JCS. To that end, this study offers a JCS model of an IMT and to present three metrics for resilient performance based on the JCS model of the IMT.

5.2.3. Modeling a joint cognitive system

Two cyclic models for a JCS were proposed by Hollnagel and Woods (2005). By accounting for the context in which cognition takes place, the two models describe how a system dynamically adapts its functions to maintain control. First model, the Contextual Control Model (COCOM), explains the adaptive process connecting actions, events and constructs of a single entity (e.g., individual, organization). COCOM represents a control loop in which a current understanding of the situation, evaluating encountered events, and choosing actions to deal with those events take place in a cyclic manner. If such understanding is informed by the currently occurring event and previous understanding, the system behavior is reactive based on feedback. If the actions are selected by the current understanding and expected consequence, it becomes proactive based on feedforward. Second model, the Extended Control Model (ECOM), expands this basic cyclic model to multiple layers allowing for interactions across different levels. For example, goals and targets of a higher layer become action plans for a lower layer, and then these action plans guide specific courses of action for its subordinate layer. In ECOM, therefore, the higher layers orient towards targeting and monitoring based on feedforward and the lower layers lean towards regulating and tracking based on feedback.

An IMT's structure makes it a suitable platform for incorporating these models and studying measures for resilience. The IMT operations occur in a cyclic manner called an 'incident action planning process' (FEMA, 2017). In addition, this cyclic planning process occurs across different layers of the IMT. For example, field responders generally implement the plan to respond to an individual adverse event while a higher-level organization such as the Command Section establishes or modifies the plan based on the actions taken by the field responders. Finally, the performance of the IMT is largely situation- and context-dependent. That is, the IMT is highly likely to adjust its operations even with the identical structure and composition as it encounters different situations. For instance, the Operations Section focuses on putting out fire in wildfire; the same section, however, may perform search and rescue activities in earthquake disasters.

In order to create a JCS model for the IMT and to identify resilient performance of the IMT, naturalistic observations were conducted in a representative IMT simulation as detailed below. When necessary, several relevant government documents (e.g., NIMS, Comprehensive Planning Guide) were consulted to inform the modeling approach.

5.3. Material and methods

A naturalistic observational study was conducted in high-fidelity emergency response simulation provided by the Emergency Operations Training Center (EOTC), managed by Texas A&M Engineering Extension Service (TEEX). The EOTC training programs impose realistic work demands on participants allowing for observations of resilient performance in the context of a naturalistic emergency response. A typical training course invites 40 to 45 trainees under the supervision of about 20 highly skilled instructors in a simulated Incident Command Post (ICP). Two training courses conducted through 2017 were selected for data collection.

5.3.1. Participants

Participants in this study were recruited on the first day of a scheduled training course in the EOTC. A majority of participants had moderate to high level of emergency operations experience since the prerequisite for this training includes the basic to intermediate level ICS certificates such as ICS 100, ICS 200, IS 700 and IS 800. For the first observation, 39 out of 44 trainees consented, and 32 out of 46 consented to participate in the second observation. Participants also included the instructors who were present throughout the training. Participants were diverse in terms of their discipline (e.g., firefighting, law enforcement, emergency medical) and their geographical location (e.g., different States and municipalities). The research protocol received approval from the Institutional Review Board (No.: IRB2016-0489D).

5.3.2. Equipment, facility and scenarios

The training facility is equipped with laptop and desktop computers, telephones, printers, photocopiers, white boards, large displays, microphones and two meeting rooms. Overall, four incident scenarios were given during each training course: three half-day sessions and one full-day session. Three half-day scenarios were identical for both observed courses, namely, a mass shooting, hurricane and aircraft crash into a populated area. The full-day scenario differed (the first observational study: earthquake, the second observation study: civil disturbance). In order to make these exercises more immersive, experienced and skilled role-players provided 'injects' which indicate pieces of virtual incident information fed into the IMT (e.g., fire containment status, number of casualties, request for perimeter setup, a report from field observation, and a call from the mayor). Scripts for injects were prepared in advance but they were often adapted to match with situations as they evolved.

5.3.3. Data collection

To collect multifaceted data, various tools including a mobile application and video/voice recorders were used to record behaviors of participants and interactions among participants and technical artifacts. The primary source of data was direct observation. Four to six observers were present in the exercises. To supplement the direct observation, and investigate internal communications, observers used a mobile application named ‘Dynamic Event Logging and Time Analysis (DELTA’) that allowed registration of events using codes from four categories: initiator of communications, receiver of communications, technologies used for communication, and content of communication. The coders used discussion of pilot data for consensus coding.

5.3.4. Data analysis

Data entered in DELTA and audio/video recordings were shared among the research team for further discussion and analysis. Several rounds of meetings were conducted subsequently to exchange each other’s findings and elicit themes relevant to the JCS modeling and resilience of the IMT. Through these meetings, the research team attempted to identify:

- How the overall incident action planning process is managed within the IMT.
- How the IMT is structured and how constituent sub-teams and individuals work with others as well as different technologies.
- What types of information are collected, communicated and disseminated.
- What challenges emerged and what resilient behaviors were conducted by the IMT and its personnel to overcome such challenges.

5.4. Results

Based on the collected data and subsequent analysis, co-agency of human actors and technical tools and their respective boundaries was analyzed and a summary of the IMT's incident action planning processes was documented. Using such co-agency and cyclic incident planning processes, a JCS model for the IMT incorporating multiple layers of JCS's is proposed.

5.4.1. Co-agency and boundaries in IMT

Among the JCS triad, basic human/technological agents and boundaries of an IMT were examined as the first step because this provided an understanding of the multilayered nature of a JCS. The observed IMT was indeed comprised of the abovementioned five core sections (Command, Operations, Planning, Logistics, Finance & Administration) and each section had several task-specific units. For example, the observed ICP had a Situation Unit and a Documentation Unit in the Planning Section. In addition, tasks assigned to each unit were accomplished by single or multiple operators. Each entity interacted with tools at different levels such as personal computer (at operator level), radio (at branch level), white board (at section level) and large displays (at team level). For instance, the Deputy Planning Section Chief mainly used a white board for maintaining up-to-date incident information but often received paper forms from other members as well as watched other members' computer to exchange information and to communicate with them. Similarly, Information/Intelligence (I/I) Unit member mostly used paper forms to document new pieces of information but he/she also used other sources of information such as telephone calls from the field and other sections' white board. The interactions among co-agency and its pertinent boundary are depicted in Figure 5.1.

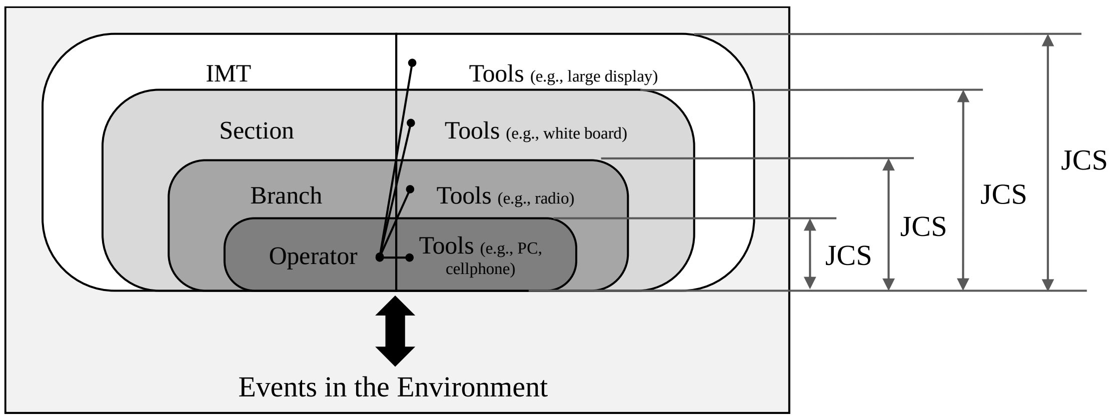

Figure 5.1 Multilayered JCS's of IMT. This figure shows co-agency of an entity at different levels and its corresponding tools.

5.4.2. IMT action planning processes

Incident action planning is a crucial process of an IMT that facilitates incident management. From the JCS triad standpoint, this is a process during which human and technical agents cope with demands from the world through continuous adaptation. A formal incident action planning cycle was comprised of the following steps and reoccurred in each operational period, either in part or in full. An operational period indicated a unit time during which one IMT assumed the incident command. This incident planning cycle was observed in the exercises and summarized as 1) initial response and situation assessment, 2) developing incident objectives, 3) planning strategies and tactics, and 4) executing plans and re-assessment of situation. A respective description for each step is provided as follows:

1) Initial response and situation assessment: When an incident occurs, field responders arrive at the scene and perform an initial response and assessment of the event. Based on this initial assessment, an incident commander (e.g., fire marshal, police chief) determines whether more resources should be deployed and a larger incident management organization such as an IMT should be established. After the IMT is established, an incident briefing is provided to the initial incident commander or unified command (IC/UC) formed of multiple incident commanders.

2) Developing incident objectives: After the IC/UC assumes the overall incident command, they start by deciding priorities and objectives for the initial operational period given constraints and concerns identified in the initial situation assessment. As the incident evolves with new threats and demands, the incident objectives are reviewed and modified for ensuing operational periods.

3) Planning strategies and tactics: Once the incident objectives are established or revised, pertinent strategies and tactics are developed to attain the objectives via meetings with Command/General Staff and other key members (e.g., Resource Specialist). As a result, an Incident Action Plan (IAP) for the next operational period is generated and agreed upon. An IAP typically consists of several key documents that specify the incident objectives, work assignment, and work protocols, for example, communication, safety, transportation and scheduled meetings.

4) Executing plans and re-assessment of situation: When the next operational period begins with a new set of emergency supervisors and responders, they are presented with the IAP during the incident briefing. With this briefing, they apprehend what their incident objectives are, what is current situation assessment and what specific tasks they are assigned to perform. Based on the results of these actions, the situation is re-assessed and reflected on new or modified incident objectives. This cyclic incident action planning process continues until the incident is controlled and the situation reaches a 'new normal state'.

The naturalistic observations revealed that the IMT sought to 'muddle through' difficulties that it faced representing characteristics of a resilient JCS. Participants formed different co-agencies by using or being supported by different technologies. Although information was originated from various sources (e.g., incident briefings, field observations, documents produced in other sections) and often flawed, the IMT strived to maintain the awareness of the evolving incident through coordination and collaboration across different levels of organizations. Based on this team cognition process, the IMT anticipated future states of the incident and developed both proactive and reactive measures that guided ensuing operations. These findings then informed the development of a JCS model in the following section.

5.4.3. Joint cognitive system modeling

5.4.3.1. JCS model of IMT

Grounded in the COCOM model consisting of *event*, *construct* and *action*, and the incident action planning process, a JCS model of the IMT was created (Figure 5.2). In this model, primary functions occur via interactions among the Operations, Planning and Command Sections. Firstly, 'uncontrolled or adverse incidents (*event*)' are typically responded to and perceived by the Operations Section, for example, fire suppression unit. Then, the Planning Section gathers the perceived situations and integrate incident data into useful and meaningful information/intelligence. Based on the integrated understanding (*construct*), key collective decisions including defining incident objectives and strategic and tactical plans are made. Then, the Command Section reviews and authorizes the plans with adequate resources (e.g., workforce, equipment and materials) so that the Operations Section implements the plans by taking actions to compensate the demands from the adverse events (*action*). The Logistics Section provides those resources to support other sections in carrying out assigned tasks. These resources include workforce, equipment, facility and materials. The Finance & Administration manages financial aspects of the incident such as costs of resources (e.g., personnel time records, expenditure on supplies and supports) so it works closely with the Logistics Section. This cyclic incident response and planning process occurs until the overall incident is kept under control.

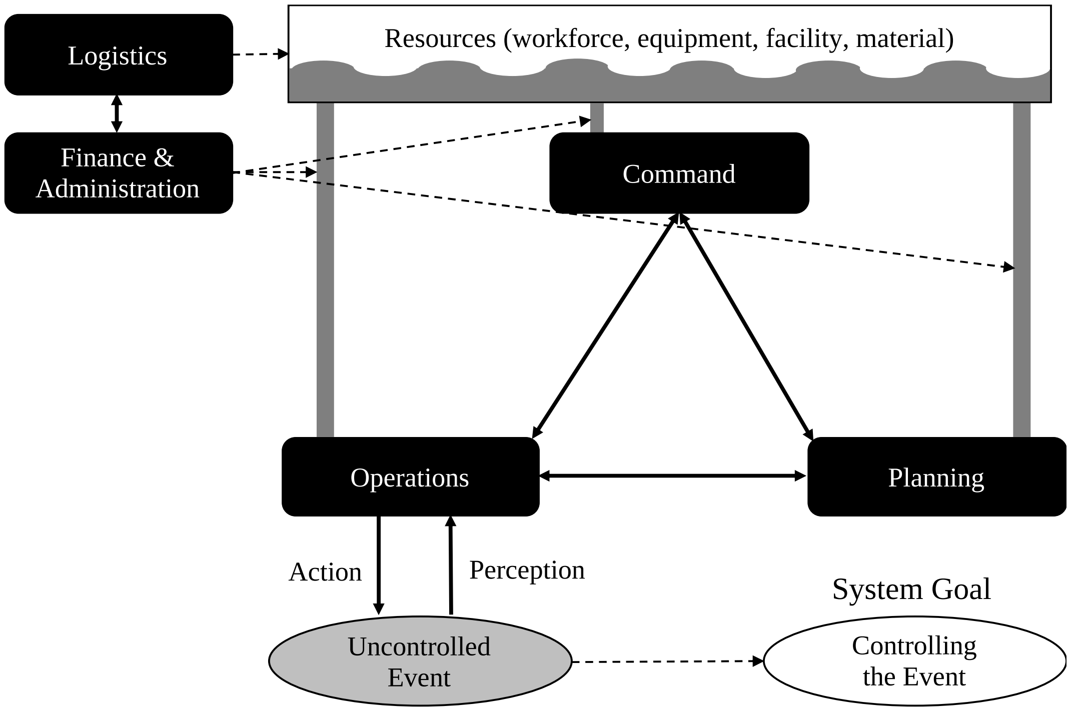

Figure 5.2 Joint cognitive system model of an IMT. This model illustrates a cyclic incident management process in which the IMT adjusts its functions through interactions among the five major sections.

5.4.3.2. Multilayered model of JCS

While Figure 5.2 illustrates a cyclic process that occurs at the section level, Figure 5.3 represents a multilayered model of the IMT that is situated across multiple levels based on ECOM. Four levels were incorporated in the multilayered IMT model: system, section, branch and unit/responder levels. At the systems level (e.g., IMT), the cyclic process results in incident objectives by anticipating future needs and opportunities. The incident objectives are specified as action plans at a section level. At branch and unit/responder levels, these action plans are implemented as tactical activities by mobilizing resources. In turn, the effects of resources mobilized inform tactical decisions on which specific resources are to be further allocated. These tactical decisions are fed into the performance status of each section. Finally, this status serves as a basis for incident action planning for future operations. In this cross-scale IMT model, anticipatory performance takes place at higher levels (e.g., system and section) and compensatory actions occur at lower levels (branch, unit and responder).

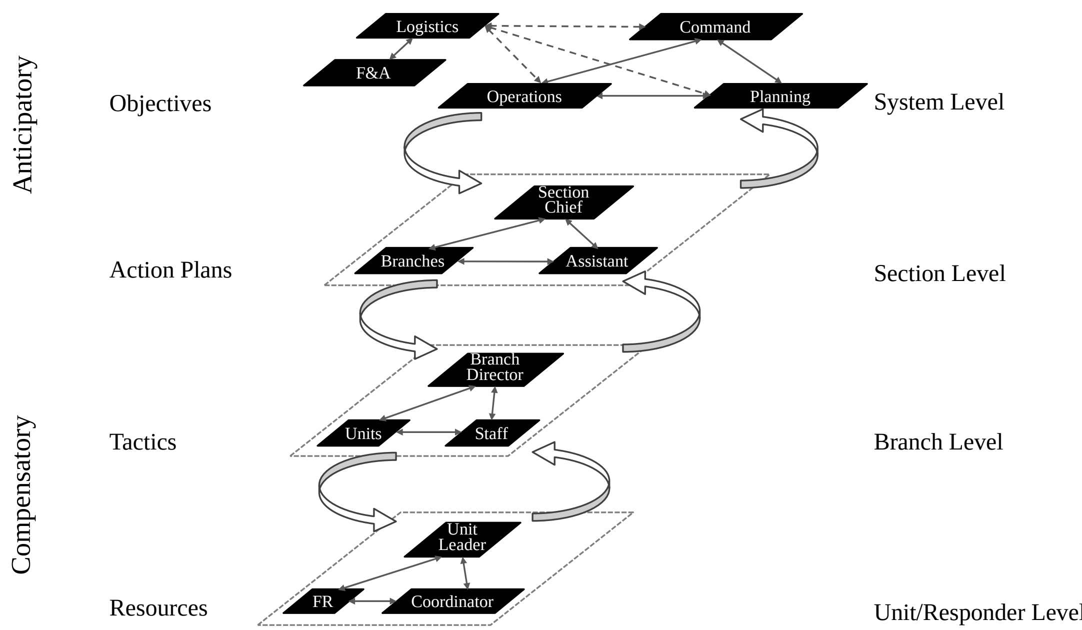

Figure 5.3 Multilayered JCS model of an IMT. This model shows how the JCS model above is situated along different levels of incident management.

5.4.4. Potential measures for resilience in IMT

Previous research provides an array of qualitative, semi-qualitative or quantitative measures for resilient performance [see Hosseini et al. (2016) for a review of definitions and measures for resilience]. Qualitative measures are mostly based on the provisions of anecdotal evidence of characteristics associated with resilience (e.g., MARL'ing). Semi-qualitative measures largely rely on subjective rating and expert judgment. For instance, Shirali, Mohammadfam, and Ebrahimipour (2013) analyzed survey results asking six resilience indicators: 1) top management commitment, 2) just culture, 3) learning culture, 4) awareness and opacity, 5) preparedness, and 6) flexibility. Quantitative measures for resilience were mostly based on highly abstract models that hardly consider the aforementioned characteristics of JCS. For example, Bruneau et al. (2003) proposed an equation that measures the resilience loss of community infrastructure after an earthquake. In this equation, resilience was described as a relative degradation of infrastructure quality to the planned or expected level during the recovery time. This measure, however, did not consider how cognitive systems including human and technical agents contribute to such performance. In recognition of this gap, this article proposes three metrics for the measurement of resilience of IMT using the JCS-based model presented: recovery time, resource status, and interactions and provides some examples to show proof of concepts.

5.4.4.1. Recovery time

One factor that typifies resilience of a system is how quickly it returns to a normal state after a perturbations (Dinh et al., 2012). To be resilient, a system must be quick in resolving disruptions and restoring its control. Nevertheless, system thoroughness is sometimes compromised in order to gain efficiency (Hollnagel, 2009). A breakdown of the system may occur when this trade-off is not adjusted well, for example, being thorough usually results in sluggish response in situations where prompt response is necessary.

Four measures of recovery time adapted from Hollnagel and Woods (2005), and Hoffman and Hancock (2016) are proposed in the present work (Figure 5.4): time to perceive (T_P), time to decide (T_D), time to act (T_A) and time to recover (T_R). T_P measures the time between the onset of an adverse event or meaningful change in such event and its perception by emergency personnel. In the IMT, T_P indicates time needed for the Operations Section to perceive an event after its onset (e.g., a fire reported to Fire Branch Director). T_D measures the time taken from the point of perception to the development and selection of decisions (e.g., time taken until the Command Section approves a relevant plan after perceiving the event via the incident action planning process). Following this, T_A measures the time lapsed from the choice of decisions until the action is actually carried out at the scene. Finally, T_R measures the time needed to gain control (characterized as recovery) after the action is taken. In the IMT, T_R can indicate time from the establishment of the IMT to its deactivation.

Time is a critical constraint in incident response operations. That is, whether the IMT maintains its control over adverse events depends on how the IMT distributes limited time to detecting the events, developing action plans, implementing the plans and regaining control. Delayed evacuation during Hurricane Katrina (Wise, 2006) and late kick detection in Deepwater Horizon (Meng, Chen, Shi, Zhu, & Zhu, 2018) exemplify the failure to keep balance among the time needed for different parts of an action; too much time to execute plans in the former and too much time to recognize threats in the latter. In this regard, having four sets of time would help the IMT understand how much time is available and how fast or slowly an incident action needs to be developed and taken in order to maintain its control for incidents.

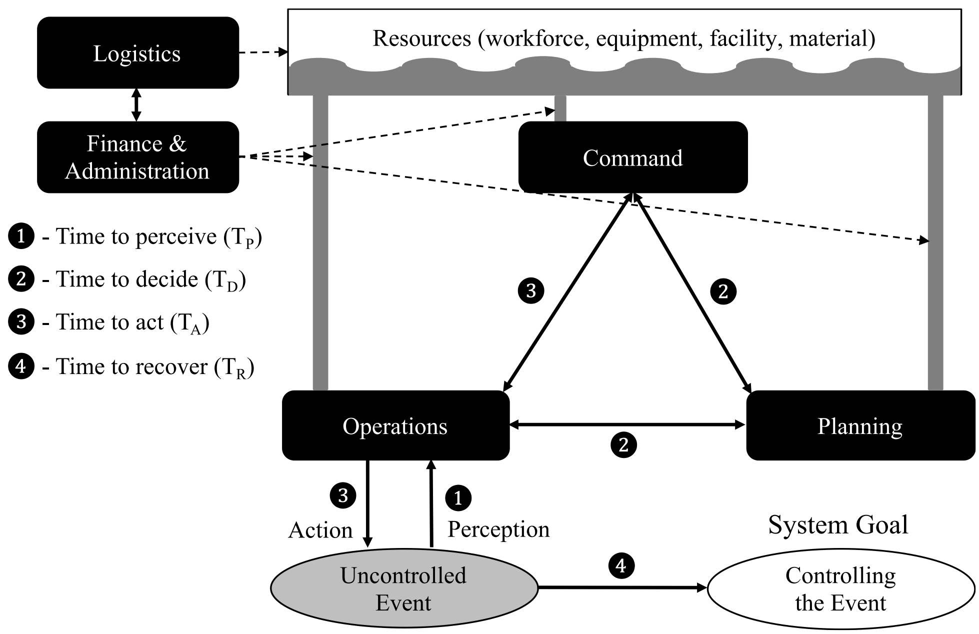

Figure 5.4 Four components of recovery time as a measure for resilience

5.4.4.2. Resource status

When the type or quantity of resources such as workforce, equipment and material are insufficient to match demands from the incident, the IMT may fall into a state of 'decompensation' (Sarter, Woods, & Billings, 1997). Often common resources are shared and conflicted among different sections of the IMT. Hence, the JCS-based IMT model assumes that there is a common resource pool that each section and its subordinate organizations draw upon. In actual emergency operations, the Logistics

Section procures and delivers these resources. Different types of resources are accounted by equivalent monetary value and the Finance & Administration Section calculates the rate of resource utilization in order to keep track of budget and cost. Arguably, information about the status of resources should be documented and shared within the IMT to improve resilience. Four types of resource status are proposed for measurement (Figure 5.5): requested resource (R_R), deployed resource (R_D), stocked resource (R_S), and procured resource (R_P). R_R indicates the amount of resources requested from the field operations (e.g., tactical units and field responders). R_D means the quantity of resources dispatched at the scene thus in use. On the other hand, R_S refers to resources in stock that are available for deployment. Lastly, R_P represents resources that are being purchased or transported.

Without monitoring the detailed resource status as above, the IMT may not be cognizant of its resilience capacity such as how much disruptive load the IMT can absorb (buffering capacity), and how closely the IMT is mobilizing its resource near the operational boundary (margin and tolerance) (Woods, 2006). Based on this monitoring, the IMT can proactively adjust resource management activities by accounting for disparity between resources of different status (e.g., amount of resources to be requested based on deployed, stocked and procured resources).

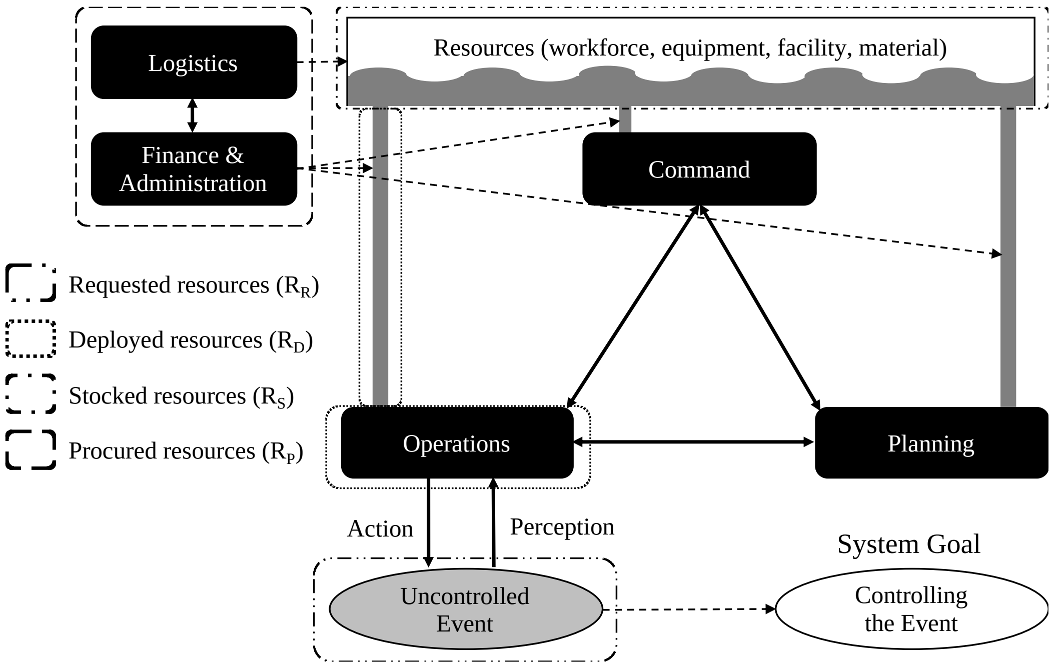

Figure 5.5 Types of resources in IMT. This figure shows four types of resources in terms of their status.

5.4.4.3. Interactions

Interactions among different human and technological agents within an IMT are an essential aspect of a system's resilience (Woods & Hollnagel, 2006). In a multilayered model presented in this article, interactions of the IMT can take place either within a layer or across different layers. In either case, an interaction occurs between a human actor and a technical tool, or between JCS's (e.g., a human-actor-cum-technical tool). To capture the different aspects of an interaction, we propose a 'three C's' framework for capturing interactions in IMT: Context, Content and Characteristics (Table 5.1). Context measures an initiator, a receiver of interaction and a technological mediator. Content indicates a description of what is communicated and actions taken. Lastly, Characteristics specify frequency and duration of the interaction.

Table 5.1 Three C's of interactions

Context			Content	Characteristics	
Initiator	Receiver	Technology		Frequency	Duration
Who initiates an interaction?	With whom?	Which technology is used in that interaction?	What is communicated for what purpose?	How often does the interaction occur?	How long does the interaction occur?

5.4.5. Proof of concept via Interactive Episode Analysis

The observational data at EOTC were used to illustrate the operationalization as a resilient performance in the IMT. To represent such resilient performance, 'Interactive Episode Analysis (IEA)' adapted from Korolija and Linell (1996) was conducted. An episode is defined as a chain of sub-events that are bounded towards a common meaning (Rankin, Dahlbäck, & Lundberg, 2013). In the IMT, an episode means a trace of interactive performance of human operators and technological tools following an inject until the IMT accomplishes a given goal. This inject typically requires further actions to meet some specific demands that the incident imposes to the human operators (e.g., dissemination of incident information within the IMT). Thus, an episode would consist of interactions from the reception of an inject until actions are taken to compensate such demands. Figure 5.6 depicts how an episode represents the IMT's interactive performance given an inject. It involves human-to-human interactions that have a direction (from a white box to a black solid box), duration and frequency of those interactions, and a type of technology used in that interaction. In addition, this episode incorporates actions performed by single personnel with a technological device (a gray box). A total episodic time measures time needed to satisfy the demands of the inject from the time it is given. Also, a sub-episodic time is measured for individual interactions.

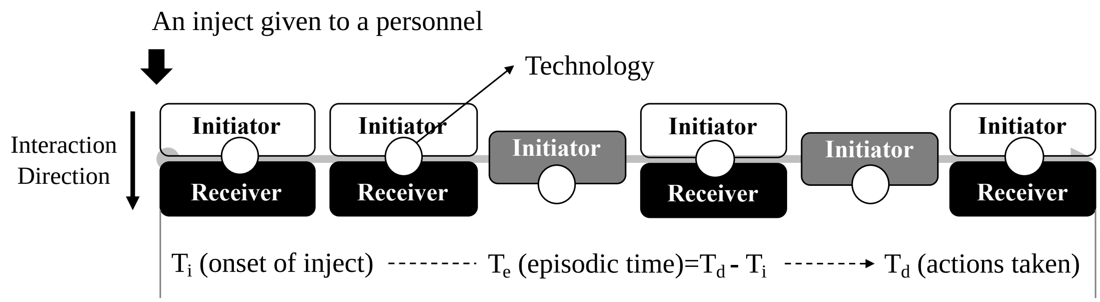

Figure 5.6 A representation of an interaction episode that shows temporal progress of interactions to deal with an inject

Two episodes were extracted from the collected data and presented to discuss the JCS model of an IMT. Figure 5.7 and Figure 5.8 illustrate each episode following an initial inject given to I/I Unit Leader (I/I Lead) in the Planning Section. During the aircraft crash scenario (El Diablo), a virtual character, role-played by a skilled staff, reported a field observation that contains information of the incident (e.g., location and consequence of the incident). The communication occurred via telephone. Next, I/I Lead took some follow-up actions in a series, for example, taking a note of what he heard from the field observer on paper, communicating it with another I/I member face-to-face, and making copies of what he wrote down. Following this, I/I Lead delivered each of the copies to other members including Documentation Unit Leader (DOCL), Situation

Unit Leader (SITL), Public Information Officer (PIO), Operations Resource Specialist (Ops. Res.), and Operations Section Chief (Ops SC). In the tornado exercise (Needland), a similar pattern was observed. Following an initial field report providing notification on the degree of damage in different locations, I/I Lead had a verbal dialogue with another I/I member, printed copies of the field report, and handed them over to other roles.

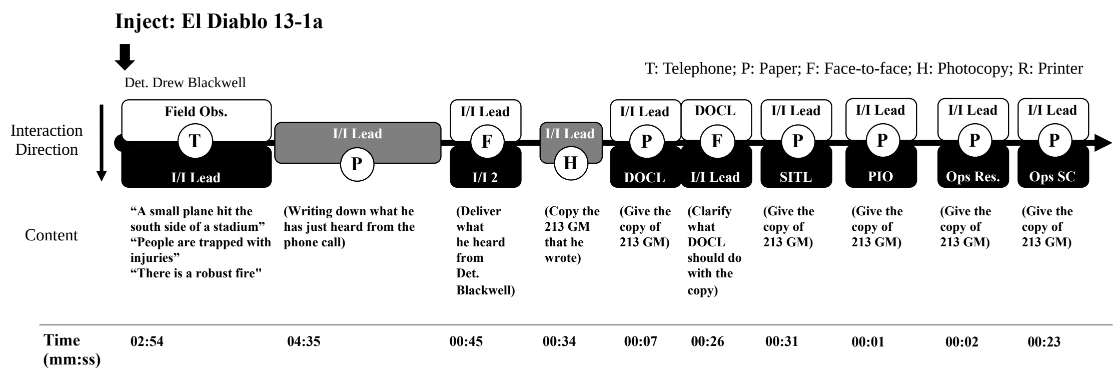

Figure 5.7 An episode following an inject El Diablo 13-1a. This episode begins with a field observation about airplane crash.

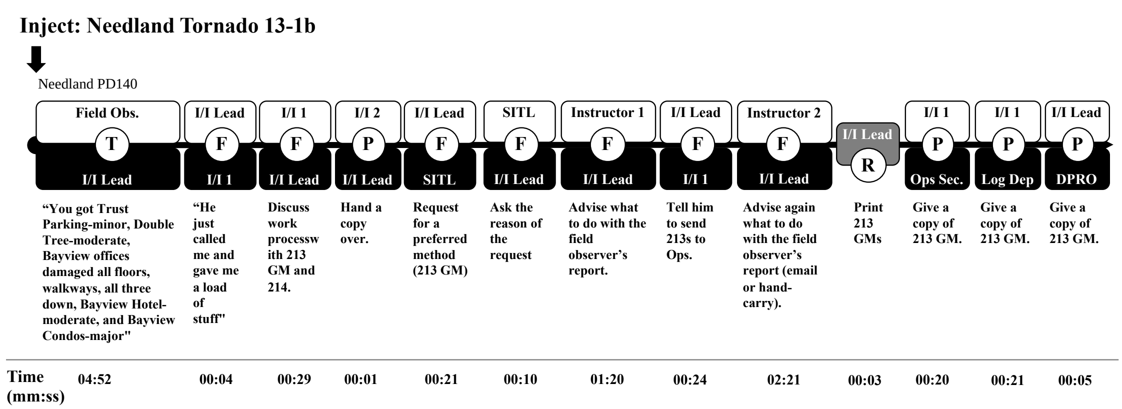

Figure 5.8 An episode following an inject Needland Tornado 13-1b. This episode begins with a field observation about tornado damage.

The episodic time was 11 minutes and 58 seconds for the first episode, while the second episode was twice as long, taking 23 minutes and 35 seconds. With respect to frequency of interactions, eight human-to-human interactions among eight roles and two human-to-technology interactions were captured for the first episode whereas 12 human-to-human interactions among 10 roles and one human-to-technology interaction were identified for the second episode.

By looking at these episodes, it is possible to investigate complex interaction patterns among human actors and technical tools on a time dimension. In particular, the episodes give an anatomy of how a demand from an incident is handled by the IMT upon interactions of multiple components. Thus, analyzing the episodes would identify where the IMT behaves in an adaptive or maladaptive manner.

As indicated in Efficiency-Thoroughness Trade-Off (ETTO) principle (Hollnagel, 2009), resilience should be understood in the context of how a balance between efficiency (e.g., quick decision and action) and thoroughness (e.g., more information and less risk) is maintained. Therefore, the measure of interaction is neutral. That is, fewer interactions may not necessarily mean more resilient performance. On the contrary, more interactions may lead to more resilient performance. Likewise, quicker actions and use of less resources may not necessarily mean that the system is resilient. Hence, such neutrality indicates that time, resource status and interaction are not measures 'of' resilience per se, but measures 'for' resilience that help in understanding this abstract construct.

5.5. Discussion

Engineering a JCS occurs in a cycle that begins with observation of field practices and abstraction of common patterns from those practices (Woods & Christoffersen, 2002). The common patterns then serve as a model in which new ideas are hypothesized and new designs are discovered. While anecdotes and stories of resilience in the incident/emergency management domain have hitherto been accumulated and contributed to better understanding of resilience engineering, few models are available that explain the real-world resilience behavior of complex IMT systems to facilitate new findings. Traditionally, disaster response and emergency management research has been approached from higher and lower levels of complex socio-systems hierarchy (Leveson, 2004; Rasmussen, 1997). Studies at the higher level have leaned towards social system, public administration and policy (cf. Bissell, 2013; Rodríguez et al., 2007). On the other hand, studies for the lower level have focused on how field responders behave and make decisions (cf. Klein, 1993). To our knowledge, this is the first study investigating the intermediate level of disaster response that focused on the IMT as a JCS. The JCS model presented in this article showed promise in facilitating the descriptive modeling of functional relationship among JCSs in the IMT. Our work in modeling a JCS for an incident management organization can inform addressing real-world complexities and enhancing resilience of an IMT through making time, resources and interactions more tangible. Indeed, lack of resilience in recent disasters has been widely acknowledged. As such, there have been persistent calls for developing metrics for resilience (Boin, Comfort, & Demchak, 2010). In responding to such calls, the descriptive models and associated measures developed here would benefit incident management systems such as NIMS or ICS in the US in their coping with time and resource constraints, and challenges to coordination and collaboration among emergency operators and organizations.

Nonetheless, further work is warranted to advance resilience engineering knowledge of incident management systems. For example, resilient performance of the IMT can be traced by investigating how the organization perceives and copes with an input. This input can be manipulated in the sense that whether it is routine and planned (therefore expected) or not. Tracing such coping behavior may include observing how resources are utilized, the timeline of such behavior, and how cognitive agents interact across different boundaries of the IMT. In other words, future studies should highlight communication and information flow that may reveal resilience of the IMT on how it monitors on-going situations, anticipates future states, learns from past experiences, to contribute to an informed response.

The present work offered the first JCS model of the IMT and provided operationalizable measures for resilient performance. Several limitations, however, need to be addressed in the future research. First, in this study, data were collected in a simulated setting. While the EOTC environment is similar to real-world emergency response operations in many aspects, evaluating models derived from a simulated setting against real response scenarios is warranted. To that end, work is currently in progress to support this model with empirical evidence through interviews with subject matter experts in this domain, and observation and data collection from real disaster responses.

Second, while IEA showed promise in operationalizing the three resilience metrics proposed, the scope of episodes collected to date are limited. Sufficient number of episodes should be collected in the future such that they can provide a full inventory of resilient IMT performance patterns. Such inventory may inform a normative model that acts as a reference for comparing resilient performance among different scenarios or IMTs using the proposed measures. It may also provide basis for developing a computational model which can render a predictive study for the IMT. Third, while this study showed a proof of concept for resilience, more research is warranted to incorporate and further validate the associated measures. Finally, experimental research is needed to manipulate these measures in isolation without severely compromising the real-world complexity. This can be managed by careful development of scenarios for experimental studies that incorporate the incident action planning process in a reduced scale and design of injects that impose different levels of high or low demands while investigating cognitive support tools and displays that facilitate adaptations.

5.6. Summary

An IMT is a core element of the US NIMS that deals with complex and high-impact incidents. Prior research has identified the needs of resilience in the centralized incident management approach for unexpected and unplanned situations. Considering that resilience is a key defining property of a JCS, the present work developed the first JCS models of the IMT based on firm theoretical grounds as well as findings from empirical, naturalistic observations of high-fidelity emergency exercises. Based on these models, this research has realized a cyclic incident action planning process, and furthermore three measures for resilient behavior in complex IMTs were developed and qualified through observational cases. As a method to make these measures visible and operationalizable, IEA was developed and applied to offer a proof-of-concept. By acknowledging that our data collection was less than ideal, future work is necessary to further instantiate aspects of the model as well as the measures presented. Regardless, the models presented in this study address an important gap in understanding resilience behavior of IMTs and provide a venue for addressing most outstanding challenges of disasters to time pressure, insufficient resources and complex interactions among the IMT's human and technical components.

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CHAPTER 6 ARTICLE #5

EVALUATION OF WORK-AS-DONE IN INFORMATION MANAGEMENT OF MULTIDISCIPLINARY INCIDENT MANAGEMENT TEAMS VIA INTERACTION EPISODE ANALYSIS[5]

6.1. Overview

Multidisciplinary incident management teams (IMTs) are required to operate in resilient ways as emergency situations unfold unexpectedly. Although resilience in emergency management has been widely studied in many emergency contexts, the development of a new method to investigate actual resilient performance of the IMTs under realistic settings has been limited. To address such gap, this article first introduces Interaction Episode Analysis (IEA), a novel approach to capture and describe emergent team performance. As an exploratory observation study, we apply the IEA to an information management aspect of the IMTs in two emergency exercises carried out in a high-fidelity environment. The application of the IEA provides comparable sets of episodes as instances of work-as-done, rendering opportunities to further analyze essential elements of interactions between team members as well as information management activities. Moreover, the use of the IEA to analyze episodes enables comparisons between the observations and identification of challenges faced by the team

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in managing incident information and adaptive behaviors used to address the challenges. By gathering more evidence as well as addressing limitations identified in this study, the IEA is expected to serve as a method that facilitates the analysis of work-as-done of complex team work and the reconciliation between work-as-done and work-as-imagined to promote resilience in emergency management.

6.2. Introduction

Economic losses incurred by disasters have gradually increased since 1990, reaching an annual average of $250 billion to $300 billion globally (UNISDR, 2015) and nearly $100 billion in the US (USGCRP, 2018). Despite the growing threat, responding to disasters remains challenging due to a large amount of uncertainty, unexpectedness of events, finite resources, and inadequacy of emergency plans and procedures. Moreover, information necessary to make sense of evolving situations to inform decisions is often inaccurate and outdated (Perry, 2007; Perry & Lindell, 2003). Therefore, a key to effective responses to disasters is the capacity to flexibly adjust performance to changing conditions and to quickly recover from disturbances, a property of social systems defined as *resilience* (Boin, Comfort, & Demchak, 2010; Woods & Hollnagel, 2006b)

One such social system's key component to disaster response is an incident management team (IMT) that is designated to provide on-scene support during a disaster. An IMT includes emergency responders and managers with various expertise and from multiple disciplines such as firefighting, law enforcement, and medical service (FEMA, 2017) who work collaboratively to achieve common goals (Boin & McConnell,

2007) usually in a collocated facility (Bigley & Roberts, 2001; Smith & Dowell, 2000). Diverse and multidisciplinary IMTs' ability to adapt its performance to unpredictable conditions has been considered a key factor to success or failure of emergency operations (Kendra & Wachtendorf, 2003; Weick, 1993).

Previous research to understand resilient performance of multidisciplinary IMTs has generally focused on comparing 'work-as-done (WAD)' with 'work-as-imagined (WAI)' to investigate adaptations and improvisations exhibited by IMT members during response. Two main approaches have been used to operationalize such comparison: narratives and resilience modeling. First, narratives have been used to describe how the IMTs are operated in the real-world or high-fidelity simulated emergency situations (WAD). Such narratives include accounts and patterns of adapted behaviors found in emergency operations in different types of incidents such as terrorist attack (Kendra & Wachtendorf, 2003; Mendonça, 2007), nuclear incident (Costa et al., 2008; Furniss, Back, Blandford, Hildebrandt, & Broberg, 2011; Gomes, Borges, Huber, & de Carvalho, 2014), major sports event (de Carvalho et al., 2015; Filho et al., 2014), search and rescue (Lundberg & Rankin, 2014; Rankin, Dahlbäck, & Lundberg, 2013), or firefighting (de Carvalho et al., 2018; Weick, 1993; Woltjer, Trnka, Lundberg, & Johansson, 2006). A common goal pursued in these studies was to provide a practical understanding of resilience under various emergency contexts. Second, there have also been a few attempts to model resilience of the IMTs. For example, Aguilera, Bastos da Fonseca, Ferris, Vidal, and de Carvalho (2016) modeled an emergency command center's response to an oil spill using Functional Resonance Analysis Method (FRAM); a method that represents variability of everyday practices and analyzes how such variability leads to desired or unwanted outcomes (Hollnagel, 2017). This analysis facilitated understanding of how human operators adjusted their activities for key functions such as oil spill assessment, as well as strategic planning and execution. Lundberg, Tornqvist, and Nadjm-Tehrani (2012) proposed the Resilient Sensemaking and Variety Control Model (RESCOM) for an emergency response which explains how the emergency response team manages disturbances through a cyclic process of monitoring adverse events, implementing control actions, and adjusting the actions based on monitored feedback.

While the literature on resilience narratives and models has contributed to improved theoretical understanding of resilience in various emergency management contexts, only a few plausible proposals for measurement and operationalization of resilience in emergency management exist (Righi, Saurin, & Wachs, 2015). One such effort is Hollnagel (2011)'s resilience analysis grid (RAG) that enables the investigation of essential resilience functions of monitoring, anticipating, responding, and learning. Similarly, Woods (2006) sets forth resilience factors such as buffering capacity (how a system absorbs disruptions), margin (how a system operates near performance boundaries), tolerance (how a system gracefully degrades), flexibility (how a system restructures itself), and cross-scale interaction (how local and management levels influence each other). Later, these factors were used to assess resilience in response to the 9/11 disaster (Mendonça, 2016). Although these frameworks provide a rich descriptive understanding of resilience in complex emergency response scenarios, methods utilized to inform such frameworks rely heavily on self-reported data and may fall short in describing complex interactions as WAD among system components (e.g., members and technologies of the IMT) in team environments.

Based on the premise that resilience is a property of a system that emerges through interactions among human operators and technical tools to address given demands (Woods & Hollnagel, 2006a), previous research has focused on interactions among the system components. In the context of emergency response, Gomes et al. (2014) attempted to capture interaction patterns between members of an emergency coordination center so as to identify how distributed members engage in information flow and to detect communication overload and bottlenecks. Similarly, Aguilera et al. (2016) studied interactions between human operators, operating procedures, and equipment to investigate how an emergency response team adjusts its performance given potential inadequacy of procedures for some unexpected events and limitations of resources. This is in line with some team researchers who use interactions between team members to understand team resilience or adaptability (Burke, Stagl, Salas, Pierce, & Kendall, 2006; Salas, Sims, & Burke, 2005). Given the growing recognition of interactions as an essential lens through which resilient performance of social systems can be analyzed, adequate methods are needed to facilitate the analyses. Nonetheless, such methods are largely absent in the resilience literature (Hosseini, Barker, & Ramirez-Marquez, 2016; Patriarca, Bergström, Di Gravio, & Costantino, 2018).

To address this gap, we propose a novel approach called Interaction Episode Analysis (IEA), which enables documentation and analysis of emergent performance, and challenges and resilient behaviors, using analytical units called *episodes* that represent complex temporal interaction patterns in large multidisciplinary teams. In order to analyze multiple facets of an interaction in the IMTs, we propose to investigate 3C's of interactions: *Context* in which an interaction occur (e.g., initiator, receiver, and technical mediator), *Characteristics* (e.g., frequency and duration of the interaction), and *Content* of the interaction (e.g., spoken words or actions) (Sasangohar, Donmez, Easty, Storey, & Trbovich, 2014; Son et al., 2018).

The particular focus of this study is on the IMT's information management activities which have been shown to be one of the key areas of multidisciplinary emergency operations (Comfort, 2007). In what follows, we first provide some background on organization and information management in the IMTs. We then introduce the IEA methodology and document a study of emergency response teams in a high-fidelity simulation to show the efficacy of the IEA in investigating the IMT's resilient performance.

6.3. Background

6.3.1. Organization of the IMT

Once the demands of an incident exceed one jurisdiction's capabilities, multiple organizations are required to coordinate and collaborate in order to work as a single IMT. One of the issues in forming the IMT is difficulty of harmonizing different incident management principles developed and adopted for a specific region or a discipline such as fire service and police (Perry, 2003; Waugh Jr, 2009). To address this issue, also observed in response to 9/11 attack, the US Government developed and launched a common framework called National Incident Management System (NIMS) that is applicable to the IMTs at all levels of government and for all types of incidents as a national template. Among many protocols incorporated into the NIMS, Incident Command System (ICS) provides guidelines for reorganizing various resources such as personnel and equipment, and establishing incident action plans (IAPs) for continuing operations (FEMA, 2017).

Following the ICS, an IMT is composed of five major functional sections: Command, Planning, Operations, Logistics, and Finance/Administration (F/A). The Command Section directs the overall operations and consists of incident commanders (e.g., fire chief, police chief) and other command staff: Public Information Officer (PIO) who interfaces with the public and media; Safety Officer who oversees the health and safety of emergency personnel; and Liaison Officer who facilitates coordination between agencies. The Planning Section gathers, evaluates and shares information related to the incident and the IMT's operations. Based on this information, the Planning Section prepares IAPs for operational periods to come. As the main focus of the present study is the information management of the IMT, the layout and descriptions of roles in the Planning Section are provided in Figure 6.1. The Operations Section implements tactical activities specified in the IAPs in concert with field responders. Thus, the Operations Section usually owns different tactical branches such as fire, search and rescue, medical, and law enforcement. The Logistics Section supplies resources and services needed for or requested by the Operations Section. Lastly, the F/A Section manages financial matters of the emergency operations such as budget and expenditure (FEMA, 2017).

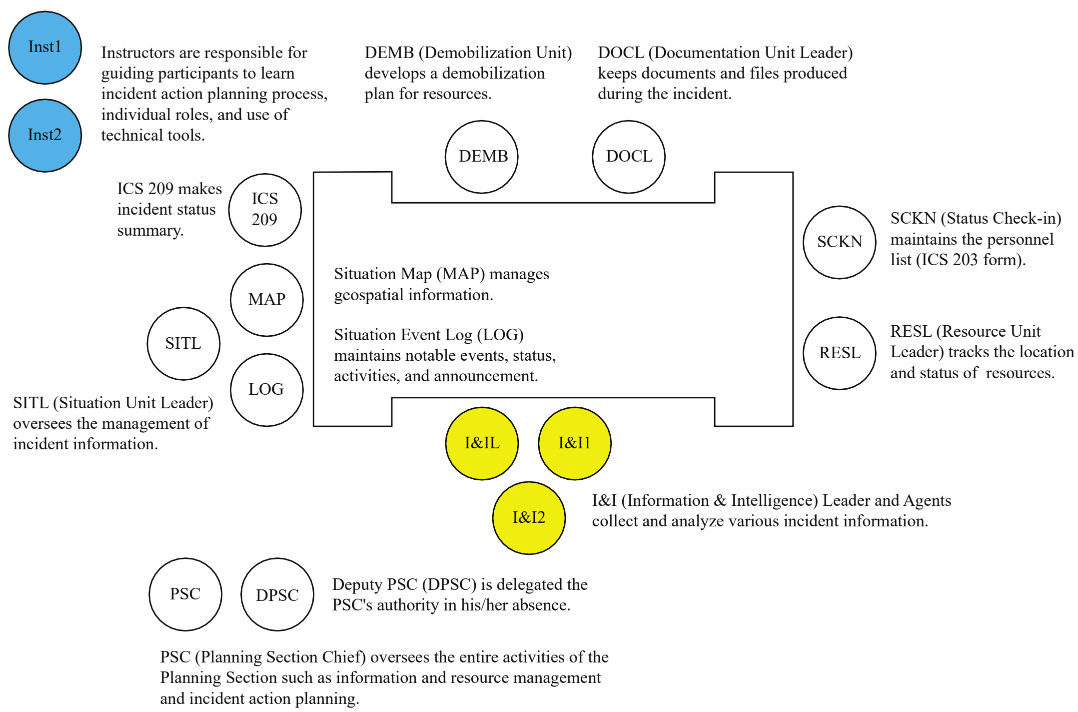


Figure 6.1 Layout and roles of the Planning Section. The section consists of different functional units and each unit is comprised of multiple roles, involving the leader of the unit.

6.3.2. Information management in the IMT

With the five functional sections in place, the IMT is operated largely for three interdependent areas of incident management: resource management, command and coordination, and information management (FEMA, 2017). Among these, managing information under a multidisciplinary environment has been problematic and thus considered critical to effective emergency operations (Militello, Patterson, Bowman, & Wears, 2007; Salmon, Stanton, Jenkins, & Walker, 2011). In particular, the overall incident management is likely to fail without members adequately recognizing evolving threats and communicating such information and resultant decisions with relevant parties (Paton & Flin, 1999). Well-managed information system facilitates learning from the past, monitoring current situations and anticipating what actions need to be taken so that the IMT can remain resilient, especially under fluid and unpredictable circumstances during an emergency (Burke et al., 2006; Comfort, Ko, & Zagorecki, 2004).

Information management in the IMT is expected to take a series of steps (refer to Chapter 1 for more details of the cyclic process of information management in the IMT). The information management begins with the initial assessment of the situation, followed by continuous cycles of collection, evaluation, integration, dissemination, and updating of incident-related data (Son et al., 2018). Although the entire Planning Section is primarily responsible for the information management, Information & Intelligence Unit (I&I) and Situation Unit play a major role in the flow of incident information (FEMA, 2017). Based on government documents (e.g., NIMS) and instructions from skilled instructors in the EOTC, the following steps are considered what is expected to occur and thus considered as WAI of information management in our study.

6.3.3. Interaction Episode Analysis (IEA)

6.3.3.1. Conception of IEA

An episode refers to a sequence of actions and conversations among multiple agents bound towards a certain topic or subject over a specific period of time (Annabi, Crowston, & Heckman, 2008; Korolija & Linell, 1996). Indeed, episodes have been used as the unit of analysis to report an account of resilient performance of an IMT. As an initial attempt, Aminoff, Johansson, and Trnka (2007) reported topical episodes from a forest fire exercise such as establishing a staging area and searching a missing child, based on the text messages exchanged between team members. In addition to the narrative accounts, Trnka and Johansson (2009) provided some metrics for interactions, for instance, the number of text messages sent and received between roles and criticality of the roles based on the relative communication frequency. With more emphasis on constituent elements of resilience, Furniss et al. (2011) provided some episodes that narratively describe markers, strategies, and enabling conditions for resilience during nuclear emergency scenarios. Gomes et al. (2014) analyzed emergency planning activities by laying out different roles and their actions on a timeline. Rankin et al. (2013) illustrated how sub-episodes temporally progress in parallel within a main episode regarding a wildfire. More recently, researchers began to use episodes to represent WAD of emergency operations. As an example, de Carvalho et al. (2018) described an emergency response exercise carried out in the field (as an instance of WAD) and compared with standard operating procedures (SOPs) used (as an instance of WAI). While these studies show promise in modeling WAD during an emergency response, methods are limited in capturing the complex interactions between human and technical agents and their relations to resilient performance.

To address this gap, we developed an Interaction Episode Analysis [IEA] (Son et al., 2018), which provides detail on *Context*, *Content* and *Characteristics* (Three C’s) of interactions (Figure 6.2). The IEA documents the *Context* of an interaction, namely, which roles are involved in an interaction and the technology used in the interaction. Regarding the *Characteristics*, the IEA provides a timeline of interaction events which can be used to analyze the frequency and duration of specific interactions. The *Content* of the interaction such as conversation and action is also available in the IEA as an essential component to describe the episode.

On one hand, the IEA is similar to topical episode analysis (TEA) developed by Korolija and Linell (1996) in that both methods can cover multiparty conversation and trace the evolution of a certain topic over time. On the other hand, the IEA provides additional advantages of capturing human-technology interactions and quantifiable temporal aspects of the interactions, which is an important basis for measuring adaptive team performance (Gorman, Cooke, & Amazeen, 2010). In addition, the IEA generates a visual representation of the episode, facilitating viewers' understanding of the episodic progress that otherwise requires more efforts to comprehend compared to text-based narratives (e.g., Furniss et al., 2011)

Since major endeavors assumed by the IMT include the management of incident-related information, an episode in the IEA is defined as a series of interactions between members that emerge in the course of coping with information demands given to the team. As shown in Figure 6.2, the initiation of the episode may be triggered by external or internal events in a simulated environment. External events–also called 'injects'–are information provided by role-playing staff to the team. The inject generally contains several pieces of information that require further actions to be taken (e.g., identifying an updated number of injuries). The episode may also commence internally as team members recognize the needs to handle particular information based on the instructions from instructors or incident objectives specified in the current IAP. Once triggered either externally or internally, ensuing interactions are manually searched and selectively chosen by analysts if the interactions include terms or data associated with the given or identified demand for the information (e.g., 'fatalities' or '2 dead people' for injury information). The episode concludes when no such terms or data are identified. As the information management in the IMT requires efforts across different sections, multiple roles can participate in the episode. Figure 6.3 presents the color codes and labels of the sections of the IMT and technical tools used in the IMT.

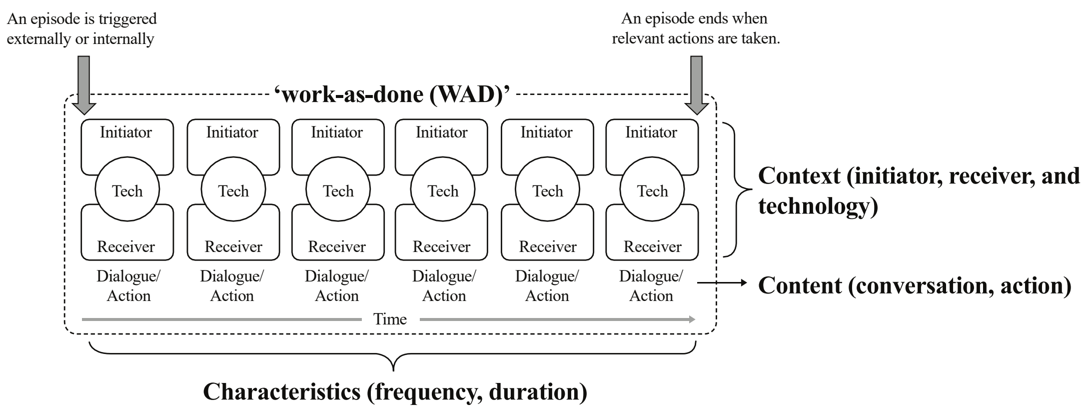


Figure 6.2 A schematic of Interaction Episode Analysis that incorporates context, content, and characteristics of an interaction

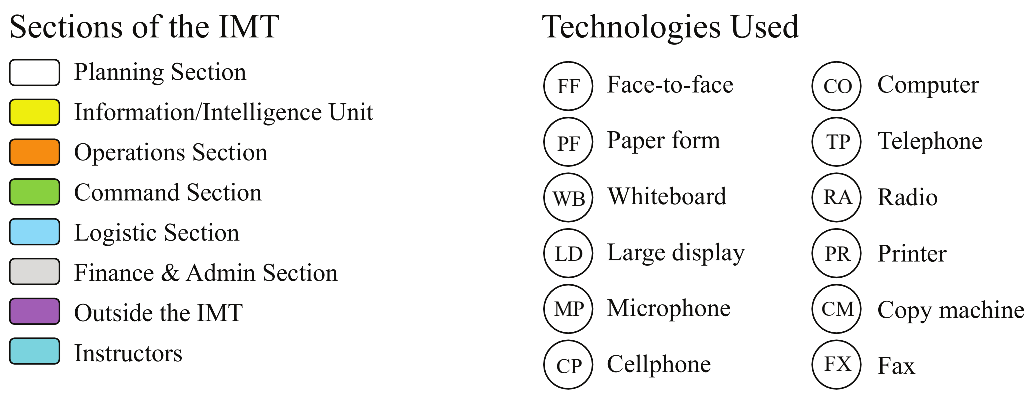


Figure 6.3 Color code for sections and labels for technologies

6.3.3.2. An example of IEA

Figure 6.4 is presented as an example of how the IEA is applied to team interaction data to generate an episode. First, identifying episodes requires analysts to pre-survey transcripts or video to capture potential topics that need further analysis (Korolija & Linell, 1996). The binding topic of this example is Joint Information Center (JIC), a designated facility that oversees public information activities. The beginning of the episode is determined when the term, 'Joint Information Center' or 'JIC' appears for the first time. By tracing this initial context (e.g., roles interacting, types of information sought), the episode is being developed by involving associated interactions that ensue. For instance, the first four interactions between MAP and Command Section personnel result in the fact that I&I Unit has the information about the JIC. By searching and inspecting MAP's subsequent interactions with I&I1 and I&I2, the episode regarding the JIC is further established, finally leading to the point where the location of the JIC is obtained. The episode is considered to be ended when the analysts do not find addition terms or interactions related to the binding topic (Aminoff et al., 2007; Korolija & Linell, 1996).

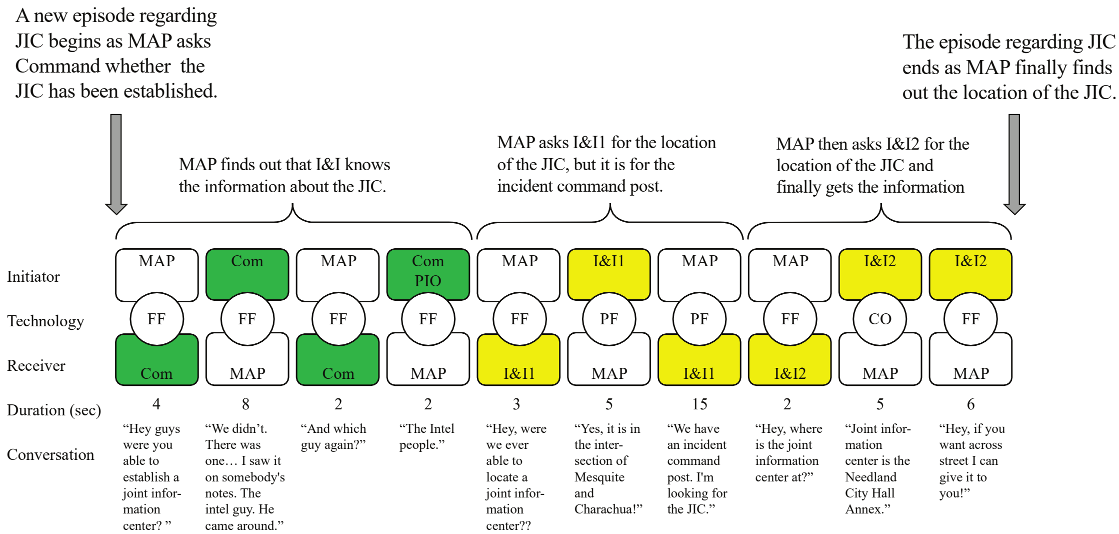


Figure 6.4 An episode regarding Joint Information Center (JIC). The episode consists of three sub-episodes regarding the location of the JIC between different roles in the IMT.

In what follows, we document two naturalistic observational studies conducted in a high-fidelity emergency training facility to describe the IEA further and to illustrate the IEA's efficacy and utility in assessing emergent resilient performance of a representative IMT.

6.4. Methods

6.4.1. Research setting

The work presented in this article is part of a larger research project that aims to investigate complex interaction patterns among members of a multidisciplinary team through naturalistic observations. The observations and collection of associated data were carried out in the Emergency Operations Training Center (EOTC) at Texas A&M Engineering Extension Service (TEEX). The EOTC is regarded as a high-fidelity emergency training facility thanks to its similarity in term of physical and functional characteristics to the actual operational circumstances (Feinstein & Cannon, 2002). For instance, the layout of the EOTC is configured as a common facility established during an emergency (e.g., an incident command post [ICP], or an emergency operations center [EOC]) as shown in Figure 6.5. Also, a variety of real-world tools in addition to face-to-face communication are used to mediate interactions: ICS paper forms, computers, whiteboards, large screen-projected displays, microphones, landline phones, personal cellphones, printers, copy machines, and radios. A training course typically accommodates 40 to 45 trainees to form a realistic IMT and takes 3 to 4 days. To replicate the functions of the IMT, more than 200 injects that stimulate trainees' response behavior are given per exercise in an *ad hoc* manner. The goal of the training courses available in the EOTC is to provide incident managers, supervisors, and jurisdiction's officials with skills necessary to respond to and recover from large-scale incidents. The training was designed to practice core incident management protocols in the US such as the ICS and the NIMS through realistic incident scenarios. Data for the project were collected from two separate training courses in 2017. Out of four emergency exercises given in each course, only the third exercise was included in the current analysis due to high degree of realism (e.g., support from instructors, stress, time pressure) as indicated by skilled instructors in the EOTC. The two exercises were carried out using the same incident scenario designed for a response to a tornado that hit a virtual city named ‘Needland’. Each of the two simulated IMTs is called IMT-a and IMT-b in the remainder of this article.

Figure 6.5 Simulated emergency response training facility. Trainees perform a specific role for an IMT and wear a vest corresponding to a section and a role.

6.4.2. Participants

Participants were recruited on the first day of each training course in the EOTC. Most of participants had moderate to high levels of incident management expertise as the course required ICS certificates prior to registration. In two training courses, 39 out of 44 participants (IMT-a) and 32 out of 46 (IMT-b) agreed to participate in the study. Instructors also consented to participate. Participants’ area of expertise was diverse in terms of discipline (e.g., firefighting, police, medical service) and location (e.g., different states and municipalities). For a retrospective analysis of verbal conversations, audio recordings were obtained from key roles involved in information management of the IMT (Table 6.1). This research was approved by the authors' Institutional Review Board (IRB No.: 2016-0489D).

Table 6.1 Key roles for information management and audio-recordings obtained

Key roles in the Planning Section for information management	Audio-recorded?	
	IMT-a	IMT-b
Planning Section Chief (PSC)		✓
Deputy Planning Section Chief (DPSC)	✓	✓
Situation Unit Leader (SITL)	✓	✓
Situation Unit Event Log (LOG)*	✓	✓
Situation Unit Map (MAP)	✓	✓
Incident Command System 209 (ICS209)		✓
Information & Intelligence (I&I) Unit Leader (I&IL)	✓	✓
Information & Intelligence Agent 1 (I&I1)		
Information & Intelligence Agent 2 (I&I2)		✓
Planning Section Instructor 1 (Inst1)	✓	✓
Planning Section Instructor 2 (Inst2)	✓	

* assumed by SITL in the exercises included in the current research. Empty cells indicate that the role did not consent for participation.

6.4.3. Data collection and processing

Five members of our research team, trained in human factors engineering, conducted directed observation of the two training courses to understand incident scenarios and interactions between participants. To facilitate real-time coding, observers used the Dynamic Event Logging and Time Analysis (DELTA) tool (Sasangohar, 2015) on Apple iPad Mini 3rd Series devices. Portable voice recorders were attached to each participant’s vest to record team verbal communications. Three camcorders were used to record the video of physical interactions from different angles (one at the left front, another at the right front, and the other near the Planning Section). Audio and video recordings were obtained for the duration of each exercise, which lasted about two hours and 20 minutes. The audio and video files were then synchronized using Premiere Pro CC (Adobe Systems Inc., 2017). Researchers then used synchronized recordings to transcribe the verbal communication between the IMT members and code associated metadata to understand *Context*, *Content*, and *Characteristics* of interactions. The metadata coded were: roles of the persons who initiated and received an interaction; a technical tool used in the interaction; start- and end-times of the interaction; and actions or conversations that appear in the interaction. Inter-coder agreement was 72% and 74% for the metadata from IMT-a and IMT-b, respectively. The transcripts and metadata were documented in a spreadsheet (e.g., Excel) to facilitate the searching and filtering of interactions for an episode. Duplicate metadata (e.g., an interaction captured by multiple voice recorders) were excluded. In addition, since a computer was a major tool that the participants used, computer screens were also recorded using Camtasia® (TechSmith, 2017) to see how they used computer software including electronic forms and a propriety simulation software called ‘Emergency Management*Exercise System [EM*ES]’ (TEEX, 2014).

Based on the initial survey of the transcripts and metadata, the elicitation of episodes was carried out by manually and iteratively searching recurrent topical terms and selecting specific interactional conditions, for example, filtering MAP as an initiator and a receiver for the *Joint Information Center* episode. Metadata for roles, technologies, and timestamps were used to assess contextual and temporal characteristic measures. To capture challenges and resilient behaviors from the episodes, themes reported in the literature were referenced such as barriers to team resilience (Militello et al., 2007; Rankin et al., 2013) and types of behavioral improvisations including the use of tools for a different purpose, alterations to task protocols, or extending an individual's role (Mendonça, Webb, Butts, & Brooks, 2014; Webb, 2004).

Once preliminary representations of the episodes were generated, several meetings between our research team members and experts (e.g., managers and instructors in EOTC) were held to further confirm and adjust the analysis results and to discuss possible rationales behind differences between episodes. In the discussion, multiple aspects of interactions such as sequence of interacting roles and technical tools, time spent on the interactions, and conversations and actions associated with the topic of the episodes were used to speculate why the development of the episodes varied with the same topic.

6.5. Results

Findings related to several important utilities of the IEA to facilitate the understanding and analysis of complex human-human and human-technology team interactions are discussed below. First, descriptions of individual episodes are presented to showcase the utilities of the IEA, which are to describe WAD and to highlight distinct emergent information management activities of the IMTs. In addition to the descriptive accounts of the episodes, we present the utility of the IEA to conduct a comparative analysis using several measures related to *Context* and *Characteristics* of interactions. Second, we present examples of how the IEA facilitates the identification of information management phases in the episodes. Third, we illustrate how the IEA's utilization of *Content* of the interactions along the information flow, enables the elicitation of several challenges that the IMT members encountered and adaptive behaviors to cope with the challenges. Finally, we demonstrate the visualization features of the IEA that help illustrate the overall duration of an episode, sections/roles and technologies involved in the episode, and different interaction patterns of the episode.

6.5.1. Overall description of episodes

Eight episodes pertaining to the information management of the IMT were identified using the IEA method (Table 6.2). Each episode represents how the IMT deals with a specific incident information demand during an emergency: initial assessment, updated injury and damage, name and location of emergency medical centers, financial expenditure rate, ingress and egress points of a secured perimeter, joint information center, location of mass evacuation facility or shelter, and response to leaked gas. Half of the episodes were triggered by an inject that the role-playing staff put into the team.

As shown in Table 6.2, six of the episodes emerged from both IMTs while two episodes (*Financial Burn Rate*, *Ingress/egress Points*) were identified in either of two IMTs. The IEA was used to compare the *Content* of the six common episodes between the two IMTs and thus to identify variations in behaviors or interactions to achieve the same goal.

Table 6.2 A list of episodes identified from two exercises using the IEA

Episode Name	Description	Triggered by	Identified from	
			IMT-a	IMT-b
Initial Field Report	A field observer reports his/her initial size-up including initial injuries and damages incurred by a tornado.	Inject	✓	✓
Emergency Medical Center	Two emergency medical centers were established and the Planning Section seeks to find out their names and locations.	Non-inject	✓	✓
Injury/damage Update	Injury/damage status such as casualties, those trapped, and damaged building and equipment is updated throughout the operations.	Inject	✓	✓
Financial Burn Rate	The Planning Section monitors the cap and the 'burn rate' of the funds as the IMT deploys personnel and other resources.	Non-inject		✓
Ingress/egress Points	To secure safe perimeter, ingress and egress points are established and the locations need to identified and shared.	Non-inject	✓	
Joint Information Center (JIC)	JIC is established to coordinate media release. The Planning Section needs to know whether the JIC has been established and where.	Inject	✓	✓
Mass Evacuation Point	As the tornado caused mass evacuation, the Planning Section needs to know where the mass evacuation point or shelter has been established.	Non-inject	✓	✓
Potential Gas Leak	A possible gas leak is reported by a field observer. The Planning Section needs to notify this to Fire Branch and verify it.	Inject	✓	✓

While the comparative analysis is beyond the scope of this introductory study, it yielded interesting findings regarding the variability in response. For instance, the episode of *Initial Field Report* began when a field observer (FOB), role-played by a skilled instructor, reporting to I&IL an initial assessment such as the size of impacted area and the moving direction of the tornado. After collecting data regarding a field assessment report from FOB, I&IL shared the reported information with other personnel in the IMT. In IMT-a [Figure 6.6 (a)], I&IL confirmed with I&I2 if the information had been validated by PSC and asked I&I2 to share the information with other sections and roles. In IMT-b [Figure 6.6 (b)], I&IL directly shared the reported information with SITL so that SITL disseminated the information. In other words, the field report was conveyed to SITL more quickly but distributed less widely in IMT-b than in IMT-a.

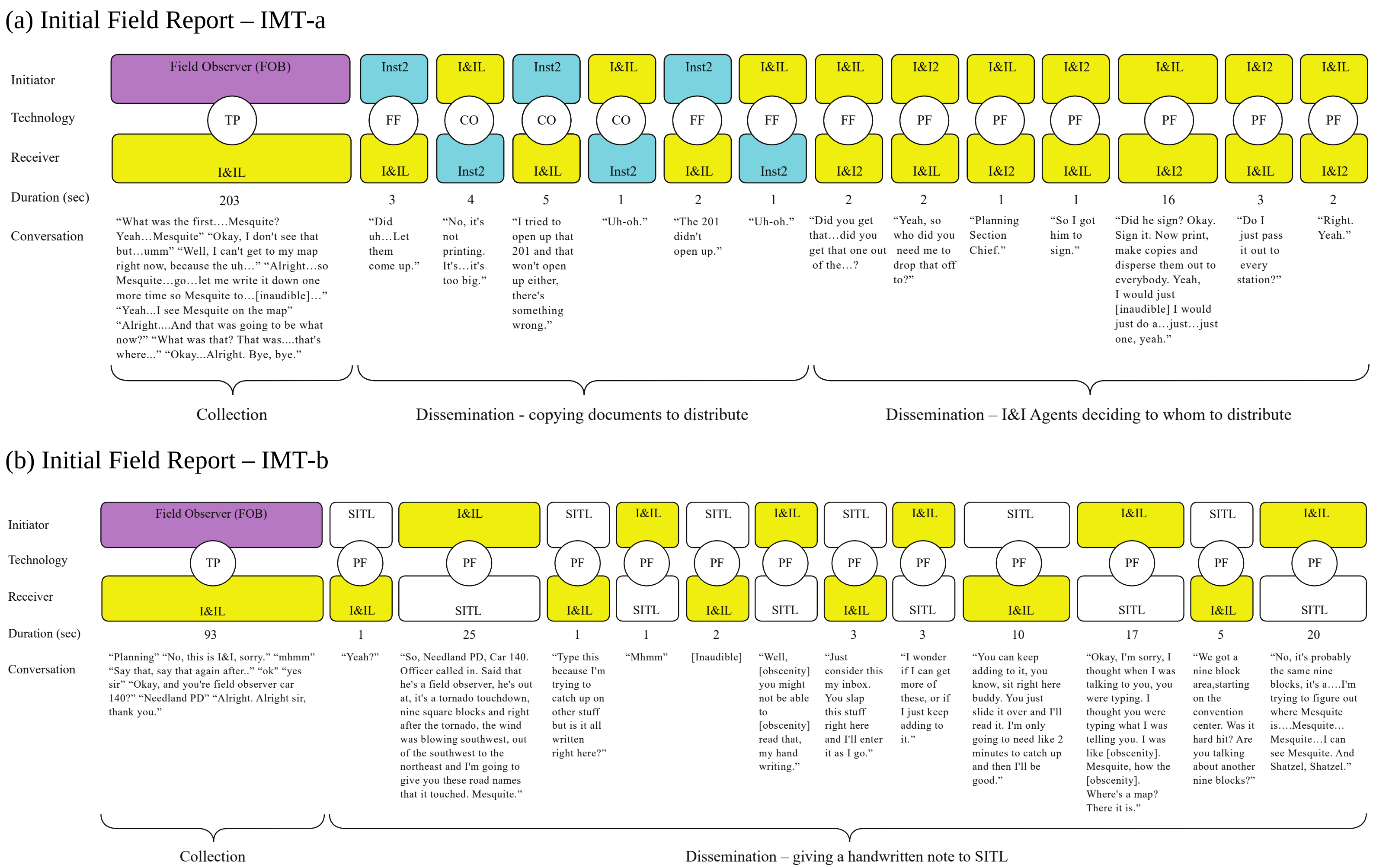


Figure 6.6 Graphical representations of Initial Field Report episodes

6.5.2. Evaluating team interactions via IEA

In addition to the detailed narrative analysis of the episodes' *Content*, another important utility of the IEA is to analyze and compare measures of the emergent team performance related to *Context* and *Characteristics* of interactions between members and technical tools. As shown in Table 6.3, five such measures were used to compare the six common episodes across two IMTs.

Table 6.3 Sample measures of context and characteristics of interactions in the episodes

Episode Name	Measure	IMT-a	IMT-b
Initial Field Report	Frequency of interactions (count)	14	13
	Episode length (sec)	261	208
	Sum of individual interactions' length (sec)	246	192
	Three most involved roles (as initiator or receiver) (%)	I&IL (50%) I&I2 (25%) Inst2(21%)	I&IL (50%) SITL (46%) FOB (4%)
	Three most used technologies (%)	Paper form (43%) Face-to-face (29%) Computer (21%)	Paper form (69%) Face-to-face (23%) Telephone (8%)
Emergency Medical Center	Frequency of interactions (count)	29	147
	Episode length (sec)	4,267	4,654
	Sum of individual interactions' length (sec)	309	803
	Three most involved roles (as initiator and receiver) (%)	MAP (34%) DPSC (19%) Inst2 (11%)	I&I2 (30%) MAP (20%) SITL (10%)
	Three most used technologies (%)	Face-to-face (44%) Computer (28%) Paper form (19%)	Paper form (58%) Computer (22%) Face-to-face (17%)
Injury/damage Update	Frequency of interactions (count)	196	191
	Episode length (sec)	5,613	6,527
	Sum of individual interactions' length (sec)	1,553	1,069
	Three most involved roles (as initiator and receiver) (%)	I&IL (25%) I&I2 (16%) SITL (17%)	ICS209 (16%) SITL (15%) I&I1 (14%)
	Three most used technologies (%)	Face-to-face (52%) Paper form (39%) Computer (5%)	Paper form (44%) Face-to-face (35%) Computer (14%)

Table 6.3 Continued

Episode Name	Measure	IMT-a	IMT-b
Joint Information Center	Frequency of interactions (count)	10	22
	Episode length (sec)	255	5,715
	Sum of individual interactions' length (sec)	52	184
	Three most involved roles (as initiator and receiver) (%)	MAP (50%) I&I1 (15%) I&I2 (15%)	I&IL (26%) MAP (18%) Com PIO (14%)
	Three most used technologies (%)	Face-to-face (70%) Paper form (20%) Computer (10%)	Face-to-face (50%) Paper form (23%) Computer (19%)
Mass Evacuation Point	Frequency of interactions (count)	43	99
	Episode length (sec)	763	3,627
	Sum of individual interactions' length (sec)	349	468
	Three most involved roles (as initiator and receiver) (%)	Inst2 (33%) DPSC (25%) I&IL (6%)	MAP (43%) Inst2 (14%) ICS209 (10%)
	Three most used technologies (%)	Face-to-face (76%) Computer (15%) Whiteboard (8%)	Computer (65%) Paper form (19%) Face-to-face (15%)
Potential Gas Leak	Frequency of interactions (count)	19	50
	Episode length (sec)	569	485
	Sum of individual interactions' length (sec)	243	280
	Three most involved roles (as initiator and receiver) (%)	I&IL (32%) SITL (26%) Inst1 (21%)	I&IL (33%) SITL (16%) I&I2 (10%)
	Three most used technologies (%)	Paper form (53%) Face-to-face (37%) Computer (5%)	Paper form (44%) Face-to-face (36%) Whiteboard (10%)

Frequency of interaction refers to the number of overall interactions between the IMT members in an episode. This measure may indicate more coordinated efforts in coping with the same demand given to the team. Depending on the context, a large number of interactions may indicate difficulties in assessing the situation or missing information. Except for *Initial Field Report*, there were large differences in the frequency of interactions between two episodes. To take *Emergency Medical Center* as an example, 32 interactions were identified in IMT-a whereas 195 in IMT-b. A large number of interactions (55 out of 195) occurred in IMT-b to find additional information to inform the assessment (in this episode, finding out specific names of two medical centers).

Temporal characteristics of interactions may provide valuable insight on team's collective performance and resilient behaviors. For example, relatively long duration of episodes (or sub-episodes) may indicate difficulties in information management and communication. Two measures were used to capture the temporal characteristics of the episodes. First, *Episode Length* (EL) measures how long the overall episode took. This can be operationalized as $EL = T_e - T_s$, where T_e and T_S represent end-time and start-time of an episode, respectively. Second, *Sum of Individual Interactions' Length* (SIIL) is the measure of how much time the IMT members collectively spend on interactions with other members to address a specific work demand operationalized as $SIIL = \sum_{i=1}^{n} L_i$, where L_i represents the length of i^{th} individual interactions and n is the total count of interactions in an episode. In some episodes, a large difference between the two duration measures was identified. In *Joint Information Center (JIC)* for example, the episode in IMT-a took 10 interactions with 52 seconds of SIIL and 255 seconds of EL while that in IMT-b was composed of 22 interactions taking 184 seconds of SIIL and 5,715 seconds of EL. A greater difference in EL than in SIIL largely results from interactions between Command PIO and I&IL regarding the confusion about the location of JIC that appeared at the later part of the exercise, which add only a few additional counts of interactions but make the end-time of the episode significantly longer.

With regard to the *Context* of interactions, an analysis was performed to identify key roles (the roles who were involved in most interactions) and key mediators (the technologies that were used most frequently to mediate the interactions). For the purposes of this article, three most involved roles and mediators were identified for each episode (Table 6.3). An aggregate analysis of episodes across two IMTs shows that the most frequently interacted roles were I&I2 (15%), I&IL (15%), SITL (12%), MAP (12%), and DPSC (7%). As for the mediator of the interactions, paper form (38%), face-to-face (37%), and computer (19%) were mostly used across the common episodes. A comparative analysis suggests some different patterns of interactions between two IMTs. With respect to roles, I&IL (21%), I&I2 (14%), and DPSC (13%) were three most frequently interacted roles in IMT-a whereas MAP (19%), I&I2 (17%), and SITL (12%) were the roles with the most interactions in IMT-b. In terms of technologies involved in the interactions, three most used were face-to-face (55%), paper form (30%), and computer (10%) in IMT-a while paper form (44%), face-to-face (26%), and computer (25%) were the top three ones in IMT-b.

6.5.3. Evaluating information management phases in episodes

In addition to the focused analysis of, and comparison between episodes, the IEA also enables the evaluation of how information has been handled within an episode and facilitates comparison among similar contexts. For example, the episode of *Potential Gas Leak* describes how the same inject of a potential gas leakage is dealt with differently in two different teams. In IMT-a, an FOB provided a field report of a potential gas leakage in the incident area and advised to check this with a Fire Branch in the Operations Section. While the same inject was given, ensuing interactions differed in two IMTs. In the IMT-a [

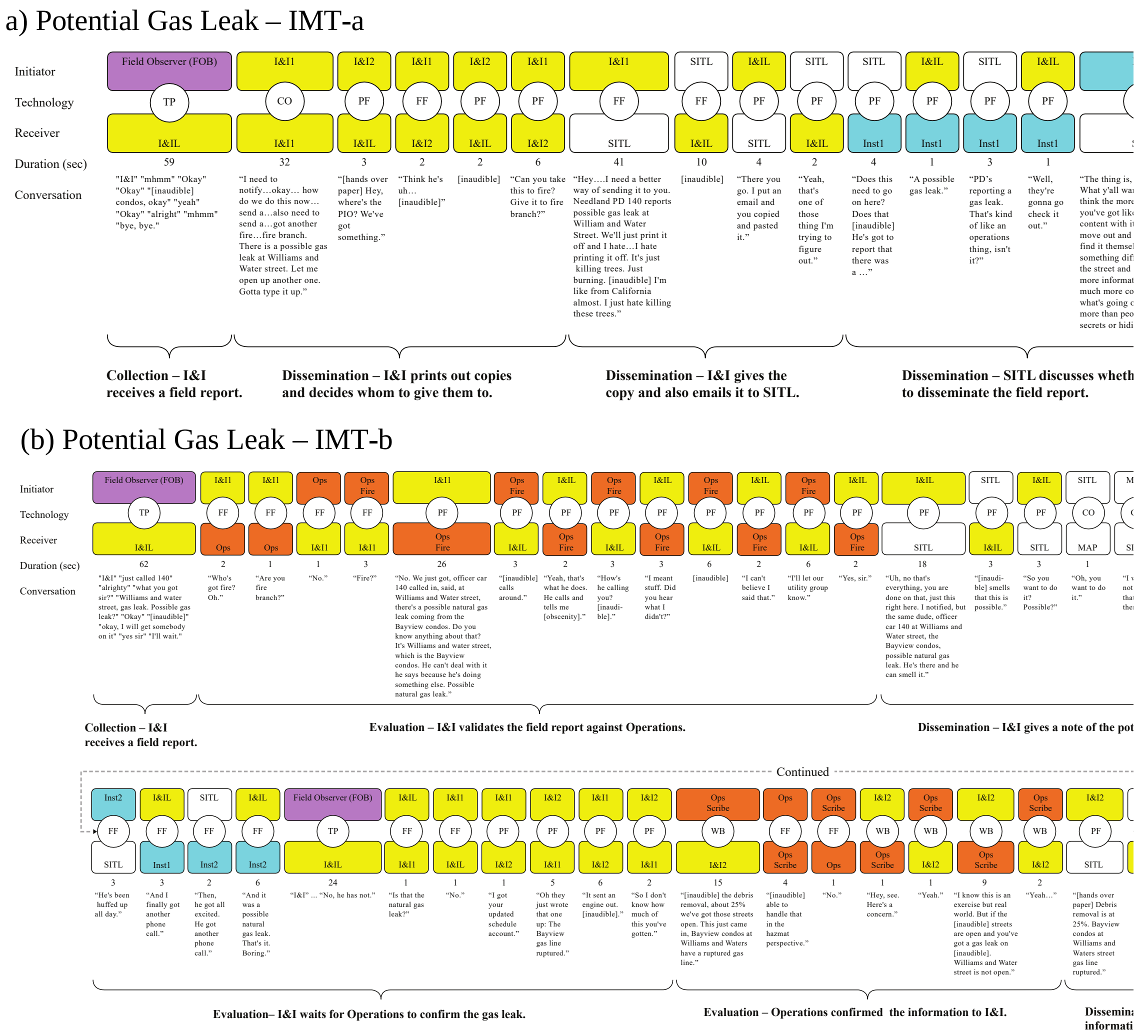
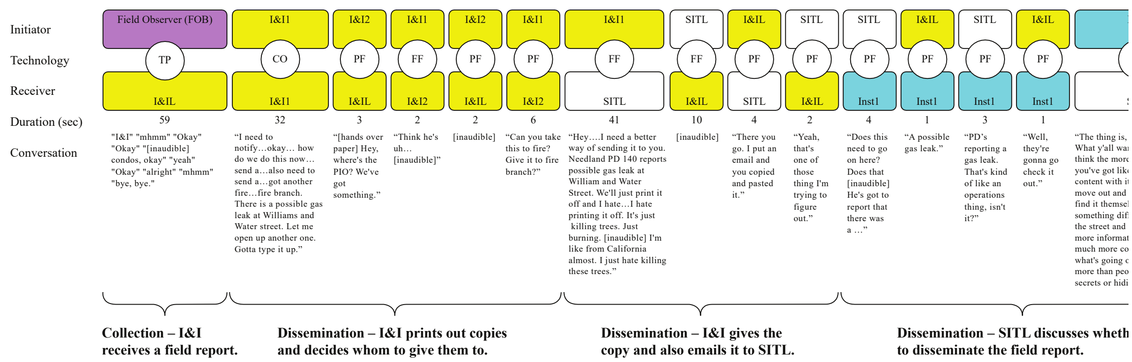


Figure 6.7 (a)], the information management phases that occurred were: initial size-up – collection – dissemination – updating. For example, FOB reported the potential gas leak to I&IL. Then, I&IL passed the information about the potential gas leak to SITL and then SITL discussed with an instructor whether sharing of the information is

necessary. Once the information regarding the potential gas leak was disseminated via event log, SITL checked for any update to be shared in an upcoming meeting.

In IMT-b [

a) Potential Gas Leak – IMT-a



(b) Potential Gas Leak – IMT-b

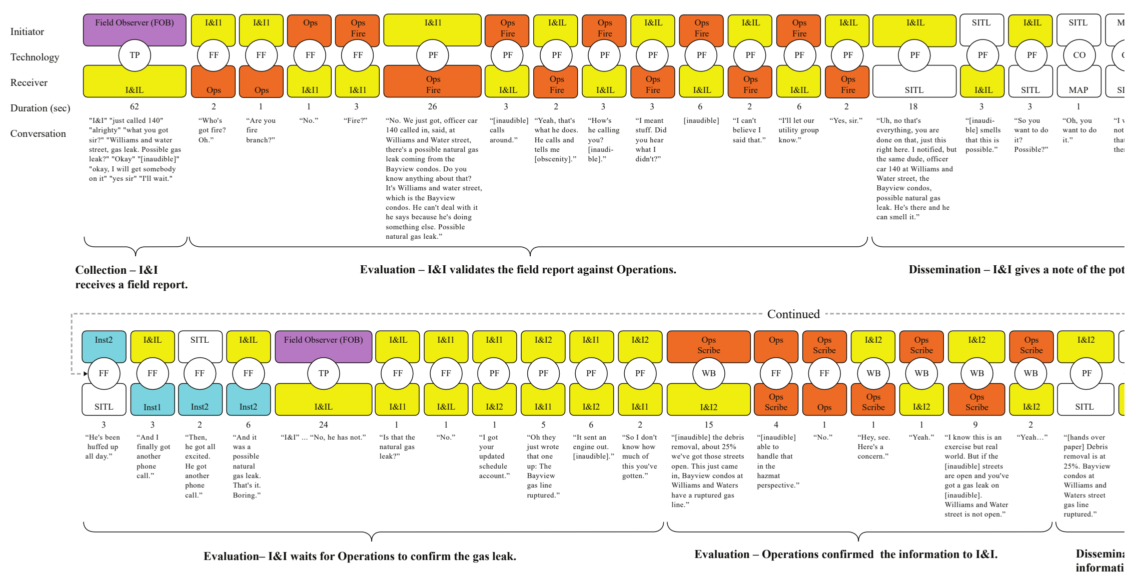


Figure 6.7 (b)], more evaluation-related interactions took place, following initial size-up – collection – evaluation – dissemination phases. To give more details, after receiving an initial report of the potential gas leak from FOB, I&IL attempted to confirm the potential gas leak with Operations Fire Branch. Then, I&IL passed that information to SITL but SITL wanted to wait for the potential gas leak to be confirmed by the

Operations. After the Operations had confirmed the gas leak, I&I2 passed it to SITL and SITL posted it to the event log.

Differences observed in the information management phases, may explain differences in the quality of the disseminated information in the *Potential Gas Leak* episode. Although the information about the gas leakage was disseminated in both IMTs, more specific information was provided in IMT-b. For example, while only street names, “William & Water St.”, were offered in IMT-a [Figure 6.8 (a), the red-dotted box], the specific name of the building, “Bayview Condo”, and the cause of the gas leak, “gas line rupture”, were disseminated in IMT-b [Figure 6.8 (b), the red-dotted box]. Considering the frequency (IMT-a: count=19 vs. IMT-b: count=50) and durations (IMT-a: EL=569s, SIIL=243s vs. IMT-b: EL=485s, SIIL=280s) taken for this episode (Table 6.3), the IMT in IMT-b exhibited more coordinated efforts (e.g., a higher interaction count) for a similar time period (e.g., EL and SIIL) and produced the information of better quality.

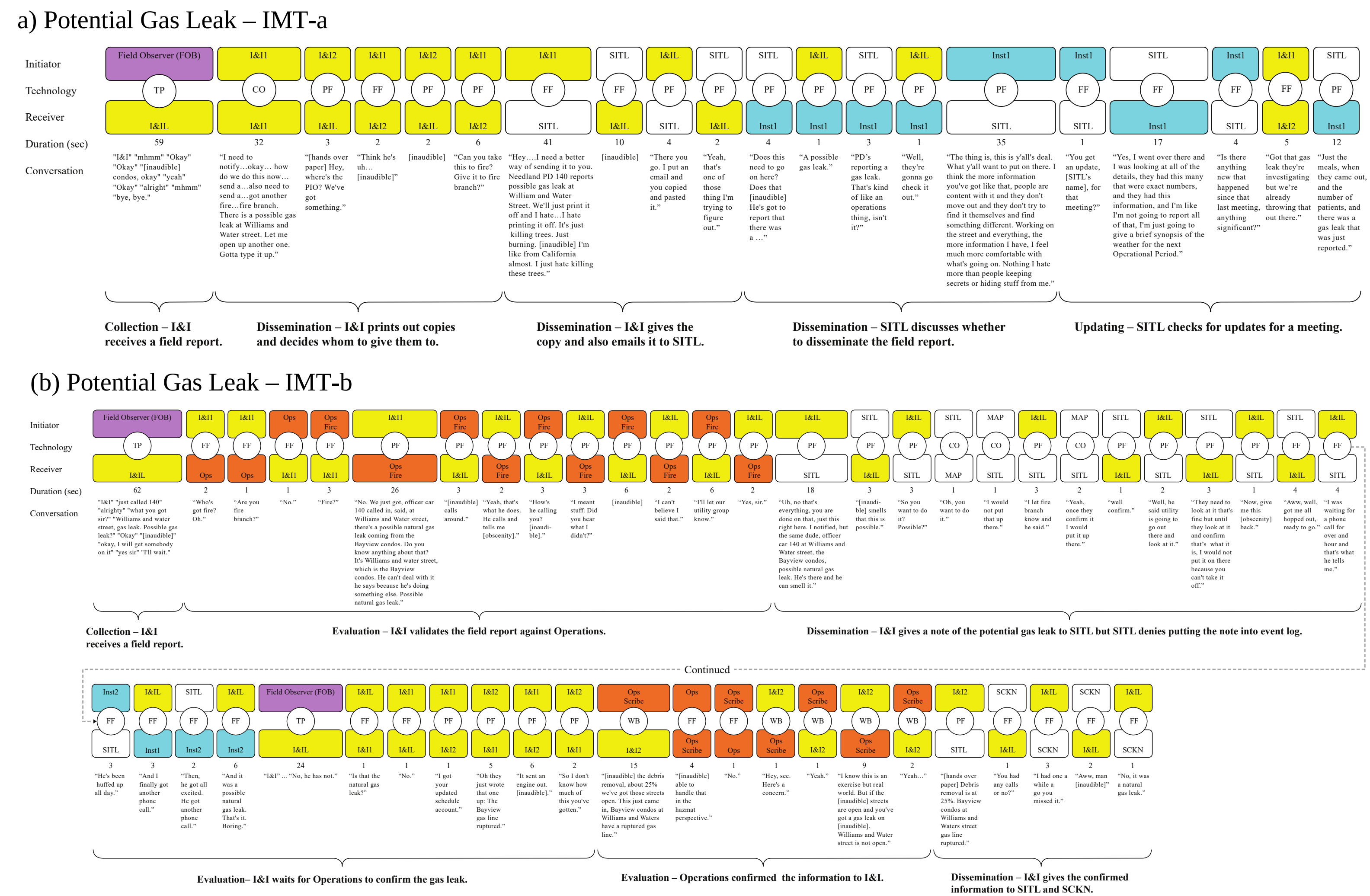
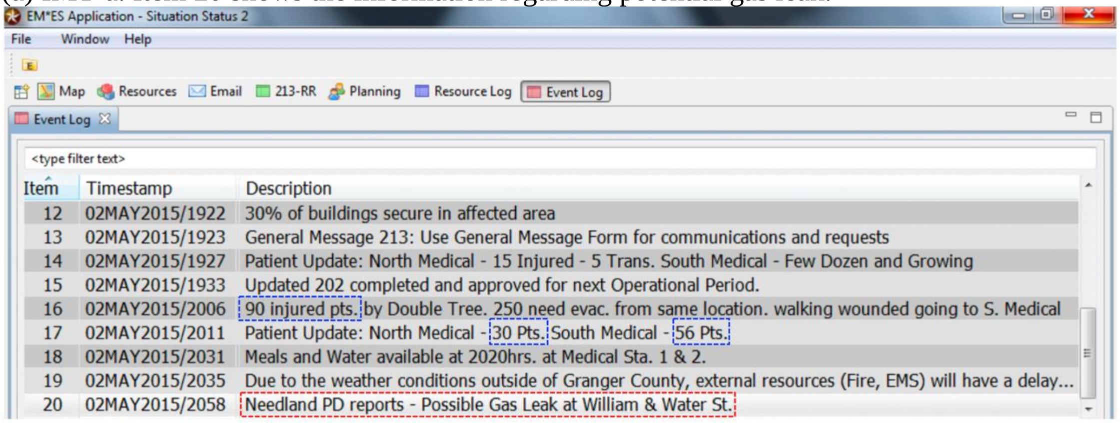


Figure 6.7 Graphical representations of Potential Gas Leak episodes

(a) IMT-a. Item 20 shows the information regarding potential gas leak.



(b) IMT-b. Item 33 shows the information regarding potential gas leak.

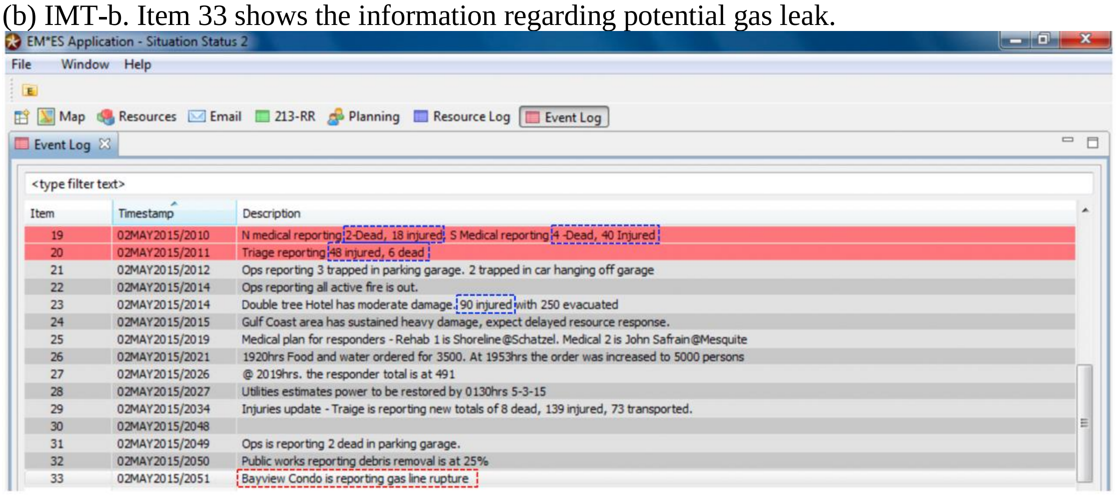


Figure 6.8 Screens captured from EM*ES event log for Potential Gas Leak. The information disseminated for the gas leak is highlighted in red-dotted boxes and numbers of casualties in blue-dotted boxes.

6.5.4. Evaluating challenges and resilient behaviors via IEA

IEA enables the identification of WAD in IMTs, which facilitates the investigation of challenges and resilient behaviors to address such challenges. By placing more emphasis on analyzing the *Content* of the episodes, 40 sub-episodic instances (i.e., part of interactions bounded for a sub-topic within an episode) regarding challenges that the IMT had faced or resilient behaviors were exerted by the team members (or lack thereof) were identified. Among them, four most frequent categories of such instances are presented below:

6.5.4.1. Difficulty of integrating multiple incident data (17 instances)

The most frequently observed challenge in the IMT's information management was associated with integrating and classifying multiple pieces of incident data as the situation evolved. Especially, key roles for information management (e.g., SITL, I&Is, MAP) which were primarily responsible for evaluating and integrating incident data had confusions about number of casualties. From the *Injury/damage Update* episode in IMT-a, for example, SITL found out from the event log a discrepancy between numbers of injuries such as "90 [patients] by Double Tree" vs. "30" plus "56"in "North" and "South Medical" centers [Figure 6.8 (a), the blue-dotted boxes]. To clarify the discrepancy, SITL, I&IL, and I&I2 had over 90 interactions spending additional 287s of SIIL. A similar challenge was also identified in IMT-b [Figure 6.8 (b)]. SITL and MAP discussed inconsistencies among numbers, for example, "18 injured" in "N[orth] Medical", "40 injured in "S[outh] Medical", "Triage reporting 48 injured", and "90 injured" in "Double tree Hotel". Although the discussion regarding these discrepancies took relative fewer interactions and shorter durations than in IMT-a, findings from two IMTs indicate that the members of the IMTs had difficulties integrating multiple pieces of incident information.

6.5.4.2. Confusing and inconsistent information (9 instances)

Although collocated in one facility, the IMT members had confusion over specific terms or event-specific information communicated from different sources. In the *Mass Evacuation Point* episode from IMT-b, ICS209 and MAP sought to find correct street names of the shelter between “Angelo” or “Antelope”, and between “Westpoint” or “West Point”. As a result of the confusion, the members experienced difficulties in locating and labeling the shelter on the incident mapping tool. A similar confusion occurred in naming the *Emergency Medical Center* in IMT-b. For example, I&I2 asked MAP, “Are these centers or stations?” and MAP answered, they are “medical groups”. The confusion over words and inconsistent terms caused 11 more interactions spending additional 46s of SIIL among associated members whereas no such confusion was found in IMT-a. Several instances of ambiguity about event-specific information were identified. In particular, the IMT members took efforts in identifying names of specific facilities to ensure proper event logging. To give an example, as illustrated in Figure 6.9, SITL and I&I2 were looking for specific names of the two medical centers so that they could display the names on the incident mapping tool. They asked different roles such as Operations personnel and Command Liaison Officer. After they realized that the medical centers could be broadly categorized as “north and south”, they began to use “N medical” and “S medical”. This instance shows that an attempt to increase the thoroughness of information (e.g., identifying the exact names of the medical centers) came at a trade-off of reduced efficiency, resulting in 55 more interactions and 200s of SIIL (23% of the episode’s SIIL).

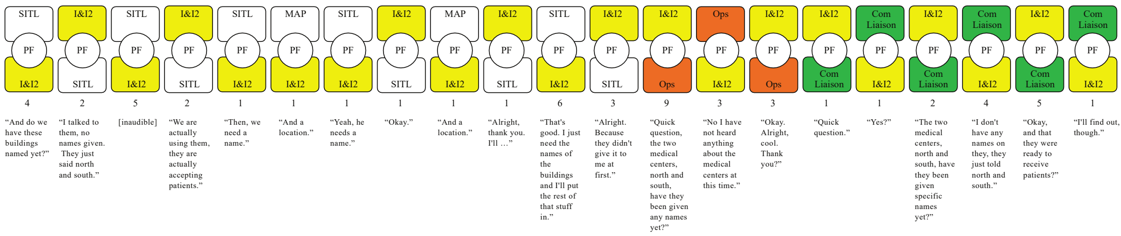


Figure 6.9 An excerpt from Emergency Medical Center from IMT-b regarding the names of two medical centers.

6.5.4.3. Adaptive behavior to excess information (4 instances)

Our analysis showed an excess amount of incident data was fed to Situation Unit (5.5 minutes and 3.3 minutes per new incident input in IMT-a and IMT-b). With the higher incoming rate of incident data, recipients may have had to adapt by improvising their own ways. During the *Initial Field Report* episode in IMT-b, SITL exhibited such improvisation when he grabbed a small plastic box near him and placed the box next to his computer stating to I&IL, "Just consider this my inbox. You slap this stuff [e.g., a field assessment report] right here and I'll enter it as I go." By putting an inbox as a buffer for the influx of incident data, SITL was able to enter information into the event log at his own pace. Actual interactions that happened between SITL and I&IL are presented in Figure 6.10.

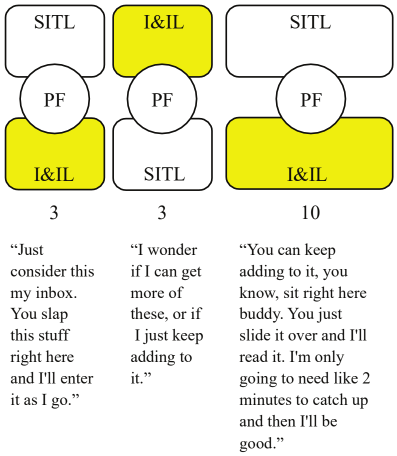


Figure 6.10 An excerpt from Initial Field Report in IMT-b

6.5.4.4. Addressing inadequacy of interaction mediators (4 instances)

To follow incident management protocols such as ICS, the IMT members were expected to use designated paper forms (e.g., ICS 213 general message). However, users of the paper forms often expressed their complaints regarding readability of handwritten notes and additional efforts for typing the handwritten notes and printing copies of typed documents. In the *Injury/damage Update* episode of IMT-a, I&IL after taking a note of a field report stated, “Okay, [a field observer] just gave me a bunch of [expletive] and [SITL] can never read my handwriting”. In the *Potential Gas Leak* episode of IMT-a, I&IL also expressed a nuisance of printing copies for conveying a field report to others saying, “Hey, I need a better way of sending it to you. Needland PD 140 reports possible gas leak at William and Water street. We’ll just print it off and I hate, I hate printing it off.” To that end, I&IL quickly changed his communication method to an email to address the issues associated with the paper forms.

6.6. Discussion

Investigating resilient behaviors in the IMTs has proven to be challenging. While Resilience Engineering (RE) literature provides several important frameworks, operationalization of these frameworks to understand resilience in the IMT requires context-dependent metrics as well as methods for focused evaluation of complex team interactions. While comparison between WAD and WAI shows promise in identifying important resilient behaviors in this domain, a rigorous approach to describe WAD remains a major gap (Patriarca et al., 2018). To fill such research gap, the present study introduced the Interaction Episode Analysis (IEA); a novel method to facilitate detailed investigations of WAD through modeling the three C's of interactions among IMT team members. To better describe the IEA and illustrate its efficacy in the field of practice, two naturalistic observations of the IMTs were conducted. By utilizing data obtained from high-fidelity emergency exercises, we extracted multiple episodes as instances of WAD and provided some measures that characterize the episodes (e.g., frequency, duration, frequently interacted roles, and mediating technologies). Moreover, the IEA enabled the identification of the information management processes, challenges experienced in such processes and adaptive behaviors exhibited to address the challenges. The IEA's utilities and limitations as well opportunities for future research are discussed below.

6.6.1. IEA as a descriptive method for WAD in complex team environments

This article provides some preliminary evidence suggesting that the IEA can be used as a descriptive method to delineate a multidisciplinary team's WAD of coping with given demands (i.e., injects). In particular, using *episodes* as the unit of analysis shows promise in providing convenient boundaries to such complex phenomenon and facilitates focused analysis of abstract constructs such as resilience. While the construct of episode has been advocated for in the research methods literature (Annett, Cunningham, & Mathias-Jones, 2000; Miles & Huberman, 1994; Polkinghorne, 1995), operationalization of episodes as a methodical way has been limited (Annabi et al., 2008).

By applying the IEA to the data collected from two observational studies of representative IMTs, multiple common episodes were obtained. The representative episodes identified in this study, were used to assess primary incident-related information needed and information management phases of collection, evaluation, and dissemination. While previous approaches to model WAD have been interpretive in that they relied on analysts' observations and knowledge to explain the team activities in the field (Furniss et al., 2011; Kendra & Wachtendorf, 2003; Mendonça, 2007), the interaction-based approach taken in the current study shows its utility to describe a team's actual emergent performance focusing on three crucial elements, namely, *Context*, *Characteristics*, and *Content* of an interaction between team members. While content analysis has shown promise in qualitative research to describe team actions or communications, the analysis of context and characteristics of interactions provides a fuller picture that enables the investigation of what roles and technologies in the team are more coordinated to handle a particular demand on a temporal dimension. Given the prevalence of complex interactions among human system elements and the vital role such interactions play for the system to adapt to given demands (Woods & Hollnagel, 2006a), the IEA serves a need for reliable, generalizable, and operationalizable interaction analysis and modeling methods.

6.6.2. IEA as a comparative analysis method

In addition to its utility to enable the focused investigation of episodes by depicting WAD in complex teamwork scenarios, the IEA can be used to compare WAD in similar scenarios. While previous studies that employed episodes illustrated a simple temporal progression of the episodes (Gomes et al., 2014; Rankin et al., 2013), the studies rarely utilize evaluation criteria that allow comparisons between similar contexts. In the current article, several evaluation metrics were introduced to demonstrate the efficacy of the IEA to enable comparisons between the episodes with similar demands. For instance, the *Emergency Medical Center* episode shows a large difference in *frequency of interactions* and *sum of individual interactions' length* between the two IMTs (IMT-a: 29 interactions for 309 seconds of SIIL vs. IMT-b: 188 interactions for 803 seconds of SIIL). In addition, the *most involved roles* and *most used technologies* were different [MAP (34%) and face-to-face (44%) in IMT-a and I&I2 (30%) and paper form (58%) in IMT-b] (Table 6.3). Such differences may trigger additional inquiries to investigate deviations from known WAIs (e.g., expected interactions between specific roles mediated by certain technologies).

In addition, this article shows that the IEA can be used to evaluate if expected phases of information management in the IMTs (i.e., WAI) are realized in the episodes as instances of WAD. Despite promise shown in the current study, defining context-dependent WAI remains an important challenge. For example, while general phases of initial size-up, collection, evaluation, dissemination, and updating were expected in our study, our findings suggest that not all phases of information management were present and that different interaction patterns existed under each phase. Previous research has used SOPs to operationalize WAI with their implementation investigated as WAD (de Carvalho et al., 2018). Nevertheless, making SOPs that cover all the possible incident scenarios is an onerous undertaking, especially in the disaster management domain. Therefore, future work is needed to examine how WAI can be established in different incident contexts to facilitate the comparison between WAI and WAD.

Furthermore, the IEA advocates the utility to capture and interpret particular instances of interest from field practices. We presented four narrative accounts of the challenges and associated resilient actions of IMTs as achieved in the literature (Furniss et al., 2011; Militello et al., 2007; Patterson, Su, & Sarkar, 2020; Rankin et al., 2013). In line with recent WAD visualization methods (Walter, Raban, & Westbrook, 2019) the IEA makes it possible to further describe how often such instances occur, what roles are primarily involved, and how a technical tool mediates interactions between roles. It should be noted that the findings regarding challenges and resilient behaviors were mostly derived from a particular section or unit (e.g., Situation Unit or I&I Unit) of the IMT. Thus, future research is needed to examine how the IMT at a system level can exhibit resilient strategies (e.g., avoiding an anticipated hazard) depending on essential resilience functions (e.g., monitoring and anticipating) (Hollnagel, 2011; Lundberg & Johansson, 2015) in dealing with a specific hazardous scenario.

Lastly, the IEA provides a visual representation of episodes that can further facilitate the understanding of WAD emerging from complex work settings. As shown in the graphical illustration of episodes, the IEA first supports viewers of episodes in readily perceiving its relative length generally determined by the number of interactions involved in the episode. While the temporal progression of episodes was depicted as a single bar in a previous study (Rankin et al., 2013), the episodes illustrated in this article provide much richer visual features such as graphical symbols for roles, technologies, and colors for different sections (Figure 6.3). Taking advantages of these features, viewers can easily recognize which sections are involved and how the involvement changes over time. Such visual features also enable viewers to quickly recognize cross-sectional interactions, that is, a mixture of role symbols of different colors. For instance, three cross-sectional interactions (I&I Unit – Situation Unit, I&I Unit – Operations, and I&I Unit – Command) and their relative lengths can be easily conceived from Figure 6.11. Also, the graphical representation readily reveals that a paper form is a dominant mediator of the interactions.

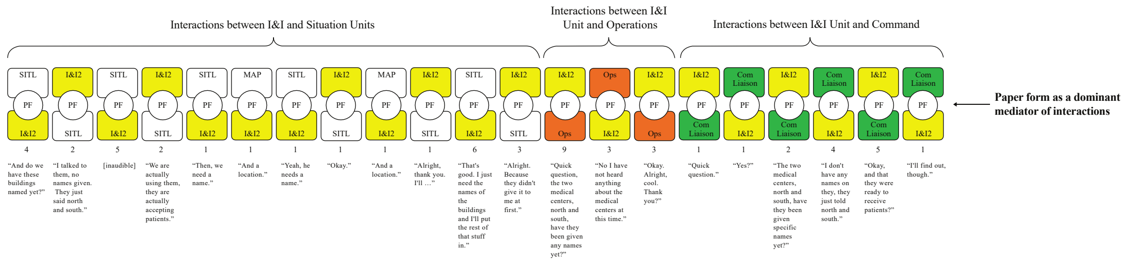


Figure 6.11 Three blocks of cross-sectional interactions in the episode of Emergency Medical Center in IMT-b

6.6.3. Limitations and future work

Several limitations should be addressed in future work. There were some limitations related to the observational context. First, it is to be noted that our study was conducted in a simulated environment. Thus, some features induced from a real incident such as stress or fatigue may have not been rendered well. However, given that opportunities to observe a real emergency are rare and the risks involved in doing so, the EOTC is considered a reasonable alternative as it serves the gold standard in high-fidelity emergency management simulation by replicating the functional and physical settings of an incident command facility and providing realistic incident scenarios. An additional limitation is that not all IMT trainees participated in the study. Therefore, these roles were excluded from audio-recording. Due to such missing data, some episodes were analyzed only in one of the two exercises, not both. Having an identical set of roles in a future study would enable a comparison between two episodes under more homogeneous conditions. One of the challenges in naturalistic studies including ours that involve audio-recording is the presence of noise. The noise recorded in the audio often prevented our research group from accurately transcribing and extracting metadata, sometimes resulting in '[inaudible]' in the transcripts. While audio-recorders were attached to participants' vests for convenience and unobtrusiveness, future studies may utilize headsets for improved audio quality. Another important challenge for the data collection was the large size of the IMT (about 45 members). This resulted in difficulties in identifying certain roles for real-time and retrospective coding, particularly, when a role incumbent of the Planning Section was interacting with another from other Sections (e.g., Operations, Command).

Second, there exists a limitation that arises from different compositions of the IMTs between the two observations. Variability in the IMT members' level of expertise and area of specialization (e.g., law enforcement vs. firefighting) may have affected the team task performance such as information management. Hence, a future study needs to reduce the variability by balancing such individual characteristics of IMT members. Furthermore, a relationship between the layout of the simulation facility and interaction patterns may exist. As indicated in Table 6.3, interactions frequently took place between adjacent units such as Situation and I&I Units. While the influence of proximity on communication between members has been studied (Roberts, Stanton, Fay, & Pope, 2019), future research is necessary to examine how spatial configurations and layout affect interaction patterns in the IMT setting.

Third, the IEA facilitates the analysis of *how* episodes developed differently in coping with the same information input (e.g., locating Emergency Medical Center) and the speculation of *why* such difference might have occurred (e.g., confusing names of the

Center). Nonetheless, the IEA requires further methodological rigor to better support analysts in unraveling the underlying reasons why the IMT members exhibit different behaviors, for instance, through debriefing sessions where participants can revisit their situational awareness, decision-making, and actions taken during the episodes.

Finally, while the IEA shows promise as an analytical method to investigate IMT interactions, the utility of the method to capture complex multi-tasking scenarios should be further investigated. To alleviate the substantial amount of efforts and expert knowledge required for the application of the IEA, a computerized software tool that eases the entry, analysis, and display of the interaction data is worth being developed. In addition, while representing interactions on a temporal dimension is a strength of the IEA, such presentation is sequential. To address the weakness, social network approaches that provide relational structure established over a certain period (e.g., Stanton & Roberts, 2019) may be adopted. Some interactions in a complex team environment may take place in parallel whereas the IEA represents serial dyadic interactions in its current form. In our study, we observed that interactions among more than two roles often occurred. For example, the first part of interactions in Figure 6.11 took place among I&I2, MAP, and SITL. Although the overall interactions appeared to be polyadic (i.e., involving more than two actors), such multiparty interactions were largely composed of multiple dyadic interactions, which were captured by the IEA in line with the original development of episode approach (Korolija & Linell, 1996).

6.7. Summary

This study introduced a novel approach called Interaction Episode Analysis (IEA) to extract and describe WAD in complex team work, and applied the IEA to naturalistic emergency operations exercises to demonstrate its efficacy. Based on interactions between members of a multidisciplinary team, the IEA shows promise to enable the analysis of the IMT's emergent information management performance. Given previous studies' reliance on narrative accounts of actual team activities, the IEA provides an alternative method to investigate complex team work. By providing a rich descriptive representation of WAD, as well as comparative and evaluative utilities, the IEA may help understanding emergent interactive team performance and the impact of mediating tools in coping with either expected or unexpected demands, often referred to as resilience. While several limitations need to be addressed, the IEA shows potential to serve as an analytical method to understand WAD in a wide range of collaborative domains, facilitating the comparison with known WAIs to create more resilient team performance.

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CHAPTER 7 ARTICLE #6

ANALYZING WORK-AS-IMAGINED AND WORK-AS-DONE OF INCIDENT MANAGEMENT TEAMS USING INTERACTION EPISODES ANALYSIS[6]

7.1. Overview

Resilience is an important attribute of incident management teams (IMTs) for managing disasters. Previous research on resilience of IMTs has focused on comparing work-as-imagined (WAI) and work-as-done (WAD) but predominantly used narrative analyses which limited comparisons between IMTs. This article presents a novel Interaction Episode Analysis (IEA) method to identify the IMT's WAI and WAD episodes by analyzing dynamic interactions that occur between different roles to carry out information management tasks. Observations and audio-visual recordings of two high-fidelity IMT exercises were conducted to capture WAD episodes, and semi-structured interviews with experts elicited corresponding WAI episodes. Quantitative analyses using five interaction-based measures were carried out to detect differences of the WAD episodes between two IMTs. Next, qualitative analyses were focused on identifying reasons why such differences may have occurred by comparing the gaps between WAI and WAD episodes. Some of the reasons for WAI-WAD gaps included the non-occurrence of critical interactions that were expected and occurrence of unexpected interactions between IMT members. This article also identifies cases of

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preparatory, proactive, and reactive performance adjustment that can be used to characterize IMT resilience. The IEA method shows promise for investigating how and why the gaps between WAI and WAD in IMTs occur. With the identification of these gaps, future research can be conducted to reconcile the gaps between WAI and WAD episodes, and thus enhance resilience of IMTs in future disasters.

7.2. Introduction

Humans have confronted overwhelming threats of disasters, occurring as natural events, industrial incidents, and public health crises. Annual global economic losses incurred by weather-related events have soared from $14 billion in 1985 (inflation-adjusted) to over 300 billion dollars in 2017 (UNDRR, 2019). Between 1980 and 2019, the US has experienced 263 natural disasters that cost at least one billion dollars (NOAA, 2020). Industrial catastrophes have also revealed unforeseen risks during hazardous industrial processes. The Deepwater Horizon disaster in 2010, for example, has caused over four million barrels of oil spill, resulting in 145 billion dollars in expenses for oil recovery, settlement, and liabilities (Lee, Garza-Gomez, & Lee, 2018). At the time of this writing, the world is experiencing an unprecedented pandemic crisis caused by the novel corona virus disease (COVID-19). As of March 17, 2021, nearly 120 million people were confirmed positive and over 2.6 million people died of the virus (Johns Hopkins University of Medicine, 2021). The global economic losses due to the COVID-19 are estimated to exceed 21 trillion US dollars (McKibbin & Fernando, 2020), which is equivalent to the annual US GDP in 2019 (The World Bank, 2020).

In response to large-scale crises in the US, incident management teams (IMTs) are assembled to direct and support on-scene tactical activities (FEMA, 2017). An IMT involves various disciplines such as firefighting, law enforcement, and emergency medical service, and aims to sustain emergency operations for a longer period by generating and updating incident action plans. However, IMTs face major logistical and operational challenges. A catastrophic disaster usually starts from a sudden onset of local emergencies and propagates to larger consequences in unexpected ways, requiring more human and physical resources than planned. Within the IMTs, members have to rely on inaccurate information, make high-stake decisions under time pressure, and change pre-established emergency plans continuously (Perry, 2007). Thus, resilience—an ability to flexibly adjust team performance to changes and disturbances (Boin, Comfort, & Demchak, 2010)—has emerged as a key attribute of IMTs to cope with these unpredictable and overwhelming challenges during a disaster.

Resilience indicates a system's ability to function dynamically in the face of disruptions and thus reflects what a system *does* rather than what a system *is* or *has* (Hollnagel, 2011; Woods, 2015). What the system does has been analyzed through two analytical lenses: work-as-imagined [WAI] and work-as-done [WAD] (Braithwaite, Wears, & Hollnagel, 2016). WAI refers to work that should be done or is expected to occur whereas WAD represents work as actually carried out in the field. Gaps between WAI and WAD have been framed as inevitable, even necessary, to make the system remain functional in the presence of complexity and uncertainty (Hollnagel, 2015). For example, in their study of emergency departments, Sujan, Spurgeon, and Cooke (2015) revealed that a second hand-over was informally practiced between nurses and paramedics, as opposed to a single hand-over protocol, in order to ensure critical patient safety information has been clearly communicated. Rather than eliminating the difference between WAI and WAD, researchers insist that the variability between the two be reconciled so that a system does not drift into a failure (Hollnagel, 2008; Steen & Aven, 2011).

From a methodological standpoint, analyzing WAI and WAD in IMTs has predominantly relied upon narrative methods aimed at providing descriptive accounts of what had occurred in IMTs (i.e., WAD) during a real incident or a simulated emergency. For example, Weick (1993) delineated a firefighting crew's response to unexpected difficulties that arose during the Mann Gulch fire in 1949. Kendra and Wachtendorf (2003) illustrated resilient actions of IMTs in the reestablishment of an emergency operations center (EOC) in the aftermath of 9/11 World Trade Center attack. For the IMT's operations in a simulated emergency, Militello, Patterson, Bowman, and Wears (2007) observed a simulated EOC and identified common challenges to communication and coordination in the IMT such as asymmetric expertise and information among team members and lack of shared understanding about evolving situations. The narrative methodology was effective in eliciting IMTs' adaptive and improvised actions based on analysts' subjective interpretation and self-reflection. Nonetheless, subjective findings from individual cases are difficult to compare and generalize into a common IMT context (van Ruijven, 2011).

To provide more objective accounts of WAI and WAD in IMT operations, previous studies adopted different approaches. One such approach was an episode analysis to capture a chain of topically-related verbal conversations between IMT members. An episode has been defined as a series of actions and conversations among multiple agents that are bound by a specific topic over a finite time period (Annabi, Crowston, & Heckman, 2008; Korolija & Linell, 1996). An initial study that used episodes in the context of the IMT (Aminoff, Johansson, & Trnka, 2007) generated various episodes from a wildfire exercise (e.g., setting up a staging area and searching a missing person), based on text messages exchanged between IMT members. Further, Trnka and Johansson (2009) presented metrics derived from interactions between IMT personnel to indicate role criticality, such as text communication frequency. Recent studies have illustrated temporal progression of episodes and used a timeline analysis to juxtapose WAI and WAD episodes of IMT operations. For example, Rankin, Dahlbäck, and Lundberg (2013) applied the episode analysis to a simulated wildfire response timeline and identified a list of episodes such as issues with face masks and mask distribution plans. Gomes, Borges, Huber, and de Carvalho (2014) used a similar method to show a series of major events, actions, and communication behaviors (e.g., questioning, giving orders) that occurred over time during a nuclear emergency exercise. Although the episode analysis in this literature provided a detailed description of actual activities in IMTs, thus making it a suitable method to describe the WAD, less attention has been given to operationalizing WAI to enable a comparison between WAI and WAD episodes of IMTs. To address this gap, de Carvalho et al. (2018) used an emergency standard operating procedure (SOP) as an instance of WAI during a simulated train collision incident. In their study, gaps between individual steps in the SOP and implemented actions in the field were identified using an Event Management SOP TimeLine (EMSTL) analysis.

Despite abovementioned attempts to identify and compare between WAI and WAD episodes of IMTs, the research in this area (Gomes et al., 2014; Rankin et al., 2013) relies mostly on narrative approaches (e.g., dialogues between members) and quantitative measures to identify differences between WAD episodes are largely absent. In addition, although de Carvalho et al. (2018) found gaps between the emergency SOP and implemented actions, no analysis has been conducted to identify reasons behind such gaps.

To address these gaps, I have developed the Interaction Episode Analysis [IEA] (Son et al., 2018), a novel method to incorporate interactions between cognitive system components, and identified WAD episodes in high-fidelity IMT exercises (Son, Sasangohar, Neville, Peres, & Moon, 2020). The objective of the current article is to present the efficacy of the IEA in analyzing both WAI and WAD episodes of two simulated IMT exercises as well as to offer quantitative and qualitative metrics to enable the investigation of *how* WAI-WAD gaps emerge as well as *why* such gaps occur. In addition to the comparison between WAI and WAD episodes, individual responders' adaptive and improvisational behavior has been examined to characterize resilient behavior of IMT members as practiced in previous studies (Rankin et al., 2013; Webb, 2004). Expanding this approach further, our study aims to identify three categories of

IMT members' adaptive actions (i.e., preparatory, proactive, and reactive) by referring to a recent framework regarding resilient performance (Hollnagel, 2015). The following sections describe the elicitation of WAI episodes that correspond to the WAD episodes identified previously (see Chapter 6 for more detail). Next, quantitative measures of the WAD episodes are analyzed to find differences between the two IMTs. Then, the WAI-WAD gaps are examined qualitatively to understand how expected interactions differ from actual interactions in the IMTs. In addition, cases of the three categories of IMT members' performance adjustment are presented.

7.3. Materials and methods

7.3.1. Research setting

Data used in this study were collected from naturalistic observations of IMT exercises and interviews with experts at Texas A&M Engineering Extension Service [TEEX] Emergency Operations Training Center [EOTC] (refer to Chapters 5 and 6 for more details of IMT exercises provided at EOTC).

7.3.2. Methods to inform WAI and WAD episodes

Data needed to develop WAI and WAD episodes using the IEA were collected from two different yet interrelated sources. The WAD episodes of the IMTs have been developed from two naturalistic observations at EOTC (refer to Chapter 5 for more details of the WAD episodes). Next, the associated WAI episodes were elicited using semi-structured interviews with program managers, course designers, and instructors at

EOTC. The research protocol for this study was approved by the Texas A&M University Institutional Review Board (No.: 2016-0489D).

7.3.2.1. WAI episodes for IMT's expected information management process

Participants

To elicit WAI episodes corresponding to the WAD episodes captured from the naturalistic observations at EOTC, semi-structured interviews were conducted with seven emergency training program managers, training course designers, and instructors working at EOTC. A program director, who helped arrange the previous observations, provided a convenience sample of participants for the interviews based on their expertise. The lead author recruited the participants and conducted individual interviews. The mean (SD) age of the participants was 57.1 (9.4) years. The mean (SD) years of experience in emergency service was 25.7 (7.1) years and the mean (SD) years of experience in emergency training was 10.0 (3.3) years.

Data collection and analysis of WAI episodes in IMTs

The elicitation of WAI episodes followed two steps: the identification of expected interactions from six experts (P01-P06) and the final adjustment by the main Planning Section instructor (P07) of the IMT exercises previously observed. First, semi-structured interviews were conducted with the six participants in May 2019. Participants were asked about their expectations of roles in the Planning Section and interactions between the roles. Next, a brief description of the WAD episodes identified from the previous observations was provided, followed by a series of questions about their expectations related to interactions between sections and between roles in the IMT (Table 7.1). Each interview took about 100 minutes on average.

The recorded interviews were transcribed and analyzed by the lead author to elicit WAI episodes pertaining to individual topics of the WAD episodes identified previously. To elicit an anticipated information management process in the IMT, the interviewees were asked to illustrate expected interactions between roles and expected conversations during the interactions. Finally, the expected interactions for each topic were synthesized and presented to the main Planning Section instructor (P07) in order to reconcile discrepancies between the episodes and finalize them.

Table 7.1 Questions used in the semi-structured interviews

Theme	Questions
Expected roles	• What are expected roles of the Planning Section? • What are expected roles of individual members of the Planning Section?
General expected interactions between roles	• What are expected interactions between the Planning Section and other sections? • What are expected interactions between roles in the Planning Section?
Episode-specific expected interactions between roles	• What roles do you think should interact in this episode? • What are expected interactions between roles in this episode?

7.3.3. Analyzing WAD-WAD and WAD-WAI differences

The analysis of the WAI and WAD episodes was conducted in steps. First, the differences between WAD episodes of the two IMTs (i.e., WAD-WAD differences) were analyzed quantitatively to quickly discern how the two IMTs adapted their performance to the same task in different ways. In other words, the analysis of WAD-

WAD differences was focused on comparing quantitative measures of each IMT's WAD episode by its topic (e.g., Initial Field Report, Potential Gas Leak). Since no quantitative measure of IMT resilience was available, I developed quantitative measures that represent two common attributes of IMT resilience: *rapidity*, namely, how quickly an IMT processes a task input (Chang & Shinozuka, 2004; Kendra & Wachtendorf, 2003) and *team interaction*, that is, how an IMT collectively handles a task input (Gomes et al., 2014; Hartmann, Weiss, & Hoegl, 2020). To operationalize the quantitative measures related to rapidity and team interactions, a set of notations has been made to an episode, using the contexts (i.e., roles) and temporal characteristics (i.e., frequency and duration) of interactions (Figure 7.1). A series of interactions between roles such as an initiator and a receiver is noted as i (e.g., 1, 2, …, N). To capture temporal characteristics of the interactions, a time duration of individual interactions is noted as T_i. T_s represents the time when an episode starts and T_e refers to the time when the episode ends.

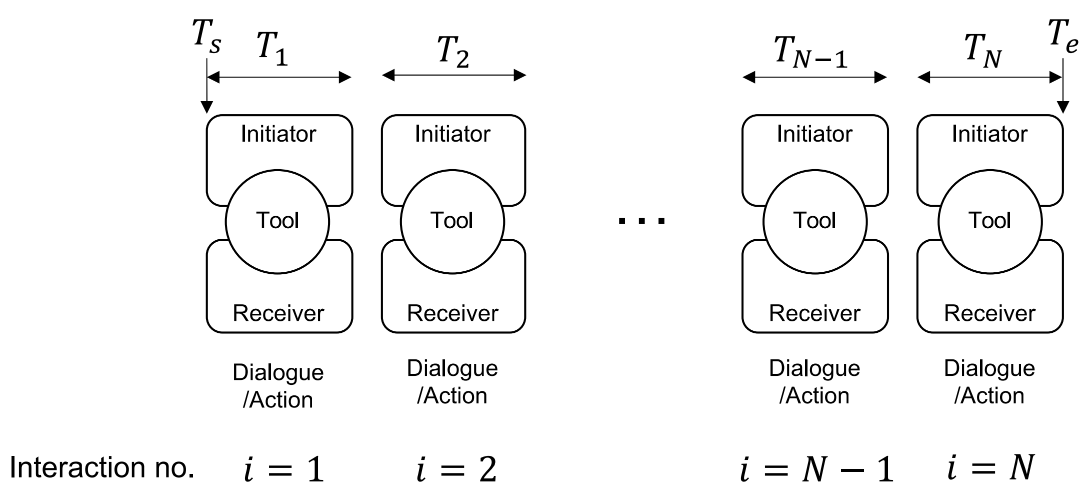


Figure 7.1 Notations of an episode for quantitative measures

7.3.3.1. Quantitative analyses

Using the notations above, I developed two groups of measures relevant to two important attributes of IMT resilience: Three rapidity-related measures developed in our study are Frequency of Interactions (FI), Episode Length (EL), and Sum of Individual Interactions' Length (SIIL). In addition, two team interaction-related measures have been developed. Interactions within an IMT can be categorized either as occurring between different sections (e.g., Planning – Operations) or between different members (e.g., Planning Situation Unit Leader – Operations Fire Branch Director). For the respective type of team interactions, Cross-sectional Interaction Ratio (CSIR) and Cross-agent Diversity Index (CAID) were developed.

1) Frequency of Interactions (FI): FI quantifies how many interactions between roles of an IMT have occurred during an episode and thus is expressed as Equation 7.1. The number of interactions between team members has been used to indicate a degree of collaborations across different roles that are required for the IMT to exhibit resilient performance (Klimek, Varga, Jovanovic, & Székely, 2019; Li, Dong, & Mostafavi, 2019). Therefore, the higher FI indicates more interactions between different roles to convey or exchange incident information and make decisions based on such information.

$$FI = N \qquad \text{Equation 7.1}$$

2) Episode Length (EL): EL refers to the time elapsed from the beginning of an episode (T_s) to its end (T_e). Hence, EL is expressed as Equation 7.2. The EL has been initially used to represent how long it takes for an IMT to finish a team task (Rankin et al., 2013). In the context of disaster response, previous research (Boin et al., 2010; Mendonça, Beroggi, van Gent, & Wallace, 2006) claim that quicker IMT incident planning and actions (i.e., smaller EL) can be used as a marker of resilient IMTs.

$$EL = T_e - T_s \qquad \text{Equation 7.2}$$

3) Sum of Individual Interactions' Length (SIIL): SIIL quantifies how much time the IMT members collectively spent interacting during an episode. SIIL is expressed as Equation 7.3.

$$SIIL = \sum_{i=1}^{N} T_i \qquad \text{Equation 7.3}$$

where T_i is the duration of the i^{th} interaction of the episode. As FI does not differentiate between short and long interactions and EL considers only the beginning and the end of an episode, it is necessary to calculate the sum of durations of individual interactions that constitute the episode. In such regards, SIIL complements FI and EL by characterizing the density (i.e., more frequent interactions with the same EL or longer interactions with the same FI). Thus, the larger SIIL value indicates more condensed interactions during an episode.

4) Cross-sectional Interaction Ratio (CSIR): CSIR measures the ratio of between-section interactions to within-section interactions. Thus, CSIR is expressed as Equation 7.4.

$$CSIR = \ln\left(\frac{N_{inter}}{N_{intra}}\right) \qquad \text{Equation 7.4}$$

where N_{inter} is the number of interactions between sections and N_{intra} is the number of interactions within a section during an episode. A negative CSIR indicates more interactions within the same section than between different sections in the IMT. Interactions between different functions or groups have been indicated as another marker of IMT resilience (Gomes et al., 2014; Pramanik, Ekman, Hassel, & Tehler, 2015). Therefore, it is necessary to consider the number of interactions that have occurred across different sections of the IMT. In fact, experts of IMT training indicated that cross-sectional interactions are necessary to establish a common operating picture and thus to make adaptive decisions to emerging problems (J. Grassinger, personal communication, June 14, 2017).

5) Cross-agent Interaction Diversity (CAID): CAID quantifies interactions between different members in an IMT. While CSIR is a measure of section-level

interactions, CAID measures the interactions between roles in the IMT regardless of the sections they belong to. CAID has been adapted from ecological diversity (Magurran, 2013), which is also known to be an important factor of resilience of an ecosystem (Elmqvist et al., 2003). The CAID is expressed as Equation 7.5

$$CAID = -\sum_{j=1}^{N_d} P_j \ln{(P_j)} \quad \text{Equation 7.5}$$

where N_d is the number of unique dyads of roles interacting in the episode and P_j denotes a portion of the j^{th} dyad's interaction frequency. Due to the way CAID is computed as above, a measure of CAID depends on two things: 1) the number of unique dyads (i.e., N_d) in the episode and 2) the portion of the dyads (i.e., P_j). The higher CAID means more unique dyads in the episode and more evenly distributed portions of the dyadic interactions.

To provide an example for each of the measures, Figure 7.2 illustrates a mock-up episode that consists of twelve interactions among four different roles in an IMT: A, B, C, and D. The start time (T_s) and end time (T_e) of the episode are noted at the first and the last interactions, respectively. In this mock-up episode, there are nine between-section interactions ($N_{inter} = 9$) and three within-section interactions ($N_{intra} = 3$). While there are twelve interactions in this example, there are four unique, undirected dyadic interactions ($N_d = 4$): A-B, A-C, C-D, and B-D. A portion of the individual dyadic interactions can be calculated. For example, since there are three interactions between A and B, the portion of A-B dyad is $P_{A-B} = \frac{3}{12} = 0.25$. Likewise, portions of other dyads can be calculated: $P_{A-C} = \frac{3}{12} = 0.25$, $P_{C-D} = \frac{2}{12} = 0.17$, and $P_{B-D} = \frac{4}{12} = 0.33$.

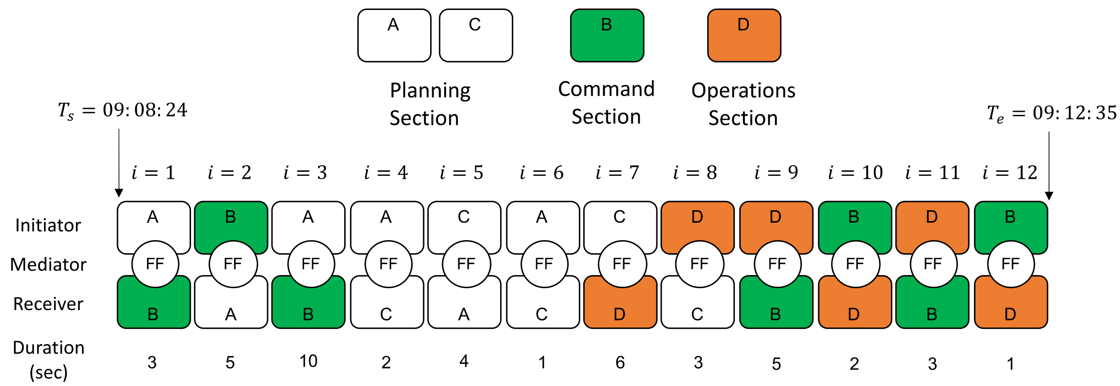


Figure 7.2 A mock-up episode and associated quantitative measures

Using these values, the five measures of the mock-up episode can be calculated as follows:

- $FI = 12$
- $EL = T_e - T_s = 09:12:35 - 09:08:24 = 251\ (seconds)$
- $SIIL = \sum_{i=1}^{12} T_i = 3 + 5 + 10 + \cdots + 2 + 3 + 1 = 45\ \ (seconds)$
- $CSIR = \ln\left(\frac{N_{inter}}{N_{intra}}\right) = \ln\left(\frac{9}{3}\right) = 1.10$
- $CAID = -\sum_{j=1}^{4} P_j \ln(P_j) = -[0.25\ln(0.25) + 0.25\ln(0.25) + 0.17\ln(0.17) + 0.33\ln(0.33)] = 1.36$

The quantitative analyses of WAD episodes were conducted upon an assumption that the quantitative measures for an episode of the same topic would be similar between IMTs. Such an assumption can be considered to be met when the IMTs received the similar task inject and had similar role composition and qualification of the role incumbents. Considering that this assumption has been met for the IMTs trained at EOTC, the five quantitative measures were calculated for the six episodes identified from the two simulated IMTs at EOTC. Due to the limited sample size, however, a quantitative difference between the two IMTs was assumed to be large if a value of one IMT was more than double that of the other IMT or if the sign of the value is opposite (e.g., positive and negative CSIR values). For such large differences, qualitative analyses were subsequently conducted to specifically investigate what has contributed to the differences.

7.3.3.2. Qualitative analyses

Qualitative analyses were focused on identifying explanations for the quantitative differences of the WAD episodes between the two IMTs took place and how such differences were related to WAI episodes. The quantitative measures informed aspects of the WAD episodes require detailed qualitative examinations. For instance, in cases where an IMT had a larger CSIR or CAID than the other IMT, a subsequent qualitative analysis was focused on what contributed to more interactions between sections or between roles. When an IMT has a larger EL, a main focus of the qualitative analysis was to find which interactions have made the overall episode last longer. To further understand why such interactions have occurred, the gaps between WAI and WAD episodes in each IMT were compared.

Also, to further demonstrate the efficacy of the IEA to capture individual members' adaptive behavior in addition to the whole-of-episode analysis, I also examined individual interactions of the WAD episodes to identify adaptive and improvisational actions. The identification of the IMT members' adaptive actions was conducted by referring to the framework of performance adjustment (Hollnagel, 2015). This framework suggests three categories of performance adjustment: preparatory, proactive, and reactive adjustment. Preparatory adjustment means creating conditions and resources for time, humans, tools, and information so that a team can initiate its functioning. Proactive adjustment refers to avoiding conditions that are likely to cause negative impacts on the team operations. Reactive adjustment indicates compensating for difficult or undesired conditions that had already occurred.

7.4. Results

7.4.1. Description of WAI and WAD episodes in IMTs

A total of six episodes were identified in the two IMTs during the 'Needland' tornado incident exercise. Each episode pertained to a different information management task to be dealt with in the IMTs: sharing initial incident assessment, updating civilian injury and property damage, disseminating locations of major facilities such as emergency medical center, joint information center, and mass evacuation point, and sharing information of a new threat during a disaster such as potential gas leak (refer to Table 6.2 for more detail).

7.4.2. Quantitative analyses of WAD episodes between IMTs

To facilitate the detection of quantitative differences between two IMTs (IMT-a and IMT-b), pairs of the five measures between two IMTs are collated per episode. Figure 7.3 presents the five quantitative measures of the WAD episode regarding Initial Field Report. A large difference between the two IMTs was found only in CAID (0.90 in IMT-a vs. 0.27 in IMT-b). Next, Figure 7.4 shows the quantitative measures of the Injury/Damage Update WAD episode. No large quantitative differences between the two IMT were found in this episode.

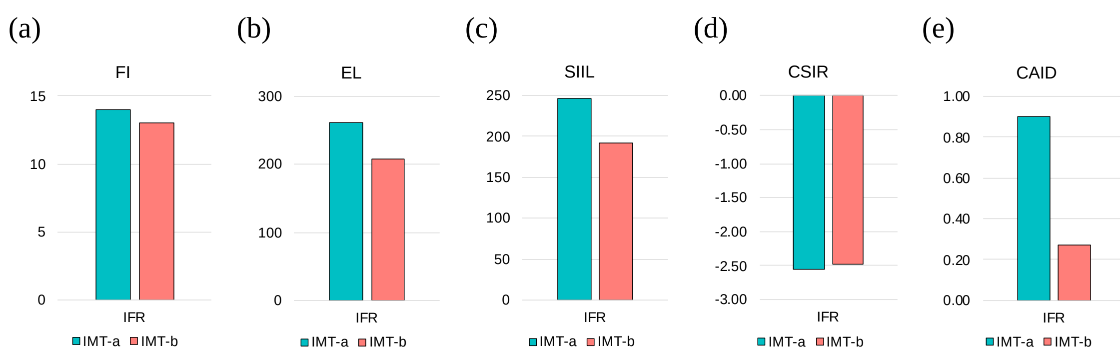


Figure 7.3 Quantitative measures of the Initial Field Report (IFR) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

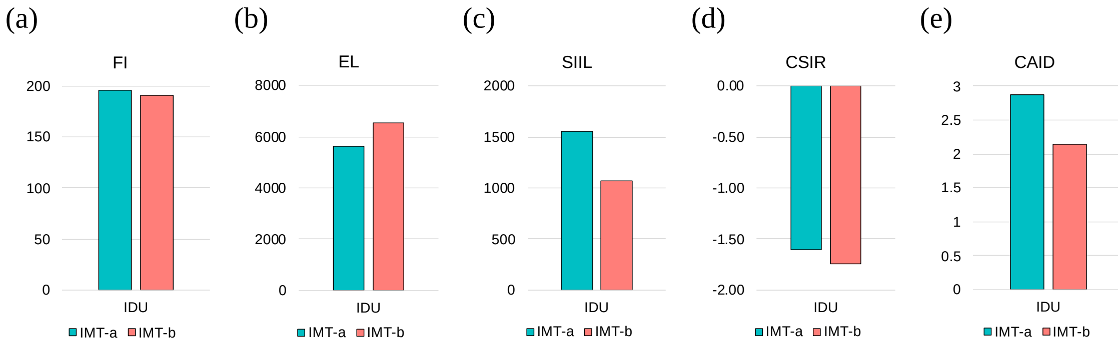


Figure 7.4 Quantitative measures of the Injury/Damage Update (IDU) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

Quantitative measures of the Emergency Medical Center (EMC) WAD episode are presented in Figure 7.5. While EL and CAID were similar, three other measures showed large differences between the two IMTs (FI=29 in IMT-a vs. 188 in IMT-b; SIIL=309 seconds in IMT-a vs. 803 seconds in IMT-b; CSIR=-0.07 in IMT-a vs. 0.01 in IMT-b). With respect to the Joint Information Center (JIC) episode (Figure 7.6), all five quantitative measures showed large differences between the two IMTs (FI=10 in IMT-a vs. 22 in IMT-b; EL=255 seconds in IMT-a vs. 5,715 seconds in IMT-b; SIIL=52 seconds in IMT-a vs. 184 seconds in IMT-b; CSIR=-0.41 in IMT-a vs. -0.18 in IMT-b; CAID=1.09 in IMT-a vs. 2.44 in IMT-b).

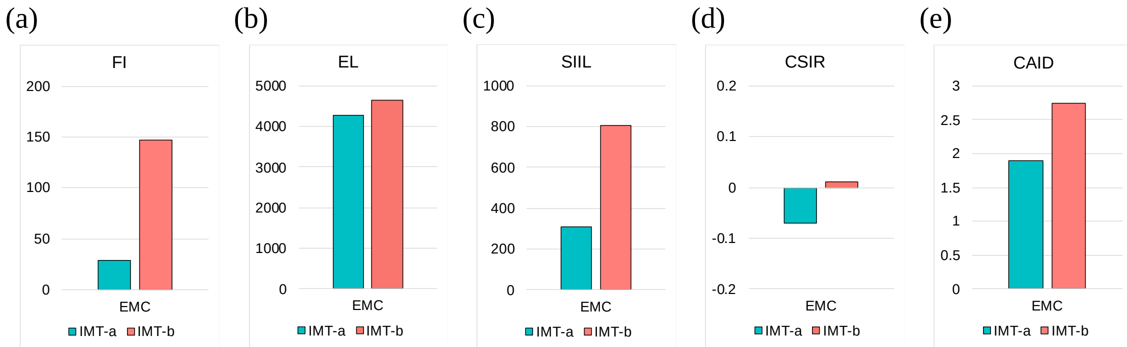


Figure 7.5 Quantitative measures of the Emergency Medical Center (EMC) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

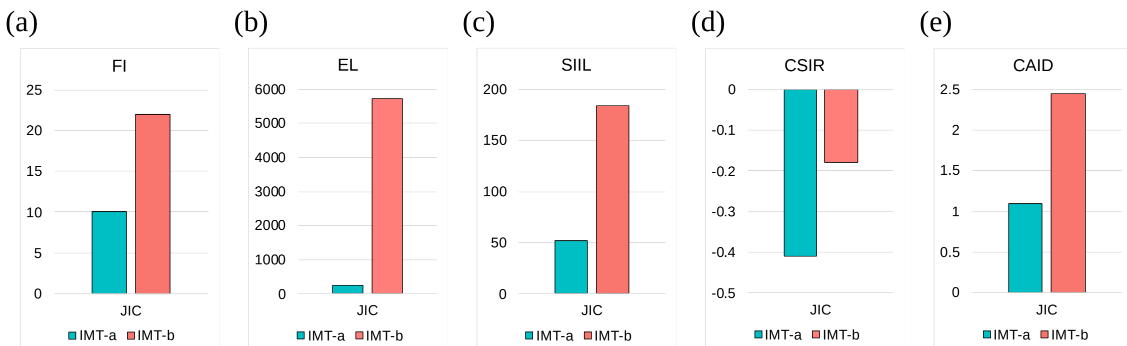


Figure 7.6 Quantitative measures of the Joint Information Center (JIC) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

With respect to the Mass Evacuation Point (MEP) episode, there were large differences in FI (43 in IMT-a vs. 99 in IMT-b) and EL (763 seconds in IMT-a vs. 3,627 seconds in IMT-b) between the two IMTs as shown in Figure 7.7.

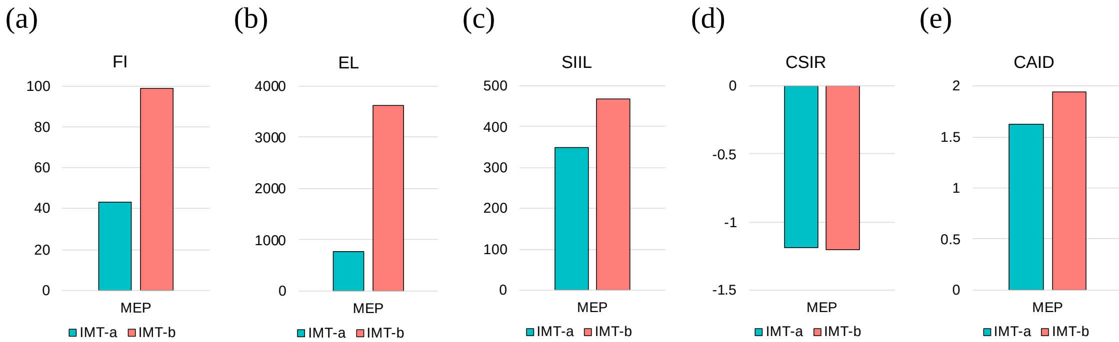


Figure 7.7 Quantitative measures of the Mass Evacuation Point (MEP) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

Figure 7.8 shows the quantitative measures of the Potential Gas Leak episode. In this episode, FI (19 in IMT-a vs. 50 in IMT-b) and CSIR (-2.94 in IMT-a vs. -0.05 in IMT-b) showed large differences whereas other measures were similar between the two IMTs.

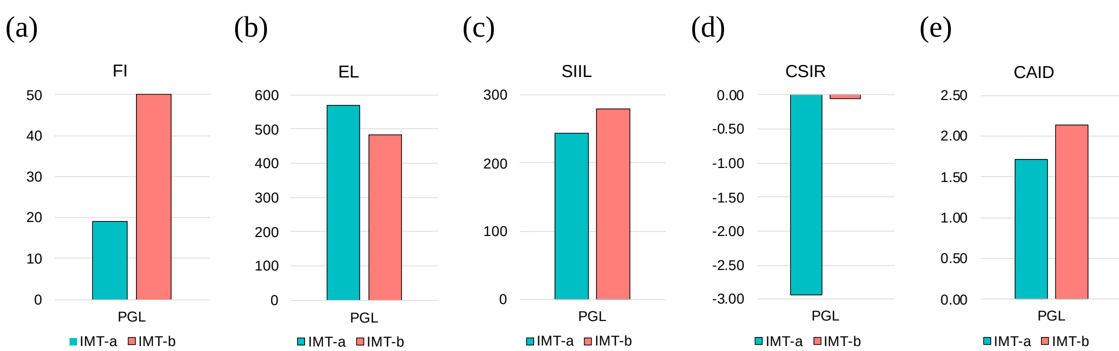


Figure 7.8 Quantitative measures of the Potential Gas Leak (PGL) episode between two IMTs: (a) Frequency of Interactions; (b) Episode Length; (c) Sum of Individual Interactions' Length; (d) Cross-sectional Interaction Ratio; and (e) Cross-agent Interaction Diversity

7.4.3. Qualitative analyses of WAI and WAD episodes in IMTs

7.4.3.1. Qualitative investigations of quantitative differences between episodes

For the large quantitative differences between the two IMTs, qualitative analyses offered possible reasons behind the differences by examining the gaps between WAI and WAD episodes.

With respect to the IMT-a's higher CAID for the Initial Field Report (IFR) episode than IMT-b, a qualitative analysis shows differences in the number of roles involved in processing the Initial Field Report information. The WAI episode [Figure 7.9 (a)] expects the Initial Field Report to be validated by Operations and disseminated via Situation Unit Leader (SITL) and Event Logger (LOG) in Planning Section. Corresponding WAD episodes show that three pairs of roles (FOB-I&IL, Inst2-I&IL, and I&IL-I&I2) interacted in IMT-b [Figure 7.9 (b)] and two pairs of roles (FOB-I&IL and SITL-I&IL) interacted in IMT-a [Figure 7.9 (c)]. The qualitative analysis informed by the difference in CAID revealed that the I&IL in IMT-a had a technical issue with a printer and had to communicate with Instructor 2, which was I&IL's cross-sectional interactions, leading to a higher CAID in IMT-a.

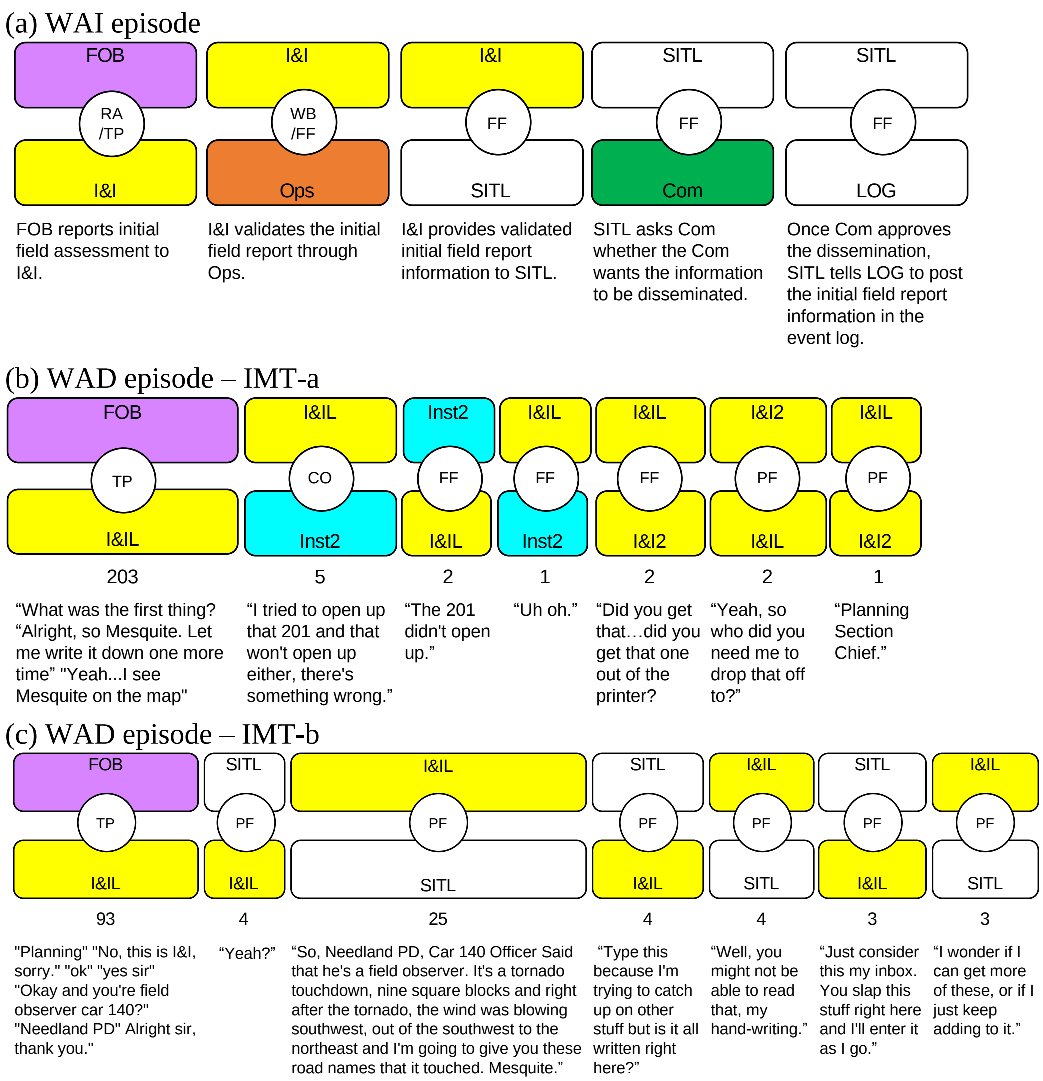


Figure 7.9 The WAI episode and part of the WAD episodes for the Initial Field Report: (a) In the WAI episode, the IMT is expected to validate and disseminate the initial field assessment reported from a FOB; (b) In IMT-a's WAD episode, I&IL prints out paper copies of the initial field report and tells I&I2 to give it to Planning Section Chief; (c) In IMT-b's WAD episode, I&IL shares the initial field report directly with SITL

Regarding the higher FI, SIIL, and CSIR in IMT-b for the Emergency Medical Center episodes, it was found that interactions between Logistics Medical and the SITL were expected to occur to convey specific names and locations of the Emergency Medical Center to MAP [Figure 7.10 (a)]. However, a corresponding WAD episode in

IMT-a showed that Logistics Medical provided the information of Emergency Medical Center directly to MAP without involving SITL [Figure 7.10 (b)]. In IMT-b, the expected interactions between Logistics Medical and SITL have not occurred [Figure 7.10 (c)]. The direct interactions between Logistics Medical and MAP in IMT-a indicate expedited processing of the Emergency Medical Center information with relatively smaller FI and SIIL. In IMT-b, however, due to the absence of such critical interactions between Logistics Medical and SITL, IMT-b had more between-section interactions (i.e., higher FI) and spent longer time between members from different sections (i.e., higher SIIL) to identify the names and locations of the Emergency Medical Center alternatively. The interactions across different sections also contributed to higher CSIR in IMT-b than in IMT-a.

(a) WAI episode

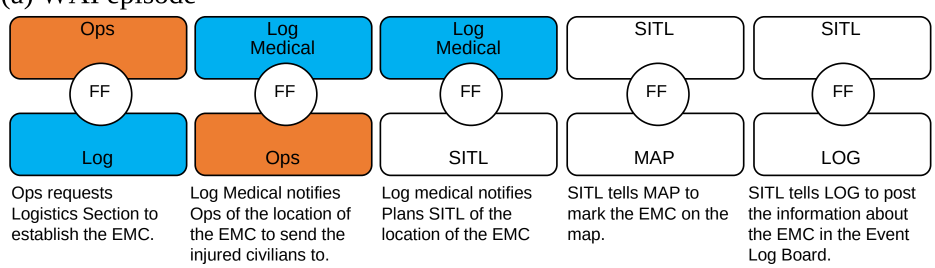
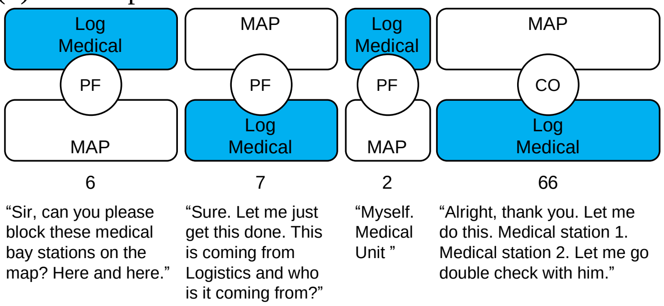


Figure 7.10 The WAI episode and part of the WAD episodes for the Emergency Medical Center: (a) the WAI episode shows expected interactions regarding the location of the Emergency Medical Center. Logistics Medical is expected to provide the location to SITL; (b) the WAD episode of IMT-a where Logistics Medical provides names and locations of two medication stations to MAP; (c) the WAD episode of IMT-b where I&I2 seeks names of Emergency Medical Centers to Operations and then Command Liaison as Logistics Medical did not provide such information.

(b) WAD episode – IMT-a



(c) WAD episode – IMT-b

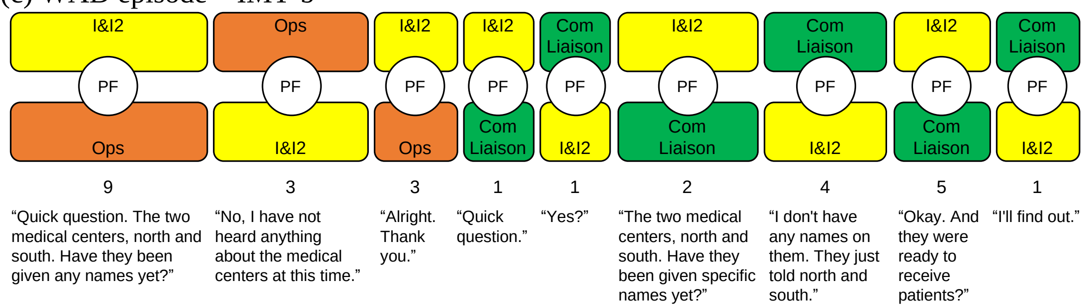


Figure 7.10 Continued

The WAI episode of the Joint Information Center shows that an IMT is expected to disseminate the Joint Information Center information (e.g., location) via the incident map and event log. The WAD episode of IMT-b shows unanticipated interactions between a FOB and I&IL and between Command Liaison and I&IL [Figure 7.11 (a) and (b)]. These interactions have occurred to respond to the FOB’s request for the location of the Joint Information Center to I&IL. The presence of such unexpected interactions to further share the location information with the FOB have increased FI, EL, and SIIL in IMT-b. In addition, I&IL’s interactions with the roles outside the Planning Section such as the FOB and Command Liaison led to the higher CAID in IMT-b than that of IMT-a.

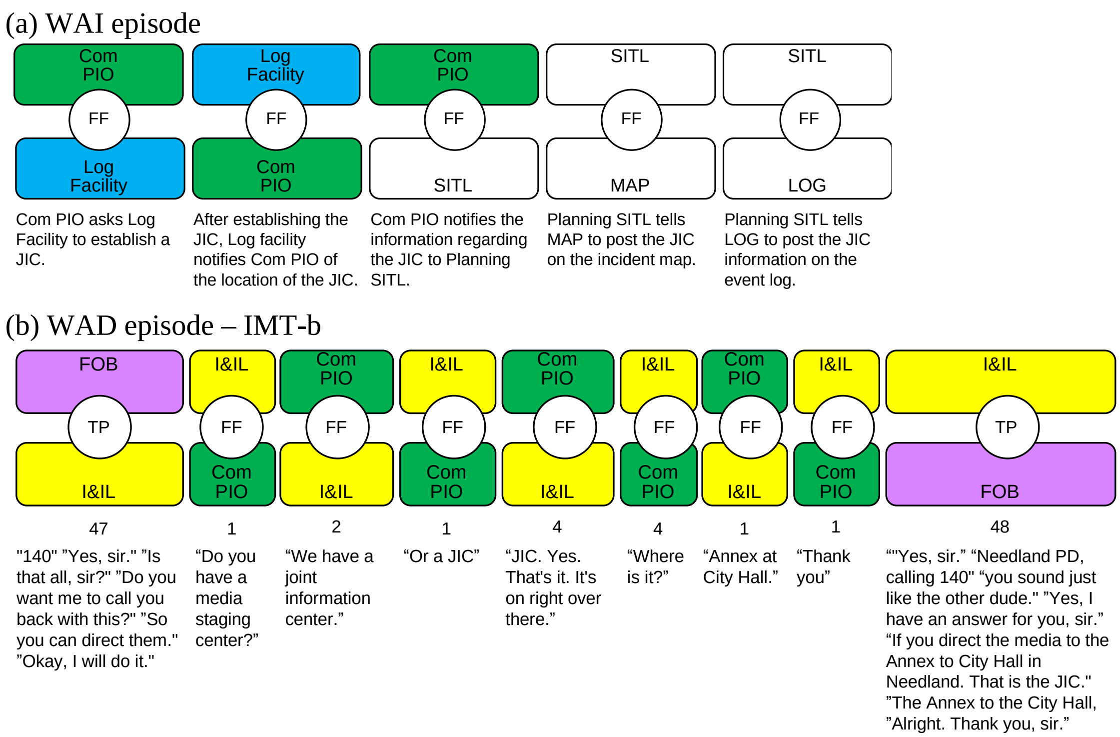


Figure 7.11 The WAI episode and part of WAD episode for the Joint Information Center in IMT-b: (a) No interaction between a FOB and I&I is expected; (b) In IMT-b, A FOB asks I&IL to find out the location of a Joint Information Center. I&IL obtains such information from Command PIO and replies to the FOB.

Concerning IMT-b’s higher FI and EL for the Mass Evacuation Point episode, the qualitative analysis shows that although a shelter (i.e., Mass Evacuation Point) for evacuees has been established, IMT-b was having difficulty putting the location of the shelter into an incident map due to confusing street names of the shelter (Figure 7.12). For example, two members of IMT-b, MAP and ICS209 (a role in charge of providing an incident summary), were trying to find correct street names of the shelter (e.g., “Antelope” vs. “Angelo”). In addition, the two members were not able to locate the streets at the incident mapping program.

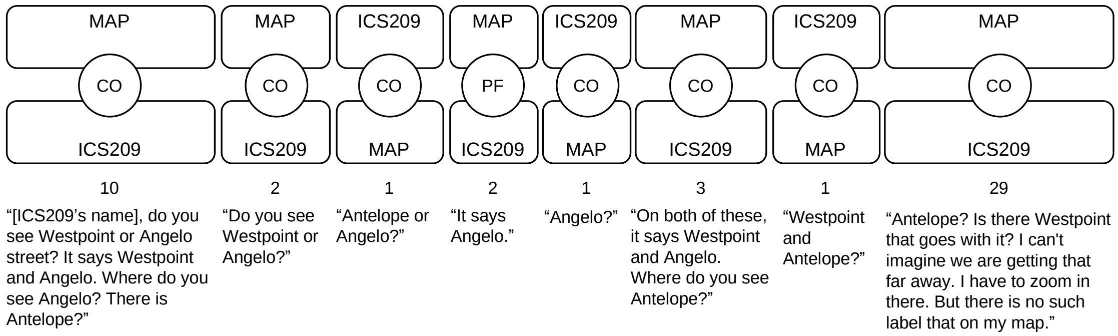


Figure 7.12 Part of the Mass Evacuation Point episode in IMT-b: MAP and ICS209 are experiencing difficulty finding the street names ("Westpoint" and "Angelo") from the incident mapping program.

For the Potential Gas Leak episode, it was expected that the possible gas leak would be reported to I&I, validated against Ops Fire and Command Liaison, and disseminated through SITL and MAP [Figure 7.13 (a)]. While the first interaction expected between a FOB and I&IL via telephone has actually occurred to an initial gas leak report, subsequent interactions showed differences between the WAI and WAD episodes. In IMT-a, the possible gas leak report has been disseminated without validation, resulting in fewer interactions [Figure 7.13 (b)]. In IMT-b, on the contrary, I&IL located Ops Fire and asked him to validate the possible gas leak report [Figure 7.13 (c)], which is aligned with the WAI episode. Such a difference between the two IMTs was the reason for IMT-a's smaller FI, compared to IMT-b. Also, the absence of the cross-sectional validation of the gas leak report in IMT-a is also reflected in the lower CSIR of IMT-a compared to that of IMT-b.

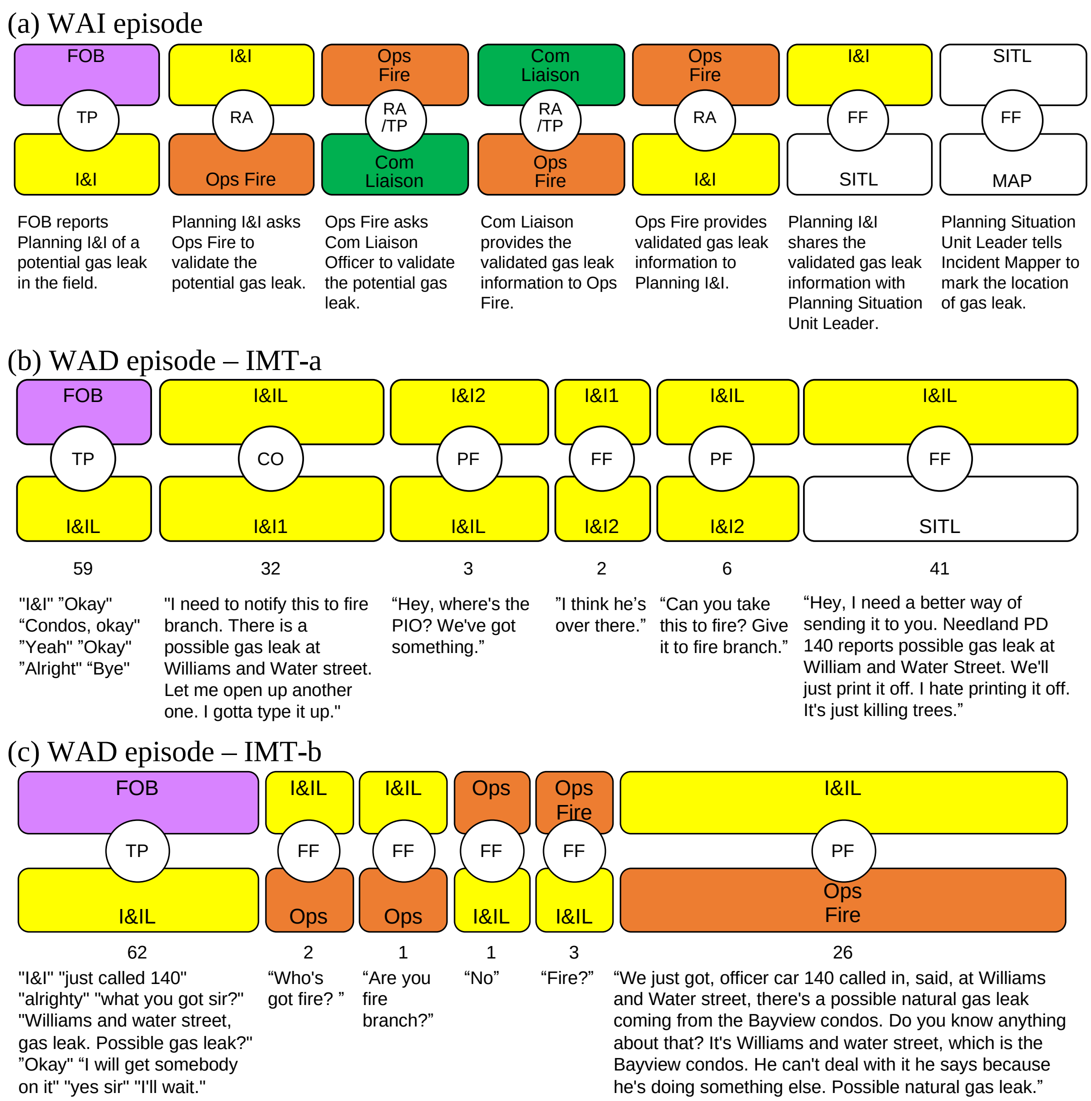


Figure 7.13 The WAI episode and part of the WAD episode for the Potential Gas Leak in IMT-a: (a) The IMT is expected to validate the potential gas leak report against Ops Fire; (b) In IMT-a's WAD episode, I&IL provides the possible gas leak report directly to SITL without validating it against Ops Fire; (c) In IMT-b's WAD episode, I&IL goes to Ops Fire and asks him to validate the gas leak report.

7.4.3.2. Adaptive actions of IMT members in WAD episodes

In addition to the benefits of investigating why there was a gap between the overall WAI and WAD episodes, the IEA facilitated the identification of individual IMT members' adaptive or improvisational behaviors exhibited during the WAD episodes by displaying a short chain of conversations and actions they took to deal with specific conditions or issues. Table 7.2 provides the examples of preparatory, proactive, and reactive performance adjustment in terms of time, roles and responsibilities, tools and materials, work processes, and data and information.

Table 7.2 Examples of performance adjustment in the WAD episodes

Aspect	Preparatory adjustment	Proactive adjustment	Reactive adjustment
Time	Pre-determining an operational period (e.g., 8 am to 8 pm, IDU, IMT-b)	Avoiding disseminating unvalidated information too early (possible gas leak - PGL, IMT-b; anticipated power restoration, IDU IMT-b)	Recognizing unvalidated information has already been disseminated (PGL, IMT-a)
Roles	Clarifying the role of Logistics sections in the IMT regarding shelters (MEP, IMT-a)	Eschewing duplicating efforts among members with similar duties. I&I2 did not want to collect the same information as I&I1, IDU, IMT-a)	Assuming an additional role while the original incumbent for the role was absent (IDU, IMT-b; MEP, IMT-b)
Tools and materials	Pre-setting an ICS form as a preferred method of communication at the onset of an operational period (IDU, IMT-a)	Placing ICS forms at every section so that the forms can be readily located and used (MEP, IMT-b)	Improvising existing tools for another purpose (e.g., using a paper tray as an inbox for incoming documents, IFR, IMT-b; IDU, IMT-b)
Work processes	Determining to whom validated information needs to be distributed (IFR, IMT-a) Ensuring that any document should have an initial of the person who provided the information for traceability (EMC, IMT-b)	Requesting the incident map to be updated continuously throughout an operational period (EMC, IMT-a)	Typing information being collected rather than taking a note (IFR, IMT-a) Revising a communication method from paper hand-carrying to emailing to save efforts for delivery (IFR, IMT-b; PGL, IMT-a)

Table 7.2 Continued

Aspect	Preparatory adjustment	Proactive adjustment	Reactive adjustment
Data and information	Establishing criteria of disclosing sensitive information (e.g., fatalities, possible gas leak, PGL, IMT-a)	Checking information is up to date before attending a meeting (IFR, IMT-a) Proactively seeking necessary information (e.g., location of the JIC) rather than waiting for others (e.g., Logistics) to provide it (JIC, IMT-a; JIC, IMT-b)	Verifying that the disseminated information (e.g., injuries, evacuees) is accurate (IDU, IMT-a; IDU, IMT-b) Noticing a planned action (e.g., establishing a new shelter) has not actually occurred and speaking this with a responsible role (MEP, IMT-a)

Instances of preparatory adjustment included pre-determining the IMT's operational period (e.g., 12-hour shift from 8 am to 8 pm), clarifying a role responsible for a specific task subject (e.g., Logistics Section for managing shelters), pre-setting a standard form of communication (e.g., using ICS forms), pre-determining information management processes (e.g., selecting recipients, putting initials on the forms), and pre-establishing criteria for sharing sensitive information (e.g., posting fatalities in the event log).

Examples of proactive adjustment behavior were avoiding disseminating unvalidated information prematurely, reducing duplicate efforts among members, placing the required paper forms at every section in advance, and keeping the incident map up to date. As an illustrative example, the Injury/Damage Update episode in the IMT-b shows that I&I2, who was assuming the same role as I&I1, mentioned he would avoid collecting the same information in order to reduce duplicating efforts:

> [I&I2 to I&IL] "*He (I&I1) was taking notes for a second but he disappeared. I don't want to duplicate what he's got. So, I'm going to wait and see if he doesn't have the same information.*"

Finally, reactive performance adjustment included instances in which IMT members recognized that unvalidated gas leak information has been posted at the event log, took an additional role when the original role incumbents were not present, improvised existing tools for another purpose, changed data entry method (typing vs. note-taking), or verified whether the disseminated information was correct. For example, in the Initial Field Report episode in IMT-b, I&IL realized that the use of printed copies was inconvenient so he began to use an email as his communication method despite the announcement that required that paper forms be used as a standard method of communication in the IMT.

> [I&IL to SITL] "*Hey, I need a better way of sending it to you. Needland PD 140 reported possible gas leak at William and Water street. […] I hate printing if off. I just hate killing these trees. […] I will put an email and you copy and paste it.*"

7.5. Discussion

This article has shown the application of the IEA to analyze differences between WAI and WAD of IMTs. Compared to the existing episode analysis approaches and resultant findings (de Carvalho et al., 2018; Gomes et al., 2014; Rankin et al., 2013), our study has shown the efficacy of the Interaction Episode Analysis (IEA) for more granular and objective understanding of how and why the gaps between WAI and WAD episodes have occurred. Such knowledge is crucial to inform the development of future interventions to reconcile the gaps between WAI and WAD, and thus ultimately to enhance resilience of IMTs.

7.5.1. Utilities of Interaction Episode Analysis

One of the advantages of the IEA is that it incorporates three cognitive system elements (i.e., human, tools, and tasks) into a concept of an episode. In our study, the IEA has made it possible to capture dynamic interplays between individual team members that occurred to perform information processing tasks. By using objective sources of data such as audio and video recordings from high-fidelity IMT exercises, our study showed that the interaction-based episodes served as more specific and objective units of analysis, addressing the existing methodological gaps of prevalent narrative and subjective methods to analyze WAI and WAD in IMTs (Gomes et al., 2014; Rankin et al., 2013).

Another advantage of the IEA is that it enables the generation of WAI episodes that have the similar IMT components (e.g., roles) and interaction patterns comparable with WAD episodes. Previous research on organizational resilience has predominantly used standard operating procedures (Anderson, Ross, & Jaye, 2016; Wachs, Saurin, Righi, & Wears, 2016) or emergency action plans (de Carvalho et al., 2018) as a proxy for an anticipated course of actions (i.e., WAI). In IMTs where such procedures and plans are not available or cannot be made for all the possible incident scenarios, the approach taken in our study to elicit WAI episodes from experts may serve an alternative route to generate the instances of WAI. Moreover, the WAI episodes provide additional aspects regarding necessary elements of teamwork such as context, characteristics, and content of interactions while the procedures and plans are mostly focused on taskwork. In such regards, the IEA is applicable to other similar contexts in which a team task is processed through interactions between humans and technical tools, for instance, medical teams of physicians and nurses, air traffic control crews, and military squads.

7.5.2. Detection and diagnosis of gaps between WAI and WAD episodes

To the best of our knowledge, this article is the first contribution that developed and used quantitative measures of interaction episodes to detect differences between multiple IMTs. Such quantitative differences then informed the qualitative investigation of the gaps between WAI and WAD episodes to understand why such differences between IMTs have occurred. While previous studies (de Carvalho et al., 2018; Rankin et al., 2013) have simply presented the overall time taken to handle individual tasks in IMTs (i.e., Episode Length, EL) as the main resilience metric, our study provided two additional measures to quantify the number of interactions that happened during that period (Frequency of Interactions, FI) and the sum of time spent by IMT members during the interactions (Sum of Individual Interactions' Length, SIIL). In addition, this article proposed two new measures of resilient team interactions, namely: Cross-sectional Interaction Ratio (CSIR) and Cross-agent Interaction Diversity (CAID), to quantify interactions between different sections and between different members of IMTs, respectively.

Findings of this chapter provided the preliminary evidence for the efficacy of the quantitative measures to detect differences between the IMTs across various episodes. In particular, our analysis revealed inconsistencies among the five quantitative measures, which have led to ensuing qualitative investigations focused on why such inconsistencies have taken place. From our qualitative investigations of four cases, several reasons why the gaps between the two IMTs have occurred were identified. First, it was found that a common gap between WAD and WAI in IMTs was the omission of key expected interactions. Of the Emergency Medical Center episode in IMT-b, for example, the absence of interactions between Logistics Medical and SITL made other members have an increased number of interactions and longer time to complete the given task, resulting in higher FI and EL (Figure 7.10). However, the omission of expected interactions did not necessarily lead to additional efforts to compensate for the missed interactions. In the Potential Gas Leak episode, IMT-a shared the possible gas leak report without confirming it through interactions with Operations (Figure 7.13). As a result, the same gas leak report was processed in fewer interactions in IMT-a (i.e., smaller FI) yet with the risk of disseminating unvalidated information. Therefore, both significant differences in FI regardless of direction (e.g., higher or lower FI values compared to other WAD episodes) may signify a barrier to resilient performance of an IMT. Another common reason for WAI-WAD gaps is the presence of unexpected interactions that occur in WAD episodes. For instance, the interactions between a FOB and I&IL and between Command Liaison and I&IL in IMT-b's Joint Information Center episode (Figure 7.11) were not anticipated in the WAI episode. These additional, unexpected interactions have expanded the boundary to which the information was disseminated at the cost of increased frequency (i.e., higher FI), larger duration of team interactions (i.e., higher EL, and SIIL), and more between-section interactions (i.e., higher CSIR). In IMT-a's Joint Information Center episode, the direct interactions between Logistics Medical and MAP were not expected but such interactions expedited the dissemination of the location information. With these two contrasting examples, it is noteworthy that higher or lower values of the quantitative measures alone are not sufficient to indicate the degree of resilience of IMTs. Rather, the combination of the quantitative and qualitative analyses presented in this paper is necessary to evaluate resilient performance of the IMTs. Third, our findings indicate that the gaps between episodes can be caused by issues associated with communication content and technical tools used in IMTs. For example, the Mass Evacuation Point episode revealed the difficulty of finding correct street names of a shelter and inefficacy of the incident mapping program in locating the street names (Figure 7.12).

Overall, the detection and diagnosis of the gaps between WAI and WAD episodes using the IEA addressed important research gaps in the literature on IMT resilience. Previous studies have largely been aimed at narratively describing WAD of IMTs in practice (Kendra & Wachtendorf, 2003; Weick, 1993). While the narrative methods provided how and why the gaps between WAI and WAD occurred in IMTs, findings from individual narratives were difficult to compare and limited to specific contexts of the IMTs under examination. The current study filled these gaps by comparing two simulated IMTs' WAD episodes quantitatively and then qualitatively examining differences between WAI and WAD episodes to find out why the two IMTs' team processed for the same task have differed. Such findings are deemed critical for developing future interventions to reconcile the gaps between WAI and WAD in IMTs and eventually enhance resilience of IMTs. One of such interventions can be redesigning IMT training programs where trainees learn about essential roles they should interact with in order to prevent critical interactions from being omitted. In fact, the importance of increasing the knowledge of what other roles increase team resilience has also been emphasized in the team cognition literature (Moon, Sasangohar, Son, & Peres, 2020). Additionally, the training programs can be better designed to help trainees practice uninstructed and goal-oriented actions that would contribute to an effective execution of tasks in IMTs.

7.5.3. Identifying IMT members' performance adjustment

In addition to analyzing a full course of episodes, this article presented specific examples of IMT members' preparatory, proactive, and reactive adjustment behavior to cope with changing conditions and emerging problems enabled by the IEA methodology (Table 7.2). Indeed, the identification of types and patterns of performance adjustment in the context of a particular system (e.g., incident management teams, emergency departments) has been indicated as one of the recommended research efforts in the resilience engineering literature (Ham, 2020). While previous studies (Mendonça, Webb, Butts, & Brooks, 2014; Webb, 2004) classified adaptations by different aspects of IMTs such as roles, tools, and spaces, our study provided an additional assessment layer indicating whether such adaptations took place either preemptively, proactively, or reactively in reference with the framework of performance adjustment (Hollnagel, 2015). With respect to roles, it was found that members of the IMTs exhibited adaptive behaviors similar to the ones documented in previous studies (Lundberg & Rankin, 2014; Rankin et al., 2013). For instance, IMT members took adaptive actions to lessen duplicate efforts among similar roles and took on additional roles when the original incumbent for that role was absent. Similar proactive and reactive adaptations were seen in the way the IMT members used tools and materials. While the IMTs had an established operational protocol of using standard paper forms, some members flexibly adapted from the protocol by using emails to satisfy such individuals' needs. In fact, the flexibility of 'adopting' and 'adapting' protocols shown in this example was one of the resilience strategies of IMTs during an actual disaster (Son, Larsen, Sasangohar, & Peres, 2020; Son, Sasangohar, Peres, & Moon, 2020b).

7.5.4. Limitations

Notwithstanding the unique findings presented in this article, several limitations need to be mentioned. Our study employed semi-structured interviews to elicit WAI episodes and used the main Planning Section instructor of the observed exercises as the final moderator to reconcile discrepancies between WAI episodes. To reduce the variability between experts' expectations, group discussion methods such as a focus group or the Delphi method (Helmer-Hirschberg, 1967; Okoli & Pawlowski, 2004) are recommended in future studies. In addition, it should be noted that eliciting WAI episodes may not be always straightforward and that expected interactions shown in the WAI episodes are more abstract and of lower fidelity compared with very concrete WAD episodes. Such a different level of the abstraction between WAI and WAD episodes may make the comparisons between the two types of episodes more difficult. In addition, while the IEA was originally designed to capture all the three elements of a cognitive system (i.e., humans, tool, and tasks), a major focus of the current study was interactions between human operators, rather than interactions between humans and technical tools. Hence, future studies are recommended to specifically examine how human operators in an IMT interact with technical tools and how such interactions are associated with resilience of the IMT.

Next, simulated IMT exercises at EOTC, although highly realistic in organizational structure and functions, may not adequately instigate stress or fatigue to the extent that a real emergency would impose. Considering the risks and difficulties of observing actual incidents, however, a high-fidelity emergency simulation facility such as EOTC seems a reasonable alternative to accommodate future research needs for IMTs. Also, it should be noted that not all the trainees at EOTC participated in our observations. Therefore, conversations and actions of such missing roles may have affected the data integrity and resultant WAD episodes. In addition, difference in the level of knowledge and experience among the participants should also be acknowledged. Future studies need to balance individual characteristics (e.g., knowledge, experience, demographic traits) when multiple IMTs are compared.

Also, limitations related to the quantitative measures proposed in this article should be stated. Due to the small sample size and other uncontrolled variables (e.g., team composition), no statistical analyses were conducted. Also, it was not possible to generate quantitative measures of the WAI episodes because interviewees (e.g., course designers and instructors) were not able to provide measures of anticipated frequency, duration, and patterns of interactions for the WAD episodes. To infer generalizable findings (e.g., testing hypotheses) using the quantitative measures presented in this article, a simplified IMT testbed (Son, Sasangohar, Peres, & Moon, 2020a) is recommended, a larger sample size obtained, and confounding variables controlled. Although the current study could not draw inferential findings due to the characteristics that are intrinsic to the naturalistic environment, the demonstrated benefits of analyzing interaction-based episodes with both quantitative and qualitative approaches are worth consideration.

Another limitation of the current study is that there is a lack of understanding about the relationships between the team interaction processes (e.g., WAI and WAD episodes) and resultant impacts on an incident response (e.g., saving lives, reducing property damage). Hence, future research is recommended to examine the relationships between qualitative and quantitative findings from the interaction episodes and the IMT's performance outcomes. With respect to measuring the IMT's performance outcomes, Incident Action Plans (IAPs) can be analyzed as they delineate what the incident objectives are and how the IMT has achieved such objectives.

7.6. Summary

Our study has shown that both quantitative and qualitative analyses of team interactions are needed to fully delineate and analyze the gaps between WAI and WAD episodes in IMTs. Particularly, the Interaction Episode Analysis has demonstrated its unique benefits that allow for quickly noticing quantitative differences between WAD episodes and then qualitatively investigating reasons behind such differences by comparing the gaps between WAI and WAD episodes. Based on the findings of the current study, future research is needed to develop interventions to reconcile the gaps between WAI and WAD. Additional efforts can be focused on redesigning IMT training programs and technical tools used in IMTs. Ultimately, these efforts would reduce the gaps between WAI and WAD in IMTs and enhance resilience of IMTs in coping with challenges of future disasters.

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CHAPTER 8 CONCLUSIONS

This final chapter provides summary of key findings, contribution to the current knowledge, practical implications, limitations, and future work based on the six articles presented in my dissertation.

8.1. Summary of key findings

This dissertation provided diverse findings from a multifaceted approach to understand resilience of IMTs by addressing two general research questions: what are characteristics of IMT resilience and how can we analyze the characteristics of IMT resilience? For the first question regarding the characteristics of resilience of IMTs, my dissertation has provided key traits of resilient IMTs from the comprehensive body of disaster resilience literature as well as from actual IMTs' response to Hurricane Harvey in 2017. An integrative review of the literature (Chapter 2) identified four key traits of resilience of IMTs such as collective sensemaking, team decision-making, reconciling work-as-imagined (WAI) and work-as-done (WAD), and interaction and coordination. Next, semi-structured interviews with government IMT managers and supervisors who responded to Hurricane Harvey (Chapter 3) revealed six major characteristics of resilient IMTs in practice: establishing a common operating picture, adopting and adapting plans and procedures, making proactive, re-prioritizing, and unconventional decisions, increasing resourcefulness and redundancy, learning for improved anticipation and response readiness, and promoting interorganizational relationships. To further expand the knowledge of real-world IMTs' resilience in a different setting, additional semi-structured interviews with hospital IMT personnel who responded to Hurricane Harvey (Chapter 4) highlighted challenges imposed on the IMTs in a hospital and characteristics of IMT resilience specific to the context of hospital incident management. Specific findings included the hospital IMTs' adaptive actions and decisions in terms of organizing IMTs, carrying out individual roles, establishing communication and situational awareness, adapting operating plans and protocols, improvising human and physical resources, using lessons learned from previous incidents, and exercising leadership and high-level decision-making to remain functional during Hurricane Harvey.

For the second question regarding the analysis of the traits of IMT resilience, I developed the Interaction Episode Analysis (IEA) to document and analyze the differences between WAI and WAD episodes utilizing mixed methods consisting of interviews with SMEs and naturalistic observations of two high-fidelity IMT exercises at Emergency Operations Training Center (EOTC). To understand how an IMT functions as a resilient system, Chapter 5 documented the modeling of the IMT as a joint cognitive system that continuously adjusts its performance by receiving and processing team inputs (e.g., incident data) and producing team outputs (e.g., incident information and intelligence, incident action plans). In addition, Chapter 5 presented three ways to analyze resilient performance of IMTs by using: i) time to perceive undesired events, to make team decisions, to implement the decisions, and to recover from the undesired events; ii) resources that are requested, procured, stocked, and deployed; and iii) interactions between three cognitive system elements (i.e., humans, technical tools, and tasks to be carried out). By applying the IEA, which is designed to analyze the interactions between the system elements, to two high-fidelity simulated IMT exercises, Chapter 6 presented six WAD episodes that described the IMTs' actual team processes to deal with six different topics of incident information: Initial Field Report, Injury/Damage Update, Emergency Medical Center, Joint Information Center, Mass Evacuation Point, and Potential Gas Leak. The WAD episodes were then analyzed quantitatively using three numerical measures related to rapidity–an important attribute of IMT resilience–of the team process: Frequency of Interactions (FI), Episode Length (EL), and Sum of Individual Interactions' Length (SIIL). The quantitative analysis indicated that the number of interactions and length of the WAD episodes varied between the episode topics and between the two IMTs. To analyze both WAI and WAD episodes in IMTs, Chapter 7 elicited WAI episodes corresponding to the identified WAD episodes by conducting semi-structured interviews with seven experts in EOTC. With two additional quantitative measures (Cross-sectional Interaction Ratio [CSIR] and Cross-agent Interaction Diversity [CAID]) related to team interactions–another important attribute of IMT resilience, Chapter 7 presented the quantitative differences between the two IMTs across the six episodes. Subsequent qualitative analyses of the WAI and WAD episodes revealed possible factors that contributed to the differences between the two IMTs. Such factors included the non-occurrence of critical interactions that were anticipated in the WAD episode and the occurrence of unexpected interactions outside the WAI episodes. In addition to the whole-of-episode analysis, Chapter 7 provided concrete examples of individual members' preparatory, proactive, and reactive behavior exhibited to adapt to changing conditions in the IMTs.

8.2. Relationships between findings of individual articles

While the individual articles included in this dissertation have taken different approaches such as literature review, interviews, and naturalistic observations, overall findings from these articles are complementary and inter-related. With respect to the traits of resilient IMTs identified from the integrative literature review (Chapter 2), findings from two semi-structured interview studies (Chapters 3 and 4) show more concrete characteristics of IMT resilience in the context of a hurricane disaster. For instance, the integrative literature review has identified four characteristics of IMT resilience: collective sensemaking, team decision making, harmonizing WAI and WAD, and interaction and coordination. In a real-world incident, government IMT personnel emphasized the importance of maintaining a common operating picture (COP), a practical term used to indicate the IMT's collective sensemaking (Wolbers & Boersma, 2013). Interviews with hospital IMT members further confirm the importance of establishing the COP to identify emerging response needs and develop countermeasures against challenging situations. With respect to team decision making, interviews with actual IMT personnel have indicated specific examples of team decisions made during Harvey. For instance, the government IMTs made proactive decisions to prepare for possible impacts of the hurricane and dynamically adjusted their decisions to meet critical needs with limited resources during the course of the disaster. On the contrary, the hospital IMTs exhibited lack of proactive decision making in that they delayed the activation of hospital emergency operation plan, which prevented hospital staff designated to respond to the disaster from returning to the hospital.

Next, the two interview studies have provided empirical evidence of how gaps between WAI and WAD has been reconciled, showing another major trait of resilient IMTs identified from the literature and the need to investigate such gaps (Aguilera, Fonseca, Ferris, Vidal, & de Carvalho, 2016). Specifically, both government and hospital IMTs exhibited such a trait of resilience by flexibly adapting emergency plans and protocols. For example, the government IMTs during Hurricane Harvey modified food distribution plans from fixed locations to field responders on the move to address civilian's reduced mobility in flooded areas. In the hospital IMTs, administrative operating procedures such as paperwork were skipped to meet urgent medical requests.

Another key trait of resilient IMTs identified from the literature review was interaction and coordination between individuals responding to an incident. More specifically, findings from the literature review suggest that such interaction and coordination promote the manifestation of other traits of resilient IMTs, namely, collective sensemaking, adaptive team decision making, and reconciling WAI and WAD during an incident. Indeed, the interviews with IMT members who responded to Harvey indicated that the interactions between IMT personnel have facilitated the establishment of the COP by sharing updated incident information and the coordination between multiple IMTs in making joint decisions such as ground and aerial evacuations from flooded areas.

In addition to providing such concrete examples of traits of resilient IMTs identified from the literature, Chapters 3 and 4 also presented additional themes that characterize resilience of real-world IMTs such as learning lessons from previous incidents and resourcefulness and redundancy of resources, which further confirm findings from previous studies (Hollnagel, Paries, Woods, & Wreathall, 2011; Kendra & Wachtendorf, 2003).

The last three articles (Chapters 5, 6, and 7) contribute to further understanding of the characteristic of IMT resilience examined in the first three chapters. Chapter 5 presents the cognitive system model of an IMT in which collective sensemaking and decision making of the IMT occurs via interaction and coordination between its sections and individual members, incorporating the key characteristics of resilient IMTs identified from the literature review (Chapter 2). Next, Chapters 6 and 7 are focused on two analytical lenses of system resilience: WAI and WAD. Based on findings from the literature review (e.g., reconciling WAI and WAD, Chapter 2), the semi-structured interviews (e.g., adopting and adapting plans, Chapters 3 and 4), and the modeling of an IMT (e.g., dynamic interplays between humans, tools, and tasks, Chapter 5), I have developed the Interaction Episode Analysis [IEA] (described in Chapters 6 and 7) to enable the analysis of WAI and WAD episodes and conducted case studies in Chapter 7 to show the efficacy of the IEA. While the first three chapters (Chapters 2, 3, and 4) addressed the importance of reconciling the gaps between WAI and WAD to make an IMT resilient, the ensuing two chapters (Chapters 6 and 7) presented findings regarding how and why such gaps took place by employing quantitative and qualitative approaches. However, it should be noted that while the last three chapters were focused on further examining the gaps between WAI and WAD, other practical characteristics of IMTs (e.g., establishing a common operating picture, adopting and adapting plans, Chapters 3 and 4) and other measures of IMT resilience (e.g., time- and resource-based measures, Chapter 5) were not specifically investigated in these chapters.

In summary, the six articles included in my dissertation have not only provided comprehensive findings regarding IMT resilience from multiple approaches, but also such findings are interrelated and complementary toward an advanced understanding about IMT resilience.

8.3. Contributions to the current knowledge

The multifaceted research efforts made for this dissertation advance the existing knowledge of resilience of IMTs. The integrative literature review (Chapter 2) provides synthesized knowledge pertaining to resilience in the field of incident management. Previous reviews have covered the literature regarding general status of resilience engineering (Patriarca, Bergström, Di Gravio, & Costantino, 2018; Righi, Saurin, & Wachs, 2015), healthcare resilience (Patriarca et al., 2017), and resilience for safety management (Bergström, van Winsen, & Henriqson, 2015; Peñaloza, Saurin, Formoso, & Herrera, 2020). A unique contribution of Chapter 2 is that it is the first literature review of resilience in incident management that summarized and synthesized the current knowledge of IMT resilience, filling an important gap with respect to reviewing the literature relevant to disaster resilience. Findings provided in Chapter 2 including essential traits of resilient IMTs, common technical tools to support resilience of IMTs, and design factors of emergency simulations serve as a knowledge basis to identify future research opportunities to further investigate resilience of IMTs.

Interviews with IMT personnel who responded to Hurricane Harvey (Chapters 3 and 4) revealed characteristics of real-world IMTs' resilience during an actual disaster. Compared to previous studies that captured partial aspects of IMT resilience such as challenges associated with coordination (Militello, Patterson, Bowman, & Wears, 2007) and improvised decision making (Kendra & Wachtendorf, 2003; Mendonça, 2007), Chapters 3 and 4 document comprehensive and interrelated traits of resilient IMTs. Specifically, Chapters 3 and 4 presented traits of IMT resilience in terms of organizational structure, collective awareness, adaptive decision making, operating plans and protocols, resources for incident response, and lessons learned from past incidents. In addition, these two articles presented not only common characteristics between government and hospital IMTs but also differences of challenges faced and resilient actions exhibited in response to the same disaster.

My dissertation also makes a significant contribution to the methodology of resilience engineering by addressing prevailing research gaps with a novel Interaction Episode Analysis (IEA) to analyze WAI and WAD in IMTs. Although WAI and WAD are two primary concepts to understand resilient performance of a cognitive system (Hollnagel, 2015), previous research (de Carvalho et al., 2018; Wachs, Saurin, Righi, & Wears, 2016) has predominantly relied on prescribed documents (e.g., SOPs) for WAI and individual researchers' subjective interpretation of actual activities for WAD. Due to the prevalence of such narrative approaches, not only were the findings from individual studies difficult to be compared but also no quantitative analysis of WAI and WAD in IMTs has been attempted in the literature (Hosseini, Barker, & Ramirez-Marquez, 2016). Moreover, previous studies (de Carvalho et al., 2018; Rankin, Dahlbäck, & Lundberg, 2013) did not fully consider the interactions between cognitive system components (i.e., humans, tools, and tasks), although such interactions are a major source of system resilience (Woods & Hollnagel, 2006). In such regards, Chapters 6 and 7 of this dissertation fill these gaps by utilizing the IEA to analyze WAI and WAD episodes of IMTs. Specifically, this dissertation has generated WAI episodes for expected team processes of handling incident information based on inputs from emergency operations experts where no specific SOPs or emergency action plans were available to formulate WAI episodes of the IMT tasks. Beyond the narrative comparisons between WAI and WAD commonly practiced in the literature (Ayabe et al., 2020; Sujan, Spurgeon, & Cooke, 2015), Chapters 6 and 7 present more objective and granular representations of expected (i.e., WAI) and actual (i.e., WAD) team processes of the IMTs and analyze them quantitatively and qualitatively. To my best knowledge, this dissertation is the first contribution that developed quantitative measures (FI, EL, SIIL, CSIR, and CAID) that represent rapidity and team interactions, two important attributes of IMT resilience. While the quantitative measures themselves may not be absolute indicators of resilience of IMTs (Hollnagel, 2009), Chapters 6 and 7 demonstrated the benefits of using the quantitative measures to quickly notice differences between multiple IMTs' actual activities (i.e., WAD) for the same task and informed the subsequent qualitative analysis to unveil what has contributed to such differences. Specifically, the quantitative metrics were effective to point out irregular or anomalous situations that the IMTs were experiencing in carrying out given tasks. The ensuing qualitative analysis then described whether or not overall interactions for the IMT's information management tasks occurred as expected and what unanticipated actions happened in the IMTs. This two-step approach (i.e., quantitative and qualitative analyses) would expedite the identification of gaps between the WAI and WAD in IMTs and therefore the development of interventions to reconcile the gaps, which can ultimately lead to improved resilience of IMTs.

Another methodological contribution of the IEA is that it complements existing resilience engineering methods such as Functional Resonance Analysis Method [FRAM] (Hollnagel, 2017). FRAM was designed to model a cognitive system's functions and relationships between the functions and illustrate how variability of such functions leads to either desired or undesired events. While FRAM has demonstrated its efficacy to model complex non-linear relationships between functions on a system space (Patriarca et al., 2020), it has a limitation in describing dynamic and temporal progressions of how the functions are adjusted. The IEA addresses this limitation by presenting a series of interrelated interactions between cognitive system elements that occur to adapt to emerging tasks and changing situations.

8.4. Practical contributions

In addition to the aforementioned theoretical and methodological contributions, this dissertation makes practical contributions to the field of incident management in terms of IMT training and real-world IMT operations.

Findings from this dissertation can be used to inform the evaluation and redesign of IMT training programs such that they cultivate resilience skills among trainees. A summary of design factors of IMT training such as scenario design and role assignment (Chapter 2) can be used to assess and revise the tempo (fast vs. slow), intensity (low vs. high consequence), and uncertainty (expected vs. unexpected events) of simulated emergency scenarios in a way that the trainees can foster skills and knowledge for adaptive actions. Furthermore, the evaluation of the IMT training courses can be better accomplished through granular illustrations of how trainees have interacted with tasks assigned, other role incumbents, instructors, and technical tools during the exercises. Traditionally, such an assessment primarily has relied on an after-action review or debriefing, which is subject to individual trainees' memory and biases (Keiser & Arthur Jr, 2020). Thus, findings from Chapters 6 and 7 regarding the WAI and WAD episodes help IMT training course designers and instructors more accurately understand what specific difficulties the trainees experienced (e.g., confusion about a total injury number), whether and how the trainees received, processed, and disseminated the injected incident information (e.g., sharing an unvalidated potential gas leak report), and whether individual trainees have carried out intended roles properly. In particular, the comparisons between the WAI and WAD episodes highlight the context (e.g., roles and tools involved), content (e.g., conversations and actions), and characteristics (e.g., frequency and duration) of interactions in which the discrepancies between expected and actual activities have taken place. Such discrepancies inform the course designers and instructors in redesigning the IMT training courses such that trainees are not only able to perform assigned roles as instructed but also flexibly adjust their actions to unanticipated situations in a way that such actions contribute to the accomplishment of the IMT's goal. For instance, instructions or didactic sessions generally given prior to the IMT training exercises can be redesigned so that the trainees can develop adaptive skills and knowledge to deal with such unexpected conditions and problems. Adaptations in roles, tools, space, and work processes employed in similar contexts (Rankin et al., 2013; Son, Sasangohar, Rao, Larsen, & Neville, 2019; Webb, 2004) can inform the redesign of the instructional sessions.

Another practical contribution of my dissertation to IMT operations is that the five quantitative measures based on team interactions (Chapters 6 and 7) can further improve the evaluation of the IMT operations. The evaluation of the IMT's operational effectiveness generally relies on Incident Action Plans (IAPs), the IMT's final products that document what the IMT's incident objectives were (e.g., life safety, incident stabilization, property protection) and how the IMT achieved such objectives in each operational period. While the incident objectives are – also should be – measurable such as the number of evacuees, percentage of wildfire containment (Leonard Jr & Gibeault, 1999), no quantitative measures are available to evaluate the processes through which the IMT has arrived at such outcomes. Addressing this gap in practice, the IEA enables both quantitative and qualitative analyses of team processes that occur in the IMT. Particularly, the five measures developed in this dissertation can be used to quantify two important attributes of IMT resilience: rapidity (FI, EL, and SIIL) and team interaction (CSIR and CAID). Using these measures, it is expected that practitioners in an IMT can understand how quickly and how collectively the IMT copes with a given task and how such team processes are related to the IMT's operational effectiveness (e.g., accomplishing incident objectives).

Findings of this dissertation make another contribution to real-world IMT operations. Chapters 3 and 4 present challenges of Hurricane Harvey and resilient actions that real IMTs have shown in response to such as a catastrophic disaster. Considering the increasing frequency and severity of weather-related events in the US (NOAA, 2020) and needs for learning lessons from recent disasters in a timely manner, findings from Chapters 3 and 4 highlight modern IMTs' strengths to be fostered and weaknesses to be addressed for similar disasters in the future. More specifically, these articles point out that creating and maintaining a common operating picture is a persistent challenge among practitioners working for IMTs (Wolbers & Boersma, 2013). Yet, findings from the articles further support the efficacy and flexibility of incident management guidelines (e.g., ICS and NIMS) for managing information and resources, and coordinating between multiple IMTs during Hurricane Harvey. These findings would inform real-world IMTs in better preparing for and responding to future similar incidents.

Lastly, this dissertation has informed the design of a Web-based Interaction Episode Analysis Tool (WIEAT) in order to facilitate actual practitioners' use of the IEA for either IMT training courses or real-world IMT operations. The WIEAT is currently under development and is designed to make it easier to enter data related to interactions (i.e., context, characteristics and content), visualize episodes, and calculate quantitative measures of the episodes. The following images show sample web pages designed to enable the entry of interaction data (Figure 8.1), the visualization of episodes (Figure 8.2), and the generation of quantitative measures of the episodes (Figure 8.3). To further improve the design of this web-based tool, additional efforts are ongoing to test its usability and incorporate users' feedback into its design.

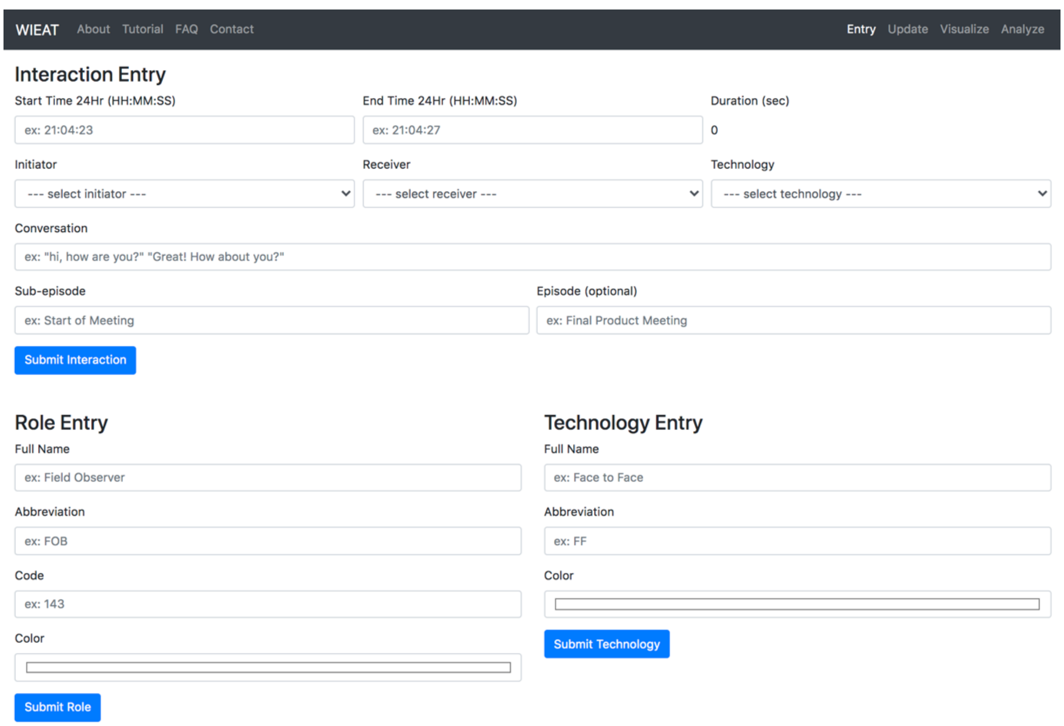

Figure 8.1 Data entry webpage of Web-based Interaction Episode Analysis Tool

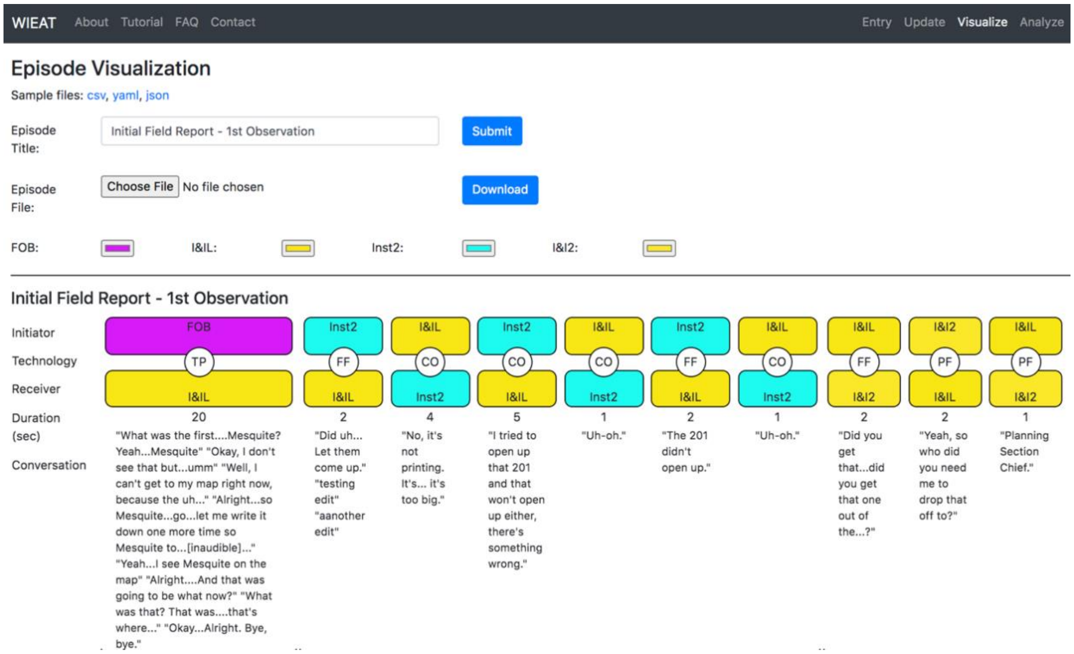

Figure 8.2 Data visualization webpage of Web-based Interaction Episode Analysis Tool

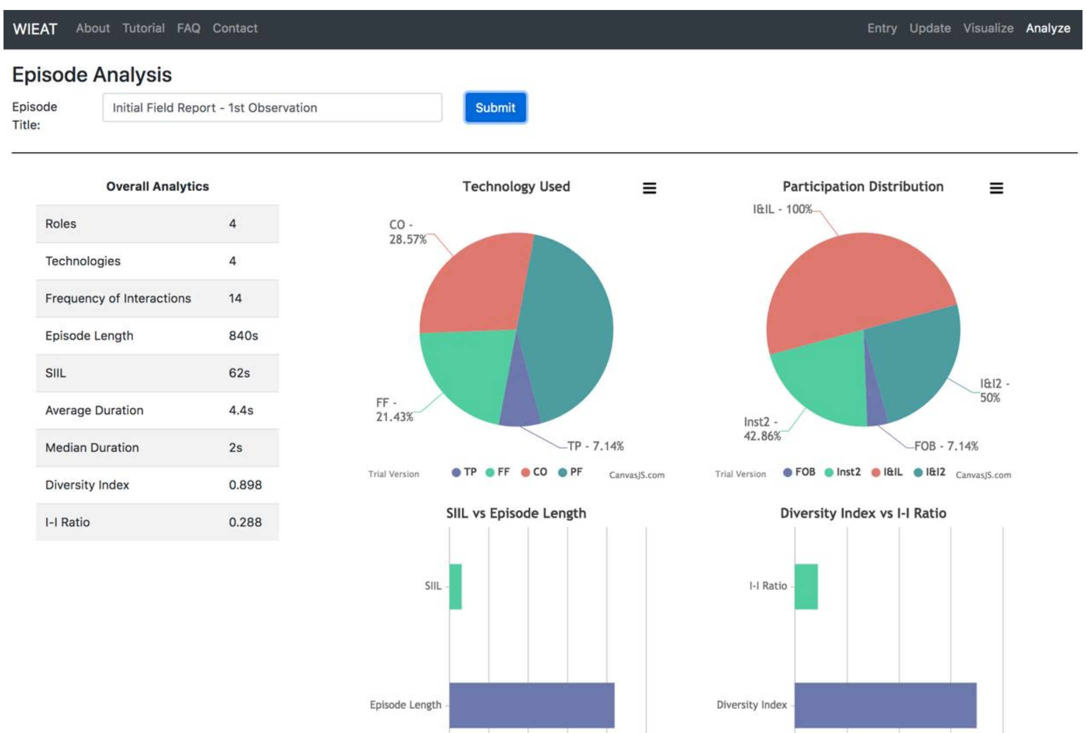

Figure 8.3 Data analysis webpage of Web-based Interaction Episode Analysis Tool

8.5. Limitations

The studies conducted for this dissertation have several limitations to be stated. First, the IMTs examined in this dissertation are based in the US. Hence, findings from this dissertation may not be directly applicable to other countries with different incident management systems. For instance, the Swedish Civil Contingencies Agency requires safety, security, and liaison as separate sections (Monet et al., 2020), while the US ICS designates them as staff of the Command Section. Second, this dissertation did not differentiate between IMTs that are established at different levels of incident management hierarchy. For instance, IMTs at incident command posts (ICPs) are more focused on on-scene tactical activities whereas IMTs at emergency operations centers (EOCs) provide coordination of multiple ICPs. In this regard, it is recommended that future studies examine resilience of IMTs that exist at multiple hierarchical levels of incident management. Third, the validity and fidelity of the simulated IMT exercises needs to be mentioned as IMTs examined in Chapters 5, 6, and 7 were operated in a training environment. Also, although the IMT emergency exercises have been designed to emulate real-world incident responses, they may not induce stress and fatigue to the trainees to the extent an actual incident would impose. Fourth, limitations associated with the recruitment of participants should be stated. A limited number of participants have participated in the interviews (10 government IMT personnel and six hospital IMT personnel). Hence, the findings from these participants may not be generalizable for the overall IMT settings or disaster contexts. In addition, not all the trainees of two IMT exercises at EOTC (39 out of 44 and 32 out of 46) have participated in the observation study, undermining the integrity of data necessary to generate WAD episodes. In addition, it is to be noted that the observation was largely focused on the Planning Section, rather than the entire IMT. Fifth, no statistical analyses were conducted with respect to the quantitative measures derived from the IEA due to the limited sample size and lack of control over confounding variables, notwithstanding a high external validity of the IMT exercises. In a similar sense, no predictive analysis was conducted to identify variables (e.g., participants' expertise) that predict the quantitative measures developed in this dissertation. Sixth, the limitations related to the IEA need to be addressed. Although this dissertation showed the utilities of the IEA to detect and diagnose gaps between expected and actual team processes, it remains to be seen whether the IEA can be applied to actual IMT environments (e.g., IMTs responding to a real disaster) and other similar team contexts that require resilient performance (e.g., a team in emergency departments). Seventh, difficulty of capturing WAI episodes from experts and absence of quantitative measures of WAI episodes need to be stated. Although experts were able to provide anticipated interactions in detail, discrepancies between the experts' expectations need to be better reconciled through different research methods such as focus group. Also, it was found that the experts had difficulty providing quantitative measures of the episodes. Hence, future research needs to develop ways to measure WAI episodes in a quantitative manner so that the WAI and WAD episodes can be directly compared. Lastly, it required excess time and efforts to collect and analyze the data from EOTC due to the size of the IMTs and complexity of interactions between the IMT members.

8.6. Future work

Future studies should address the limitations of this dissertation. While the advantages of using externally valid research settings such as EOTC are worth being acknowledged, it is necessary to develop a controlled research environment that allows researchers to infer more generalizable findings indicated by statistical analyses. As part of such efforts, a simplified IMT testbed named 'Team Emergency Operations Simulator [TEOS] (Son, Sasangohar, Peres, & Moon, 2020)' is currently under development. TEOS simulates a small IMT that consists of three key roles for information management tasks: Planning Section Chief (PSC), Information & Intelligence (I&I) Unit, and Situation Unit. To render TEOS a team environment, sub-tasks for individual roles are designed to be interdependent (for more detail, see Son et al., 2020). Additional efforts need to be made to fully embody TEOS into a physical experimental environment.

With respect to excessive amount of time and efforts required to collect data for the IEA, it is recommended for future studies to devise more effective and efficient ways to collect and analyze data regarding team interactions (e.g., using Web-based IEA Tool).

In addition, this dissertation has focused on identifying characteristics of real-world IMTs during Hurricane Harvey; however, findings from this one incident may not be generalizable to other types of incidents such as wildfire and pandemic events (e.g., COVID-19). Thus, it is recommended that future studies investigate how the traits of resilient IMTs documented in this dissertation will be similar or different in future disasters. Such findings would inform future efforts to make IMTs more adaptable to various types of incidents.

Also, this dissertation has paid relatively less attention to the interactions between IMT members and technical tools used in IMTs (i.e., human-machine interaction) compared to the interactions between IMT members. Therefore, future studies are required to further examine the current use of the technical tools (e.g., event log, incident map, mobile devices) in IMTs and improve their design to support the IMT members' adaptive decisions and resilient actions during disasters.

Lastly, future research efforts are required to bring practical impacts on resilience of IMTs. This dissertation (more specifically Chapters 5, 6, and 7) has examined team interaction processes that occurred to manage incident information within IMTs. Thus, it is still unclear how such team interaction processes actually affect the outcomes of IMTs' operations (e.g., satisfying incident objectives). To address this limitation, future studies need to identify specific incident objectives for a particular type of incidents, measure how an IMT accomplishes such objectives, and investigate relationships between the fulfillment of the objectives and the team interaction processes. In particular, qualitative and quantitative analyses of the team interaction processes based on the IEA would facilitate such investigations. Results from these studies can inform practitioners in IMTs to identify challenges in their teamwork, develop resilient actions for unexpected events, and thus better respond to future disasters.

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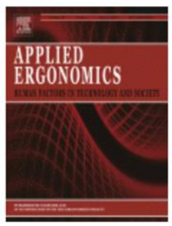

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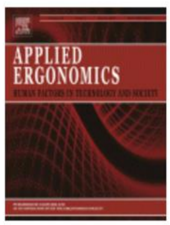

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APPENDIX F. A SUMMARY OF INTEGRATIVE LITERATURE REVIEW

Authors (year)	Publication type	Research focus	Research design	Study methods	Type of event studied	Study location
Abbasi, Hossain, Hamra, and Owen (2010)	Conference	Examining the relationship between incident management team members' coordination and their adaptive behavior	Qualitative	Survey	Wildfire	Australia
Aguilera, Fonseca, Ferris, Vidal, and de Carvalho (2016)	Journal	Describing how functional variability in planning, execution, and resources impacts nuclear emergency response activities.	Qualitative	Observation, interview, audio-visual recording	Chemical spill	Brazil
Bergström, Petersen, and Dahlström (2008)	Conference	Investigating whether non-domain specific training improves crisis management team's ability to handle emergency situations.	Qualitative	Observation	Maritime incident	Sweden
Bharosa and Janssen (2009)	Conference	Identifying types of adaptive capabilities in disaster information management.	Qualitative	Observation, interview, document analysis	Flooding, chemical spill	The Nether-lands
Brown and Eriksson (2008)	Journal	Discussing limitations of emergency plans and proposing ways to develop the plans that support resilient operations.	Theoretical			
Caldwell (2014)	Journal	Proposing a concept of resilience boundary framing for managing large-scale emergency events.	Theoretical			
de Carvalho et al. (2015)	Conference	Describing how an integrated command and control center responded to a civil disturbance during a major sports game.	Qualitative	Observation, interview	Sports event	Brazil
de Carvalho et al. (2018)	Journal	Comparison between WAI represented in SOPs and WAD identified from simulated emergency training for firefighter captains.	Qualitative	Observation, interview, audio-visual recording	Railroad incident	Brazil
Comfort (2002)	Journal	Developing a model of auto-adaptation aimed at improving inter-governmental performance in extreme events.	Qualitative	Case study, document analysis	Terrorism	USA
Comfort (2007)	Journal	Claiming that cognition is essential to adaptive performance in emergency management jointly with communication, coordination, and control.	Theoretical			
Comfort, Dunn, Johnson, Skertich, and Zagorecki (2004)	Journal	Designing integrated spatial information system and reporting findings from its demonstration in a local jurisdiction.	Qualitative	Observation, interview	Hazardous material release	USA

Authors (year)	Publication type	Research focus	Research design	Study methods	Type of event studied	Study location
Domeneghetti, Benamrane, and Wybo (2018)	Journal	Identifying the relationship between pre-established action plans and mid-incident decision making based on expertise for mass protection.	Qualitative	Observation	Nuclear incident	France
Field, Rankin, van der Pal, Eriksson, and Wong (2011)	Conference	Suggesting necessary elements for emergency training scenarios to foster adaptive skills.	Theoretical			
Franco, Zumel, Holman, Blau, and Beutler (2009)	Conference	Evaluating the effect of improvisational behaviors (e.g., changing roles, authority, or communication flow) on decision making team's performance.	Quantitative	Experiment	Six different cases	USA
Frye and Wearing (2016)	Journal	Describing the role of bushfire responders' metacognition in adapting to changing conditions.	Qualitative	Interview, survey, document analysis	Wildfire	Australia
Gomes, Borges, Huber, and de Carvalho (2014)	Journal	Describing sources of resilience and brittleness in a simulated nuclear incident.	Qualitative	Observation, audio-visual recording	Nuclear incident	Brazil
Harrald (2006)	Journal	Arguing that both agility (e.g., adaptability, improvisation) and discipline (e.g., command, control) can be achieved during disaster response.	Theoretical			
Hermelin et al. (2019)	Journal	Describing how generic resilience training concepts are applied to specific contexts of a regional medical command and control team.	Qualitative	Group discussion, survey	Five different cases	Sweden
Hollnagel and Sundström (2006)	Book chapter	Describing a state-space model of a resilient system in escalating events.	Theoretical			
Hunte (2017)	Book chapter	Providing characteristics of resilient behaviors of an emergency department in response to a large civil disorder.	Qualitative	Case study	Sports event	Canada
Klimek, Varga, Jovanovic, and Székely (2019)	Journal	Developing quantitative measures of resilient organizational behavior using social network analysis.	Quantitative	Document analysis	Storm	Hungary
Longstaff and Yang (2008)	Journal	Analyzing the relationship between trust and communication in the face of crisis surprise.	Quantitative	Document analysis	82 various cases	USA
Lundberg, Tornqvist, and Nadjm-Tehrani (2012)	Journal	Proposing a model for describing resilience in emergency management using disturbance, sensemaking, and control variety.	Qualitative	Observation, audio-visual recording	Storm	Sweden
Lundberg and Rankin (2014)	Journal	Identifying types of role improvisation in small response teams and their negative effects.	Qualitative	Interview, group discussion	Tsunami, warfare	Sweden

Authors (year)	Publication type	Research focus	Research design	Study methods	Type of event studied	Study location
Mendonça (2007)	Journal	Identifying requirements for designing a computer-based system that supports improvisation in emergency events.	Qualitative	Interview, group discussion, document analysis	Terrorism	USA
Mendonça (2008)	Book chapter	Developing and evaluating a set of measures for resilience in critical infrastructure restoration.	Qualitative	Interview, survey, document analysis	Terrorism	USA
Mendonça and Hu (2007)	Book chapter	Investigating the role of event severity on cognitive and decision processes in an emergency management team setting.	Quantitative	Experiment	Maritime incident	The Nether-lands
Mendonça, Webb, Butts, and Brooks (2014)	Journal	Analyzing cognitive and behavioral improvisations in two major terrorism events.	Quantitative	Document analysis	Terrorism	USA
Mendonça, Beroggi, and Wallace (2001)	Journal	Proposing a concept of blackboard-based decision support systems for improvisation in emergency response.	Qualitative	Interview, survey, document analysis	Maritime incident	The Nether-lands
Mendonça, Beroggi, van Gent, and Wallace (2006)	Journal	Evaluating the effect of a group decision support system for improvisational decision making behaviors of emergency response teams.	Quantitative	Experiment	Maritime incident	The Nether-lands
Mendonça and Wallace (2007)	Journal	Developing a cognitive model of improvisation in emergency management using a theory of jazz music.	Theoretical			
Neville, Doyle, Sugrue, and Muller (2013)	Conference	Identifying strengths and weaknesses of commercial decision support tools for flexible multi-agency coordination.	Qualitative	Document analysis	Public health events	European countries
Petersen (2015)	Conference	Comparing and contrasting centralized and distributed mapmaking approaches toward collective sensemaking.	Qualitative	Observation, interview	Wildfire	USA
Pramanik, Ekman, Hassel, and Tehler (2015)	Journal	Investigating whether higher familiarity and expectation of future cooperation increases the likelihood of working with other organizations.	Quantitative	Experiment, interview	Storm	Sweden
Rankin, Dahlbäck, and Lundberg (2013)	Journal	Analyzing factors that hamper role adaptation in information and communication flow in a crisis management team.	Qualitative	Observation, audio-visual recording, document analysis	Wildfire	USA
Rankin, Lundberg, and Woltjer (2014)	Book chapter	Developing a framework for sharp-end adaptations and analyzing a crisis management	Qualitative	Case study	Wildfire	USA

Authors (year)	Publication type	Research focus	Research design	Study methods	Type of event studied	Study location
		team's response to a reduced team size.				
Reuter, Ludwig, and Pipek (2014)	Journal	Examining how inter-organizational collaboration is supported by a mobile geospatial system.	Qualitative	Observation, interview, group discussion	Storm	Germany
Righi, Huber, Gomes, and de Carvalho (2016)	Conference	Identifying sources of resilience and brittleness in a crisis management exercise in relation to emergency SOPs.	Qualitative	Case study, observation, audio-visual recording	Railroad incident	Brazil
Robinson, Maddock, and Starbird (2015)	Conference	Describing issues associated with emergency information and communication technology and strategies to overcome them.	Qualitative	Interview	Landslide	USA
Rose, Seater, and Norige (2015)	Conference	Examining key decision making skills required for emergency managers to respond to unexpected incidents.	Qualitative	Interview, survey	Terrorism	USA
Roux-Dufort and Vidaillet (2003)	Journal	Examining conditions that hinder resilient behavior in multidisciplinary and divergent team environments.	Qualitative	Case study, interview, document analysis	Chemical fire	France
Son et al. (2018)	Journal	Modeling information management and team decision making based on interaction among team components.	Qualitative	Observation, audio-visual recording	Storm, terrorism	USA
Stachowski, Kaplan, and Waller (2009)	Journal	Distinguishing patterns of changing interaction (number and complexity) between high- and low-performing teams.	Quantitative	Audio-visual recording	Nuclear incident	USA
Trnka, Lundberg, and Jungert (2016)	Journal	Identifying types of situations where role improvisations are manifested and suggesting how a simulation exercise can be designed to prompt the role improvisations.	Qualitative	Observation, interview, group discussion, audio-visual recording, document analysis	Tsunami, warfare, wildfire	Sweden
Tveiten, Albrechtsen, Waero, and Wahl (2012)	Journal	Finding out challenges and opportunities for resilient emergency management with respect to advanced technology and distributed response organizations.	Qualitative	Group discussion	Chemical spill	Norway
Vecchiola et al. (2013)	Journal	Providing design principles for resilient disaster information systems and applying them to a public firefighting organization.	Qualitative	Case study	Wildfire	Canada
Voshell, Trent, Prue, and Fern (2008)	Conference	Assessing challenges in coordination between urban firefighting teams.	Qualitative	Observation, interview,	Urban fire	USA

Authors (year)	Publication type	Research focus	Research design	Study methods	Type of event studied	Study location
				audio-visual recording		
Webb (2004)	Journal	Classifying role improvisations by the type of disasters: natural, technical, or civil incident.	Quantitative	Interview, document analysis	304 various cases	USA
Webb and Chevreau (2006)	Journal	Suggesting characteristics of organizations that impede flexibility in responding to a crisis.	Theoretical			
Weick (1993)	Journal	Proposing potential sources of resilience in a firefighting crew's response to a wildfire.	Qualitative	Interview, document analysis	Wildfire	USA
Westrum (2006)	Book chapter	Suggesting a typology of resilient organizations during emergency events.	Theoretical			
Woltjer, Trnka, Lundberg, and Johansson (2006)	Conference	Investigating how role-playing exercises influence resilient performance of an emergency management team.	Qualitative	Observation, interview, audio-visual recording, document analysis	Wildfire, blackout	Sweden
Woods and Branlat (2011)	Book chapter	Describing basic patterns in the failure of adaptive systems in the context of urban firefighting.	Qualitative	Observation, interview, document analysis	Urban fire	USA
Wybo, Jacques, and Poumadere (2006)	Conference	Understanding the role of observers in an emergency simulation in capturing resilient behaviors of an organization.	Qualitative	Observation	Road incident	France
Zhuravsky (2018)	Book chapter	Examining core resilience capabilities in a regional emergency medical team’s response to an earthquake disaster.	Qualitative	Case study	Earthquak e	New Zealand

APPENDIX G. QUESTIONS FOR INTERVIEWS WITH GOVERNMENT IMT PERSONNEL

Hurricanes Harvey: Emergency Responders Interview Questions

As we explained to you and obtained your agreement, we are carrying out a study that focuses on how emergency response personnel responded following Hurricane Harvey or Irma, what were the major challenges during the hurricanes, how hurricane response tasks were carried out, how your organization as a whole worked together on these tasks, and what lessons were learned during those response activities.

As you agreed, we will record this interview using voice recorders. Just as a reminder from what we said during the Informed consent process, that we will not be sharing any of this information with anyone directly or specifically. Further, we are not evaluating you, we are interested in improving the emergency response system. As someone involved in emergency response, you know better than anyone and are our best source of information! Your honest responses will really help us a lot. However, if you are not comfortable replying to something, that's fine, just say so and we will move on to the next questions.

[Turn on the voice recorder and ensure it is functioning well]

I. General Questions

1. Can you tell us about your role in responding to Hurricane Harvey?

*The purpose of this question is to understand the interviewee's role in Harvey and their experience in general.
*Check if the interviewee answered:

- <u>What role he/she played, when, and how long?</u>
- <u>How long have you worked in that role? (years)</u>
- <u>How long have you worked in overall disaster/emergency management area? (years)</u>
- <u>Have you had ICS 300 training?</u>

*The purpose of this question is to see if the interviewee was trained about the Planning P process.

- How was your role or duty changed during the response operations of Hurricane Harvey? Was the change planned and at least commonly experienced in other previous responses?
- Was there any instance in which you needed to take additional or new role that you are not supposed or planned to take?

(Probe: If taking such new roles were not planned, how were decisions made about your involvement in those activities?)

2. What were the major characteristics of the Hurricane Harvey that you had not expected or experienced from previous incidences?

*The purpose of this question is to hear about the interviewee's experience of Harvey response in general.
*Check if the interviewee answered:

- How was the incident different from your expectation or experience?
- How many times have you responded to the extreme events such as Hurricane Harvey, in your career?
- What were major goals that you tried to achieve in the Harvey response and how did you accomplish your goals?
- What were the major challenges in responding to Hurricane Harvey?

II. Questions on the Incident Command Post to validate the EOTC

1. Can you describe the ICP/EOC/DOC you worked at (or with) during Hurricane Harvey?

*The purpose of this question is to understand the interviewee's working environment and to check the ecological validity of our research environment (EOTC).
*Check if the interviewee answered:

- [Level] ICP, EOC, or DOC? (If others, where?)
- [Location] Where was it located? Which region was it covering?
- [Functions] What functions did it serve? What was your role in it?
- [Structure] How were those functional sections organized?
- [Procedures] What procedures did you follow?
- [Scenarios] How dynamic and uncertain were the disaster unfolding?

2. Can you tell us more specifically about your organizational structure and team composition in response to Hurricane Harvey?

*The purpose of this question is to understand the organizational structure for coordination in Harvey.
*Check if the interviewee answered:

- What was the normal organizational structure during the daily operations?

<u>How did the structure change as the situation evolved?</u>
(Probe: Ask organizational hierarchy, span of control, commanding and reporting structure. Ask for an org chart.)

- What other organizations and agencies did you work with?

<u>How were such inter-organizational collaboration managed and coordinated?</u>
(Probe: what kind of division of labor developed? Any organization chart to share?)

- Did your organization have a representative at the City's or State's Emergency Operations Center (EOC) or Incident Command Post (ICP) that were set up for the hurricane response?

(Probe: If there was a representative, where was the location? When was the representative first sent? How did the organization know where and when to send the representative?)
(Probe: **How did you work with any roles within the Planning Section?**)

3. Have you worked with or at the Planning section during Hurricane Harvey?

(Only if the answer is <u>YES</u>)

Can you describe the Planning section (team) you worked at (or with) during Hurricane Harvey?

*The purpose of this question is to check the ecological validity of Planning section in EOTC.
*Check if the interviewee answered:

- How did you work with any roles within the Planning Section?
- [Functions] What functions did it serve? What was your role in it?
- [Structure] How were those functional sections organized?

III. Questions on Cases, Stories, and Narratives regarding Team Cognition and Resilience

1. Can you tell us about the process you used to create a common operating picture or make sense of the evolving situation in Hurricane Harvey? How did you know what's going on?

*The purpose of this question is to hear how the interviewee could understand what's going on in Harvey.
*Check if the interviewee answered:

- <u>When, Where, and How</u> did you get information that you needed to know what's going on?
- Could you check the discrepancies between your own understanding and others? How?
- <u>What challenges did you face</u> in maintaining up-to-date incident overview or common operating picture?

2. Can you tell us about the process you used to communicate and manage information in Hurricane Harvey?

*The purpose of this question is to elicit any cases of communication and information management and associated challenges in Harvey.
*Check if the interviewee answered:

- What kind of communication and information management tasks did you perform during Harvey?
- What type of information did you need the most during the hurricane response? <u>Can you tell us what procedures you used to get the information?</u> (pulling information)
- How was it different from what you expected? Have you received information from the role or team that you have not expected?
- Was there any time lag?
- <u>Was there any instance in which your decisions/actions were dependent on others' information, yet did not realize?</u>
- <u>What were the major challenges for communication and information management in Harvey?</u>
    - How did you overcome such challenges?

- What communication tools, equipment or technologies did you use to deliver or receive information? Were there any challenges associated with the use of communication technologies?

3. **Can you tell us about the process you used to make key decisions or solve problems in Hurricane Harvey?**

*The purpose of this question is to elicit any cases of decision-making challenges in Harvey.
*Check if the interviewee answered:

- What kind of decisions did you make in response to Harvey?
- What important knowledge or skills were needed to make such decisions?
- Was there any information deviation? How did it change your decision-making process?
- Can you describe some key decisions that required further consultation and coordination with other personnel or organizations?
- How did you coordinate such a decision-making process with other responders or other organizations? Can you describe such collective decision-making process?
  (Probe: Was there any formal, structured decision-making process?)
- What were the major challenges in such a collective decision-making process?
  (Probe: Was there time pressure (ask scales of time pressure: within minutes, hours or days), lack of information, lack of coordination, lack of resources, etc.)
- How did you overcome such challenges?

4. **Can you tell us about the procedures, plans, or guidelines you used in response to Harvey?**

*The purpose of this question is to elicit any cases of procedure adaptations in Harvey.
*Check if the interviewee answered:

- What are the names of the emergency response plans or guidelines? Could you articulate some details of the plan or guideline?
  (Probe: ask the interview to explain action steps or protocols)
- How did you implement these plans? Did you carry the plans and refer to them whenever you needed? Or did you use your experience or expertise to implement them?
- Was there any instance in which you had to take actions for which there was no plan?

IV. Wrap-up Questions

1. **Is there anything additional that you would like to mention other than we have discussed so far? Is there anything you would like to share with us regarding the hurricane response?**

2. **Who else would you recommend that we speak with for this study? (Probe: to your own organization or with other emergency response organizations)**

3. Can you tell us of your age (for demographic information reporting in the paper)?

*Fill in the blanks:

Age	Gender

Final Summary and Appreciation

I think we have had a useful data for our study through this interview. I would like to thank you for your participation in this study. I will try my best to use this data to improve the emergency response operations. If you have questions or issues, please feel free to contact the Principal Investigators listed in the form you signed or myself.

[After finishing the interview, ask for and all relevant documents]

[Stop the voice recording and make sure the recording is well saved.]

APPENDIX H. QUESTIONS FOR INTERVIEWS WITH HOSPITAL IMT PERSONNEL

Hurricanes Harvey: Emergency Responders Interview Questions

As we explained to you and obtained your agreement, we are carrying out a study that focuses on how emergency response personnel in a hospital has responded following Hurricane Harvey, what were the major challenges during the hurricanes, how hurricane response tasks were carried out, how your organization as a whole worked together on these tasks, and what lessons were learned during those response activities.

As you agreed, we will record this interview using voice recorders. Just as a reminder from what we said during the Informed consent process, that we will not be sharing any of this information with anyone directly or specifically. Further, we are not evaluating you, we are interested in improving the emergency response system. As someone involved in emergency response, you know better than anyone and are our best source of information! Your honest responses will really help us a lot. However, if you are not comfortable replying to something, that's fine, just say so and we will move on to the next questions.

[Turn on the voice recorder and ensure it is functioning well]

I. General Questions

1. Can you tell us about your role in responding to Hurricane Harvey?

*The purpose of this question is to understand the interviewee's role in Harvey and their experience in general.
*Check if the interviewee answered:

- <u>What role he/she played, when, and how long?</u>
- <u>How long have you worked in that role? (years)</u>
- <u>How long have you worked in overall disaster/emergency management area? (years)</u>
- **<u>Have you had ICS 300 training?</u>**

<u>*The purpose of this question is to see if the interviewee was trained about the Planning P process.</u>

- How was your role or duty changed during the response operations of Hurricane Harvey? Was the change planned and at least commonly experienced in other previous responses?
- Was there any instance in which you needed to take additional or new role that you are not supposed or planned to take?

(Probe: If taking such new roles were not planned, how were decisions made about your involvement in those activities?)

2. What were the major characteristics of the Hurricane Harvey that you had not expected or experienced from previous incidences? (What really made your response to Harvey different from prior emergency events?)

<u>* Please make sure to cover the characteristics of the hospital emergency management in addition to Harvey itself.</u>
* The purpose of this question is to hear about the interviewee's experience of Harvey response in general.
* Check if the interviewee answered:

- How was the incident different from your expectation or experience?
- How many times have you responded to the extreme events such as Hurricane Harvey, in your career?
- What were major goals that you tried to achieve in the Harvey response and how did you accomplish your goals?
- What were the major challenges in responding to Hurricane Harvey?

3. Can you tell us about the process you used to make key decisions or solve problems in Hurricane Harvey? (this section was pulled up from Section III)

*The purpose of this question is to elicit any cases of decision-making challenges in Harvey.
*Check if the interviewee answered:

- What kind of decisions did you make in response to Harvey?
- What important knowledge or skills were needed to make such decisions?
- Was there any information deviation? How did it change your decision-making process?
- **<u>Who had involved in key decision-making processes during Harvey?</u>**
- **<u>Who else do you think should be included in the decision making loop in your organization?</u>**
- <u>What were the major challenges in such a collective decision-making process?</u>

(Probe: Was there time pressure (ask scales of time pressure: within minutes, hours or days), lack of information, lack of coordination, lack of resources, etc.)

- How did you overcome such challenges?

II. Questions on the Incident Command Post to validate the EOTC

4. Can you describe the ICP/EOC/DOC you worked at (or with) during Hurricane Harvey?

*The purpose of this question is to understand the interviewee's working environment and to check the ecological validity of our research environment (EOTC).
*Check if the interviewee answered:

- [Level] ICP, EOC, or DOC? (If others, where?)
- [Location] Where was it located? Which region was it covering?
- [Functions] What functions did it serve? What was your role in it?
- [Structure] How were those functional sections organized?

<u>How did you work with other hospitals in the Texas Medical Center, and with other entities under HMH?</u>

- [Procedures] What procedures did you follow?

- [Scenarios] How dynamic and uncertain were the disaster unfolding?

5. **Can you tell us more specifically about your organizational structure and team composition in response to Hurricane Harvey?**

*The purpose of this question is to understand the organizational structure for coordination in Harvey.
*Check if the interviewee answered:

- What was the normal organizational structure during the daily operations?

<u>How did the structure change as the situation evolved?</u>
(Probe: Ask organizational hierarchy, span of control, commanding and reporting structure. Ask for an org chart.)

- What other organizations and agencies did you work with?

<u>How were such inter-organizational collaboration managed and coordinated?</u>
(Probe: what kind of division of labor developed? Any organization chart to share?)

- Did your organization have a representative at the City's or State's Emergency Operations Center (EOC) or Incident Command Post (ICP) that were set up for the hurricane response?

(Probe: If there was a representative, where was the location? When was the representative first sent? How did the organization know where and when to send the representative?)
(Probe: How did you work with any roles within the Planning Section?)
<u>(Probe: Was there a Liaison Officer in other response organizations?)</u>
<u>(Probe: Could you draw an organization chart to illustrate structure and communication flow during Harvey?)</u>

6. **Have you worked with or at the Planning section during Hurricane Harvey?**

(Only if the answer is <u>YES</u>)
Can you describe the Planning section (team) you worked at (or with) during Hurricane Harvey?

*The purpose of this question is to check the ecological validity of Planning section in EOTC.
*Check if the interviewee answered:

- How did you work with any roles within the Planning Section?
- [Functions] What functions did it serve? What was your role in it?
- [Structure] How were those functional sections organized?

III. Questions on Cases, Stories, and Narratives regarding Team Cognition and Resilience

4. **Can you tell us about the process you used to create a common operating picture or make sense of the evolving situation in Hurricane Harvey? How did you know what's going on?**

*The purpose of this question is to hear how the interviewee could understand what's going on in Harvey.
*Check if the interviewee answered:

- **<u>From who did you get the information you needed?</u>**

<u>What challenges did you face in maintaining up-to-date information and how did you go about resolving them?</u>

- <u>When, Where, and How</u> did you get information that you needed to know what's going on?
- **<u>And how often did you receive the updated pieces of information?</u>**
- Could you check the discrepancies between your own understanding and others? How?

5. Can you tell us about the process you used to communicate and manage information in Hurricane Harvey?

*The purpose of this question is to elicit any cases of communication and information management and associated challenges in Harvey.
*Check if the interviewee answered:

- What kind of communication and information management tasks did you perform during Harvey?
- What type of information did you need the most during the hurricane response? <u>Can you tell us what procedures you used to get the information?</u> (pulling information)
- How was it different from what you expected? Have you received information from the role or team that you have not expected?
- Was there any time lag?
- <u>Was there any instance in which your decisions/actions were dependent on others' information, yet did not realize?</u>
- <u>What were the major challenges for communication and information management in Harvey?</u>
- How did you overcome such challenges?
- What communication tools, equipment or technologies did you use to deliver or receive information? Were there any challenges associated with the use of communication technologies?

6. Can you tell us about the procedures, plans, or guidelines you used in response to Harvey?

*The purpose of this question is to elicit any cases of procedure adaptations in Harvey.
*Check if the interviewee answered:

- What are the names of the emergency response plans or guidelines? Could you articulate some details of the plan or guideline?

(Probe: ask the interview to explain action steps or protocols)

- How did you implement these plans? Did you carry the plans and refer to them whenever you needed? Or did you use your experience or expertise to implement them?
- Was there any instance in which you had to take actions for which there was no plan?
- **<u>How much variability was there in following the mentioned guidelines or procedures?</u>**

<u>a) in the Texas Medical Center (local or regional perspective)</u>
<u>b) in the State of Texas (State-wide perspective)</u>

IV. Wrap-up Questions

4. **Is there anything additional that you would like to mention other than we have discussed so far? Is there anything you would like to share with us regarding the hurricane response?**

5. **Who else would you recommend that we speak with for this study? (Probe: to your own organization or with other emergency response organizations)**

6. **Can you tell us of your age (for demographic information reporting in the paper)?**

   *Fill in the blanks:

Age	Gender

Final Summary and Appreciation

I think we have had a useful data for our study through this interview. I would like to thank you for your participation in this study. I will try my best to use this data to improve the emergency response operations. If you have questions or issues, please feel free to contact the Principal Investigators listed in the form you signed or myself.

[After finishing the interview, ask for and all relevant documents]

[Stop the voice recording and make sure the recording is well saved.]

APPENDIX I. DESCRIPTION OF EMERGENCY OPERATIONS TRAINING CENTER

The following information of EOTC is available at https://teex.org/about-us/emergency-operations-training-center/

Training Areas

TEXAS A&M ENGINEERING TEEX EXTENSION SERVICE

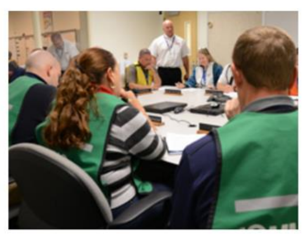
MENU

Emergency Operations Training Center (EOTC)

The 32,000-square-foot EOTC uses state-of-the-art simulation and computer-based technologies to train incident managers, supervisors, and jurisdiction officials in the management of a large-scale crisis using a unified command approach, which can be tailored to any group.

Located on a 297-acre campus that encompasses two of the top hands-on emergency response training venues in the country, Disaster City and the Brayton Fire Training Field, the multi-million-dollar EOTC includes direct links to active response in Disaster City.

Numerous cameras located throughout Disaster City allow for training observation from within the EOTC. The center can be configured as an incident command post or emergency operations center for full-scale, functional exercises held on the campus. Classrooms can be arranged for a variety of simulation exercises and courses.



The underlying training tool is the Emergency Management*Exercise System (EM*ES). The computer simulation tool was developed specifically for use within the EOTC by The Texas A&M University System Engineering Program, in conjunction with the Texas Engineering Experiment Station (TEES) and the National Emergency Response and Rescue Training Center (NERRTC).

The EM*ES simulation can support local, jurisdictional, regional, and large-scale response training and exercise operations involving human "role players" and computer-injected events. The system can be used in a distributed LAN mode, a web browser mode (or a combination of the two), and even in a wireless, stand-alone network. Participants can be in geographically different locations, if desired.

The Facility Includes

- 2 simulation-enabled classrooms with breakout rooms
- 3 classrooms
- Command vehicle pads with physical interface
- Public Information Broadcast room
- Multiple meeting rooms
- Dining facility

The EOTC can be configured as an Incident Command Post or Emergency Operations Center for full-scale functional exercises held on campus. We also have the ability to configure it as an EOC and ICP for simultaneous deliveries.

The Emergency Management*Exercise System (EM*ES) can support local, jurisdictional, and regional large-scale exercise operations involving role players and computer-injected events. Participants can be in geographically dispersed locations, if desired.

Training Areas

TEXAS A&M ENGINEERING
TEEX
EXTENSION SERVICE

MENU

Goal

The EOTC's goal is to provide participants (including government agencies, corporate industrial teams, and jurisdictions from across the nation) the skills they need to respond to, manage, and recover from large-scale incidents. The EOTC provides a wide spectrum of possible operations, ranging from the incident command post perspective to the emergency operations center and multi-agency coordination viewpoint at the local, regional or state levels. This process-focused training environment allows participants the opportunity to hone their incident management and decision-making skills through a computer simulation system that provides a realistic scenario customized to the participants' level of training. The overall incident management structure used in the EOTC replicates the Incident Command System and follows the National Incident Management System (NIMS) as required in the National Response Framework (NRF). The facility adapts existing incident management systems and procedures to the unique requirements of responding to large-scale incidents at all levels.

Methodology

The EOTC provides a total immersion in the incident-management training environment and allows supervisory-level responders a practical, simulated experience in the management of a large-scale incident. To accomplish the requested training objectives, instructors use a multidisciplinary, jurisdictional-based, team-building approach to deliver instructional material and exercises. The layout and design of the EOTC facilitate exercise delivery and after-action feedback. The training analysis team develops the after-action review during the exercise, which allows for instant, quality feedback and successful training operations. The quality and experience of the instructional staff is unparalleled. All instructors are subject matter experts in their respective fields who have participated in or managed a large-scale event and understand what constitutes a proper training environment.

Topics Covered

- Decision making
- Situational Awareness
- Information Management
- Large-Scale Incident Command Processes and Principles
- Emergency Management Processes and Principles
- Overview of Incident Command System
- Principles of Unified Command
- Organization and Staffing for Unified Command
- Resource Management and Incident Management Strategies
- Incident Action and Operational Support Plan Development
- ICS Documentation Overview
- Training Simulation Tools Overview
- All Hazards, Computer-Simulation Exercises

Location

1595 Nuclear Science Road
College Station, TX 77843-800