Identifying Traces of Resilient Performance in Incident Management Systems using Episodes

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ABSTRACT

In order to cope with increasing complexity of catastrophic disasters, resilience is considered an essential capability of an incident management system (IMS). As resilience is manifested during systems operation, a naturalistic observational study was conducted to understand how resilient performance dynamically takes place in this domain. The study results were presented using the concept of episodes, each of which uncovers a trace of such resilient performance following an information input called an inject. The episode analysis also facilitated the identification of complex and dynamic interactions among human and technological agents to satisfy work demands, representing work-as-done (WAD) in large-scale emergency response operations.

Keywords

Resilience Engineering, Incident Management, Episode Analysis, Cognitive Systems Engineering.

INTRODUCTION

Adverse events such as technical, natural, or civil disasters have revealed limitations in managing risks from various threats and have challenged society's capabilities of preparing for, responding, and recovering from such events (Mendonça, 2007). This challenge has been reflected through responses to several recent disasters, for example, the Deepwater Horizon oil spill in 2010 (Birkland & DeYoung, 2011; Sylves & Comfort, 2012), Hurricane Katrina in 2005 (Comfort, Birkland, Cigler, & Nance, 2010; Wise, 2006), and September 11 World Trade Center (WTC) Attack in 2001 (Comfort, 2002a, 2002b). In order to address these challenges and reduce impacts of the adverse events on human lives, social and environmental infrastructure, various incident management systems (IMSs) were developed and put in operation. Generally, an IMS is designed to manage adverse events of varying scales that involve multiple agents, agencies, jurisdictions, organizations and disciplines. These events also include emergency, disaster, catastrophe and even planned events (e.g., sports games). Moreover, an IMS is responsible for all the mission phases such as prevention, protection, mitigation, response and recovery (Keybl, Fandozzi, Graves, Taylor, & Yost, 2012).

An IMS is a complex socio-technical system (STS) in which human practitioners (e.g., incident managers and operators) work with technological artifacts within and across boundaries of a social structure (Qureshi, 2007). The boundaries of an IMS may lie across organizations (i.e., one fire department to another), geographical areas (i.e., from rural to urban area), dissimilar cultures (i.e., bureaucratic to generative (Westrum, 2004)), and time periods (i.e., day shift to night shift) (Carayon, 2006). Within the IMS, there are complex and dynamic *'interactions'* among human and technical agents, hazardous tasks and a built/natural environment that surrounds them (Wilson, 2000).

In order to address the increasing complexity of STSs, Resilience Engineering (RE) has emerged as a new safety

paradigm (Hollnagel, Woods, & Leveson, 2007). RE views success and failure as different outcomes of the same system's adaptation process of coping with real-world complexity (Dekker, Hollnagel, Woods, & Cook, 2008). Resilience, however, does not simply mean changing system's performance reactively given a certain demand. Resilience is "the intrinsic ability of a system to adjust its functioning prior to, during or following change or disturbance, so that it can sustain required operations under both the expected and unexpected conditions" (Hollnagel, 2011, p. xxxvi).

Disasters and catastrophes impose severe disturbances that require continuous change in incident management performance. In this context, resilience is considered a crucial capability of an IMS during emergency response and recovery (Boin, Comfort, & Demchak, 2010; Caldwell, 2014; Comfort et al., 2010; Harrald, 2006).

BACKGROUND

There have been continuous efforts to conceptualize and define resilience in incident/emergency management in the literature. Weick (1993)'s seminal work offered four dimensions of resilience that facilitate sense-making through a scrutiny of a wildfire at Mann Gulch, Montana in 1949 that took 13 smokejumpers' lives. Those four potentials are improvisation, virtual role system, attitude of wisdom, and respectful interaction. Improvisation means a capacity to rework knowledge in a novel way for problem-solving. Virtual role system helps maintain a role structure in individual's mind if a certain role becomes unavailable. Wisdom is an attitude that doubts exiting skills, belief and knowledge whether these are true and valid. Respectful interaction includes respecting other's report as well as one's own perception and reporting honestly to others. Subsequent work was conducted in more specific aspects of emergency response operations: role performance, resource management and communication/ information management.

With respect to roles in disaster responses, Mendonça and colleagues identified characteristics of improvised cognitive and behavioral events in the bombing of the Alfred P. Murrah Federal Building in Oklahoma in 1995 and the attack on the World Trade Center (WTC) in New York in 2001 (Mendonça et al., 2014). The results of this study showed that about 10 to 13 percent of the emergency responder's behaviors were improvised, and procedural improvisation that refers to a departure from a normally prescribed way of performing a role was most predominant. Lundberg and Rankin (2014) unveiled instances of role change, negative impacts of taking new roles and ways to improve resilience. For example, the authors suggested that it would be necessary to include improvised roles during regular exercises to foster resilience skills (Lundberg & Rankin, 2014).

With regards to resources management efforts, research was focused on an adaptive use of materials. Kendra and Wachtendorf (2003) conducted a timely on-site data collection after the WTC attack to capture elements of resilience in New York City's Emergency Operations Center (EOC). The authors examined how a new EOC had been reestablished and run after the initial EOC, located inside the WTC, was demolished. According to Kendra and Wachtendorf (2003), the elements of resilience in that restitution process include adaptive performance of incorporating resources, for example, physical facility, personnel, equipment and supplies necessary to operate the EOC. Webb (2004) found out that changing equipment usage was the second most common behavior following procedural change, supporting Mendonça and colleagues (2014)' study. Mendonça and colleagues proposed two types of instances that entail resilience when: 1) the use of available resources at-hand is blocked, and 2) necessary resources are not available (e.g., too far to obtain) (Mendonça, 2007). In order to address this challenge, the authors developed a decision support tool that is able to generate alternative resources and investigated its effect on 5-person team's resource allocation decision-making processes (Mendonça, Beroggi, & Wallace, 2003; Mendonça & Wallace, 2007).

Another major process of emergency response organizations is communication and information management (Comfort, 2007) A study performed by de Carvalho and colleagues (2018) highlighted how standard operating procedures of Brazilian emergency responses framed as work as imagined (WAI), are realized into actual practices or work as done (WAD). The study revealed that the WAD is the outcome of team adaptation through communication among team members under complex emergency situations (de Carvalho et al., 2018). Rankin and colleagues (2013) identified communication and information flow of improvised role incumbents of a Swedish Response Team and presented such work flow in several episodes, a chain of communication sub-events that are bound together for a common meaning.

The existing literature on resilience in the emergency domain indicates that, for large-scale incident management operations, activities such as management of resources, information or communication, are distributed among multiple actors, and developed with their respective manner and tempo (Woods, 2017). Thus, interactions among different human and technological agents within an IMS are an essential aspect of a system's resilience (Nemeth, 2008). To that end, this study aims to use episode analysis to model a continuum of such interactions that take place in the course of satisfying demands from an incident.

METHOD

Research Setting

The present work employed a naturalistic observational study in high-fidelity emergency response simulation provided by the Emergency Operations Training Center (EOTC), managed by Texas A&M Engineering Extension Service (TEEX)[1]. EOTC training programs impose realistic work demands on participants allowing for observations of resilient performance in the context of a realistic emergency response. Each training course invited 40 to 45 trainees under the supervision of about 20 highly skilled instructors in a simulated Incident Command Post (ICP). Two training courses were selected for data collection: one in June and another in August, 2017.

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. For the first observation, 39 out of 44 trainees consented, and 32 out of 46 consented to participate in the second observation. All instructors participated in both studies. 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 obtained pertinent approval from authors' Institutional Review Board (IRB) for the compliance with research ethics and for the protection of human subjects' right (IRB No.: IRB2016-0489D).

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. In particular, a proprietary intranet software named EM*ES (Emergency Management * Exercise System) was used to help participants communicate each other (e.g., bulk email, event log, incident map). 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: Columbia State University (mass shooting), Needland Tornado (hurricane), and El Diablo (a plane crash into a stadium). The full-day scenario differed (the first study: earthquake, the second study: civil disturbance). In order to make these exercises more immersive, experienced and skilled role-players provided 'injects' that were pieces of virtual incident information fed into the IMS (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.

To collect sufficient data, multiple technologies (e.g., iPad application, camcorders, voice recorders, screen capture tool) were used to record interactions among participants and technical artifacts. These interactions were observed and coded with respect to 'three C's': Context, Content and Characteristics as shown in Table 1.

Table 1. Three C's of Interaction

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?

Materials and Procedure

Participants attended a simulated incident management training course for three and a half days. In the morning of the first day, an instructor held an instructional session to provide participants with training tutorials, objectives, expected learnings, and overall incident management and planning processes. The instructor also explained roles and responsibilities, and forms and technologies to be utilized. After lunch on the first day, the first incident scenario began at 1 p.m. Initially, another instructor gave the participants an incident briefing for the scenario and assigned them to each of five sections of an ICP, namely, Command, Operations, Planning,

[1] For more information, visit http://teex.org

Logistics and Finance/Administration. The main scope of the study was the Planning Section because it was primarily in charge of communicating incident information within the ICP. Once the participants were gathered at each section, two other instructors provided specific tutorials for the objectives and functions of the section and the description of each role. The instructors gave additional instruction when the participants needed to learn how to use the software. Participants were encouraged to ask questions from instructors and also the instructors often approached participants to instruct role performance or to check in for the work progress. In the morning of the second day, the second incident scenario began at 8 a.m. without providing any additional instructions.

At the first scenario, an instructor presented an incident briefing for the different scenario and assigned the participants to different sections. The assignment was not random because the EOTC staff considered assigning them to a different section from the previous sessions to increase the level of exposure to various roles. Upon the assignment, instructors gave specific tutorials for the section and each role in the section. This process occurred in a very similar way for the third and the fourth scenarios. Camcorders and screen capture recordings were started before the training session began not to interrupt the training. Voice recorders were put on participants' vests once their roles were determined. Four to six trained observers (three undergraduate and three graduate students) conducted direct observation after roles were assigned. Observers recorded interactions between participants, both verbal and material as well as working with technical artifacts.

Data Analysis

Multiple audio/video recordings obtained from each exercise were synchronized using Adobe Premiere Pro CC 2018. Next, trained undergraduate research assistants began transcribing participant's actions and communications. The transcribers also measured time taken for each episode, an initiator and a receiver of such actions and communications, and a technological device used in these where applicable. The iPad application was used to capture moments where such episode began and finished.

To analyze communications and interactions that occur among multiple agents, an episode analysis similar to (Korolija & Linell, 1996) is used. In incident management operations, such episode is translated into a series of actions from the reception of an incident data input to the dissemination of the processed information to other members. Figure 1 depicts how an episode can be composed of interactions among different human and technological agents. It involves human-to-human interactions that have 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). Consequently, episodic time (T_e) is obtained by measuring time when an inject is given (T_i) and time when its related demands are met (T_d). The outcome of these episodes is the dissemination of processed information displayed in an event log. The number and quality (e.g., accuracy and currency) of information threads in that event log are also used to assess the system's performance output.

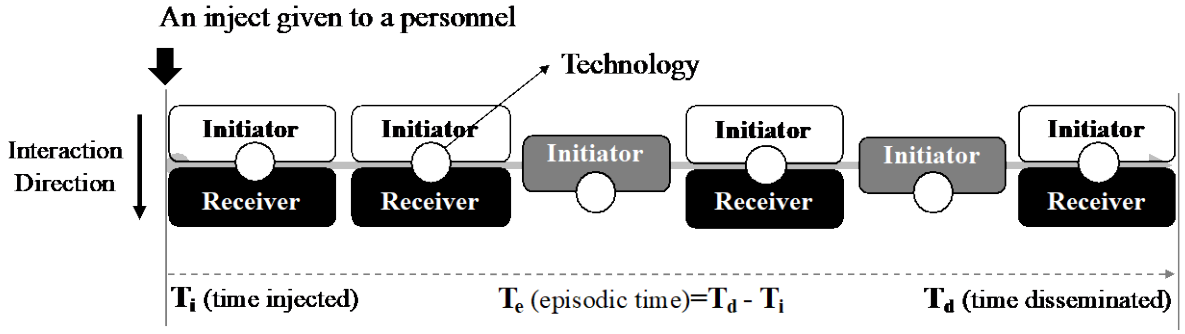

Figure 1. Schematic of Episode Analysis

PRELIMINARY RESULTS

While transcription and episode analysis are ongoing, in this paper we present two episodes to discuss our theoretical model of emergency response episodes. Figure 2 and Figure 3 respectively illustrate each episode following an initial inject given to Information/Intelligence Unit Leader (I/I Lead) in the Planning Section. During the exercise of El Diablo (Figure 2), a virtual character, role-played by a skilled staff, reported a field observation that contains incident information (e.g., location and consequence of the incident). This communication occurred via Telephone. Next, I/I Lead took some follow-up actions, for example, taking a note

of what he heard from the field observer (on Paper), communicating it with another I/I agent (Face-to-face), and making copies of what he wrote down (Photocopier). Following this, I/I Lead delivered each of the copies (213 GMs[2]) to other roles that he considered may need such information such as Documentation Unit Leader (DOCL), Situation Unit Leader (SITL), Public Information Officer (PIO), Operations Resource Specialist (Ops Res.), and Operations Section Chief (Ops SC) through various technologies and artifacts. In another exercise of Needland Tornado (Figure 3), a similar pattern was observed.

For example, following an initial field report that notifies degree of damage in different locations, I/I Lead had a verbal dialogue with another I/I agent, printed copies of the field report (213s), and handed them over to other roles. These patterns are marked as dotted boxes (e.g., red, blue, green and purple) that indicate sub-episodes. For example, after having conversation with a field observer (red), I/I Lead had internal communication within other I/I agents (blue). And then, I/I Lead made copies of a message that contain incident information (green), and disseminated the copies to other roles (purple). The episodic time was 11 minutes and 58 seconds for the first episode and 23 minutes and 35 seconds for the second one. This indicated that the second episode was twice as long as the first one. 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.

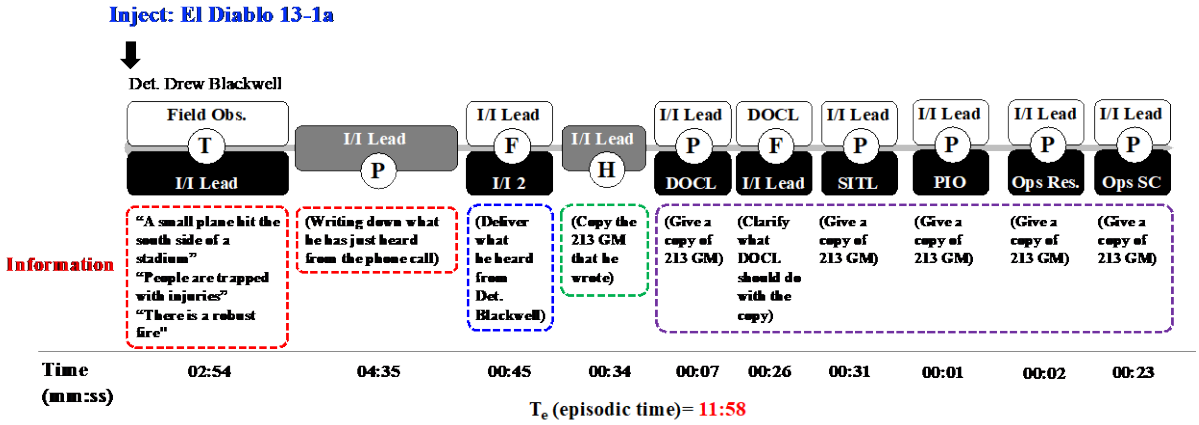

Figure 2. Episode after Inject El Diablo 13-1a

Note: a white box: initiator, a black box: receiver, a circle in the middle: technology, a gray box: working alone, a dotted box: sub-event with a recurring pattern.

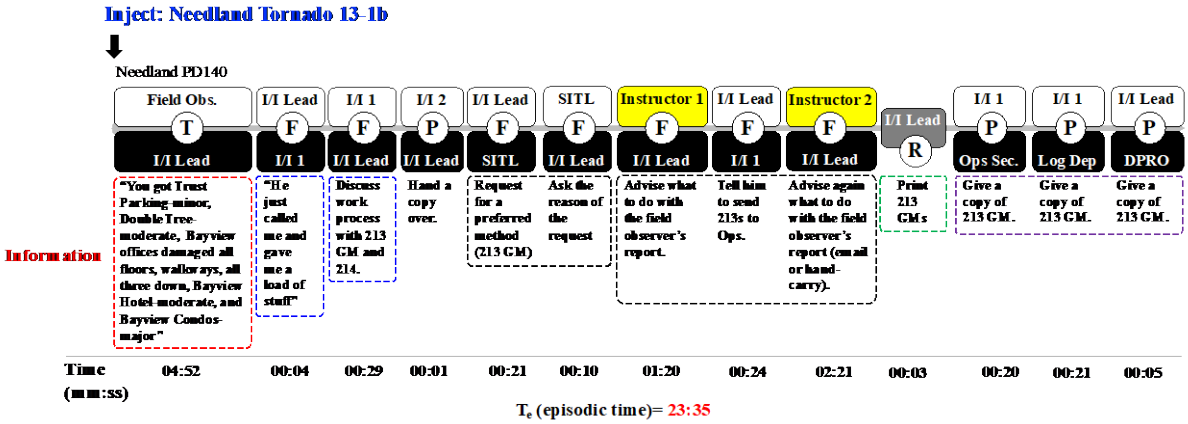

Figure 3. Episode after Inject Needland Tornado 13-1b

Note: a white box: initiator, a black box: receiver, a circle in the middle: technology, a gray box: working alone, a dotted box: sub-event with a recurring pattern.

[2] A 213 GM is one of standard forms included in FEMA Incident Command System (ICS) which is used to document incoming messages.

DISCUSSION

Tracing Resilient Performance

The findings from the current study showed a non-linear, dynamic process of 'compensating' demands within an incident management team of distributed multiple roles. As Woods (2006) noted, resilience of a system may not be manifested until it encounters disruptions, which may fall outside design capacity (Woods, 2006). Hence, the episode analysis was conducted to understand the information handling function of the IMS following an inject composed of various incident data. From the preliminary extraction of two episodes, some similarities and differences were identified. The major difference between two episodes is that I/I Lead in the second episode interacted with SITL and two instructors to discuss a preferred method of communication on whether it should be emailed or hand-carried. This might be reflected in the longer episodic time and a higher number of interactions. In a similar vein, the measures in episode analysis may show promise as a diagnostic method to investigate interactions in a team environment in which multiple human and technological agents function together.

Measuring Resilient Performance

Resilience is known to be a difficult concept to measure, and even systematic attempts to measure it in unplanned-for situations (e.g., disaster, catastrophe) were severely limited (Mendonça, 2008). Features of episodes, for example, time taken to cope with injects, duration and frequency of actions and communications provide measures for resilient performance of an IMS. It is important to note that being resilient does not mean making faster and shorter paths of compensation of work demands (Woods, 2006). Rather, it means how the system absorbs a shock, reorganizes its functions and how interactions occur across different levels to achieve system goals (Mendonça, 2008). Hence, our suggestion for future research is to characterize differences in those work demands as well as in subsequent organizational behaviors. Furthermore, it is worth understanding how four processes of resilience, namely, Monitoring, Anticipating, Responding and Learning (Hollnagel, 2011) occur in incident management operations.

Limitation

While this study is the first attempt to systematically analyze resilient performance following an external input to an IMS, several limitations need to be addressed in the future research. First, in this study, data were collected in a simulated setting. While EOTC environment is similar to real-world emergency response operations in many aspects, evaluating models of derived from this high-fidelity simulation setting against real response scenarios is warranted. (Mendonça, 2008), it is necessary to validate, or at least support, such findings with real-world evidences. In addition, more episodes are required to provide more reliable and generalizable findings that enable statistical analyses. Furthermore, the present work did not examine the effect of different technology on the information handling performance. Work is in progress to examine how different technologies are used in those episodes.

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