Modeling Team Cognition in Emergency Response via Naturalistic Observation of Interactions

Team cognition has not been adequately addressed in the field of emergency response, especially due to its lack of theorizing efforts. A naturalistic observational study was conducted as an initial attempt to build a theoretical model of team cognition in emergency response by understanding interactions of an emergency response planning team for cognitive tasks of perceiving (P), diagnosing (D), and adapting (A) to the changes in the status of critical elements. For an illustrative purpose, a P·D·A (Perceive·Diagnose·Adapt) model is proposed as a proof-of-concept that depicts nonlinear, interdependent, and dynamic interactions observed within and among three functional sub-teams of a Plans team at a simulated incident command post. Overall, this paper shows potential benefits of a network representation of team interactions in investigating team cognition for context-specific cognitive tasks in emergency response.

INTRODUCTION

Emergency responders work collectively as an ad hoc team to save lives and infrastructures at risk, despite their varying experience, knowledge, cultural backgrounds, and difficult working conditions with high-levels of uncertainty and time-pressure. Catastrophic man-made and natural events such as the terrorist attacks on September 11, 2001 and hurricanes Katrina and Harvey enlightened the importance of collective response efforts for a catastrophic disaster. To provide a consistent collective incident management, the U.S. Department of Homeland Security developed the national incident management system (NIMS), utilizing standardized organizational approaches such as the incident command system (ICS) (FEMA, 2017).

Cognition, in particular, has gained attention as one of key constructs to consider in collective response efforts in emergency management. According to Comfort (2007), cognition plays a critical role in initiating, connecting, and altering interaction among the three (otherwise disconnected) Cs of the emergency management process – communication, coordination, and control. Specifically, Comfort (2007) defined cognition as "a process of continuing inquiry, building on prior knowledge of the region at risk and integrating incoming information on changing conditions and system performance into a current assessment of vulnerability of the community" (p.193).

Team cognition, however, has not been fully appreciated or adequately addressed in the field of emergency response (Bigley & Roberts, 2001). The scarcity of literature on team cognition in emergency response can be traced back to lack of efforts in providing context-dependent theories. Indeed, more broadly, theoretical growth of team cognition has been primarily driven by application needs – i.e., "there was no time to wait for a psychology of team cognition" because applications were "needed yesterday" (Cooke et al., 2007). In other words, even before theorizing team cognition for the context of emergency response, there has been a need to study and improve responders' collective efforts. Also, team cognition and behavior literature have constantly documented the need to study real-world teams in the context of "broader sociotechnical systems" (in situ or in naturalistic settings, outside of controlled laboratory environments), which fits perfectly with the description of emergency response teams (Salas, Cooke & Rosen, 2008).

Instead of context-dependent theories, researchers in the emergency response discipline have been seeking the 'right' construct or model of team cognition. In a scoping review on team cognition in emergency response, Moon, Peres, & Sasangohar (2017) found that a heavy reliance on constructs from other disciplines without full appreciation of their distinctive features has hindered the operationalization of team cognition specific to the unique context of emergency response. As it stands, there are at least five research domains of team cognition (Wildman, Salas, & Scott, 2014), i.e., team mental models (TMMs, first invoked by Cannon-Bowers & Salas, 1990), transactive memory systems (TMSs, first invoked by Wegner, 1987), team situation awareness (TSA, Cooke, Kiekel, & Helm, 2001), strategic consensus (e.g., Floyd & Wooldridge, 1992), and interactive team cognition (ITC, first invoked by Cooke & Gorman, 2009; Cooke et al., 2013). In addition to those five domains, collective sensemaking (Weick, 1993) and common operating picture (COP; Kalloniatis et al., 2017) are the other two domains commonly adopted by emergency response literature from organizational behavior and military disciplines, respectively. While each of these domains reflects some aspects of the multifaceted nature of team cognition, the direction of future research in emergency response hinges on theorizing for this specific context.

Team cognition has been generally defined with two perspectives – shared cognition vs. interactionist perspective (Cooke et al., 2013). With the shared cognition perspective, team cognition is defined as an emergent product, state, or knowledge structures existing within team members' heads that are combined or aggregated to represent the team. With the interactionist perspective, team cognition is defined as "cognitive processes or activities that occur at a team level" and "the process of team members interacting to complete a cognitive task" (p. 256, 269, Cooke et al., 2013). For this perspective, the level of analysis lies at a team level, measuring interactions among team members, "not a property of the individual team members or the products produced by the team" (p. 267, Cooke et al., 2013). This interactionist perspective (or interactive team cognition) effectively captures team cognition in heterogeneous and dynamic teams prevalent in the real-world (Cooke & Gorman, 2009; Cooke et al., 2013). Team cognition in emergency response, for instance, can be manifested as interactions among responders of heterogeneous experience, knowledge, and cultural backgrounds.

Although researchers in the emergency response discipline appreciate the value of viewing team cognition as interaction (Comfort, 2007; Bergeron & Cooren, 2012; Wolbers & Boersma, 2013; Jobidon et al., 2017), an associated empirical or interventional attempt using this perspective remains scarce. Tracing the scarcity of literature back to lack of context-specific theorizing efforts (Moon, Peres, & Sasangohar, 2017), an observation-based theory building approach is being utilized here to address this gap.

The naturalistic observational study presented here is an initial effort to explore team cognition for an incident management team (IMT) as an interactive system. An IMT is an ad hoc team of command-level responders, e.g., ICS-qualified incident commanders, co-located at the incident command post (ICP) of a major incident such as Hurricane Harvey. With the delegated authority to act on behalf of the affected jurisdiction, an IMT provides an incident action plan (IAP) to subordinate branch directors or supervisors in the field for the planned operational period, generally between 12-24 hours. To develop an IAP with clear objectives and "a comprehensive listing of the tactics, resources, and support needed to accomplish the objectives", an IMT continuously manages information based on incoming cues from outside, following a cyclical ICP planning process (p.105, FEMA, 2017). Despite the significance of team cognition within an IMT, there have been few studies exploring this phenomenon (e.g., McLennan et al., 2006; Bearman et al., 2015).

Interestingly, an IMT is a team of functional sub-teams or sections (i.e., Command, Planning, Operations, Logistics, and Finance/Administration), following the structure of incident command system (ICS). Within each sub-team there is also a team of functional units. Therefore, considering this team-of-team structure in an IMT, this study put its focus of observation on a Planning section (or a Plans team), one of the functional sub-teams in an IMT. A Plans team personnel "collect, evaluate, and disseminate incident situation information" and "prepare status reports, display situation information, maintain the status of assigned resources, facilitate the incident action planning process, and prepare the IAP based on input from other sections" (p.28, Federal Emergency Management Agency, 2017). A Plans team is composed of the functional units of information management, including an Info/Intel (information or intelligence) unit, a Situation unit, and a Section Chief unit.

The purpose of this study is to develop a theoretical interactionist model of team cognition in emergency response, to inform future interventional attempts to improve team decision-making. According to a working definition provided in a prior scoping review of literature (Moon, Peres, & Sasangohar, 2017), team cognition for an IMT can be viewed as interactions among responders to perceive (P), diagnose (D), and adapt (A) to the changes in the status of critical elements. Such a view on team cognition as interactions for P, D, and A is hypothesized to be generally applicable to a team of teams in the context of emergency response. For an illustrative purpose, a P·D·A (Perceive·Diagnose·Adapt) model is proposed as a proof-of-concept that depicts nonlinear, interdependent, and dynamic interactions actually observed within and among three functional sub-teams of a Plans team, i.e., an Info/Intel unit, a Situation unit, and a Section Chief unit.

METHOD

Research Setting

This naturalistic observational study was conducted at the emergency operations training center (EOTC), College Station, TX. The EOTC is a high-fidelity simulator replicating a generic IMT facility, specifically in the structure of the IMT, the technology used, the ICP planning process employed, and the scenarios exercised. Emergency responders from diverse backgrounds come to the EOTC to be trained together as an ad hoc IMT for three and a half days, responding to four emergency scenarios through the course of their training. The emergency scenarios can range from earthquakes and tornados to terrorist attacks, and civil disturbances. Incoming cues from outside of an IMT are injected in a verbal manner, usually through phone calls or radio communications from instructors playing various roles such as emergency operation center, field observers or field branch director.

Data Collection

Data collection was designed to capture interactions among responders with a specific focus on the Plans team. A coding system, for instance, was devised to capture three Cs – context, content, and characteristics (see Table 1) – of an interaction that occurred between a Plans team member and others. Interactions were observed and coded in terms of who initiated the interaction and with whom, which technology was being used (if any), and what was communicated and for what purpose. The coding system was designed in conjunction with a pre-study survey and interviews with subject matter experts (SMEs), i.e., two full-time instructors at the EOTC.

Table 1. A three Cs coding system of an interaction

Context			Content	Characteristics	
Initiator	**Receiver**	**Technology**	**Content**	**Frequency**	**Duration**
Who initiated	With whom	Using which technology	What's communicated for what purpose	How often	How long

The three Cs of interactions were first captured during a live observation at the EOTC using the Dynamic Event Logging and Time Analysis (DELTA) *iPad*-based tool for the ease of coding with time-tracking. A researcher shadowed a Plans team member of interest through the course of a scenario, coding the member's interactions with others in real-time *(coded in situ)*. Three internal discussion sessions were conducted to train researchers and let them reach a consensus on each code, as an attempt to ensure inter-coder reliability prior to the observation. During the observation, interactions of the Plans team were also video-, audio-, and screen capture-recorded to augment and enrich the live observation data *(coded in retrospect)*.

Data Analysis

Network analysis. Coded interactions can create a bipartite directed network with two types of nodes (i.e., human and technology) and edges (or links) weighted by frequency and duration. Centrality of a node shows how central a node is in a network, and for this study degree and betweenness centrality are also being used. Degree centrality is simply based on the number of edges connected to the nodes. Betweenness centrality, on the other hand, measures the extent to which a node lies on paths between other nodes. In a network created from coded interactions, a node with high betweenness centrality can be interpreted as the node with control over information passing between other nodes. The networks identified in this study are currently being examined in terms of centrality measure to identify critical contributors of team cognition in terms of P, D, and A, and thereby corroborate and enrich the proposing P·D·A model.

Content analysis. Transcribed contents of verbal communications are being qualitatively analyzed to present themes, patterns, or cases associated with team cognition in terms of P, D, and A.

MODEL DEVELOPMENT

To develop a theoretical interactionist model of team cognition in emergency response, this study views a Plans team as a cognitive system capable of managing information through interdependent, nonlinear, and dynamic interactive behaviors for perceiving (P), diagnosing (D), and adapting (A) to the changes in the status of critical elements (Adapted from Moon, Peres, & Sasangohar, 2017). Such a view on team cognition as interactions for cognitive tasks of P, D, and A is hypothesized to be generally applicable to a team of teams (a team and its sub-teams) in the context of emergency response. For instance, just like a Plans team, each of the three functional sub-teams of a Plans team (i.e., an Info/Intel unit, a Situation unit, and a Section Chief unit) perceives, diagnoses, and adapts to the changes in the status of critical elements. Based on the hypothesis, a P·D·A (Perceive·Diagnose·Adapt) model is proposed as a proof-of-concept that depicts team cognition for a Plans team as interactions within and among three functional sub-teams of the Plans team, for context-specific cognitive tasks of P, D, and A (See Figure 1).

Proposing a P·D·A (Perceive·Diagnose·Adapt) Model

The proposed P·D·A model posits the following three premises: (1) a Plans team is a cognitive system where its team cognition is interactions of team members to complete a cognitive task; (2) team cognition for each of the three sub-teams of a Plans team is tied to the context-specific cognitive tasks of perceiving (P), diagnosing (D), and adapting (A) to the changes in the status of critical elements; and (3) team cognition for a Plans team is manifested as nonlinear, interdependent, and dynamic interactions within and among P, D, and A of the three sub-teams of the Plans team.

The first premise explains the visual resemblances between the P·D·A model of team cognition and the information processing model of individual cognition (See

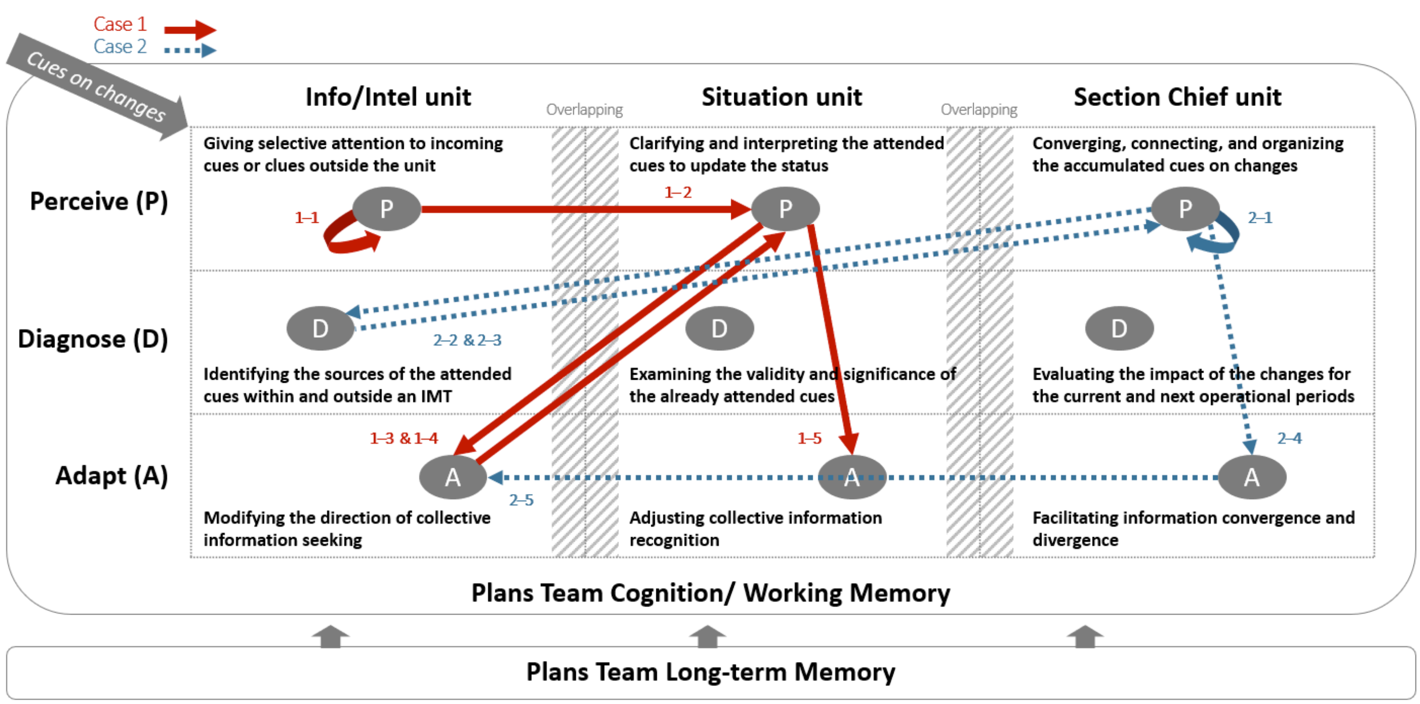

Figure 1. A P·D·A (Perceive·Diagnose·Adapt) model of team cognition as interactions within and among three functional sub-teams of an emergency response Plans team

Figure 1). As the information processing model views an individual as a cognitive system or a human information processing system (Wickens, 1992), the P·D·A model views a team as a cognitive system capable of managing information. The interactionist perspective on team cognition helps the P·D·A model to realize its potential to extend an individual cognition model to a team level. The shared cognition perspective, following an Input-Process-Output (I-P-O) framework (Hackman, 1987), treats collective knowledge of team members as inputs to team communication processes affecting team outcomes. This is a mere extrapolation of the information processing model of individual cognition (Wickens, 1992) to team level. On the other hand, the interactionist perspective of team cognition enables true extension by counting more than the simple aggregation of individual cognitive activities of team members. The interactionist perspective is "compatible with the view of human-machine system as a unitary system" (Cooke & Gorman, 2009, p.28).

The second premise explains the effectiveness of a 3x3 grid representation in capturing team cognition for a team of teams (Figure 1). The rows of the grid represent team cognition for each member of the Plans team in terms of the three context-specific cognitive tasks of P, D, and A. Perception in a Plans team is a process of selectively attending to, clarifying, interpreting, converging, connecting, and organizing the cues on changes (the first row of the 3x3 grid). Diagnosis in a Plans team is a process of identifying sources, examining the validity and significance (i.e., vetting), and evaluating the impact of the attended cues on changes (the second row of the 3x3 grid). Adaptation (A) in a Plans team is a process of modifying courses of action for seeking and recognizing information and facilitating the information convergence and divergence (the third row of the 3x3 grid). Hypothesizing the working definition of team cognition as interaction for P, D, and A to be generally applicable to a team of teams, the columns of the grid represent the overall role each of the three sub-teams of a Plans team play in terms of P, D, and A of the cognitive system.

The third premise explains the benefit of a network representation in showing the complexity of interactions for a team of teams. For an illustrative purpose, two cases were extracted through a content analysis of transcribed and coded interactions during the third simulated operation in response to a Tornado (the solid and dotted arrows in Figure 1 for Case 1 and 2, respectively). Case 1 starts with an Info/Intel unit giving selective attention to an incoming cue on changes in the number of injured and transported people in a certain area (1–1 in Figure 1 and Table 2). Then, a Situation unit clarifies the attended cue by asking "Wait, south side of what?" (1–2 in Figure 1). The Info/Intel unit modifies the direction of collective information seeking into checking what 'south side' means and brings the answer back to the Situation unit (1–3 and 1–4 in Figure 1). The Situation unit puts the information on the event log presented through a large shared display, and thereby adjusts collective recognition of the information (1–5 in Figure 1). Case 1 is a good example of showing the differences between the P of an Info/Intel unit and the P of a Situation unit. An Info/Intel unit perceives a cue on changes by giving selective attention to it while a Situation unit perceives the cue by clarifying and interpreting it.

Table 2. Transcribed and coded interactions for Case 1 (Figure 1)

	Initiator	Receiver	Technology	Transcript
1–1	Info/Intel 2	Info/Intel unit Lead	Paper Form	"I just talked to Med Branch and this is what they have currently. This is what we'll pay attention to. We've got north side, we have 15 injured, 5 transported. On the south side, they say there's a few dozen and growing fast."
1–2	Info/Intel 2	Situation unit Lead	Paper Form	"I talked to Med Branch and this is all they have currently. The North side you have 15 injured, 5 transported, on the south side, said there's a few dozen and growing fast."
	Situation unit Lead	Info/Intel 2	Face-to-face	"Got it. **Wait, south side of what?** South side of the area? Or south side of the convention center?"
1–3	Info/Intel 2	Situation unit Lead	Face-to-face	**"Oh, very good question. We'll find out."**
1–4	Info/Intel 2	Situation unit Lead	Face-to-face	"Ok, the north and south are the med stations. On the map there's a north and south, so that's what the labels on it. You've got one here and one up here. They're just calling it north and south. That's what they have on the board over there."
	Situation unit Lead	Info/Intel 2	Face-to-face	"Ok, so this is at the medical. Ok, got it."
1–5	Situation unit Lead	Working Alone	Computer	[Putting in information on the event log]

Case 2 starts with the P of a Section Chief unit. By converging, connecting, and organizing the accumulated cues on changes, the Section Chief unit perceives a discrepancy in the number of injured ("90 injured or 30 injured?", 2–1 in Figure 1). The Section Chief unit asks the Info/Intel unit "Do you know where this came from?" and the Info/Intel unit identifies the sources of the cues ("Fire Branch") in return (2–2 and 2–3 in Figure 1). Then, the Section Chief unit adapts by facilitating the dissemination of the corrected number of injured, simply by asking the Info/Intel unit to catch the person in need of this information (2–4 and 2–5 in Figure 1). As illustrated by Case 1 and 2, team cognition for a Plans team is manifested as nonlinear, interdependent, and dynamic interactions within and among P, D, and A of the three sub-teams of the Plans team.

Interactive Team Cognition from a Network Perspective

In the P·D·A model, all three sub-teams contribute to team cognition for a Plans team in terms of P, D, and A. However, more detailed investigation is needed to understand specific contributions of Plans team sub-teams to overall team cognition. Preliminary results from a content analysis of transcribed and coded interactions suggest that an Info/Intel unit, a Situation unit, and a Section Chief unit can be hypothesized to be critical contributors of team cognition for a Plans team in terms of P, D, and A, respectively. These hypotheses can be represented with network centrality measures as follows:

Hypothesis 1. *An Info/Intel unit has high in-degree and out-degree centrality with non-Plans teams.*

Hypothesis 2. *A Situation unit has high betweenness centrality within a Plans team.*

Hypothesis 3. *A Section Chief unit has high in-degree and out-degree centrality within a Plans team, and high betweenness centrality between the Plans team and non-Plans teams.*

An Info/Intel unit is hypothesized to be the one frequently interacts with the outside of the Plans team, either by giving selective attention to incoming cues (high in-degree) or clues outside the unit (high out-degree) (Hypothesis 1). A Situation unit, on the other hand, is hypothesized to be the one with control over information passing within a Plans team (high betweenness) (Hypothesis 2). A Section Chief unit is hypothesized to be the one with control over information passing between the Plans team and non-Plans team(high betweenness) (Hypothesis 3).

A network analysis of coded interactions in a Plans team is currently in progress to illustrate the benefits of utilizing network centrality measures to test hypotheses regarding interactive team cognition.

DISCUSSION

The proposed P·D·A model serves as a proof-of-concept that illustrates the benefits of viewing team cognition as interaction within and among a team of teams, for context-specific tasks of P, D, and A. Most importantly, the model effectively captures the nonlinear, interdependent, and dynamic nature of team cognition as interaction in complex socio-technical systems (STS, Vicente, 2002).

The P·D·A model not only extends the Wickens' information processing model to a team level but also provide a framework to explain the role of team cognition as a platform, i.e., a base upon which cognitive activities are facilitated. Team cognition as a platform "allows experts to coordinate and negotiate their plurality of points of view through general procedures of exchange, without making their perspectives uniform or completely transparent to each other" (p.189, Wolbers & Boersma, 2013).

Technology can be interpreted as a 'teammate' (Fiore & Wiltshire, 2016) or a contributor to team cognition. In the P·D·A model, a whiteboard or a large display can be viewed as a Plans team working memory or a platform technology that enables the team to interact without the need to memorize every details of what's communicated. A Plans team long-term memory, on the other hand, can be viewed as a repertoire of patterns based on responders' experience and knowledge.

By proposing a model of team cognition as interaction, this study illustrates potential benefits of observation-based theory building, particularly in informing future interventional investigation of team cognition in emergency response. In addition to the theoretical and practical implications, this study has methodological implications. Measuring interactive team cognition with network-based metrics (currently in progress) will open a new chapter. The need of incorporating a network perspective into team cognition in emergency response is in line with the literature (Wolbers & Boersma, 2013; Steigenberger, 2016). As a future work, the P·D·A model will be further developed with a network and content analysis and validated through interviews with SMEs involved in the Hurricane Harvey.

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