Investigating Incident Management Teams as Cognitive Systems of Systems via Real-time Observation of Naturalistic Interactions

[Author information blinded for review]

Team cognition has emerged as a coordinating mechanism in safety-critical disciplines; however, little is known about incident management team (IMT) cognition as a system-level coordinating mechanism. IMTs are multidisciplinary multiteam systems formed to manage information and make high-stakes decisions with delegated authority to act on behalf of affected jurisdictions. Despite elevated levels of uncertainty and time pressure, IMT functional teams (and sub-teams) need to coordinate effectively and efficiently to provide incident action plans to field responders. This paper investigates how IMTs function as cognitive systems-of-systems via live observation of interactions at a simulated environment. Interactions of a Plans team (one of the IMT components) were live-coded to create a directed interaction network. Using the resulting network's centrality measures, we characterized how central the Plans team's sub-teams are in terms of system-level cognitive functioning. The preliminary finding offers future research agenda to better understand, diagnose, and support system-level cognition in IMTs.

INTRODUCTION

Large-scale disasters such as Hurricane Katrina and the terrorist attacks on September 11, 2001, have shown us the significant consequences of coordination breakdowns. To save lives and infrastructures at risk, effective and efficient coordination is required among incident management personnel and teams with multidisciplinary background and experience. The U.S. Department of Homeland Security launched a standardized yet flexible approach called the national incident management system (NIMS; Federal Emergency Management Agency [FEMA], 2017). Following the NIMS, an incident management team (IMT) is staffed as an ad hoc command-and-control (C2) team of five functional sub-teams, i.e., Command, Planning, Operations, Logistics, and Finance/Administration. Each sub-team is also a networked team of functional sub-sub-teams. This paper investigates IMTs' coordinating mechanisms to inform future policies and practices.

IMTs are multidisciplinary, multiteam systems that continuously manage information and make high-stakes decisions with the delegated authority to act on behalf of the affected jurisdictions (FEMA, 2017). Despite elevated levels of uncertainty and time pressure, IMTs' functional teams (and their sub-teams) need to coordinate effectively and efficiently to provide incident action plans (IAPs) to field responders (Smith & Dowell, 2000; Militello, Patterson, Bowman, & Wears, 2007). 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 the team (e.g., field responders), following a cyclical planning process (FEMA, 2017, p.105).

As highlighted by catastrophic disasters such as Hurricane Katrina, coordination breakdowns in incident management – within teams as well as between teams – may result in significant consequences (DeChurch and Zaccaro, 2010). As such, researchers have invested their efforts on finding better ways to support coordination in incident management. Militello, Patterson, Bowman, & Wears (2007) identified coordination challenges to emergency operations center (EOC) teams through a naturalistic observation of simulated exercises. Their findings suggested that the information flow within and outside the EOC team can be better coordinated by overcoming three challenges, i.e., "asymmetric knowledge and experience, barriers to maintaining mutual awareness, and uneven workload distribution and disrupted communication" (p.27). Also, van Ruijven, Mayer, & de Bruijne (2015) used video observations at a virtual training environment and studied how on-scene command teams coordinate, and how their coordination determines the overall team performance through. They found that decentralized coordination patterns (represented by centrality measures of communication networks) better explain team performances than the overall amount of coordination.

Cognition, in particular, has gained attention as one of key constructs to consider for better coordination in incident management (Comfort, 2007; Steigenberger, 2016). Researchers have attempted to understand cognition in IMTs by applying various constructs and theories such as cognition in teams (e.g., Majchrzak, Jarvenpaa, & Hollingshead, 2007; Sætrevik & Eid, 2014; Mohammed, Hamilton, Tesler, Mancuso, & McNeese, 2015; Jobidon et al., 2017), extended or externalized cognition (e.g., McLennan, Holgate, Omodei, & Wearing, 2006; Plant & Stanton, 2016), common operating picture (e.g., Baber, Stanton, Atkinson, McMaster, & Houghton, 2013; Bunker, Levine, & Woody, 2015), and collective sensemaking (e.g., Wolbers & Boersma, 2013; Benamrane & Boustras, 2015). Yet, investigations of IMTs' cognition remains largely absent, especially due to the research focus on team performance and outcomes rather than coordinating mechanisms or processes (Fleştea, Fodor, Curşeu, & Miclea, 2017; Uitdewilligen & Waller, 2018).

Therefore, this research investigates IMT's cognition via real-time operationalization in naturalistic settings. In previous work, the author and colleagues proposed an expanded definition of IMT's cognition that deliberately takes into account IMT's unique contextual characteristics – *a collective cognitive process serving as an open communication platform* *for adaptive coordination which manifests itself as nonlinear, interdependent, and dynamic interactions among humans, teams, and technologies to achieve the system-level goals of perceiving (P), diagnosing (D), and adapting (A) to information* ([citations censored for blind review, with space added for eventual blocking]). Then, this definition was operationalized via naturalistic observations of interactions at a high-fidelity simulator.

Specifically, interactions of a Plans team (or a Planning section) were live-coded, i.e., interactions of one of the five functional teams of an IMT were coded, and a directed interaction network was created. According to the NIMS, a Plans team is in charge of coordination within 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" (FEMA, 2017, p.28). A Plans team is also composed of functional sub-teams that are expected to perform the roles described in Table 1. This paper specifically focuses on three key sub-teams: (1) an Information/Intelligence (Info/Intel; or Intelligence/Investigations) unit; (2) a Situation unit; and, (3) a Section Chief (SC) unit. Using the resulting network's centrality measures, we aim to characterize their different roles for an IMT to function as (joint) cognitive systems-of-systems (Son et al., 2018).

Table 1. Expected roles of a Plans team (FEMA, 2017, pp.91–92, 99)

Sub-teams	Members	Description
(1) Plans Information/ Intelligence (Info/Intel) Unit	· Info/Intel Lead · Info/Intel Agents 1 & 2	"... [Info/Intel unit] enhances the section's normal information collection and analysis capabilities. It helps ensure that investigative information and intelligence is integrated into the context of the overall incident management mission."
(2) Plans Situation Unit	· Situation Lead · Situation Event Log · Situation Map	"Situation Unit staff collect, process, and organize situation information, prepare situation summaries, and develop projections and forecasts related to the incident. They gather and disseminate information for the IAP. This unit produces Situation Reports (SITREP) as scheduled or at the request of the Planning Section Chief or Incident Commander."
(3) Plans Section Chief (SC)	· Planning SC · Deputy Planning SC · Documentation Lead	"The Planning Section Chief oversees incident-related data gathering and analysis regarding incident operations and assigned resources, facilitates incident action planning meetings, and prepares the IAP for each operational period."
(4) Plans Instructors	· Instructors 1 & 2	Instructors are responsible for guiding and teaching participants regarding incident action planning process, individual roles, and use of technical tools.
(5) Plans Others	· Resource Lead · Resource Status Check-in · Demobilization · ICS 209	"Resource Unit staff track the location and status of all resources assigned to an incident. They ensure all assigned resources have checked in at the incident"

METHODS

Research Settings

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 (Table 2) – 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 2. A three Cs coding system of an interaction

Context			Content	Characteristics	
Initiator	Receiver	Technology	Content	Frequency	Duration
Who initiated	With whom	Using which tool	What is communicated for what purpose	How often	How long

The three Cs of interactions were first captured during a live observation at the EOTC. Throughout the course of a scenario, each Plans team member of interest was shadowed by an observing researcher. The member's interactions with others were coded in real-time (in situ) using the Dynamic Event Logging and Time Analysis (DELTA) iPad-based tool for the ease of coding with time-tracking (Figure 1).

Figure 1. An example of the DELTA iPad-based tool

Three internal discussion sessions (two hours per each session) 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.

Data Analysis

The centrality measures of three Plans sub-teams (i.e., Info/Intel, Situation, and SC units) were examined in their interaction network to investigate their roles in overall cognitive functioning. A directed (and weighted) network was created from the interactions observed and live-coded for three and a half day throughout four different scenarios. Centrality of a node shows how central a node is in a network. Three commonly used centrality measures (i.e., degree, closeness, and betweenness centrality) were weighted by frequency and duration, separately, as their results and implications may differ (Table 3).

Table 3. Network centrality measures

	Centrality measures	Definitions and operationalizations
(a)	frequency-weighted *degree* centrality	Number of incoming and outgoing links that a node has, weighted by frequency
(b)	duration-weighted *degree* centrality	Number of incoming and outgoing links that a node has weighted by the duration
(c)	frequency-weighted *closeness* centrality	Normalized average length of the shortest path between a node and other nodes, weighted by frequency
(d)	duration-weighted *closeness* centrality	Normalized average length of the shortest path between a node and other nodes, weighted by duration
(e)	frequency-weighted *betweenness* centrality	Normalized number of times a node acts as a bridge along the shortest path between two other nodes, weighted by frequency
(f)	duration-weighted *betweenness* centrality	Normalized number of times a node acts as a bridge along the shortest path between two other nodes, weighted by duration

In total, 39 out of 44 IMT members agreed to participate in this observational study. Note that Plans team members were mapped into either one of the following five nodes: (1) Plans Info/Intel unit, (2) Plans Situation unit, (3) Plans SC unit, (4) Plans instructors, and (5) Plans Others. Likewise, the rest IMT members were mapped into either one of the following five nodes: (6) Command team, (7) Operations team, (8) Logistics team, (9) Finance team, and (10) Non-IMT (outside the IMT). Figure 2 illustrates how this mapping scheme puts 39 observed humans into 10 nodes in a mutually exclusive and collectively exhaustive manner.

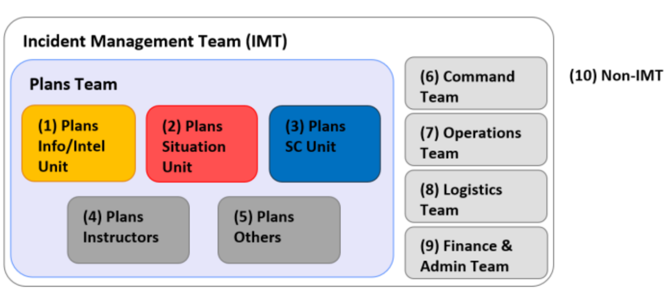

Figure 2. Representation of 10 nodes included in a simplified interaction network

PRELIMINARY FINDINGS

On average, 641 interactions were live-coded for each disaster scenario. About 71% (454 out of 641) of those interactions occurred to coordinate within the Plans team for about 73% of the total time spent (8.8 out of 12 hours). Table 4 presents the six different centrality measures of 10 nodes calculated using the average frequency and duration as weights.

Table 4. Network centrality measures of 10 nodes

Nodes	Frequency-weighted centrality			Duration-weighted centrality		
	(a)	(b)	(c)	(d)	(e)	(f)
(1) Plans Info/Intel Unit	320.50	0.80	0.20	23274	0.022	0.22
(2) Plans Situation Unit	170.50	0.84	0.38	19524	0.028	0.11
(3) Plans SC Unit	325.75	0.60	0.21	16067	0.007	0.25
(4) Plans Instructors	219.75	0.67	0.04	12650	0.020	0.18
(5) Plans Others	51.50	0.56	0.00	2830	0.023	0.10
(6) Command Team	24.75	0.63	0.00	983	0.016	0.00
(7)Operations Team	143.00	1.16	0.00	9351	0.345	0.17
(8) Logistics Team	15.50	0.74	0.26	573	0.029	0.33
(9) Finance Team	3.50	0.55	0.21	627	0.007	0.21
(10) Non-IMT	7.25	0.514	0.236	657	0.005	0.00

The resulting network of live-recorded interactions can be visualized with relative node sizes adjusted according to six different centrality measures (Figure 3). For our purpose of characterizing the central roles of three Plans sub-teams, i.e., an Info/Intel unit, a Situation unit, and an SC unit, we color-coded them in *yellow*, *red*, and *blue*, respectively. Note that the node sizes in Figure 3 are intended to be used only for comparing relative centrality among the three sub-teams.

Degree centrality measures the number of links a node has with other nodes, weighted by frequency or duration of interactions (Figure 3a and 3d, respectively). An Info/Intel unit has the high degree centrality in both frequency and duration. An SC unit has even higher degree centrality in terms of frequency but low in terms of duration. It is the opposite case for a Situation unit.

Closeness centrality measures the extent to which a node is near all other nodes, weighted by frequency or duration of interactions (Figure 3b and 3e, respectively). A Situation unit has the highest closeness centrality in both cases yet particularly high in terms of duration. In other words, a Situation unit is near all other nodes especially in terms of the time spent. Notably, an SC unit has the lowest closeness centrality in both weights, even lower than Plans Instructors and Plans Others. Additionally, Operations and Logistics teams turned out to be the ones most near the Plans team especially in terms of duration.

Betweenness centrality measures the extent to which a node lies on paths between other nodes (i.e., a node is connected to other nodes that are not connected to each other), weighted by frequency or duration of interactions (Figure 3c and 3f, respectively). Interestingly, a Situation unit has the highest betweenness centrality in terms of frequency yet the lowest in terms of duration. An SC unit on the other hand, has the highest betweenness centrality in terms of duration.

DISCUSSION

Investigations of IMTs' cognition remains largely absent. We address the knowledge gap via its operationalization in naturalistic settings. We defined IMTs' cognition as *interactions for adaptive coordination*, viewing IMTs as cognitive systems-of-systems where cognition emerges through interactions at its multiple levels, i.e., within and among its component teams as well as between its inside and outside.

Thus, our aim was to investigate how IMTs function as (joint) cognitive systems-of-systems via live observation of naturalistic interactions. We were particularly interested in characterizing how three Plans sub-teams contribute to an IMT's system-level cognitive functioning in different ways. An examination of network centrality measures resulted in the following preliminary findings.

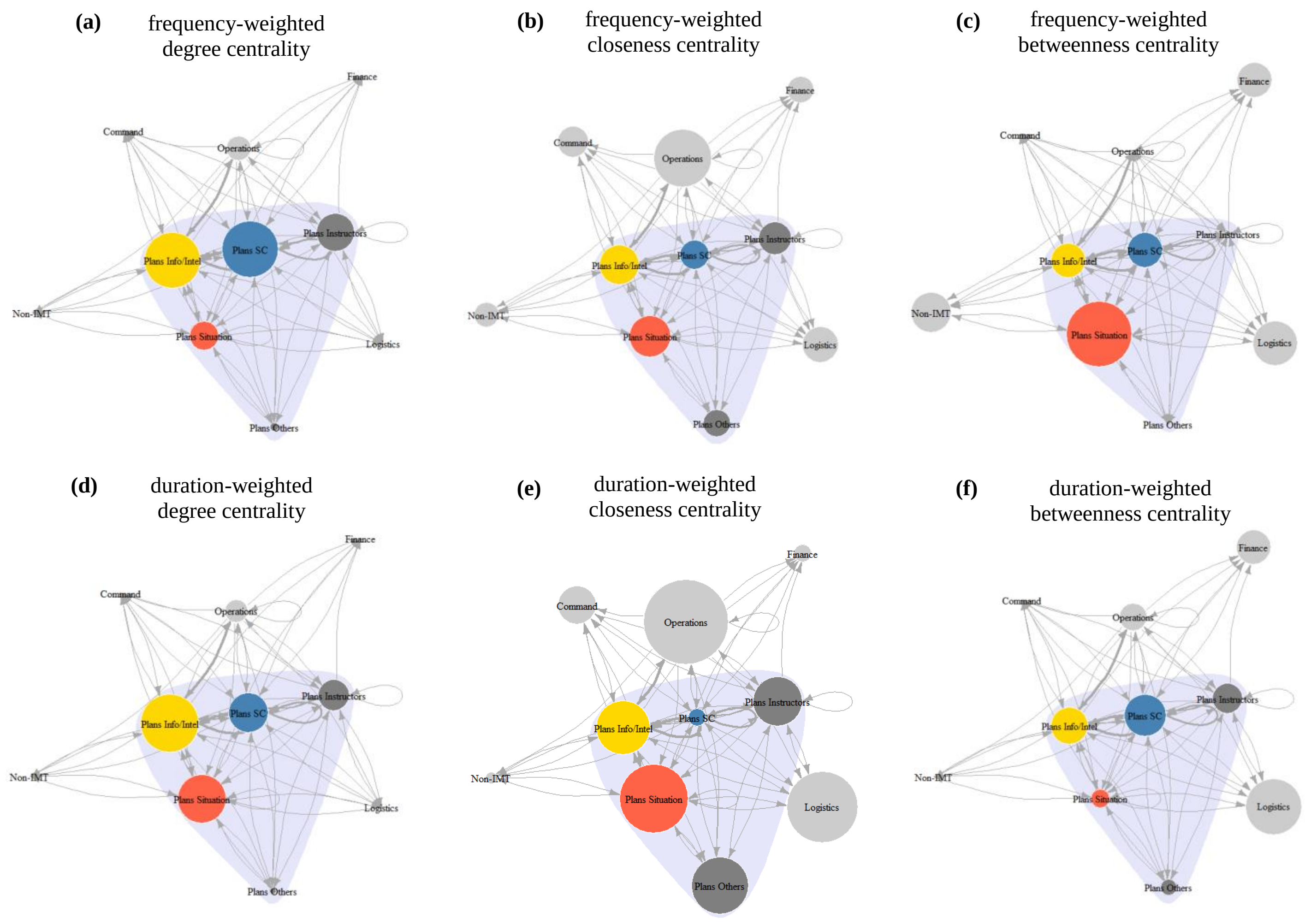

Figure 3. Visualization of the live-coded interaction networks. Node sizes are adjusted to represent six different weighted centrality measures (see Table 3 for the definitions of measures). The networks were created using the measures presented in Table 4. Note that *yellow* = Info/Intel unit; *red* = Situation unit; *blue* = SC unit; *shaded area* = Plans team.

First, an Info/Intel unit contributes to system-level cognition through its greatest number of links with others that occurs most frequently and for the longest time. While collecting, analyzing, investigating, integrating, and sharing information (as expected in Table 1), an Info/Intel unit naturally becomes prominent and influential (not only within a Plans team but also across all other nodes).

Second, a Situation unit contributes to system-level cognition through its highest closeness with all other nodes and its most frequent control over information passing between other nodes. While collecting, processing, organizing, summarizing, projecting, and disseminating information (as expected in Table 1), a Situation unit most frequently serve as a bridge between other nodes (not only within a Plans team but also across all other nodes).

Third, a SC unit contributes to system-level cognition through its control over information passing between other nodes over the longest time, despite its lowest closeness with all other nodes. While facilitating incident action planning meetings, preparing IAPs, and recording the major steps of such process (as expected in Table 1), a SC unit naturally spends the longest time serving as a bridge between other nodes yet becomes distant from other nodes.

Our preliminary findings highlight potential benefits of adopting an interactionist approach, incorporating systems perspective, and employing network centrality measures, particularly for the purpose of investigating multiteam systems' cognitive functioning. By accounting for all the interactions of the Plans team, we could characterize its sub-teams' system-level contributions. Methodologically, in situ observation and live-coding of interactions enabled us a quick exploration of a highly context-dependent (joint) cognitive system-of-systems.

This paper, however, is limited to exploratory research phases aiming for hypotheses generation (rather than hypotheses testing). Additionally, a live-coding approach did not allow us to investigate the contents of interactions, i.e., what's communicated for what purpose (Table 2). Our proposed definition of IMTs' cognition, therefore, could not be fully operationalized. A retrospective coding approach is further needed to operationalize IMTs' cognition as interactions for the system-level cognitive goals of perceiving (P), diagnosing (D), and adapting (A) to information.

As such, our future work (in progress) include transcribing and coding (in retrospect) the audio- and video-recorded naturalistic interactions. We are currently working on developing a descriptive model of a Plans team's system-level cognitive adaptation processes. We expect the resulting P·D·A (perceive·diagnose·adapt) model to be a base platform to discuss practical ways to better support scenario-based training practices and thereby lead to a more rapid and better coordinated decision-making in saving lives and infrastructures.

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