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ORIGINAL ARTICLE

The role of information sharing on decision delay during multiteam disaster response

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Abstract

Multiteam systems (MTSs) are comprised of two or more interconnected teams working toward shared superordinate goals but with unique sub-goals. To date, research has predominantly focused on how decisions are made and has viewed these cognitive processes as occurring within individuals. However, for MTSs operating in extreme environments such as disasters, it is often not a question of how decisions are made, but what is causing delays and failures to make decisions. To understand the causes of decision delay within these complex networks, it is important to focus on decision processes at the multiteam level. Using naturalistic observational and interview data collected during a multi-site, multiteam emergency response to a large-scale disaster exercise, this study examines both information sharing (what was shared, with whom, how long this took), and decision processes across teams (situational awareness—SA, plan formulation, and plan execution). Findings demonstrate that interdependencies in cognitive processes exist across individuals where goals overlap. Decision delay is not only caused by failure to develop SA within a team preventing their ability to formulate and execute plans but also by the inability of other teams to execute their plans. The implications of these findings for developing targeted interventions are discussed.

Keywords Naturalistic decision making · Situation awareness · Information sharing · Decision delay · Multi-team system

1 Introduction

Naturalistic Decision Making (NDM) research examines how decisions are made in dynamic, real-world contexts characterized by time pressure, risk, uncertainty, shifting and competing goals, and accountability pressure (Lipshitz et al. 2001). This often includes extreme environments in which lives are at stake, such as military combat (Thunholm 2005), firefighting (Klein et al. 1986), counter-terrorism policing (van den Heuvel et al. 2012), and disaster response (Waring et al. 2018). Findings from this domain highlight the importance of access to relevant information for developing an accurate understanding of the situation and how it may progress to tailor decisions and actions (Rankin et al. 2013). For example, during an industrial fire, information about building layout and hazardous or explosive chemicals would be vital for understanding risks and subsequently deciding where to deploy emergency responders, along with the types of protective equipment required. Findings also highlight that lack of information increases situational uncertainty and the probability of making decision errors, with potentially devastating consequences (Lipshitz et al. 2001). For example, the gas pump that exploded at Piper Alpha oilrig in 1988, killing 167 people, had been sanctioned as unfit for use due to a missing safety valve, but this information was not shared with the on-duty custodian.

However, it is not only decision errors that can have devastating consequences. So too can decision delay, allowing rapidly altering incidents to escalate (van den Heuvel et al. 2012). Over 30 years' worth of UK public inquiries into disaster response repeatedly highlight the impact of decision delays on implementing actions (Pollock 2013), including delays of over 2 h in deploying firefighters to the site of the Manchester Arena bombing (Kerslake 2018) and evacuating residents during the Grenfell Tower fire. Similar problems have also been identified internationally, including delays to delivering aid after the Boxing Day Tsunami that affected 14 countries along the coast of the Indian Ocean (Rencoret et al. 2010), and slow response and poor prioritization of information in the aftermath of the Haiti earthquake (Patrick 2011). Yet little research has focused on identifying

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the mechanisms that underpin decision delay, despite the implications for improving disaster response and allowing communities to recover in the shortest possible time with limited disruption (Manyena et al. 2011).

To date, the small numbers of studies focusing on decision delay have predominantly been conducted by NDM researchers seeking to understand cognitive processes at the individual level within single agencies operating in extreme environments (van den Heuvel et al. 2013). However, disasters are not managed by individuals working in isolation, but by multiteam systems (MTSs) comprised of single-and inter-agency teams working toward a shared superordinate goal but with unique and interdependent sub-goals at individual, team and agency levels (Marks et al. 2005). This poses implications for understanding the interplay between decision processes across individuals and teams operating in extreme environments and how this may contribute toward decision delay. In contrast, organizational researchers have sought to study inter-team processes within MTSs. But this body of work does not specifically focus on decision delay and is predominantly conducted with naïve student participants using laboratory simulations that do not reflect the complexity of extreme environments, limiting the development of evidence-based interventions (Shuffler et al. 2015). Neither NDM nor MTS domains alone are able to explain the underlying causes of decision delay within complex multiteam networks that form to respond to extreme environments such as disasters.

Accordingly, drawing on data from a large-scale disaster response exercise, the following study examines decision processes at the multiteam level to improve understanding of the underlying causes of decision delay in extreme environments. Findings contribute to both NDM and MTS theories and highlight a need for these theories to connect to improve understanding of complex team structures operating in extreme environments.

2 Disaster context

Disasters are large-scale incidents involving mass casualties and major disruptions, including natural and man-made disasters and attacks on humans (Home Office 2018). In the UK and many other countries internationally, the system that forms to respond to disasters is comprised of multiple teams from across agencies (e.g. police, fire, ambulance, health, local council and other supporting agencies) operating under a three-tiered hierarchical command structure (Bharosa et al. 2010; Civil Contingencies Act 2004; Home Office 2018; Majchrzak et al. 2007), with decisions flowing from strategic (responsible for setting overall objectives) to tactical (setting parameters and level of autonomy for operational commanders) and operational commanders (managing the incident ground). This MTS is, therefore, characterized by (1) high skill differentiation between teams from across agencies, (2) high authority differentiation as figures from each agency across each command level are responsible for making key decisions, and (3) low stability as teams disband once the incident is resolved (see Hollenbeck et al. 2012 for a team taxonomy).

As with other MTSs, the agencies involved have an overarching shared superordinate goal (save life) at the multiteam level and unique sub-goals (for example, collect evidence and investigate suspects, extract trapped casualties, treat injuries) at agency, team and member levels (LePine et al. 2008). They are, therefore, faced with the challenge of coordinating and prioritizing the order in which interdependent sub-goals are addressed to avoid conflicting actions that would jeopardize the superordinate goal (Mathieu et al. 2001). Accordingly, exchanging relevant information in a timely manner is integral to developing situation awareness (SA) at individual and team levels so that appropriate actions for addressing problems are identified within teams, but also for ensuring actions are coordinated across teams and agencies (DeChurch and Mesmer-Magnus 2010; Waring et al. 2018). But as public inquiries repeatedly highlight, information sharing within these complex networks can be problematic (Hale and Hale 2005; Kerslake 2018; Pollock 2012).

Part of the issue is that the agencies responding to disasters tend to work independent of one another on a day-to-day basis, limiting familiarity (Schraagen and Van de Ven 2011). This means that during an incident, members may need to learn to function across areas of expertise as well as understanding how each team contributes to the superordinate goal (Shuffler et al. 2015). This creates difficulties for knowing 'who' needs 'what' information, 'when' and 'why' (Kozlowski and Ilgen 2006). Teams are also often geographically dispersed (e.g. operational teams dispersed across a large incident ground, command levels-based separately; Schraagen and Van de Ven 2011), which can reduce and slow information exchange (Maynard et al. 2012). Similarly, differences in knowledge and expertise can lead to representational gaps, differences in how problems are conceptualized, affecting what information is viewed as being relevant to share and pay attention to, and how it is interpreted (Cronin and Weingart 2007; Waring et al. 2018). These information-sharing difficulties are not restricted to UK disaster response but have been observed across several countries, including the USA (Majchrzak et al. 2007), and Netherlands (Bharosa et al. 2010). It is against this challenging backdrop that decision processes in MTSs are examined.

3 Decision processes

The field of NDM has produced several models that seek to describe how individuals make decisions in challenging contexts, most of which share the common assumption that certain stages are undertaken when solving problems (Bales and Strodtbeck 1951), including collecting, confirming and analyzing information (Cook and Tattersall 2008). One such model is the SAFE-T (van den Heuvel et al. 2012), which is founded on an extensive evaluation of previous NDM models (e.g., Lipshitz and Bar-Ilan, 1996; Orasanu et al. 2001; Thunholm 2005; Salas et al. 2006), and detailed naturalistic observations (Alison et al. 2015). This model proposes four sequential phases for effective decision-making in extreme environments: situational assessment (SA—analogous to situation awareness); plan formulation (*F*); plan execution (*E*); and team learning (*T*). SAFE-T has been used to understand how and why various ambient, affective, cognitive and organizational factors may derail decision processes at individual and team levels. In the absence of a multiteam decision model, the current study utilizes SAFE-T to provide a framework for examining decision processes at the multiteam level, and how these processes may be linked across teams with interconnected goals.

Overall, SA is argued to be the cornerstone for subsequent decision processes because the ability to form and execute plans that are appropriate for the situation requires a good understanding of what is happening and how this might develop (Endsley 2000, 2015). Endsley (1988) proposes that SA resides in the mind of the individual and is comprised of three stages: (1) perception of elements within the environment, (2) comprehending their meaning, and (3) forecasting their future status. Failure to access relevant and timely information leads to inaccurate or outdated understanding of what is happening and inability to forecast how this may progress (Alison et al. 2015; Klein 2008; Lipshitz et al. 2001; van den Heuvel et al. 2013). This body of research examines the cognitive processes used to develop and maintain SA at an individual level (Stanton et al. 2005). However, it does not consider how what is happening within an individual's head may stem from, be influenced by, or in turn influence interactions with humans, systems or environments (Chatzimichailidou et al. 2015; Waring et al. 2018). Accordingly, neither the theoretical explanation nor the methodologies used is able to capture the complexity of developing and acting on SA within MTSs.

Another branch of NDM research has focused on understanding how similarities and differences in understanding across team members can impact performance (Salas et al. 2008). Findings highlight that ability to coordinate activities is affected by the extent to which each member has access to information relevant to developing the SA they need to undertake their responsibilities, referred to as team SA (TSA; Endsley and Jones 1997). TSA is comprised of the sum of individual and shared SA (SSA—common understanding of the situation; Salas et al. 2008; Saner et al. 2009). In particular, members must have shared knowledge of roles, capabilities and interpersonal relationships (Berggren et al. 2014) to understand the information requirements of others and match what they provide to these comprehension needs (Bolstad et al. 2002; Endsley 2015; Gorman et al. 2006). But the extent to which SA must be shared in order for information to be effectively exchanged and activities coordinated remains unknown. This is all the more complex in MTSs where multiple teams are operating toward a combination of both interrelated and unique goals (Chatzimichailidou et al. 2015). These complex networks may contain an abundance of information, not all of which will be needed by everyone to undertake their roles. This would make trying to share everything with everyone an inefficient strategy, increasing cognitive load and task distraction (Stanton et al. 2006).

In contrast, researchers studying cognition within complex networks highlight the value of taking a systems approach that sees SA as being distributed (DSA) across a network, connecting members to tasks on a 'moment-by-moment' basis (Stanton 2016). In this respect, DSA is similar to MTSs in viewing members as having different, yet compatible, goals, information requirements and views of the situation that may overlap for particular tasks (Nazir et al. 2014). DSA extends Endsley's (1988) model of SA by demonstrating that members may be (1) involved in perception, comprehension and projection of tasks separately, (2) with each member operating at different stages of SA at any point in time, and (3) that SA may differ between members depending on their task (Salmon et al. 2009). According to this theory, no individual will have a complete picture of everything, making transactions or information exchange between members important for maintaining SA across the system (Sharma and Nazir 2017; Sorensen and Stanton 2016).

DSA theory also argues that rather than seeking to share all information across the network, it is important that the right information is activated and passed to the right recipient at the right time (Stanton 2016). This notion is founded on transactive memory theory, shared knowledge of 'who knows what' (Wegner et al. 1985), which views different types of knowledge as being distributed across members, providing a larger pool of potential information. Similar to TSA, both DSA and transactive memory also highlight the importance of shared understanding of expertise for promoting efficient access to diverse information (Ren and Argote 2011; Heavey and Simsek 2015), reducing cognitive load (Miller 2008). In contrast to TSA, DSA theory views cognitive processes as connected and utilizes methods that map information elements and how these are shared across complex networks rather than comparing SA between individual members (Chatzimichailidou et al. 2015). This approach has been applied in a range of contexts such as maritime (Sharma and Nazir 2017), road design (Walker et al. 2013) and aviation (Griffin et al. 2010), but is not without criticisms. DSA can be a difficult concept to operationalize and measure (Sorensen et al. 2011) and, although it considers the connected nature of SA across components and the role of information sharing, it has been less focused on measuring the impact on subsequent decision processes (Salmon et al. 2008).

3.1 Technologies for supporting information sharing in disaster response

Technologies provide an important platform for sharing information during disaster response. For example, responders utilize handheld airwave radio devices to pass on information about what is happening and requests for resources. Different radio channels may be set up to distinguish the types of information communicated, allowing responders to selectively monitor a channel depending on their roles and informational needs. Internet-based technologies are also used to share photographic, video, audio, and text-based information across sites, and to visually display information, such as maps. In particular, visual displays can allow information to be shared efficiently without responders needing to search across a busy network, but only if they are rapidly updated as soon as information becomes available. This requires that all relevant parties are aware of who's role updating displays is so that information can be directed (Militello et al. 2007).

The effectiveness of technologies for supporting information sharing is affected by a range of other factors, including system interoperability between agencies and knowledge of how to use equipment (Waring et al., in press). Communication infrastructures can also be negatively affected by loss of power and degraded or overwhelmed radio airwaves and landlines, satellite, and Internet systems (Nelson et al. 2011), as was the case in the 9/11 attack (Chan et al. 2004). This has led to focus on Hastily Formed Networks (HFNs), portable IP-based networks that can be deployed immediately after a disaster to create new communication infrastructures for providing basic voice, video and data communications (Törnqvist et al. 2009). HFNs have been used in disasters such as the Haiti earthquake to provide vital assistance with communications but are also not without limitations, including financial cost, availability, coordination difficulties, knowledge of roles, and cognitive effort required to learn to use new technologies (Nelson et al. 2011).

Overall, technologies provide a vital platform for allowing information to be shared across geographically dispersed disaster response networks. However, their effectiveness is largely dependent on how quickly and effortlessly people can learn to adapt to technologies, financial cost, and the ability of responders to know what information to share, with whom and when (Waring et al. 2018).

3.2 Current study

Overall, findings from these different bodies of research highlight the importance of access to relevant and timely information for developing SA at individual, team and multiteam levels. They also indicate the importance of shared understanding of team roles and information requirements for promoting effective information sharing. However, these types of shared knowledge can be difficult to develop in MTSs operating in extreme environments due to limited familiarity, geographical distance, and the dynamic nature of the environment. Less is known about the impact of information sharing on subsequent decision processes, or the specific causes of decision delay in MTSs. The following study, therefore, aims to contribute to both decision and MTS theory by focusing on the role of information sharing on decision processes and how these interact across members operating within complex MTSs. Understanding the causes of decision delay in extreme environments poses important implications for developing targeted interventions to improve disaster response and recovery.

4 Methods

NDM researchers emphasize the importance of research methods with embedded contextual richness for explaining real-world decision-making (Burke et al. 2007), arguing for the use of field studies to observe and analyze decision processes "in vivo" (Dunbar and Blanchette 2001). In line with this ethos, naturalistic researchers have often used simulated training events to study decision-making. Such events can support goals of empirical research as well as organizational goals for training the psychological and nontechnical skills required to effectively manage extreme environments (Alison et al. 2013; Flin et al. 2008). For this study, data were collected during a large-scale multi-agency exercise that simulated a chemical terrorist attack. Immersive simulated environments of this type provide a useful platform for studying decision-making in MTSs by providing a vast amount of varied data surrounding the social, organizational, cultural, and political factors that are inherent in such extreme environments (Waring et al. 2018).

This live exercise was conducted across two geographically separate locations (a Police Counter Terrorism Unit [CTU] and a Military training base), and comprised three separate sites: i) a police counter-terrorism (CT) interviewing suite (at the Police CTU); ii) a clandestine laboratory; and iii) an underground transport network (both located at the Military training base). Sites 2 and 3 were approximately one mile apart, while site 1 was approximately 150 miles away. Thus, teams were geographically dispersed.

4.1 Exercise scenario

The exercise scenario consisted of a chemical related terrorist attack involving four suspects, three of whom were arrested the evening prior to an attack on an underground transport network in a metropolitan city. These three suspects (all played by actors) were arrested for terrorism-related offenses due to posting threatening messages online, along with witness reports of overhearing these individuals in a public house expressing extremist views and discussing the planning of a chemical attack using Sarin (a nerve agent previously used in attacks on humans). At 8 am on the morning of the train attack, the three men were taken to the CT interviewing suite (site 1) to be interviewed. At approximately 11 am, a specialist search conducted at an address linked with one of the suspects revealed a clandestine laboratory in the garage containing dangerous chemicals that could be used to make Sarin and explosives (site 2). At approximately 12 pm, a train travelling on the underground transport network was stopped between two stations (a purpose built 70 m steel surface tunnel, with 140 meters of rail track and a 3-carriage train located inside the tunnel) leaving more than 70 passengers onboard trapped (site 3), the cause of which was unknown to first responders on arrival. A passenger (the fourth suspect) sprayed the first two firefighters sent to gather initial information with an unknown chemical, alerting responders at this site to the hostile nature of the incident. Before the exercise could be declared over, the fourth suspect needed removing from the train, all evidence seized, and all casualties (and first responders exposed to the chemical) had to be decontaminated.

In total, the live exercise lasted for 8 h and all three sites were linked, such that effective sharing of information across locations would allow goals to be achieved more effectively (e.g. identifying the contaminant and the strength of the substance through suspect interviewing at site 1 would assist emergency services at site 3 with quickly planning appropriate decontamination procedures). To increase exercise realism, the agencies involved were not informed in advance of the existence of three separate sites, nor were they informed of the nature of the exercise. Accordingly, they were required to identify the links as the exercise progressed, making the ability to share information, both within and between agencies across sites, crucial to developing and maintaining accurate shared understanding of the situation and the information requirements needed to minimize risk to public safety.

4.2 Participants

Emergency responders from across five different regions in the UK took part in the large-scale exercise. At each of the three sites, at least one National Inter-agency Liaison Officer (NILO) was present from the Fire and Rescue Service (Fire). In the UK, the role of NILO was introduced within emergency services as a conduit for bridging intelligence, information sharing and advisory gaps across agencies, particularly in response to terrorist incidents where sensitive (i.e., restricted) intelligence may need to be shared. These practitioners have undergone specialist training and security clearance to grant them access to such information in an attempt to make better-informed decisions about the wider sharing of information across agencies within a dynamic incident. NILOs at each exercise site served an important role as the main conduit through which information was shared across locations. All information that responders sanctioned to be shared between sites was sent through the NILOs who communicated with one another via handheld airwave radios. Overall, the exercise involved in excess of 150 members of the emergency services. Table 1 contains details of responders located across sites.

4.3 Data collection and analysis

Twelve members of the research team were distributed across the three sites (four at each site). Each researcher took detailed observational notes to document what was observed and heard. Given the importance of tracking information flows between sites, one researcher was assigned to each NILO to record the information received, shared and requested by each NILO, along with a timestamp. This allowed a distinction to be made between what information was shared, with whom and how long this took. Similar to a DSA approach, this method allowed information sharing to be tracked across the network. However, in addition, detailed

Table 1 Details of emergency responders who participated in the exercise across sites

Site 1 (police CTU)	10 Police interviewers; 2 Ministry of Defense interviewers; 1 Police senior investigating officer (SIO)
Site 2 (clan lab)	1 Police SIO; 1 FRS scientific advisor; 2 FRS Hazardous Materials and Environmental Protection Officers (HMEPO); 3 FRS Detection Identification Management (DIM) teams; 1 Ambulance team
Site 3 (underground train)	1 Police operational commander; 1 Police Specialist Hazardous Materials team; 1 Ambulance NILO; 3 FRS engines manned by teams of four firefighters; 1 FRS Rapid Response Team (RRT) with team leader; 1 FRS CBRN subject matter advisor; 1 FRS operational and 1 tactical commander; 1 FRS command support officer; 2 Ambulance Hazardous Area Response Teams (HART); 1 Ambulance Specialist Operations Response Team (SORT); 1 Ambulance operational and 1 tactical commander

notes were also taken of decisions and actions subsequently implemented and how long these took to implement to capture the impact on decision processes.

In addition, after the scenario ended, participants were interviewed at the clandestine laboratory ($n=1$; fire NILO) and train site ($n=5$; fire NILO, police and ambulance operational commanders, FRS tactical commander, command support officer) using a semi-structured interview protocol (employing a Critical Decision Method [CDM] detailed by Crandall et al. 2006). This was designed by the researchers to gather emergency responder perspectives of SA development, information sharing practices and the impact on decisions and actions, in line with the aim of this research. Interviews lasted between 8 and 28 min ($M=10$ min) and were conducted using prompts to encourage feedback on particular topics. However, interview structures were flexible as prompts could be covered in a variety of orders, and interviewers could probe on additional topics depending on responses. Prompts included: what their role in the incident was; a description of what they were faced with upon arrival; what information they initially needed and why; what information they were unable to access when needed, the impact and what they did about this; and strategies used to communicate within and between agencies—what worked and what did not.

Overall, analysis was conducted in two stages. The first stage takes a quantitative approach utilizing observational data collected during the incident to identify how much information was shared, with whom and how long this took across sites. The second stage utilizes qualitative thematic analysis, "*a method for identifying, analyzing and reporting patterns (themes) within data*" (Braun and Clarke 2006, p 79), to identify common themes based on content (Simons et al. 2008). Using observational notes and interview transcripts, the aim was to identify facilitators and barriers to information sharing and the impact on SA, plan formulation and execution. Given the nature of the interviews (short, conducted "in the wild" at the end of a simulated chemical attack) and interview technique (modified CDM focused on information requirements), a mixed-method deductive and inductive approach was adopted. The deductive approach allowed outcomes of the thematic analysis to be organized (e.g. facilitators and barriers across each decision phase), and the inductive flexibility allowed important sub-themes to emerge rather than being lost during analysis.

5 Analysis

Figure 1 shows a timeline of the scenario and the key decisions that were made. The initial attack on the train site occurred at 12.10 pm (real time), after which a team of two firefighters went to investigate. These firefighters were sprayed with an unknown substance and the response then centered on the possibility of a chemical weapon and the need to evacuate and de-contaminate civilians. Of particular importance to this research is the time taken for each of these actions to be implemented and the gap between what

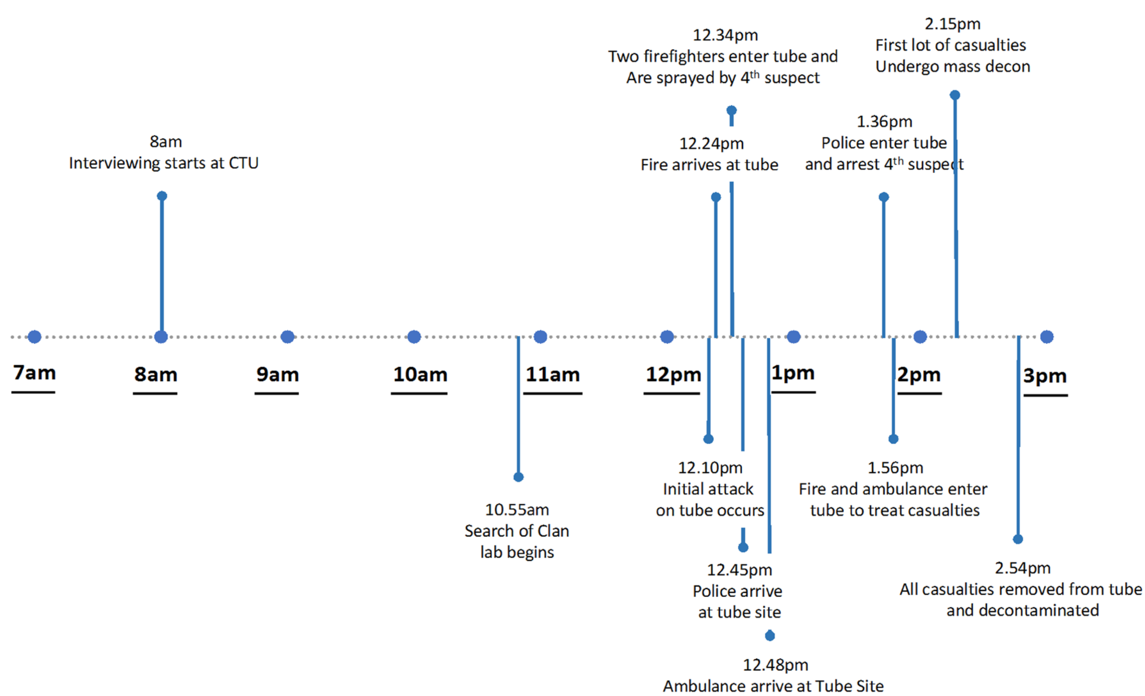

Fig. 1 Timeline of main events

would be an "ideal" and actual response time (evidence of decision delays). For example, while the police and ambulance arrived at the train scene at 12.45 pm and 12.48 pm, respectively (35 and 28 min after initial attack), an operation was not launched until 1.36 pm (51 min) and 1.56 pm (1 h and 8 min) after agencies arrived, highlighting delays to plan execution. To understand the etiology of delays, analysis is presented in accordance with the SAFE-T model. We highlight the role of information sharing within the MTS on each individual process (SA, plan formulation, plan execution) and how issues in a preceding process impacted later processes.

5.1 Developing situational awareness within a MTS

Based on the exercise planning documents and discussions with the six emergency service subject matter experts who designed the scenario, Table 2 shows the total amount of relevant information that could have been extracted across sites and the total amount that was extracted. All possible nodes of information (or evidence) were sourced at the clandestine lab (100%), and only 2 nodes were not extracted at the train site (71.43%). Although the greatest number of information nodes was extracted at the interview site (56%), 11 nodes were not extracted. As the interview team was the only set of individuals with access to the three suspects, information not extracted through interviews was unavailable to other sites. Many of the non-extracted nodes could be considered critical to the ability of teams at other sites to respond to unfolding events with regard to forming SA of potential threats and appropriate methods for managing these.

To support a shared SA, information must not only be extracted but also exchanged with the appropriate members in a suitably timely manner. Field-based observations allowed the flow of information between the three sites and the amount of time taken to share this information to be tracked. As shown in Table 2, a large quantity of information was shared between the three sites (mediated by the NILO officers). Of the information extracted (25 nodes), only 1 node was not shared (4%), suggesting that significant efforts were invested in exchanging pertinent information with other agencies.

However, as Table 3 shows, in many cases there was a significant delay in the sharing of such information. The average amount of time it took for information to be shared between sites once it had been uncovered was 31.4 min. Although there is no "gold standard" for how long each node of information should take (and this would also differ between each node of information), an average of 30 min per node would substantially slow the ability of agencies to develop and update their SA and to act accordingly during a fast-paced, dynamic, man-made attack where lives are at risk. It is important to mention that the decision to share information was not solely that of the NILO, they were often informed what they were "permitted" to share by commanding officers. Delays witnessed were, therefore, the result of multiple agents, not just the NILO at each site.

It is also important to note that some delays were site specific. Both of the frontline responding sites (clandestine laboratory, 18.5 min; train site, 25.5 min) shared information much quicker, on average than the CT interviewing site (45.5 min). In particular, there was a delay of more than 40 min in information obtained from the CT interviewing site to be shared with the train site regarding what the contaminant was and the strength of this, as well as the potential identity and criminal history of the suspect on the train. Such information would be beneficial for informing mass decontamination procedures adopted, as well as the level of protective equipment and procedures implemented by emergency services to arrest the suspect at this site.

Post-incident interviews with emergency responders highlighted a number of facilitators and barriers to information sharing within the MTS. In line with previous research, facilitators related to developing familiarity with responders from across agencies, either through training (including the National Joint Emergency Services Interoperability Programme; JESIP) and managing real incidents. Responders felt that this improved their ability to understand one another by having a shared frame of reference and avoiding use of agency-specific terminology. Barriers predominantly related to the complexity of the structure responding to the incident, including failure to collocate and working in silos, in addition to technological issues with radio devices not working between teams from different regions (see Table 4 for details).

Regardless of the cause, all responders interviewed noted experiencing delays in accessing information needed. For example, the Fire operational commander

Table 2 Number of units of information available identified and shared across locations and average time taken to share identified information

Location	Amount of information available	Amount of information identified	Amount of information shared	Average time taken to share information (min)
CTU	25	14 (56%)	10 (71%)	45.5
Clan lab	6	6 (100%)	6 (100%)	18.5
Train site	7	5 (71%)	5 (100%)	25.5

Table 3 Details of information shared across locations and time taken

Source location	Description of information available	Information extracted	Time to share	Shared with
Interview Suite (IS)	Names of the three suspects under arrest	Provided in brief	N/A	
	What suspects have been arrested for (S41 TACT 2000, suspicion of being involved in commission, preparation or instigation of acts of terrorism)	Provided in brief	N/A	
	Arrested due to reports of being overheard in a pub planning a chemical based terrorist attack on a motorway, and for posting extreme material online	Provided in brief	N/A	
	That there is a fourth suspect outstanding	Provided in brief	N/A	
	Name and description of fourth suspect—Nathan Fox	CT interview	50 min	NILO at CL
	Details of fourth suspect's place of work (CrossKeys construction)	CT interview	Not shared	
	Details of fourth suspect's car	CT interview	U/K	NILO at CL
	Garage contains sarin nerve agent	CT interview	49 min	NILO at TS
	Fourth suspect, Nathan, has access to Bishop's mother's garage	CT interview	49 min	NILO at TS
	Quantity and concentration of sarin liquid	CT interview	49 min	NILO at TS
	Effects of sarin	CT interview	49 min	NILO at TS
	Method of disseminating sarin—5L pressure spray pumps	CT interview	49 min	NILO at TS
	How to treat exposure to sarin—strip clothing and atropine sulphate	CT interview	49 min	NILO at TS
	Bishop owns flat in Peckham and the clan lab address	CT interview	20 min	NILO at CL
	Fourth suspect has learning disabilities—ADHD, dyslexia and autism	No		
	Fourth suspect has a history of violence - PNC	No		
	Details of fourth suspect's address	No		
	The career of suspect Andrew Bishop—analytical chemist	No		
	That Bishop has experience of making harmful chemicals	No		
	Bishop, Jamie and Nathan have plotted to carry out a chemical attack on the underground	No		
	A fall back 'go now' option had been planned by Bishop and Nathan to trigger attack if plans disrupted	No		
	Address of mother's garage	No		
	Bishop has provided Nathan with a syringe and told him it contains an inoculate (atropine sulphate) when it actually contains cyanide	No		
	Bishop has acquired precursors for making HMTD and TATP (explosives)	No		
	Two additional cyanide syringes are in Bishop's flat	No		
Clandestine Laboratory (CL)	Chemicals to make sarin are in Bishop's mother's garage	Found in search	0 min	NILO at IS
	Instructions to make sarin are in garage	Found in search	52 min	NILO at IS
	Method of dispersal of chemical is in garage	Found in search	26 min	NILO at IS and TS
	Precursors for making HMTD and TATP are in garage	Found in search	15 min	NILO at IS
	Materials to make methamphetamine are in garage	Found in search	15 min	NILO at IS
	Effects of exposure to sarin	Scientific Advisor	3 min	NILO at TS

Table 3 (continued)

Source location	Description of information available	Information extracted	Time to share	Shared with
Train Station (TS)	Incident reported on a tube by a station manager—three tubes stuck in a tunnel in the Jubilee line between Southwark and London Bridge. Evacuation of tube 1 and 3 is possible but tube 2 is not at platform level	Incident on train	10 min 51 min	NILO at CL NILO at IS
	Two firefighters sprayed by suspect on tube with an unknown contaminant	Reported from train	20 min 45 min	NILO at CL NILO at IS
	60-75 casualties on board tube two	Reported from train	U/K	NILO at CL
	Suspect arrested	Reported from train	27 min	NILO at IS
	Means of dispersal found—5L spray canisters	Reported from train	0 min	NILO at CL
	Cyanide syringe found on train	No		
	Identification of chemical used on train as sarin by DIM team	No		

needed confirmation about the likely attacker on the train and whether he was operating alone to inform his plan. The Fire NILO at the clandestine laboratory also needed details about this fourth suspect to inform his search strategy. He expected the CT interviewing site to receive, integrate and re-communicate information across the three scenes to consolidate and verify sources. However, the CT interviewing site was not quickly passing information down to NILOs, causing him to feel that his information alone was "dictating" the event.

> Trying to remember what I got from CT [interviewing], it wasn't a lot, I got bits and pieces around the fourth person, so there could have been a 4th person in there. We got a name from them, um, they were asking me quite a lot for the addresses, so maybe if I had gotten that sooner I could have asked our guys in the police to look for that a little sooner as they went in, um, so that might have stilted things. I thought perhaps at that stage we still might have had to make another entry. So maybe that information could have come a little bit quicker.

Emergency responders also noted that it was not just a question of lack of information affecting their understanding of the situation, but that receiving too much created confusion. One police officer referred to this as a '*vomit of information*'.

> It's more about the confusion and conflicting reports you get at the start of an incident and then as everyone starts to become acclimatized and get a grip that's when you can start getting that common intelligence picture or situational awareness… It's as the incident evolves and you start getting that clearer picture because you lose the conflict and you have got conflict."

5.2 Plan formulation

Problems with developing and updating SA led to several points of delay in formulating plans, as identified both through naturalistic observation and interviews with emergency responders. A common theme to emerge was the impact of uncertainty surrounding *who* the fourth suspect was and specifically if the individual on the train was this outstanding fourth suspect that police at the CT interviewing site were already aware of ("Nathan Fox") or if he was still unaccounted for. Information that could have helped to improve this aspect of SA was available at the CT interviewing site, but not all of this was shared, and there were time delays to doing so. This caused delays in the ability of the police operational commander to formulate a plan because not knowing if this was the suspect known to be outstanding (a lone suspect) hindered his assessment of threat levels regarding other secondary suspects or devices.

> I needed to confirm a lot quicker who the suspect was. We were looking for this Nathan Fox, but we could not confirm who he was until he had gone through the decontamination procedures which had caused a big delay because we knew we were looking for a Nathan Fox, but we did not know if our man who got arrested was Nathan Fox, if it was, happy days, we've got everyone arrested and accounted for, if it wasn't, we are like "who is this guy" and where is Nathan Fox and what is he about to do? And are there any secondary devices that we need to go and look for?

This uncertainty about who posed a risk to others on the train and to emergency services responding to the event, created further uncertainty regarding the legislative powers available (i.e., what options are legally available to the decision-maker) and, therefore, the plans that could be developed to access and arrest the suspect on the train.

Table 4 Facilitators and barriers to information sharing identified by emergency responders during post-incident interviews

Facilitator	Description	Supporting quote
Familiarity	Interviews with emergency service personnel highlighted the critical role of familiarity as a factor that facilitated their SA development within the MTS. Several participants noted that they had worked with members of teams from other agencies before, both in other training events and in real incidents, which helped with avoiding barriers in communication caused by use of different terminologies across agencies. Additionally, interviewees identified the importance of establishing a clear mission statement (superordinate goal shared across emergency services) and set of priorities at the start of the exercise. This, coupled with face-to-face communication, facilitated their ability to prioritize information and make effective decisions that did not create conflict between agencies trying to achieve different sub-goals	I think what went well was having that minibus acting as a command unit and getting everyone on that so everyone was close together, was able to get a good briefing done, without, um, it was horrendous conditions outside, without worrying about that. Um, so that worked quite well, because we would have a command unit somewhere on scene, albeit not that close to the incident, it would be located somewhere so that went quite well
Changes to National guidance	Several participants highlighted the role of the JESIP (Joint Emergency Services Interoperability Program) principles in aiding the prioritizing and sharing of information. JESIP is a UK-based program that was commissioned by the Home Office in 2012 to promote improved multi-agency response and communication during complex disasters (JESIP 2016). Most notably, the program has resulted in a set of guidelines and training to promote common use of terminology and better understanding of the way other agencies function	I am reasonably well practiced in JESIP because I helped deliver it, so the information sharing part of it wasn't trouble for me. I was quite happy that all the information that was given was relevant and exactly what was needed rather than being too onerous. So, an example, when I was talking to the NILO back at the CTU I didn't give him a list of chemicals I just broke that down into this is what could be made out of those chemicals just to cut that lengthy amount of time that would be spent on the phone or radio trying to write it all down really. That was information I felt could go on later if required
Barrier	**Description**	**Supporting quote**
Failure for technology to integrate across regions	Several units located across the train site were unable to communicate with each other because radios were not integrated across teams from different regions. This not only affected the ability of different units to share information, but also the ability of higher units of command to effectively develop an overview of the situation. Consequently, agencies had to task some of their emergency responders to act as runners to pass messages across the incident ground, delaying the exchange of information	I think different services, and I don't know because I don't know what other services have got, but I am guessing most services have different radios and different frequencies and unfortunately it doesn't seem that they were compatible today, so if we all had a better idea of what each sector was doing you know? I was struggling to communicate with certain people, what was actually happening within my sector
Failure to co-locate	Not being physically co-located created a further barrier to effective SA. Participants outlined how a lack of co-location led to additional (redundant) steps in information exchange	The other [tactical] officer from HART wasn't co-located so information was coming to me to go out like that, [rather than linking the triangle]. When they moved, when they co-located when we looked at a different approach to the incident the information coming out of them was far better so that to me was, instead of misunderstandings it was, it got better
Working in 'silos'	A further barrier to SA was the emergence of "silos" within the responding teams, with some agencies separating off into small sub-groups. Whilst working in silos may have the advantage of improving information sharing within teams, their formation is a repeated occurrence in MTSs that can often result in disastrous consequences for responding teams. For example, according to the U.S. Senate Select Committee on Intelligence (2007), silos in counter-terrorist teams prevented critical information sharing that *could* have potentially prevented several critical planning activities that led to the attack on the twin towers in 2001. Within this live exercise, the formation of silos hampered the development of SA, delayed decision-making, and created a lack of coordination across agencies in terms of coordinating goals	Um, where that information started to break down was when we did not have anyone to sort of go and get the information from other places and bring it back. That was the key bit. So we were like "right we need to make this joint decision" Oh ambulance have just gone off to their hide, oh well we will have to wait for them to come back before we can make our decision. Whereas if we were all there that means we can communicate with everyone a little bit better or kind of assist and I don't mean that big headedly, but if we had someone to go off, find that information and come back, then instead of us disappearing and re-convening, or two of us being there when we needed three, that decision making and information processing would have been a lot better because we would have been in one place all at the same time

That is going to affect my decision-making. Um, for me, I needed to identify who was involved, what their capability was in terms of, um, causing harm to others, and then from there, also their sort of intent. Sort of what they are going to do with that. So, they were my main key things. I needed to find out who my victims were, who my suspect was, the location of where anything was going on. And then from that, I could inform what I would call a threat assessment, so I would identify where my risks… So once I've identified who is at risk of this that and the others, the information that I have got will also help me decide what powers and policies as a Police Officer I can implement considerations around human rights, um, levels of force we can use, the level of equipment we can get officers to dress up in. All of that kind of stuff, and then from there I can start looking at options, to decide well to do all of that what do I need to do.

5.3 Plan execution

Lack of information regarding who the suspect was not only limited the ability of police to develop SA and formulate plans but also affected the ability of Fire and Ambulance services to execute the plans that they had already formulated. Fire and Ambulance teams were unable to enter the train to rescue, treat and decontaminate casualties until over 90 min after arriving on scene. Throughout this period, passengers remained trapped with the suspect and an unknown contaminant, and there was no form of communication with emergency services. This delay in Fire and Ambulance teams executing plans to rescue and decontaminate passengers was not the result of either team being unable to develop or formulate plans, but rather delays in Police forming plans to arrest the suspect. Fire and Ambulance were dependent upon Police to achieve their goal of arresting the suspect first before their own responders could enter the train and implement actions to achieve casualty rescue and treatment goals.

So we have turned up on the scene, we have requested the police. We are waiting for the police. We have got casualties there, our role as firefighters, we are ready but unfortunately we cannot put ourselves in risk to save that life initially while there is an assailant running through spraying people. We could not…
Because that perpetrator was physically attacking and making a scene unsafe, taking him out, neutralizing that threat was key because then that released us to undertake… I think that there was initial confusion around deployment at the beginning, there was a bit of a time lag there. Then there was the Decon time lag. There was some difficulty, um, because of the perpetrator.

Delays in sharing time-sensitive information (mainly obtained through suspect interviews), therefore, created delayed actions in dealing with the man-made threat on the train, posing potential risks to the lives of passengers exposed to the sarin gas. Once Police arrested the suspect, it took less than 30 min for all remaining passengers to be removed from carriages and to undergo mass decontamination. Figure 2 provides a flowchart to summarize the factors that contributed towards decision delay.

6 Discussion

Previous research demonstrates difficulties with information sharing in MTSs, particularly those comprised of members from different agencies (Kozlowski and Ilgen 2006; Shuffler et al. 2015), who are geographically dispersed (Maynard et al. 2012). Findings from the current study add to this literature by highlighting the impact of these difficulties on decision processes at the multiteam level. They also add to the limited psychological literature on decision delay (Alison et al. 2015). Whilst errors in selecting appropriate options have received a great deal of focus in previous research, it was decision and action delay that was problematic within the MTS observed in the current study. Findings demonstrate the role that information sharing and interconnected goals plays in mitigating and amplifying the conditions that lead to decision delay in MTS members. Decision delay resulted from both individual cognitive processes in terms of inability to develop SA and formulate plans, and interactions across MTS members. As will be discussed below, findings pose implications for developing targeted interventions to improve information sharing and decision-making in MTSs operating in extreme environments.

6.1 Information sharing and situation awareness

NDM research highlights the importance of access to relevant information for developing an accurate understanding of what is happening and how this might progress (Endsley 2000, 2015) to tailor decisions and actions to the situation (Rankin et al. 2013). Within MTSs operating in extreme environments, information sharing and interpretation is not only vital to developing accurate SA at individual (Endsley 2000) and team levels (Wright et al. 2004), but also the multiteam level to coordinate subgoals and actions, and implemented them in an appropriate order (Davison et al. 2012). Previous NDM research has focused on the impact of information sharing and poor SA on decision processes at an individual level, but not the multiteam level. MTS research has focused on interteam processes but does not specifically focus on decision delay, and is often conducted with naïve participants in laboratory-based contexts that do not reflect the complexity of extreme environments. This limits understanding of the causes of decision delay within complex networks operating in complex environments, and the development of evidence-based interventions. Accordingly, the current study adopted a data collection framework that drew on a range of methods to examine communication and decision-making behaviors in situ. In line with a DSA approach (Chatzimichailidou et al. 2015), we tracked what information was shared, with whom, and how long this took. In line with an NDM approach (Crandall et al. 2006; Burke et al. 2007), observational and interview methods were used to understand the impact of information sharing on SA, plan formulation and execution phases across the MTS operating in an extreme environment.

Analysis identified many instances in which information sharing was delayed, subsequently resulting in deferred action across the MTS. In particular, delays in information from the CT interviewing site being shared resulted in over an hour of delays in action on the incident ground with regard to arresting the suspect on the train and rescuing and decontaminating casualties. To put this point into perspective, if the concentration of sarin is high enough, paralysis (and death) can occur within 10 min. Despite the significant time pressure for Fire and Ambulance teams to enter the train carriage and deal with casualties, actions were significantly delayed by the amount of time taken for information available at a different geographical location to be shared with Police on the incident ground.

Although previous research demonstrates that being geographically dispersed can delay information sharing (Martin and Bal 2006; Maynard et al. 2012), current findings suggest this may not be the only contributing factor. All three sites were geographically dispersed, requiring use of handheld radios to communicate. However, the responding sites (tactical and operational located at the clandestine laboratory and train sites) were much quicker to share information with one another in comparison to the CT interviewing site. Many of the emergency responders located at the clandestine laboratory and train site had received training and had previously managed smaller scale incidents that required them to operate with other agencies on the front line of an incident. Accordingly, they were more familiar with one another's practices than with investigative procedures, and similarly, officers located at the CT interviewing site would be less familiar with frontline emergency response procedures. This is in line with TSA (Berggren et al. 2014; Bolstad et al. 2002; Gorman et al. 2006), DSA (Stanton et al. 2006; Stanton 2016) and transactive memory (Wegner et al. 1985) research, which show the importance of shared familiarity with roles and responsibilities for promoting a better understanding of informational needs and quicker exchange of relevant information (Waring et al. 2018).

These findings also parallel research from within the engineering domain, which highlights the negative impact that dissonance arising from conflicts in individual and collective knowledge can have on risk assessment (Vanderhaegen and Carsten 2017). Vanderhaegen (2017) notes the vital importance of attending to dissonance, assessing the probability of its occurrence and analyzing the consequences to design processes and systems to minimize this. Similarly, organizational researchers note the impact of differences in knowledge across domain expertise for conceptualizing problems, and sharing and attending to information (Cronin and Weingart 2007). Current findings indicate that greater familiarity with one another's roles and responsibilities among frontline emergency responders helped to reduce conflicts in understanding the situation, promoting quicker exchange of information. Taken together, these findings suggest that dissonance and representational gaps may contribute to decision delay by hindering the effectiveness of information sharing and subsequent SA development. However, future research is required to test these associations using methods that specifically measuring dissonance (Vanderhaegen 2017) and representational gaps (Cronin and Weingart 2007), alongside the data collection framework used in this study to identify decision delay.

Drawing on observations of behaviors in situ, the current study was also able to identify the etiology of barriers to SA and their ensuing effects on the timely formation and execution of plans. NDM models highlight that uncertainty about the situation often prevents the decision maker being able to prospectively (or at least accurately) project the outcomes of a given decision (Lipshitz and Strauss 1997). Current findings identify that uncertainty surrounding the situation and the outcomes of an action do indeed delay decisions and actions, but are not the only sources of uncertainty to do so (van den Heuvel et al. 2013). By focusing on decision and communication processes in situ at the multiteam level, additional sources of uncertainty that hampered effective SA and delayed action were identified, including inability to establish communications on the incident ground due to problems with incompatible radios across teams from different regions, and a tendency for teams to work in silos. First, this reinforces the need for investment in communication devices that operate across agencies and regions; an issue pertinent to UK emergency services as they currently undergo processes to alter software through which radio devices operate due to logistical issues. Second, it highlights that although working in silos can improve communication within teams this comes at a cost to communication between teams, which is problematic in MTSs where goals and actions need to be coordinated.

Further research is needed to understand the best structure for reducing the cognitive demands of engaging in activities to simultaneously source, process and exchange

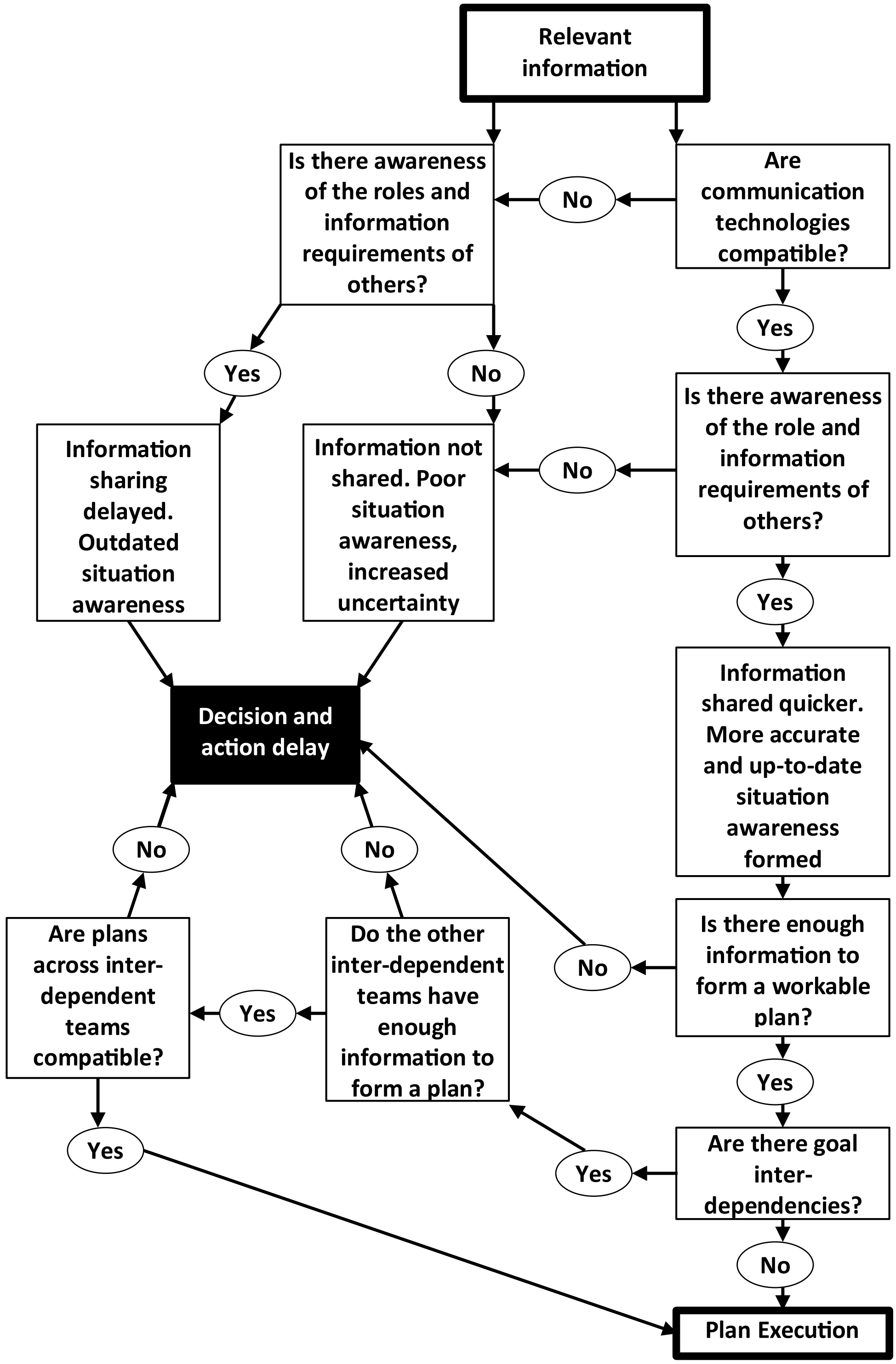

Fig. 2 A flow chart to show the role of information sharing and goal interdependencies on decision delay

information within and between agencies in extreme environments. For example, growing evidence highlights that decentralized rather than centralized structures may be better for improving access to relevant, timely information during disaster response, promoting DSA (Schraagen and Van de Ven 2011; Waring et al. 2018). However, the development and use of robust frameworks for evaluating behaviors in situ within extreme contexts, and application of these standardized data frameworks across a range of MTS contexts will be important for testing the conditions under which decentralized structures outperform centralized in improving information sharing, coordination and decision making. For example, to test whether the number of component teams, number of members within each team, number of different agencies involved, level of interconnectedness between sub-goals, variety of tasks that need completing, dynamicity of the situation or other factors affect whether centralized or decentralized structures improve the ability to share relevant information in a timely manner with those who need it, and whether this reduces decision delay.

6.2 Impact across decision processes

Findings demonstrate the interconnected nature of decision processes across individuals operating within a complex MTS. Research that focuses on SA at the individual level indicates that "inaction" is an emergent outcome of poor SA as individuals struggle to identify and implement courses of action in the face of uncertainty (Alison et al. 2015; van den Heuvel et al. 2013). Focusing on these processes at a multiteam level in situ identified several underlying causes of decision delay. Firstly, lack of information sharing across geographically dispersed locations (largely stemming from delays in the CT interviewing site sharing and integrating information) created uncertainty at the responding level, meaning that some teams were unable to effectively develop plans because they were unsure about the nature of the chemical, identity or location of the "fourth suspect". Hence, poor SA delayed the ability to effectively make and subsequently implement plans.

However, the multi-agency nature of this operation highlighted that delays to executing plans were not only influenced by the ability of the individual to develop SA but were also influenced by the cognitive processes of others. For example, whilst the Fire tactical commander had established a plan to evacuate casualties, his ability to implement this plan was postponed due to delays in Police being able to execute their sub-goal of arresting the suspect. In contrast to research that focuses on cognitive processes at the individual level, observations of behaviors in situ within a MTS operating in an extreme environment provide evidence that goal interdependencies can contribute to decision delay. Where goal interdependencies exist, failure for one team to develop appropriate SA to inform the development of plans to address their goals can impact the ability of other teams to implement actions to address theirs, even where they have developed appropriate SA to form their own plans. We observed first-hand the detrimental impact of delays in information sharing on multiple teams where sub-goals are connected.

Although these findings are based on analysis of one disaster response exercise conducted with a UK sample, they parallel behaviors observed in real incidents, both in the UK (Pollock 2013) and internationally (Patrick 2011; Rencoret et al. 2010). However, further research is needed to identify the extent to which these same patterns are observed across MTSs operating in other types of extreme context, including medical emergencies (Mathieu et al. 2001) and military contexts (DeConstanza et al. 2014). Similarly, studies adopting similar methods are also needed across different countries and cultures to test whether the same factors contribute to and result in decision delay during multiagency disaster response internationally. This is important for improving understanding of the conditions under which decision delay is likely to occur and why, along with identifying what works in practice to reduce decision delay.

6.3 Practical implications

At a practical level, findings highlight a need for agencies to focus on developing a shared understanding of the roles, goals and information available to other agencies, in line with organizational research on TMSs (Heavey and Simsek 2015; Ren and Argote 2011). Such knowledge may help agencies to proactively request information from the appropriate sources quicker. Similarly, findings also highlight the importance of understanding the types of information that other agencies need during complex operations of this type, in line with NDM research into SSA (Endsley 2015; Gorman et al. 2006). Whilst national Home Office funded JESIP has been beneficial for ensuring that agencies utilize a common language to communicate and are focused on developing a shared appreciation of the situation and risks involved, much of this work has been directed to front line emergency responders. Findings of this study highlight the importance of ensuring that all law enforcement and emergency service practitioners, even those who traditionally serve an investigative role, are aware of the roles, responsibilities and requirements of responders managing an incident on the ground to facilitate the timely sharing of relevant information obtained through investigative actions.

Findings also highlight that developing interventions to address issues with decision delay for agencies who operate in MTS contexts where goal interdependencies may exist should not only focus on decision processes at the individual level. Given that decision delay is not only caused by individual cognitive processes but also interactions between cognitive processes of multiple individuals and teams, it is important that interventions focus on encouraging consideration of the interconnectedness of goals and decisions, and of how this may impact on a situation, and developing shared frames of reference for viewing problems and goals to reduce dissonance and representational gaps. Whilst technologies continue to be developed that allow information to be communicated across locations in a variety of formats (audio, visual, text), these technologies will not automatically improve the speed and accuracy of information sharing to aid decision making in the absence of interventions that address issues with understanding roles, goals and types of information available across agencies within a MTS.

Overall, recommendations are relevant for other MTSs operating in extreme environments characterized by high risk and uncertainty. They highlight the importance of ensuring that any interventions implemented to improve information sharing and coordination across teams are not just delivered to employees working 'on the ground' but to all components who may be party to information of relevance to informing decisions and actions taken at this level. Further work is required to understand what form such training should take to best promote the effectiveness of information sharing within and between agencies, and how often such training should be delivered to maintain these complex skills. Further work is also required to identify ways of designing communication technologies to assist in prompting the sharing of relevant information across complex networks.

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