MULTIDISCIPLINARY COORDINATION OF ON-SCENE COMMAND TEAMS IN VIRTUAL EMERGENCY EXERCISES

Theo van Ruijven[(a)], Igor Mayer[(b)], Mark de Bruijne[(c)]

[(a)] Consultant at Capgemini Consulting and Guest Researcher at Delft University of Technology
[(b)] Associate Professor at Delft University of Technology
[(c)] Assistant Professor at Delft University of Technology

[(a)] t.w.j.vanruijven@tudelft.nl, [(b)]i.s.mayer@tudelft.nl, [(c)]m.l.c.debruijne@tudelft.nl

ABSTRACT
The authors present the design and results of a comparative study into multidisciplinary on-scene command teams at work in virtual emergency training exercises. The main question of the study is: How do on-scene command teams coordinate multidisciplinary objectives and tasks, and how does the way this is done determine their performance? The study involves 20 'on-scene command teams' consisting of multiple disciplines, such as police, fire and medical services, municipal officers and infrastructure operators, in a safety region in the Netherlands. Integral video observation by five synchronized cameras was used to capture the coordination processes during the virtual exercises. These integral and synchronized video recordings were then coded. Performance was operationalized by scoring the progress and completion of emergency management tasks for which individual members and/or the team as a whole were responsible. Team coordination was operationalized through network centrality and density measures. Analysis of the data shows that there is wide variation within and among the teams with regard to emergency management performance and coordination patterns. Significant findings are: 1) decentralized coordination is an important factor in emergency management performance; 2) teams that use less coordination during the intermediate phase of emergency management perform significantly better; 3) actors that have a central position in the network achieve their own goals better.

Keywords: emergency response, crisis management, team performance, serious games, game-based training, virtual team training, video observation, network analysis, XVR™

1. INTRODUCTION
Emergency response refers to all operational and procedural tasks conducted individually or jointly by qualified professionals, aimed at normalizing a situation after it has been disrupted by an incident or accident (Haddow, Bullock, and Coppola 2003; Chen et al. 2008). It generally involves tasks such as rescue, medical aid, policing, evacuation, rerouting of traffic, fire-fighting, containment of chemical spills, and many other roles. A wide range of responsibilities are attributed to specific emergency response disciplines such as ambulance and fire services, and the police. *First responders* arriving at the scene of an incident or accident will commonly follow a set of standard operating procedures (SOPs), for which they are trained in professional education. These skills are further developed and maintained in drills and simulations. For safety and efficiency reasons, such training is increasingly 'virtual' and game-based (Harteveld 2012; Benjamins and Rothkrantz 2007; Haferkamp et al. 2011; Mcgrath and McGrath 2005).

Incidents and accidents commonly occur in and around vital infrastructure, such as railways, roads, waterways, power stations and airports. In modern societies, even a small incident or accident may cause considerable disruption of the infrastructure (traffic congestion and power blackout), causing socio-economic loss that may even lead to a political-institutional crisis. Rapid repair and recovery of disrupted infrastructure is therefore an essential part of emergency response. This brings even more actors onto the scene, such as road inspectors and repair men, infrastructure operators, public utility managers and municipal officials, who all have individual objectives that they try to achieve with their own SOPs. Therefore, the objectives and procedures of all actors on the scene need to be prioritized, aligned and sequenced to form an integrated response.

Emergency (response) management refers to all tactical and strategic tasks aimed at the smooth operation of emergency response services, either during the proactive or 'cold' phase, such as planning and training, or the reactive or 'hot' phase. During the 'hot' phase, emergency response management is generally undertaken by a team consisting of representatives of the disciplines involved – a blending of mono-disciplinary professionalism and multidisciplinary teamwork. In the Netherlands, such teams are referred to as COPI, an acronym for *on-scene command team*. In the early phases of an incident or accident, an on-scene command team is faced with a great many, possibly conflicting, objectives and SOPs. Arriving at the scene, a command team needs to prioritize, align and sequence these objectives rapidly. In other words, on-scene command teams must *coordinate* in the most effective manner (Chen et al. 2008). How do they do this? What forms of coordination work well and which do not?

2. STUDY DESIGN

The main research question addressed in this paper is: *How do on-scene command teams coordinate multidisciplinary objectives and procedures, and how does the way this is done determine their emergency management performance?* This question is highly relevant, given the increasing complexity of emergency response management and its consequential gains and losses. Furthermore, there is little empirical understanding about what on-scene command teams actually do and what makes one team more effective than another.

Research into this matter is far from simple. Real-time observation during an emergency faces all kinds of practical complications, scientific limitations and moral objections. Incidents are chaotic and response management is dispersed and lengthy (hours to weeks), thereby requiring a considerable number of observers, or some other way of logging and tracking interactions. The occurrence of incidents and accidents is unpredictable, demanding researchers to 'stand by' over a longer period of time. Such factors make it virtually impossible to collect quantitative or quantifiable data while on-scene command teams are in the midst of a crisis.

Advances in research methods have used the tracking of digital communication during a crisis (data from mobile phone network, etc.) but this type of data is meaningful only for specific purposes in larger scale events (such as determining location and movements) (Landgren and Nulden 2007). Furthermore, it seems highly impractical and unethical to record on camera what first responders do, let alone to distribute questionnaires. The potential suffering of real victims may be confrontational and emotional, not a good context to start 'counting' or 'coding'. Structured interviews are likely to interfere and disturb the performance of an on-scene command team. In short, with respect to emergencies, researchers at best observe in a *stealth mode*. Although this has generally delivered valuable insights, this type of research tends to be evaluative, case-based, qualitative and interpretative if not anecdotal. Other more objective forms of research (i.e., explanatory, comparative and quantitative) seem almost impossible.

There is however a compromise solution, where larger amounts of qualitative data about multiple emergency management events can be turned into quantitative data for comparative analysis. Our study into the coordination and performance of on-scene command teams was carried out using observations of 20 teams of professionals at work in four different scenarios of virtual emergency response training. The four scenarios concerned: 1) Tunnel hazardous materials; 2) Tunnel evacuation; 3) Urban hazardous materials; 4) Port carbon monoxide scenario. The research was conducted between 2011 and 2014 with the support of one of the 25 safety regions in the Netherlands. Written permission was granted by the safety region and participants to make video recordings during all sessions. Results were anonymized and cannot be traced back to individuals or teams. Participants were operational officers – novices to experienced seniors – in one of the relevant disciplines and working in the same safety region, including police, fire services, medical emergency services, the municipality and infrastructure operators.

An on-scene command team is usually composed of officers on duty. As is the case in reality, many of the participants in the exercises did not know each other. The virtual training exercises were part of a mandatory training program for COPI members. One participant in the virtual on-scene command team was assigned a role as leading officer and another as information manager.

The virtual emergency training sessions were prepared and operated in XVR™, based on the Quest3D™ game engine, provided under license by a Dutch company. The XVR™ system allows users to build authentic 3D representations of an emergency situation with building blocks such as cars, victims, hazardous substances, fire and explosions, etc. The Tunnel Scenarios used an accurate 3D model of an actual tunnel in the region. The exercises were managed by an experienced team of professional facilitators who moderated the different aspects of the sessions, from logistics, computer technology and player briefings and debriefings. A technical facilitator operated and supported the player-computer interactions, allowing participants to focus on their task rather than on the controls.

Five synchronized cameras were placed in two adjacent rooms. One camera captured the plenary meetings of the on-scene command team, as well as the briefings and debriefings. Four cameras – roughly one for each actor – were placed in the situational assessment room, also called "the field room," where on-scene command team members engaged individually with the virtual environment while monitoring the virtual emergency situation on a large projection screen. The full on-scene command team interaction for each session was captured through time-synchronization of the five cameras. All data were coded and analyzed afterwards by the first author using the Transana video transcription software package. In addition, a questionnaire (approx. 15 min to fill out) was handed out to collect information about the participants and their experience of the virtual exercise. As the main researcher, the first author also logged notable session information, such as start and end times, facilitators, players, previous virtual training experience, technical or other disturbances. Figure 1 sketches the setting of the exercise and its observation, giving an impression of the players at work.

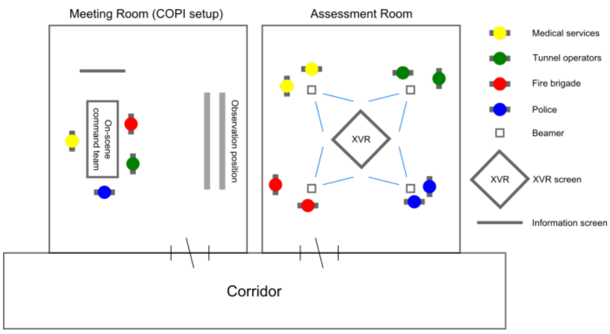


Figure 1: Setting

2.1. Centralized and decentralized coordination

Communication and coordination are crucial factors in explaining team performance (Bettenhausen 1991; Comfort 2007; J. Mathieu et al. 2008). Previous research has found that initial temporal planning contributes to time awareness, coordination and task performance in self-managing teams (Janicik and Bartel 2003). Information processing and the spread of information over emergency response actors has been found to be crucial for explaining crisis management performance (Kapucu 2005). Other studies of communication and coordination networks in emergency management teams have concluded that network analysis is a useful method for studying command and control (Houghton et al. 2006).

To conceptualize and operationalize on-scene command team coordination, we adapted a model presented by Marks et al. (Marks, Mathieu, and Zaccaro 2001). The original model (see Figure 2) breaks down the effort of emergency management teams into episodes called (a) action phases, where the team does the operational work, and (b) transition phases, where the team focuses on evaluation and planning (J. E. Mathieu and Schulze 2006; J. Mathieu et al. 2008; Ilgen et al. 2005). During the phases, Inputs (I) are transformed into Outputs (O) by Procedures (P). Temporally, the input of one phase is the output of another phase.

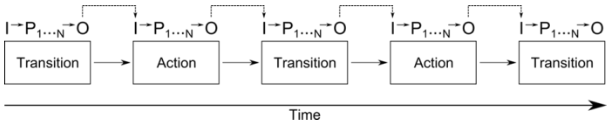


Figure 2: Recurring phase model of team performance (Marks et al. 2001)

Viewed in this way, the various emergency response services conduct their respective operational tasks during the action phases. Since the SOPs may not be aligned and need to be prioritized and sequenced, coordination is highly important. The transition phases consist of meetings of an on-scene command team, where the emergency response is coordinated. The output of the coordination meetings, therefore, can be seen as the input for the operational activities and vice versa.

This straightforward picture of coordination in on-scene command teams, however, is not fully accurate. During the meetings of on-scene command teams, all actors come together at the same location to coordinate the emergency response activities of their respective disciplines. The effectiveness of a single sequence of coordination meetings is disrupted by the chaotic nature of an emergency, most importantly due to time pressure. Many tasks, such as firefighting, rescue or rerouting of traffic, need an immediate response. In other words, they cannot wait until the next coordination meeting, although they do require some immediate form of coordination with other actors.

Another issue is that not all tasks require coordination by all actors. They can be coordinated by a subset of actors, for instance bilaterally or tripartite. Last but not least, on-scene command teams are more like a network of actors than a hierarchy (Leukfeldt et al. 2007). There is no hierarchical leader who takes, oversees or enforces the major decisions, and there are no subordinate actors who simply execute their tasks. Each member of an on-scene command team is responsible for their own decisions with respect to his or her crew, equipment and actions. Since there is no formal hierarchical leader in the form of a single coordinator and person in charge, there is considerable variety in the way coordination in an on-scene command team is organized. To a large extent, the coordination of on-scene command teams depends upon situational circumstances, although it may also depend upon factors related to team composition, team structure and team leadership. We therefore revised Marks' framework, as presented in Figure 3.

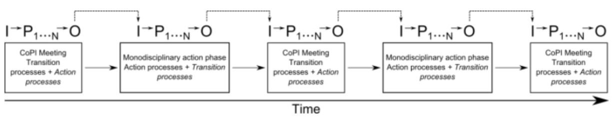


Figure 3: Revised framework of coordination in on-scene command teams

2.2. Hypotheses

Centralized coordination in an on-scene command team meeting is important, but when it is applied too rigidly and is not in sync with decentralized coordination, the team will be less effective and slow down. Decentralized coordination seems necessary to get things done immediately, while centralized coordination seems necessary to maintain sight of the bigger picture. A lack of decentralized coordination may lead to ineffective, slow emergency response. Hence, our first hypothesis (*H1*) is that more decentralized coordination will lead to better emergence response performance by a command team. Correspondingly, a lesser amount of decentralized coordination will contribute to poorer emergency response performance by an on-scene command team.

Decentralized coordination also gives more space to individual actors to pursue their own interests, to achieve their own goals and to coordinate their own preferred standard operating procedures. Hence, our second hypothesis (*H2*) argues that the active involvement of an actor in decentralized coordination is beneficial for the performance of tasks for which this actor is responsible.

2.3. Operationalization of performance

To determine and compare emergency management performance, the observable progress of each individual task during an exercise was coded over time. The continuous nature of time in a training exercise was turned into three periodic intervals – start, middle and end – which correspond with natural steps in the emergency response exercise. Tasks for which no progress was observed at the end of a time interval were coded as '0'. Tasks that had started at the end of an interval but had not yet been finished were coded '1', and completed tasks were coded '2'. A task finished at an earlier interval continued to be coded '2' at later intervals. Thus, a task completed early on in the exercise received a higher score than the same task completed at the end of the exercise.

The end performance of an individual actor could now be calculated as the sum of all scores attributed to the tasks for which this actor was responsible. The end performance of an on-scene command team could then be calculated by summating all scores for all tasks by all actors. Since the number and nature of tasks differed among the four training scenarios, we could only compare the end performances of teams playing the same scenario. Furthermore, some actors were responsible for only one task, while most other actors were responsible for two or more tasks. Thus, the performance scores of actors in the same team and the performance of teams playing different scenarios could not be compared.

In order to achieve a better standard for comparative analysis, all scores were normalized to give a value between 0 (lowest performing actor or team) and 1 (highest performing actor or team), with scores in between based upon distance to highest and lowest team/actor. The normalized scores allow comparison of the performance across all actors and teams, despite some actors having a relatively light task, while others faced severe challenges. The various performance indicators are listed in Table 1.

Level	Indicator	Operationalization
Normalized team performance	Summation of all scores of all tasks for which a team is responsible	Assigning 0, 1, 2 score based on the progress a task has made at each interval, normalized between 0 and 1
Actor performance	Summation of all scores of the tasks for which the actor is responsible	Assigning 0, 1, 2 score based on the progress a task has made at each interval, normalized between 0 and 1

Table 1: Performance indicators

2.4. Operationalization of coordination

In order to measure coordination, we operationalized it into several strong indicators that could be coded from the videos. We decided to take communication – that is, actors talking to each other during the exercise – as a proxy for decentralized coordination. We realize that communication and coordination are not identical, but communication is at least a prerequisite for coordination. Network theory was used to construct the coordination indicators. Networks are webs of ties or links (e.g., communication flows, transportation lines) interconnected by nodes or points (e.g., actors or hubs) (Scott 2000; Kossinets and Watts 2006; Borgatti et al. 2009; Scott 1988).

For our purposes, several indicators can be developed to measure ties (communication) and nodes (actors). A tie can be analyzed in a binary fashion: it exists (1) or not (0). However, ties can also be weighted, for instance on the basis of *intensity*, giving us weaker and stronger ties, commonly pictured by the weight of a line between two nodes. In communication networks, weight may be attributed, for instance, on the basis of the *duration* of the communication or the *amount of data* that is communicated.

Communication between actors during action phases can also be taken as a proxy for decentralized coordination. The amount of decentralized coordination in a team can be measured by examining the communication network's *interconnectedness*, here called *density*. Network density is the number of actual ties (i.e., the number of communication lines between two actors) in a network as a proportion of the maximum number of all possible ties. Network density can also be weighted by taking into account the weight of the ties. In our case, the network density of an on-scene command team can be calculated by looking at the duration of all communication among all actors as a proportion of the maximum number of possible ties and their maximum possible duration.

To determine the importance of an individual node within a network we can use *network centrality* measures, commonly pictured by the size of a node in a network graph (Opsahl, Agneessens, and Skvoretz 2010; Newman 2005; Borgatti 2005; Okamoto, Chen, and Li 2008). *Degree centrality* is derived by calculating the number of ties that one node has with other nodes. Taking into account the direction of communication – sending or receiving – the *In* and/or *Out-degree centrality* of a node can also be calculated. *Betweenness centrality* is an indicator of the intermediate positions of a node in-between other nodes. A high betweenness centrality score implies that an actor is an important 'hub' of information (Scott, 2011). The above indicators can again be weighted by taking into account the duration of the communication. For reasons of simplicity, we decided to develop a weighted indicator for degree centrality only.

Another issue in the analysis was that we needed to decide upon the relative importance of the number of ties (the degree) in relation to the importance of the weight of ties (the strength). In other words, is it more important to be connected to many other team members or to be connected to them for a longer period of time? Opsahl et al. (Opsahl, Agneessens, and Skvoretz 2010) proposed using a *tuning parameter* for weighted degree centrality. Setting the parameter at 0 implies that strength is disregarded, and the indicator thus becomes identical to degree centrality. Setting the parameter at 1 means that the indicator disregards the number of ties. In our analysis below, we set the tuning parameter at 0.5, allowing as much influence to the number of ties as to their weight. Table 2 gives an overview of all of the network density and centrality indicators.

Indicator	Definition	Operationalization
Density	The number of ties as a proportion of the maximum number of ties within a network	The number of communicating emergency response actors as a proportion of the maximum number of communicating emergency response actors
Weighted degree centrality	The number of ties and their weights as a proportion of the maximum number of ties and their maximum weights within a network	The number of communicating emergency response actors and the duration of their communications as a proportion of the maximum number of communicating actors and their maximum duration
Degree centrality	The number of ties between a node and other nodes	The number of emergency response actors that an actor in question is communicating with
In-degree centrality	The number of ties that run from other nodes to the node in question	The number of emergency response actors that communicate to an actor in question
Out-degree centrality	The number of ties that run from the node in question to other nodes	The number of emergency response actors that an actor in question is communicating to
Betweenness centrality	The number of shortest paths between node pairs that pass through the node of interest	The number of times that an actor in question is at the shortest communication path between two other emergency response actors
Closeness centrality	The total graph-theoretic distance of a given node from all other nodes	The distance of an actor in question to all other emergency response actors
Weighted degree centrality	The number of ties between a node and other nodes, adjusted for the weight of the ties (the tuning parameter – alpha – is set at 0.5 in this study)	The number of emergency response actors that an actor in question is communicating with, weighted by the duration of the communication
Weighted in-degree centrality	The number of ties that run from other nodes to the node in question, adjusted for the weight of the ties (alpha = 0.5)	The number of emergency response actors that communicate to an actor in question, weighted by the duration of the communication
Weighted out-degree centrality	The number of ties that run from the node	The number of emergency response actors

	in question to other nodes, adjusted for the weight of the ties (alpha = 0.5)	that an actor in question is communicating to, weighted by the duration of the communication

Table 2: Coordination indicators

3. RESULTS

3.1. Performance

The assessment of the collected data reveals variation in how on-scene command teams perform and how they coordinate. Teams playing the same scenario show marked variety in the sequence of tasks. Furthermore, some teams are significantly better than others; they finish more tasks and are quicker to finish them. Table 3 gives an overview of each team's end score before normalization. Table 4 shows the ranking of the teams after normalization.

Team/ scenario	Tunnel hazmat	Tunnel evacuation	Urban hazmat	Port CO
1	48	41	42	47
2	52	45	45	52
3	50	68	46	43
4	53	52	53	56
5	45		56	
6	46		54	

Table 3 - Team performance (before normalization)

Team/ scenario	Tunnel hazmat	Tunnel evacuation	Urban hazmat	Port CO
Best performing	Team 4 (1.0)	Team 3 (1.0)	Team 5 (1.0)	Team 4 (1.0)
	Team 2 (0.88)	Team 4 (0.41)	Team 6 (0.86)	Team 2 (0.54)
	Team 3 (0.63)	Team 2 (0.15)	Team 4 (0.79)	Team 1 (0.31)
	Team 1 (0.38)	Team 1 (0.0)	Team 3 (0.29)	Team 3 (0.0)
	Team 6 (0.13)		Team 2 (0.21)	
Worst performing	Team 5 (0.0)		Team 1 (0.0)	

Table 4: Team performance (after normalization)

Individual actors also show great variety in their level of performance and coordination. Table 5 shows the normalized performance of the fire services as an example.

Team/ scenario	Tunnel hazmat	Tunnel evacuation	Urban hazmat	Port CO
Best performing	Fire services 2 (1.0)	Fire services 3 (1.0)	Fire services 5 (1.0)	Fire services 4 (1.0)
	Fire services 6 (0.71)	Fire services 1 (0.13)	Fire services 4 (0.86)	Fire services 2 (0.83)
	Fire services 5 (0.57)	Fire services 4 (0.13)	Fire services 2 (0.71)	Fire services 3 (0.67)
	Fire services 4 (0.43)	Fire services 2 (0.0)	Fire services 3 (0.57)	Fire services 1 (0.0)
	Fire services 3 (0.29)		Fire services 1 (0.43)	
Worst performing	Fire services 1 (0.0)		Fire services 6 (0.0)	

Table 5: Performance of the fire services

3.2. Coordination at team level

Decentralized coordination within the teams is measured through *network density*, which varies between 0.16 and 0.34, with a mean of 0.25. This implies that one-third of the members in the high density team spoke with each other during the exercises, while in the low density team this is one sixth. The variation in the *weighted network density* is greater, and varies between 0.05 and 0.29, with a mean of 0.12. In conclusion, in some teams, the actors engage in coordination significantly more than in other teams. Table 6 shows the *normalized weighted densities* of the 20 teams, ranked from high to low density.

Team/ scenario	Tunnel hazmat	Tunnel evacuation	Urban hazmat	Port CO
Highest density (1.0)	Team 6 (1.0)	Team 3 (1.0)	Team 3 (1.0)	Team 3 (1.0)
	Team 2 (0.83)	Team 1 (0.71)	Team 4 (0.86)	Team 2 (0.60)
	Team 1 (0.27)	Team 4 (0.70)	Team 6 (0.85)	Team 1 (0.05)
	Team 3 (0.25)	Team 2 (0.0)	Team 1 (0.71)	Team 4 (0.0)
	Team 5 (0.25)		Team 2 (0.14)	
Lowest density (0.0)	Team 4 (0.0)		Team 5 (0.0)	

Table 6: Team coordination based upon normalized weighted density

3.3. Coordination at actor level

The centrality of individual emergency response actors in the networks varies in different ways. On average, the actors communicate with 3.7 other actors, with a standard deviation of 1.4. The weighted centrality of actors varies more strongly, with an average of 465 and a standard deviation of 307. The standard deviation indicates that the majority of the team members have a weighted degree centrality between 158 and 772, which is a substantial range. In sum, the amount of coordination in which individual emergency response actors are involved varies significantly (see Table 7).

Team/ scenario	Tunnel hazmat	Tunnel evacuation	Urban hazmat	Port CO
Most coordination (1.0)	Fire services 6 (1.0)	Fire services 3 (1.0)	Fire services 6 (1.0)	Fire services 3 (1.0)
	Fire services 5 (0.41)	Fire services 4 (0.24)	Fire services 4 (0.95)	Fire services 2 (0.59)
	Fire services 3 (0.29)	Fire services 1 (0.15)	Fire services 3 (0.76)	Fire services 4 (0.26)
	Fire services 1 (0.29)	Fire services 2 (0.0)	Fire services 5 (0.25)	Fire services 1 (0.0)
	Fire services 4 (0.01)		Fire services 1 (0.21)	
Least coordination (0.0)	Fire services 2 (0.0)		Fire services 2 (0.0)	

Table 7: Coordination of fire services (after normalization)

4. TESTING HYPOTHESES

H1: Teams with a high level of decentralized coordination show better team performance than teams with a low level of decentralized coordination.

Figures 4 and 5 give an overview of each team's weighted network density in relation to team performance. The correlations are weak and statistically not significant. More and longer decentralized coordination – that is, speaking with each other – does not seem to lead to better performance. The hypothesis is rejected.

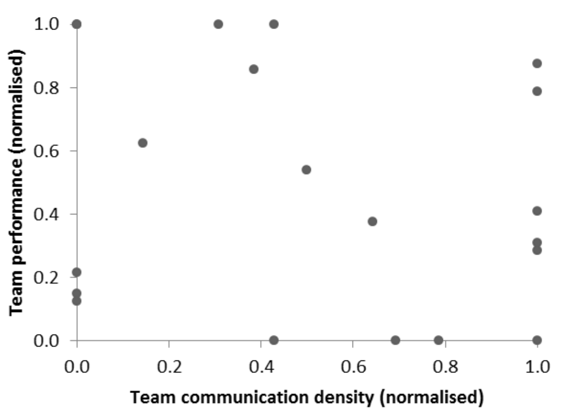


Figure 4: Communication density and performance of on-scene command teams

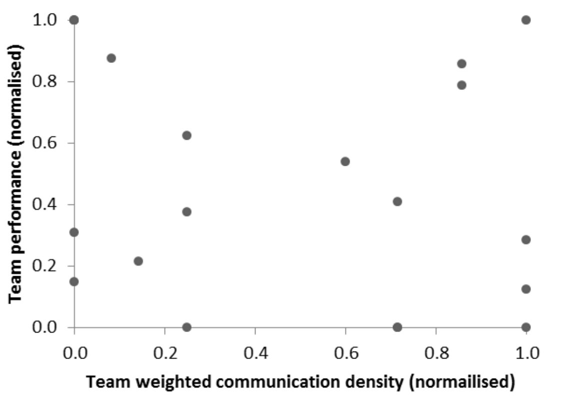


Figure 5: Weighted communication density and performance of on-scene command teams

Following the temporal framework of team coordination (Figures 2 and 3), we decided to analyze how coordination and performance were related 'over time'. We broke up the exercises into three different phases: 1) the initial phase, before the first team meeting; 2) the intermediate phase, between the first and second team meetings; 3) final phase, between the second and last team meetings. We differentiated the density and weighted density for the three episodes and then correlated the latter with overall team performance. This analysis provided interesting results. Again, coordination during the initial and final phases has no significant correlation with performance. Coordination during the intermediate phase of emergency response, however, is significantly negatively correlated with team performance (-.473*). Less coordination during the intermediate phase of emergency response seems to lead to better overall team performance. The normalized outcomes of team performance and weighted communication network density are plotted in Figure 6.

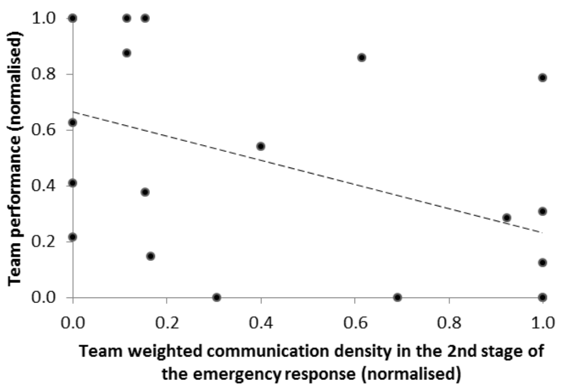


Figure 6: Weighted communication density and team performance (intermediate phase)

H2: Actors who coordinate more with other actors have a better actor performance.

Figure 7 shows the normalized weighted degree centrality – the indicator for the occurrence and duration of coordination – for all actors in relation to their performance. We found no statistically significant correlation. Being the centre point of the network does not yield better individual performance. Breaking up the exercise into three phases does not lead to refined conclusions. The hypothesis is rejected.

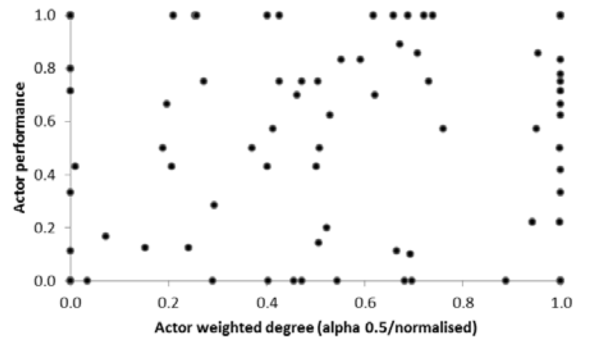


Figure 7 - Weigthed communication density of all actors in relation to their performance

Further analysis using advanced centrality measures yielded two significant results. The *in-degree* of emergency management actors during the *intermediate phase* of emergency response is positively and significantly correlated (.29**) to actor performance. The network graphs for the fire services (in Black) in the Tunnel evacuation scenario are presented in table 8. Network graphs in Figures 8 to 10 are based upon the weighted centrality of the actors, which means that the size of the nodes indicates the amount of actor communication. Network graphs in Figures 11 to 13 are based upon in-degree centrality. The larger the node, the more communication received by the actor and the higher the actor's status. The differences in results between weighted centrality and in-degree are striking. The fire services in Team One performed much better than those in the other teams.

There is also a significant correlation between the *weighted betweenness centrality* of actors and their performance (.27**). The network graphs for the medical services (in Black) based upon weighted degree centrality and weighted betweenness centrality in the Tunnel hazardous materials scenario are presented in table 9, with network graphs 14-16 indicating *weighted degree centrality* and Figure 17-19 indicating *weighted betweenness centrality*. Actors with a central position in the network have a higher betweenness centrality, indicated by a large node. Eccentric actors have no betweenness centrality and a small node.

Figure 8 - WST evacuation scenario, Team One: medium weighted degree centrality	Figure 9 - WST evacuation scenario, Team Two: high weighted degree centrality	Figure 10 - WST evacuation scenario, Team Three: low weighted degree centrality

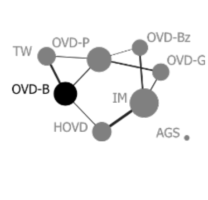
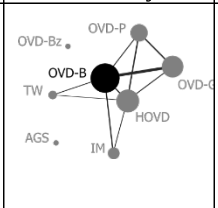
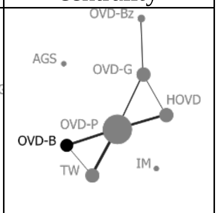

		

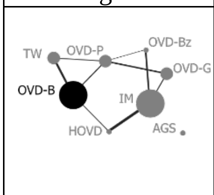
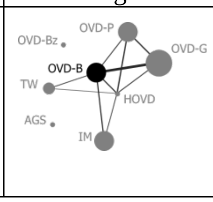
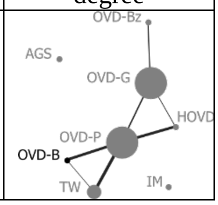
Figure 11 - WST evacuation scenario, Team One: high in-degree	Figure 12 - WST Evacuation scenario, Team Two: medium in-degree	Figure 13 - WST Evacuation scenario, Team Three: low in-degree
		

Table 8 - Network graphs of the fire services in the Tunnel Evacuation Scenario
(*Legend: AGS = advisor on hazardous materials, IM = information manager, HOVD = chief officer, OVD-B = fire services, OVD-Bz = municipality, OVD-G = medical emergency services, OVD-P = police, TW = tunnel operator*)

Visual comparison of the two types of centrality-based networks suggests a correlation between the two measures. This is confirmed statistically (.34**). The relation between *weighted betweenness* and non-weighted degree is even stronger (.54**). Taking into consideration that the weighted betweenness centrality was set at .5 (see above), the increase in correlation suggests that it is primarily the relation with an actor, and not the duration of the communication, that matters. The fact that *betweenness centrality* is positively and moderately correlated with actor performance indicates that it is the position of an actor in the network that is most important for this actor's performance.

Figure 14 - WST hazardous materials scenario, Team One: weighted degree centrality	Figure 15 - WST hazardous materials scenario, Team Two: weighted degree centrality	Figure 16 - WST hazardous materials scenario, Team Six: weighted degree centrality

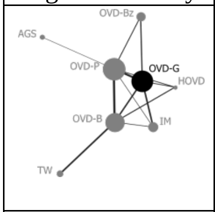
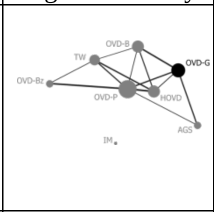
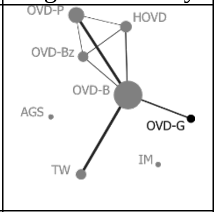

		

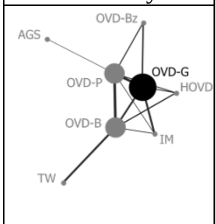
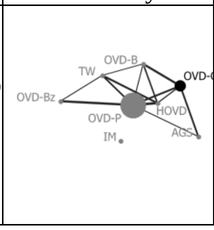
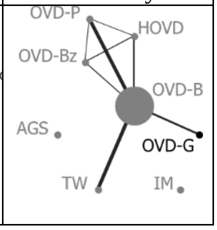
Figure 17 - WST hazardous materials scenario, Team One: weighted betweenness centrality	Figure 18 - WST hazardous materials scenario, Team Two: weighted betweenness centrality	Figure 19 - WST hazardous materials scenario, Team Six: weighted betweenness centrality
		

Table 9 - Network graphs for the medical services in the Tunnel Hazardous Materials Scenario
(*Legend: AGS = advisor on hazardous materials, IM = information manager, HOVD = chief officer, OVD-B = fire services, OVD-Bz = municipality, OVD-G = medical emergency services, OVD-P = police, TW = tunnel operator*)

5. DISCUSSION

Although the two main hypotheses are not substantiated, more in-depth analysis of the data yielded some interesting findings. The level of coordination in the intermediate phase of emergency response management seems to be determinant for the performance of an on-scene command team. This should be noted, since theory often suggests that the initial phase of an emergency is the most crucial. In contrast with expectations, less coordination, not more, during the intermediate phase, leads to better performance.

Another relevant finding is that advanced centrality measures (in-degree and weighted betweenness degree) are more useful in explaining actor performance than the more comprehensive degree indicators. It is not the overall amount of coordination in a team, but a few more complex traits of coordination that help us understand the differentiations in performance. Qualitative interpretation of the data seems necessary to understand why this is the case. However, for reasons of space, this challenge cannot be taken up in this publication.

The framework developed by Marks et al. (Marks, Mathieu, and Zaccaro 2001), which we adjusted for emergency management teams, proved useful as a starting point for understanding emergency management performance. Temporal differentiation seems to be relevant when trying to understand the relationship between coordination and emergency management performance. Decentralized coordination (network density, the advanced centrality indicators) is relevant to understanding performance. At the same time, we believe that the model needs to be further revised.

6. CONCLUSION

The core question of this study was: *How do on-scene command teams coordinate multidisciplinary objectives and procedures, and how does the way this is done determine their emergency management performance?* Our analysis led to four answers:

1. Emergency management performance and coordination patterns within and among on-scene command teams show wide variation.
2. Decentralized coordination is an important factor in emergency management performance.
3. Teams that use less coordination during the intermediate phase of emergency management perform significantly better.
4. Actors that have a central position in the network achieve their own goals better.

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