A dynamic perspective of emerging coordination clusters in crisis response networks

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ABSTRACT

Disasters and crisis create complex conditions that require intra-organizational and inter-organizational coordination throughout the duration of response operations. Emergency response plans and Incident Command Systems that are implemented at times of crisis are well defined on the intra-organizational level, following organization's own hierarchy and resources. However, in reality, units of different organizations behave differently as they form sub-networks to carry out tasks involved in response operations, despite differences in operating protocols and training background.

In this paper we introduce a novel approach to study crisis response networks: the emergence of coordination clusters. The results indicate resilience in the behavior of response units from different organizations as they re-organize into coordination clusters and collectively respond to the unfolding emergency events. Understanding characteristics of coordination clusters helps to identify critical tasks and units beside resources required during emergency response operations. Our results contribute to the continuous change in the concepts of crisis response management and the shift towards a network and function based response protocols.

Keywords

Crisis management, response operations, coordination clusters, complex networks.

INTRODUCTION

Disasters represent a disruption to the routine of society; and responding to it involves high levels of uncertainty and complexity. The complex conditions apply stress on public and private organizations in the society and require prompt reaction to safe lives and limit casualties (Dynes & Aguirre, 1979; Bram & Vestergran, 2012). Disaster response operations are the product of collaborative work carried out by different organizations to cope with complex conditions that usually accompany disasters. To understand dynamics of response operations, we need to look at response system as a *network-governed* structure, where all members work towards shared goals, responsibilities and unified action to produce a common outcome (Kapucu, 2005; Moynihan, 2009; Abbasi & Kapucu, 2012; Kapucu & Garayev, 2013).

Network governance structures can take different forms that vary from lead-organization governed, participant led and network administrative organizations (Provan & Kenis, 2008). A network administrative organization is a separate administrative entity is set up specifically to govern the network and its activities (Moynihan, 2009). The latter form is most prominently recognized in crisis management as an "Incident Command System" (ICS) (Boersma, Comfort, Groenendaal & Wolbers, 2014). ICS consists of a number of mandates and protocols describing communication and coordination between response organizations (Bigley & Roberts, 2001). ICS is

the "standard operating procedure" that is used in management and training for crisis response and is often used in military or other formalized institutions, to facilitate collaboration among different actors in a response group.

However, such highly hierarchical arrangements of organizational collaboration frameworks have proven to fail in several occasions (Comfort, 2007; Kapucu, 2009). Coordination during crisis response does not depend on command system alone, but relies upon *networked coordination*. Recent studies focus on the factors underlying the effectiveness network dynamics (Kapucu, 2009; Kapucu 2005; Kapucu, 2009; Moynihan, 2009; Hossain & Kuti, 2010; Kapucu, Bryer, Garayev & Arslan, 2010; Vasavada, 2013). The common method in this work is adoption of Social Network Analysis (SNA) to study the coordination and governance structure in response systems. In these studies SNA techniques were used to explain information flow and decision-making in response operations.

Yet, the above studies are based upon reconstructions of the overall networked relations in course of the entire response operation. This provides a static view of crisis response networks. In order to understand network dynamics it is imperative to include the time element to have a full understanding of response operations' evolution (Wolbers, Groenewegen, Molle & Bim, 2013). This is also argued by Lanham, Morgan & Carley, (2014), who combined time analysis and agent based modeling to understand the development of organizational relations during response operations.

Building on these studies, we conducted a time based analysis in combination with community detection in complex networks techniques to examine coordination processes in crisis response operations. In addition, we had to identify a tool to extract coordination specifics in such complex response operation, for which we used coordination theory as a framework to define landscape and explore the boundaries of the coordination processes (Malone & Crowston, 1990; Malone & Crowston, 1994). For this paper, we looked at two different examples of crisis response operations, the Elbe River 2002 flood in Germany and Schiphol Tunnel 2009 Fire in the Netherlands. The results presented in this paper showed a constant pattern of emerging coordination clusters throughout the response operation that is governed by the emerging demands of the emergency situation. Such findings help advance our understanding for coordination dynamics among different organizations in unstable environments and complex situations of a crisis.

CLUSTERING IN DISASTER RESPONSE NETWORKS

In the event of emergencies and disasters, small and large-scale organizations collectively coordinate efforts to handle unfolding disaster events. Interorganizational coordination becomes a critical factor to the success or the failure of response operations (Hossain & Kuti, 2010; Kapucu, Bryer, Garayev & Arslan, 2010). The wide spectrum of parties involved in response operations, from macro institutions to micro individual, creates a set of complex relationships that needs to be identified and different contributions need to be mapped and measured (Kapucu, 2005; O'Sullivan, Kuziemsky, Toal-Sullivan & Corneil, 2013). The disruptive nature of disasters forces high levels of uncertainty, such conditions require a dynamic response and an adaptive organizational structure to cope with the intense changes resulted from those disruptions (Dynes & Aguirre, 1979; Kapucu, 2009; Topper & Lagadec, 2013). Therefore, throughout the course of disaster response operations, different network structures emerge at different levels of interactions inside the overall response network.

An important factor to depict the structure in a network is based on assessing its level and form of clustering. The importance of emerging coordination clusters in response operations has been recognized by several scholars (Curtis, Topper & Carley, 1999; Comfort & Haase, 2006; Butts, Acton & Marcum, 2012). Clusters form emerging structures in response to the escalating series of disaster events and the availability of resources, such as personnel, equipment, supplies, and funds. These structures are dynamic in nature and change rapidly throughout the disaster evolution. This results in different subset of the network focusing on different tasks. Over the course of time this leads to a different information position in the network, which is related to incident location, number of victims or incident severity.

This forms the basis for our analysis where we applied coordination as a framework to identify organizations involved, activities coordinated, and distinguish the dependencies between actions and tasks required to achieve common goals (Crowston, Rubleske & Howison, 2006). Examples of such dependencies in the response operations are: sharing resources like rescue crews, vehicles, equipment, use of public spaces to evacuate affected individuals and others.

METHOD

This research utilizes data from the content analysis of police reports, official evaluation reports, press releases and news clippings of two emergency events occurred in Germany and Netherlands: the Elbe river flood 2002 and the Schiphol tunnel fire 2009.

The Elbe flood was considered one of the major disasters in Europe; it involved organizations on different levels (local, regional, national and international) due to the large scale of the disaster. The Elbe flood lasted for over 14 days and the damages covered many areas in the province of Saxony. Dresden was among the mainly damaged cities where water levels were as high as 9 meters, which was the highest since 1845. Main organizations engaged in the response were the German Armed Forces, Police, Fire Fighters and several NGO's.

On the other hand, the Schiphol tunnel fire incident involved the basic 112 (911 in North America) first responder forces such police, paramedics, and fire fighters (Boersma, Passenier, Mollee & Van der Wal, 2012). However, due to the location of Schiphol fire near Schiphol Airport; local and federal authorities were involved in the response, in addition to the airport and railway authorities. An example, there were fire engines from both Haarlemmermeer municipality and Schiphol Airport. The incident took around 1 hour and 30 min in total.

To study the dynamic nature of the coordination clusters, we used Complex Networks Clustering to construct the networks of the response operations over the time period of the crisis. To assess the nature of clustering, we extracted information about tasks and dependencies in the response operations. The result was a "Coordination Matrix", as shown in Table (1). We constructed coordination matrices based on N number of time slices (T1, T2, …, TN) over the duration of response operations. The size of Tx depends on details extracted from the data for each case. Therefore, Tx can be a day, an hour or number of minutes. The matrix itself contains information about each organization was engaged in the response at Tx, details about resources contributed and tasks carried out either separately or in collaboration with other organizations. Example of that the time slice for Schiphol fire is 15 min and for Elbe flood is 24 hours.

Time	Organization	# Of Units	Resources	Actions
Tx	Army	X Units	Soldiers, helicopters	*Establish C2 for regional level * Evacuation operation w/ local police
	Police	Y squads	Policemen, specialized units	*Search and rescue w/ Fire Fighters, NGO
	NGO	Z units	Experts from different backgrounds	*Evacuate people *Cleaning roads

Table 1. Example of Coordination Matrix for time slice Tx.

The next step to understand the emerging structure of coordination clusters was to apply Louvain community detection algorithm (Blondel, Guillaume, Lambiotte & Lefebvre, 2008) to extract coordination clusters in the response networks. The Louvain algorithm uses modularity to detect clusters, where modularity is a scalar value between -1 and 1 that measures the density of links inside a community recursively. Louvain method produced better quality cluster than other algorithms because it is based on optimizing modularity and compares local clusters to the global network.

RESULTS

The collected data were analyzed using Pajek software (version 4.04, http://mrvar.fdv.uni-lj.si/pajek/). For each Tx we constructed the response network, and subsequently used Louvain community detection to extract coordination clusters. Figure (1) represents the evolution of coordination clusters in the Schiphol tunnel network at T0 (0-15min) and T1 (16-30min). It shows several clusters that take on different areas of operations, such as railway administration, railway technical operations, fire extermination, and providing security & safety. In Figure (1-a), we see four clusters forming with different tasks like fire investigation by fire fighters in fire extermination cluster or securing airport perimeter by the Dutch Royal Police (KMar_O) in security & safety cluster. In figure (1-b), we see the emergence of different functional clusters, new actors' engagement, and redistribution of actors within the coordination clusters. For example, the Dutch Royal Police moved from the security and safety operations cluster (at T0) to the platform evacuation cluster (at T1). This indicates that based on the activities response organizations undertake, new interaction moments emerge over time. Actors in the coordination clusters thus change position over time, and nodes are constantly repositioned in the network. In addition, as new developments occur, also new actors are involved in the network. An example is the National Railway Passenger service (NS_Passengers) who assisted in the platform evacuation cluster at T1.

We witness similar clustering formation patterns in the more complex case of the 2002 Elbe flood response network. For example, in Figure (2-a) we see formation of a high number of clusters involved in dike enforcement at T0, which reflects a requirement of several similar tasks in the affected areas around Saxony. At T1, water levels had risen to unexpected levels that introduced new tasks like search and rescue, evacuation beside dike enforcement. Therefore, in Figure (2-b) the number of clusters increased sharply due to the rapid expansion of the flooded areas in Saxony. The increase in clusters highlights the segmentation in the network, which is making it more difficult to achieve an integrated response coordination. In fact, it indicates that integration across the clusters is increasingly difficult to achieve when the number of actors and tasks in the response operation expands. Another dynamic that influences the formation of the clusters is the activation of formal incident command structures. This is visible at T1 when the regional catastrophe status was declared, which called new forces and organizations to the scene, such as Federal Police and German Red Cross.

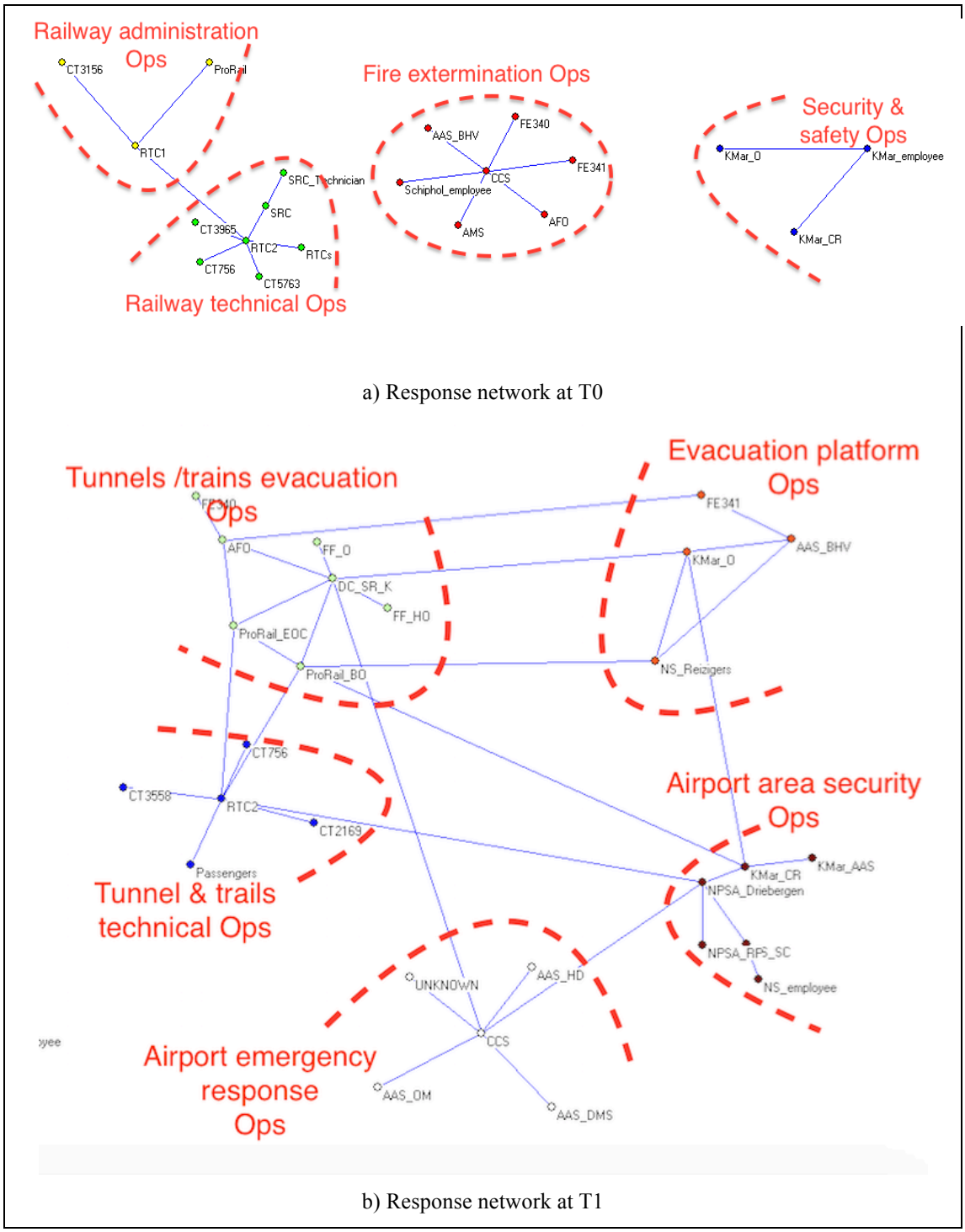
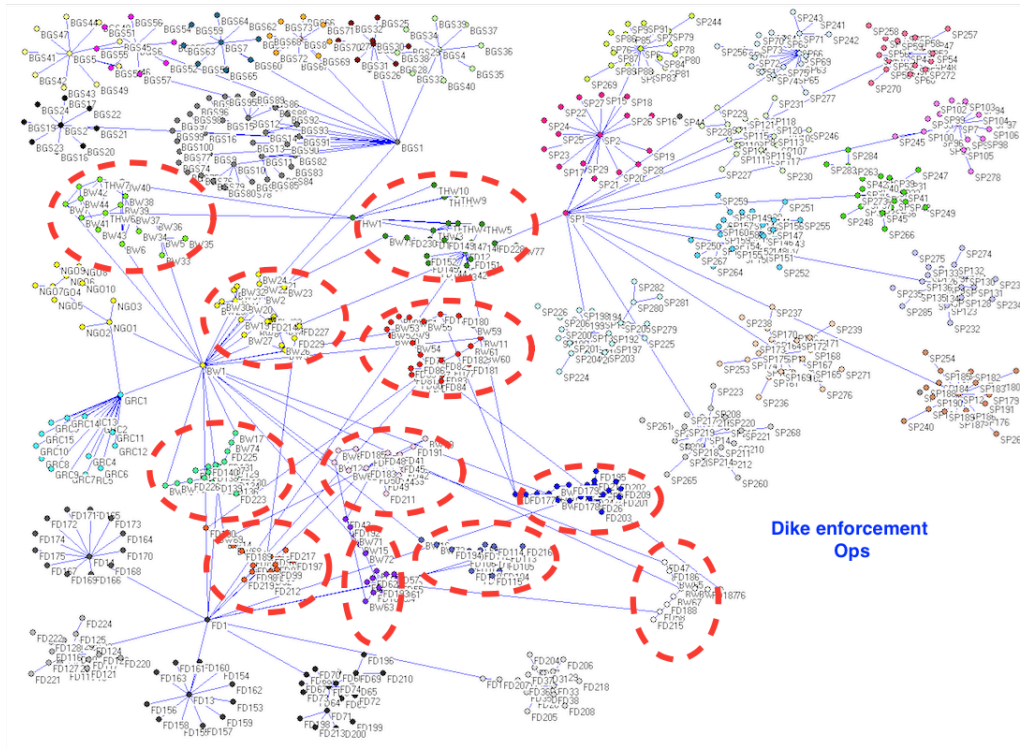
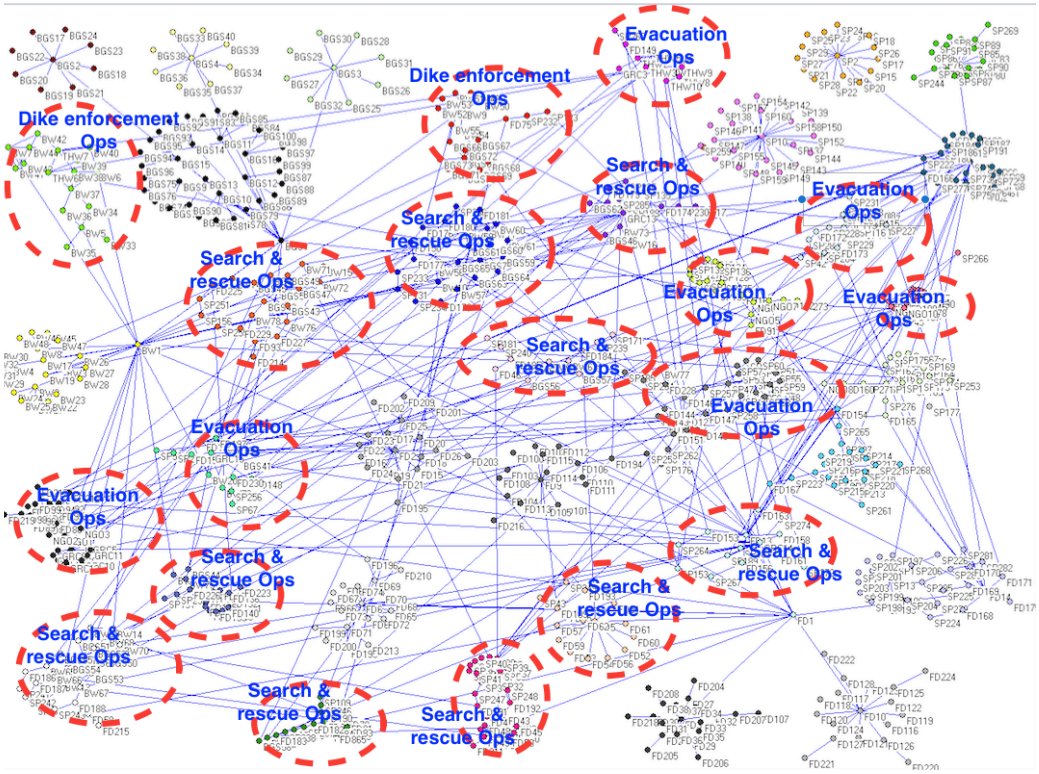


Figure 1 Coordination clusters of the Schiphol tunnel fire response network



a) Response network at T0



b) Response network at T1

Figure 2 Coordination clusters of the Elbe river flood response network

Besides the clustering itself, another measure of coordination evolution is the change in the centrality of nodes in response operation while they move across the clusters. As emergency response networks evolve, the position of nodes changes by gaining more central position, or by moving to the periphery of the network (Topper & Carley, 1999). We computed centrality values to examine the evolution of influential nodes in the coordination clusters. In figure (3) we can see changes in values of nodes' centrality as they switch clusters, which reflect the change in functionality/task carried out by those nodes. Most clusters contained at least one influential node that played a crucial role as information hub to relay information or commands to units from same organization or other organizations in clusters. The Military Police (KMar_O) is an example where its centrality changed from 1 at T0 to 4 at T1 due to the change of tasks required and engagement of new actors. Also the Schiphol Airport's internal safety team node (AAS_BHV) switches from the Fire Operations cluster to the evacuation cluster, thereby increasing its centrality. The same pattern of centrality changes was observed in the Elbe Flood response network where units from Saxon Police (SP) and Fire Fighters (FD) changed roles between T0 to T1 as they moved between "dike enforcement" clusters to "Search and Rescue" or "Evacuation" clusters.

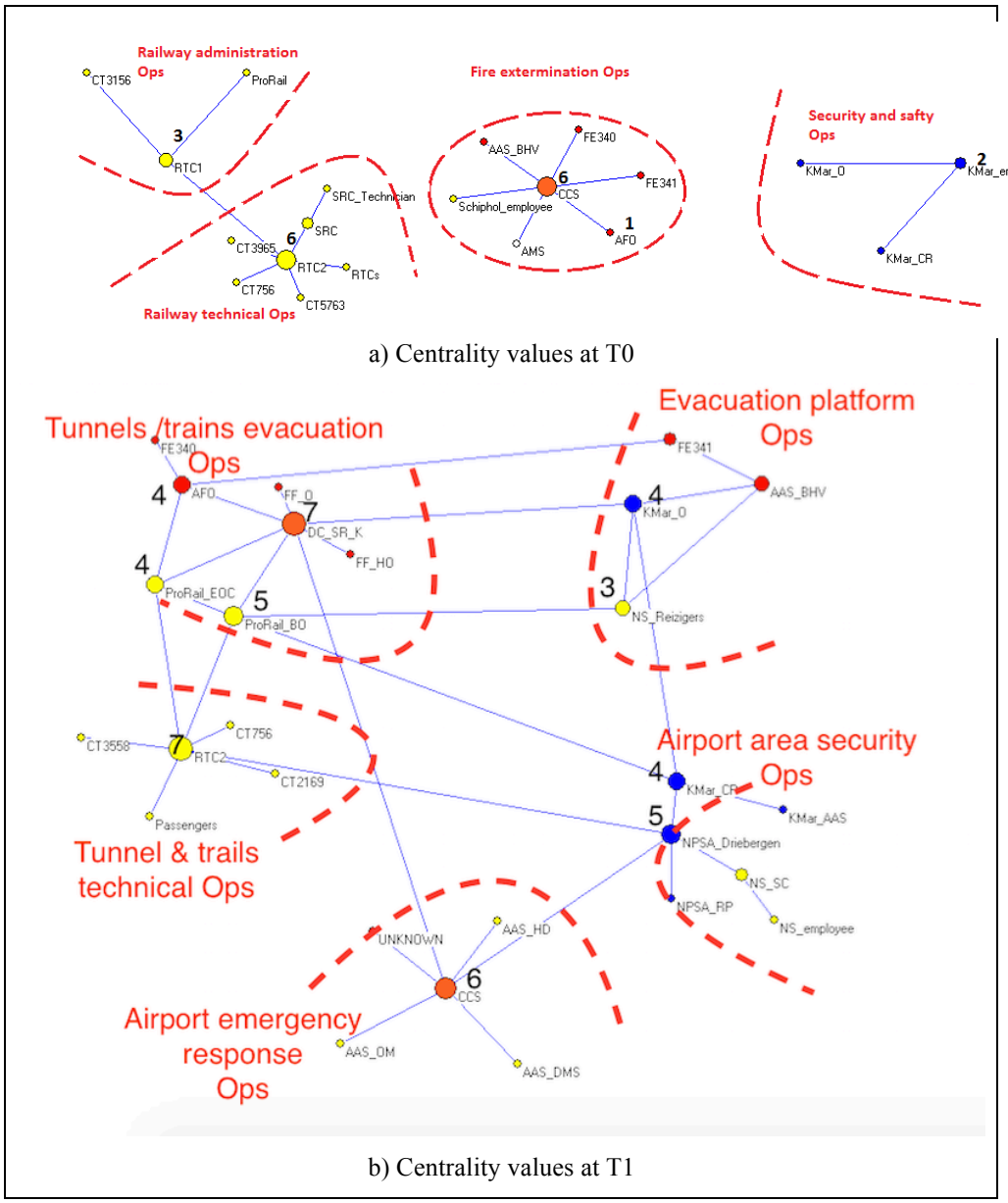


Figure 3 Influential nodes for Schiphol tunnel fire response network.

DISCUSSION

Our analysis shows that network *coordination clustering* is a crucial dynamic during incident response. Clusters form emergently based on the different task and resources that develop in the network. Important to notice is that as a result of this dynamic, the cluster formation does not necessarily move along the lines of formal Incident Command Systems. It has a more adaptive nature, which is based one emerging interdependencies between the organizations and the contingencies of the disaster. For instance, in the Schiphol tunnel case the quick evacuation of the tunnel required additional coordination between fire department and railways actors. This requires increased connectivity between these clusters. Also in the case of the Elbe flood the developments in the disaster itself required a change from evacuation towards search and rescue, which necessitates increased connectivity.

This outcome teaches us that in terms of network dynamics it is far more important to look at the capacity to increase connectivity *to switch* between the clusters (Boersma, Fergusson, Groenewegen & Wolbers, 2014). Switching is a term introduced by Castells (1996), which conceptualizes *"the ability to connect and ensure the cooperation of different networks by sharing common goals and combining resources"* (Castells, 2009: 45). Enhanced networked response capacity thus lies in the alteration between different sub-networks. Future research is required to explore how these interconnection develop and in practical sense how emergency responders can recognize and steer upon these networked coordination dynamics.

CONCLUSION

In our examples of response networks, we observed a consistent pattern of emerging coordination clusters based on tasks required at a certain point of time during response operations. Despite the diversified background of units involved, the results showed resilience in the behavior of response networks as they self-organize into function based clusters. The clusters' formation comes in response to the unfolding crisis events not purely following the rigid ICS plans. In both examples, the protocols (or ICS) became a distraction and imposed significant delays sometimes. The Elbe flood is an example of that where emergency state declaration were delayed for 24 hours which caused delays to dispatch more response units, therefore, existing fire fighters and army units had to cope with this situation till other organizations (such as Federal Police) or more units were allowed to join.

In conclusion, despite the unpredictable conditions of emergencies that can paralyze well-structured response procedures, units involved in crisis response are capable to reconfigure themselves to create new ties with other units to response to critical events. The adaptive behavior of coordination clusters proves a great deal of resilience in the networks behavior compared to the classical command and control ICS. The question of how to map and analyze the emergence of clusters and their consequent coordination dynamics, and thereby help create flexible response plans, stays open to future research.

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