Coordination Dynamics in Disaster Response Operations: A Network Based Discrete Event Analysis

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3 Research Design

In this chapter we address details of the research method adopted to examine the phenomenon of interorganizational coordination in disaster response networks. The research method is not a mere group of theories and tools used to study a phenomenon. A research method represents a framework and a guideline, which is crafted carefully to investigate phenomena to help in advancing human knowledge. While the literature review provides the solid ground for conducting scientific research, the research method is the vehicle, which enables the conduct of sound and credible research.

Moving forward, this chapter starts with introducing the reasoning behind the proposed research approach in the *Research Rational* section to examine the phenomenon at hand; that is, interorganizational coordination in disaster response networks. Afterwards, stages of the research method are discussed in the *Research Method* section where details regarding the mixed methods approach and tools will be covered. Finally the *Data Collections* and *Unit of Analysis* sections will focus on presenting methods used to collect data considering a mixed methods approach and the units of analysis used in this research.

3.1 Research Rationale

This section we provide a personal reflection of the researcher upon the research problem and the proposed solution to the problem. This section may therefore be less formal than the rest of this document. As a researcher, I am influenced by my background training in electrical and computer systems engineering where processes and events are controlled by laws of physics and operate with precision. Consequently, the path taken in order to examine the research problem was biased towards finding a systematic approach to analyze coordination dynamics and to seek a solution based on dissecting the problem and framing the situation in the form of a modular system that can be studied properly. In addition to my scientific background, being the survivor of three wars (Iran-Iraq War of 1980-1988, First Gulf War of 1991, and Second Gulf War of 2003), as well as embarking upon an international career in co-managing a business in personal protection operations in post-war Iraq, had created a unique combination of scientific training, national experience and personal passion to pursue more seriously the subject of disaster and crisis management.

As a result, one of the theories chosen was *Coordination Theory* by Malone and Crowston (1990 and 1994) and its applications in computer science and economics (Bailetti & Callahan, 1993; Crowston et al., 2006). Coordination theory presented a logical fit to examine the issues related to interorganizational coordination in disaster response operations. Coordination theory offered a framework to decompose the whole operations to sub-systems and thereafter define the scope of the problem in coordination tasks and dependencies in a disaster response event. The next logical step to analyze the coordination in response operations was to include the time factor in the study teams involved in those operations.

Time is a crucial element of study in the dynamic aspects of coordination among different actors engaged in response operations. Beside the time factor, those teams collaborated inside temporary systems that would come together and dissolve according to the unexpected needs of a disaster event. The systems involved heterogeneous groups of actors (or teams) that congregated to work together in order to achieve a common goal. Such characteristics led to describe these emerging systems as networks. Consequently, a new requirement emerged in order to investigate the relationships, information exchanged, actions propagated and decisions made in those disaster response network settings.

So came the choice of techniques such as *SNA, DNA* and *Complex Network Analysis* as a proper tool to understand the behavior of those emerging networks in disaster response operations. Concepts such as random growing networks, strategic network formation and diffusion and decision making in networks modeling; were used in social science and economic to study relationships, formation of political alliances, market trading, idea generation and innovation, disease outbreaks and information diffusion (Jackson, 2008a). Therefore, network analysis techniques offered a valuable tool to use in analyzing the data of coordination teams in response networks. Nonetheless, SNA approach is not novel to the disaster and crisis management field and it was adopted by a number of scholars to study governance and coordination (Kapucu, 2009; Moynihan, 2009; Abbasi & Kapucu, 2012; Vasavada, 2013; Lanham et al., 2014).

With *coordination theory* and *network analysis techniques*, a static perspective of the response operations was constructed but the analysis so far lacked the dynamic element in it. Thereupon, the utilization of *Discrete Events Systems,* DES, represented a logical option due to the following;

- The unpredictable nature of disasters themselves made them similar to event based systems rather than time based systems and
- The DES- Petri Nets properties to model processes with multiple actors and resources with the *colored Petri Nets* and to model nested processes with *hierarchical Petri Nets* was a perfect fit to model the flow of coordination in response operations.

In summary, the combination of theories and tools we used produced an integrated framework to study coordination dynamics in disaster response networks and provide a dynamic perspective of the evolution of those operations through the duration of the disaster event. The results are considered a valuable asset to investigate and evaluate disaster response operations that could potentially contribute to improve existing systems and help learn from past experiences.

3.2 Research Method

As it was mentioned earlier, a research method is the framework to conduct a scientific research. The focus in this section is to describe the stages of research framework that guided processes such as data collection, data analysis, case study selection and other choices made to examine the phenomenon at hand. The problem that is addressed in this research, coordination evolution in disaster response networks, inherits the complexity of the phenomenon itself. Examining the coordination dynamics in disaster response operations involves a number of variables including the human factor, resources, ethics, authority, trust, coordination and the unpredictable discourse of the disaster events themselves. Consequently, the choice of using a mixed methods research approach was made to tackle the complexity of such problem, (Johnson & Onwuegbuzie, 2004; Johnson, Onwuegbuzie & Turner, 2007; Creswell, 2013). Using the mixed methods approach offered the ability to combine both qualitative and quantitative techniques for the processes of data collection and data analysis to study the phenomenon of coordination dynamics in disaster response operations.

In Section 1.5, we described briefly the three stages of the research method. In Figure 33, we illustrate a representation of the research method stages.

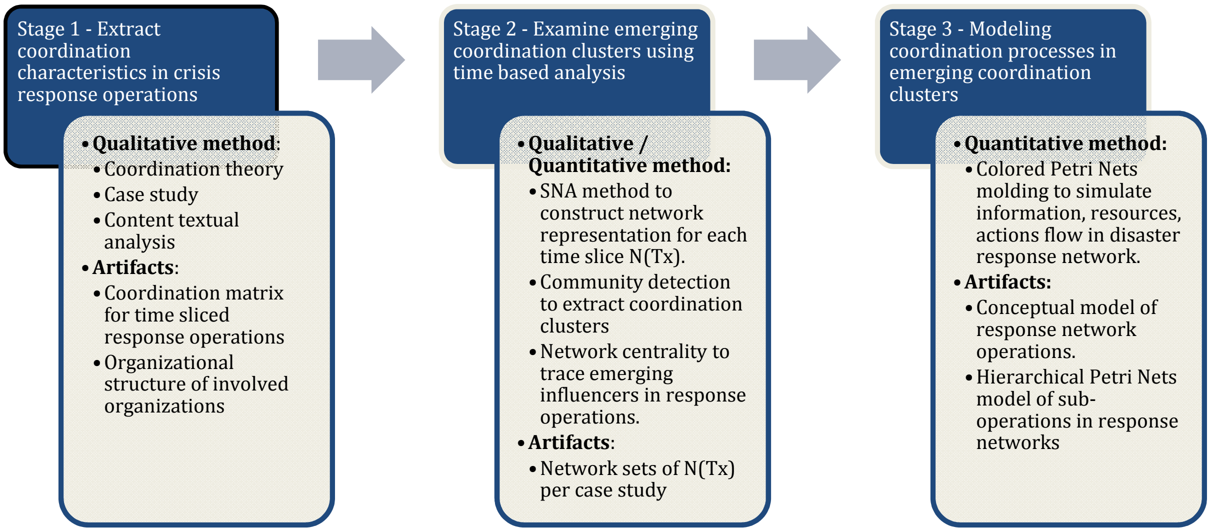

Figure 33. Three stages of the research method.

The *research method* consists of three stages: 1) qualitative stage where case study and textual analysis methods were applied for data collection and coordinating theory was adopted as a framework for data analysis; 2) qualitative/quantitative stage where SNA was used to collect and visualize the data and community detection techniques were used to analyze the data; and 3) quantitative stage where the outcome of SNA and community detection used to collect data and *colored* and *hierarchical* Petri Nets were used to analyze coordination processes in response networks. In the up coming sections we are going to discuss the details of the different stages of the research method.

3.2.1 Stage 1 - Coordination Characteristics in Disaster Response Operations

One of the lessons learned from reviewing literature on disaster management research was the research strategy. In the case of qualitative studies on disaster management, researchers often adopted a single or multiple case study method to examine different phenomena including disaster response networks (Bigley & Roberts, 2001; Comfort, Dunn, Skertich, Zagorecki, 2004; Comfort & Haase, 2006a; Comfort & Kapucu, 2006b; Kapucu, 2009; Moynihan, 2009; Bharosa, 2011; Abbasi & Kapucu, 2012; Vasavada, 2013; Lanham et al., 2014). For that reason we adopted a similar approach inspired by case study method (Eisenhardt; 1989; Yin, 2003; Gerring 2007, Baxte & Jack, 2008) as a framework for conducting Stage 1 of this research. Since, Stage 1 represents the qualitative phase of the overall research framework, we apply the case study method as a guideline for case selection, data sources and data triangulation.

Still within Stage 1, in order to extract coordination specifics, and following several studies, a *content textual analysis* method was conducted over data gathered from the selected case studies. (Bailetti, Callahan, DiPietro, 1994; Heath & Staudenmayer, 2000; Shen &Shaw, 2004; Huang, & Zhou, 2005; Arshinder, Kanda, Deshmukh, 2011).

The process of extracting coordination specifics (i.e. action, actors, resource, and dependencies) were based on a combination of coordination theory by Crowston & Malone (1994) and the framework (see Table 9) by Shen and Shaw (2004). Thus far, coordination theory framework was applied to analyze coordination actions "between" and "within" actors, processes and organizations by outlining the types of dependencies involved with achieving a certain goal within certain context. In Table 9 is an illustration of a number of dependencies examples identified by Crowston and Malone (1994).

Dependency	Example of coordination process for managing dependency
Shared resources	"First come/ First serve" priority order, budgets, managerial decision, market-like bidding
Task assignment	(Same as shared resources)
Producer/ consumer relationships	(Left empty in the original table)
Prerequisites constraints	Notification, sequencing, tracking
Transfer	Inventory management (e.g. "Just In Time", "Economic Order Quantity")
Usability	Standardization, ask users, participatory design
Design for manufacturing	Concurrent engineering
Simultaneity constraints	Scheduling, synchronization
Task/subtask	Goal selection, task decomposition

* Adopted from Malone, T. W. and Crowston, K. (1994) The Interdisciplinary study of coordination. ACM Computing Surveys (CSUR), 26(1): 87-119.

Table 9. Examples of common dependencies between activities.

The categorization process of dependencies was based on Shen and Shaw (2004) framework as shown in Table 10. That process was applied to identify the links between different parties involved in response operations and resources required in such operations.

Generic Dependency	Specific Dependency		
	Activity-Actor	Activity-Activity	Actor-Actor
Sharing	Task assignment	Activities must happen simultaneously	Response personnel share a common source
Flow	Delegation of agent to tasks	Prerequisite tasks	Sequence activities → local, regional, federal activities
Fit	Agents must be capable to perform a task	Activities interact or have counter effects	Agents must have compatible goals

Table 10. Dependencies categorization in disaster response systems.

*An adaptation of the coordination mechanisms by Shen and Shaw (2004)

In Table 10, there are three generic types of dependencies that can involve different combinations of an activity and an actor. First, *sharing* implies the ability to share resources, activities happening at the same time. Second, by delegating tasks we can see a *flow* type of dependency where some inputs are expected from previous stages in the coordination process. Third, a tailored task that must *fit* the owner task owner describes the last type of dependency.

An example of extracting and categorizing coordination specifics can be the dike enforcement task during flood response operations. The operation involves personnel from army forces and Fire Departments, where the organization is identified as an actor and the number of units is identified as resources. In addition to the personnel, the sand bags supplied by both parties are recognized as resources. The mechanisms of coordination used in this case is sharing and flow because both participating actors shared resources and delegated tasks that they are familiar with. For further details, in Appendix A we provide an example of profiles of organizations engaged in the response operation with some example text of collaboration incidents with details of resources used in the operations.

Afterwards, the outcome of the textual analysis is organized based on the time of events took place (e.g. alert announcement, dispatch units, transport victims, etc.). With the information extracted about tasks and dependencies in the response operations, a *Coordination Matrix* (as shown in Table 11) is constructed. The coordination matrix contains information about each organization was engaged in the response at certain time, details about resources contributed and tasks carried out either separately or in collaboration with other organizations.

Time	Actor	# Of Units	Resources	Tasks
Tx (e.g. Day 1)	Organization A	X units	Soldiers, helicopters	*Establish C2 for regional level * Evacuation operation w/ local police
	Organization B	Y Units	Policemen	*Search and rescue w/ Fire Fighters, NGO
	Organization C	Z Units	Experts	*Evacuate people *Cleaning roads

Table 11. Example of a Coordination Matrix for time slice Tx.

Each coordination matrix is associated with a time-stamp and the length of the time slot depends on details provided in the contents. A series of coordination matrices are organized chronologically over the duration of the incident to create dynamic view of the evolution of coordination within the response operations. The results of that process can be described as a series of snapshots of coordination matrices over the duration of the disaster response operations.

The outcome of Stage 1 represents the first step of building a dynamic perspective of the coordination evolution in disaster response networks. Moreover, we extended the coordination theory framework to include the time factor where we organize the information based on time slices. Depending on each case study, we defined a fixed time slice to analyze the response operations and construct the associated coordination matrix. This process allowed us to have an outlook of the coordination evolution in response operations.

At the same time, necessary information was extracted to construct a detailed profile for each organization participated in the response operation. The organization profile contained the following items: Organization structure, operating procedures, tasks performed routinely, planned duties in case of disaster response, collaboration examples, units distribution. Details of organizations engaged in the Elbe River Flood in 2002 are in Appendix A.

3.2.2 Stage 2 - Emerging Coordination-Clusters Using Time-Based Analysis

In Stage 1 we performed the first step towards constricting a methodology to study the evolution of coordination in disaster response networks. Following the qualitative nature of Stage 1, the case study approach was applied for gathering data and selecting cases. A combination of textual analysis, coordination theory and its derivatives was applied to analyze data for the purpose of extracting coordination specifics were designed and tailored to fit within the purpose of this research. With the outcome of Stage 1 we move to the next stage where we utilize the coordination matrices data to construct a network perspective of disaster response operations.

Stage 2 is considered a transition stage between the qualitative phase and the quantitative phase of this research. Based on the literature review, researchers had adopted a qualitative approach (such as case study methods, interviews, and observations) and quantities approach (such as surveys) in conducting SNA (Edwards, 2010). In sections 2.1.3, 2.2.2, and 2.2.3 that SNA is used as a methodology to study the composition (and a tool to visualize the relationships) of organizational networks (Borgatti & Everett, 2000; Bonacich, 2007; Jackson, 2008a & 2008b). Examination and analysis of a whole organizational network facilitates the understanding of the structure and the formation of interorganizational relationships between the nodes (organizations) and formations of their links (Zaheer, Gözübüyük, Milanov, 2010). In this stage, SNA was used to construct and visualize the hierarchical structure of the various organizations engaged in the response operations. An example of creating the organizational network of a member in the response operations is illustrated in Figure 35. The network is based on the distribution of the units listed in Table 12 and Figure 34.

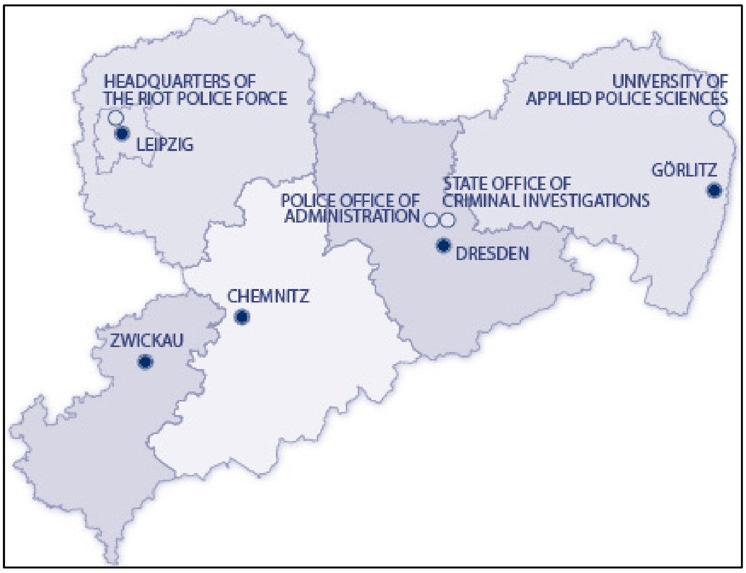

Figure 34. The police districts in Saxony.
*Retrieved from (https://www.polizei.sachsen.de/eng/3571.htm)

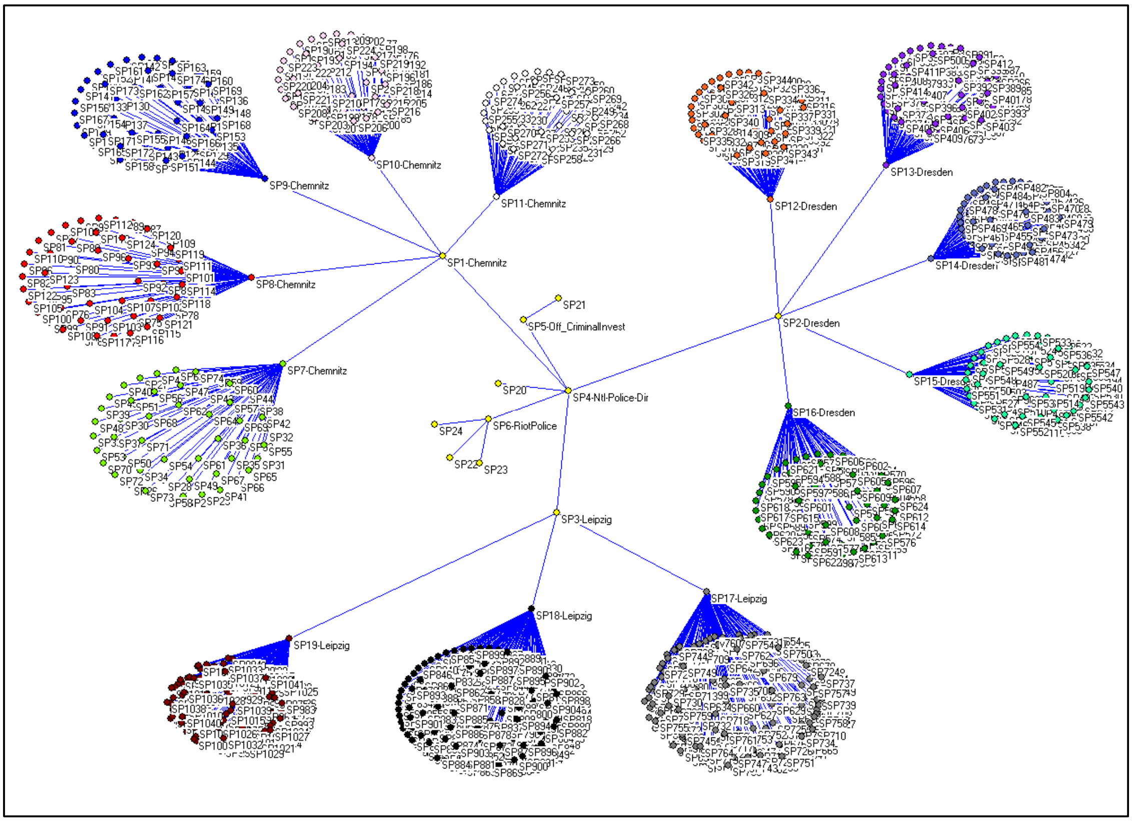

Figure 35. Network representation of Saxon Police hierarchy in Saxony.
*Network was created using Pajek Software

No.	Function	Node code
0	Based on the report, regional offices involved are, • Chemnitz • Dresden • Leipzig Other offices or units are, • National Police Directorate of Central Service • Bureau of Riot Police • Office of Criminal Investigation Total count of persons involved is 12,500 Total number of squads is 1041 based on 12 persons per squad.	SP1 Chemnitz SP2 Dresden SP3 Leipzig SP4 National Police Directorate of Central Services SP5 Office of Criminal Investigation SP6 Bureau of riot police
1	Chemnitz *Population* 259245, *area 220.84*km2	SP1 5 units SP7-SP11, sub HQ 250 units SP7 50 units SP8 50 units SP9 50 units SP10 50 units SP11 50 units
2	Dresden *Population* 477800, *area 328.8*km2	SP2 5 units SP12- SP16, sub HQ 350 units SP12 70 units SP13 70 units SP14 70 units SP15 70 units SP16 70 units
3	Leipzig *Population* 493600, *area 297.36*km2	Sp3 3 units, sub HQ SP17-SP19 417 units SP17 140 SP18 140 SP19 137
4	National Police Directorate of Central Services	SP4 1 unit SP20
5	Office of Criminal Investigation	SP5 1 unit SP21
6	Bureau of riot police	SP6 3 units SP22-SP24

Table 12. Distribution of the Saxon Police units at the different districts in Saxony.

With properties such degree of centrality, betweenness, and cliques, we were able to examine network members that are most or least beneficial to the network members, locate that nodes are most influential in the network, and finally the changes in the organization or unit position can influence the network. Figure 36 shows an example of degree of centrality visualized in a response network from the Elbe River Flood 2002 case study.

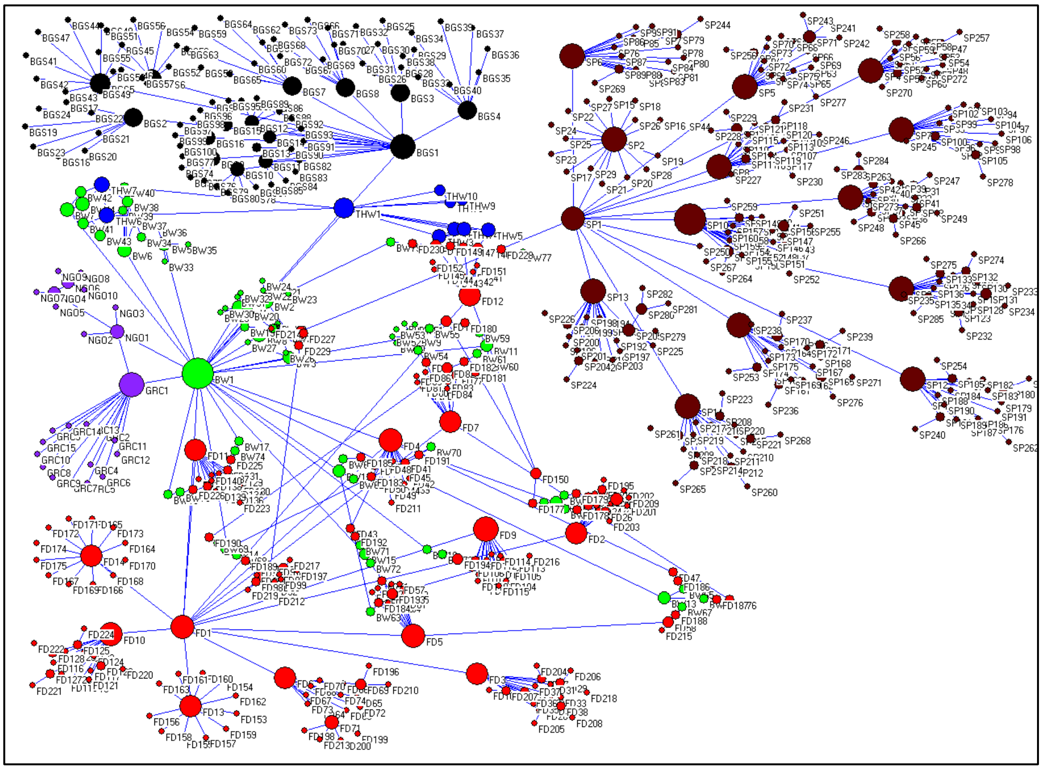

Figure 36. Response network from the Elbe River Flood 2002 with degree of centrality illustrated.

Further more, the SNA provided a vehicle to transform the qualitative outcomes (i.e. coordination matrix) from Stage 1 to a quantifiable data set and enabled a representation of the emerging relationships in the response operations.

In order to create and visualize and perform the different types of analysis on the data extracted from the response, we used a freely available software package that is called Pajek that is widely adopted to perform complex network on large networks (Škerlavaj, Dimovski, Mrvar, Pahor, 2010; Mrvar & Batagelj, 2016; da Silva, de Brito, Vijaykumar, da Rocha, de Abreu Monteiro, Costa, Francês, 2016).

We used Pajek Software to create and visualize the networks of the response operations. The Pajek software is a freely available software package for large complex networks (http://vlado.fmf.uni-lj.si/pub/networks/pajek/). In addition to visualization, Pajek contains a wide selection of network analysis tools that we used in our analysis such as calculating degree of centrality, betweeness, closeness, and clustering coefficients

In the case of analyzing data associated with the coordination-clusters, the Louvain method was applied using Pajek software as well. As it was mentioned that Louvain method is based on the Greedy algorithm and a graph modularity optimization (Blondel, Guillaume, Lambiotte, Lefebvr, 2008). The Louvain method is based on detecting clusters and optimizing the modularity values for a network partition locally. Afterwards, a new network is build out of the clusters detected. This approach also helps in realizing the clusters hierarchy is any. Further more, the Pajek software offers the ability to control granularity of the clusters by adjusting a *Resolution Factor* where the a value of 1 represents a standard Louvain Method and the higher the factor value the higher the number of communities and vice versa.

Figure 37, was created using Pajek software to represent the response network corresponding to coordination matrix of Day 1 (see Table 34 in Appendix B) of the Elbe River Flood 2002 case study. The network shown in Figure 37 is a result of applying the Louvain method with a resolution value of 1.

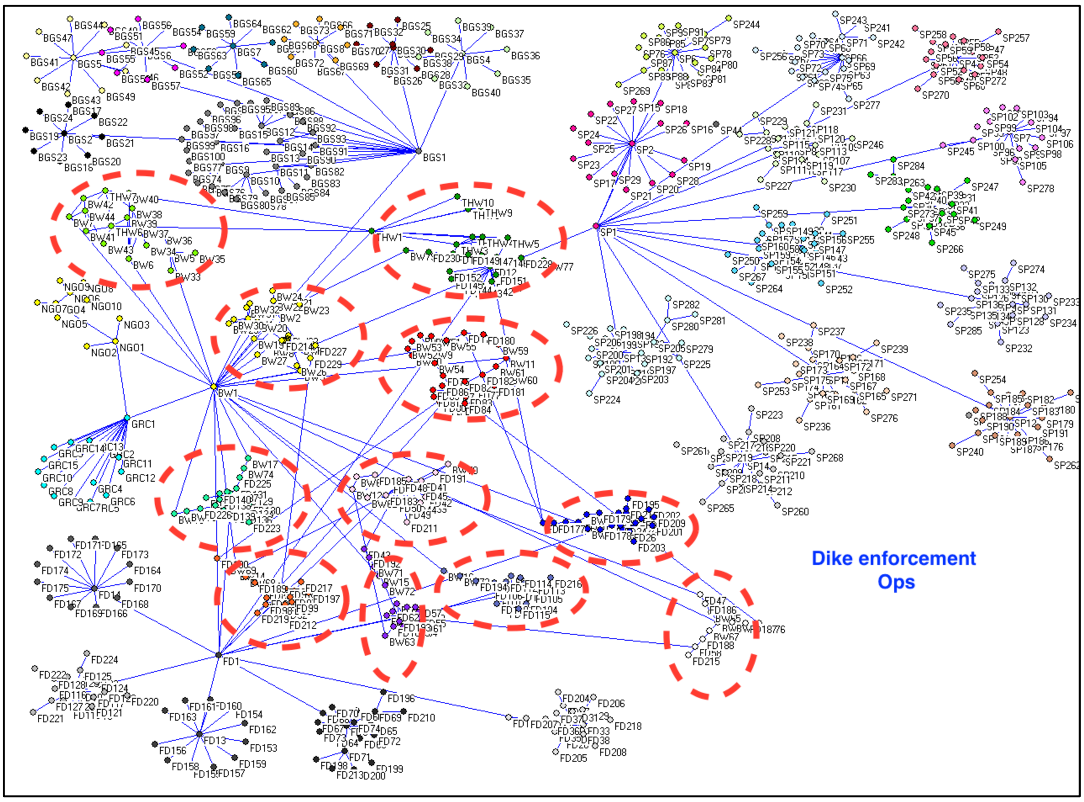

Figure 37. Example of network visualization for disaster response operation based on coordination matrix.

Incorporating the time factor provided a dynamic observation to the patterns of coordination and the evolution response networks (Wolbers, Groenewegen, Mollee, Bím, 2013; Noori, Wolbers, Boersma, Vilasis-Cardona, 2016b). Therefore, each coordination matrix was constructed to represent a response network at specific time slice and to obtain numerical readings of nodes centrality and ties strength between the nodes of the response network. Such readings enabled us to trace the changes in the roles played by different units in response operations.

The time-based SNA enabled us to examine the evolution of the disaster response networks as a whole. However, to examine the patterns of coordination we need to study the nature of the sub-networks (or clusters) forming inside the disaster response operations (Provan & Sebastian, 1998; Provan, Veazie, Staten, Teufel-Shone, 2005). The characteristics of those clusters depend on the nature of the relationships represented by the network and it can change over the time. Next step to study the patters of emerging coordination-clusters; it was necessary to identify structures (also called partitions or communities) in the network based on the individual node characteristics (e.g. connectivity) in relation to its locale and the rest of the network.

Based on that, in Stage 2, we used community detection techniques to examine the emerging coordination structures in the network representation of the snapshots of the response operations. There are several algorithms that are based on different principle to divide a network and detect clusters such as number of nodes or number of links or average number of nodes/links per cluster (Fortunato, 2010; Leskovec, Lang, & Mahoney, 2010). Those methods require initial values to the size of clusters, which was not suitable for our purposes, as we require detecting emerging structure without a having biased initial values. Therefore, we employed methods that detect clusters based on the cluster or partition modularity values. The modularity is a scalar value between -1 and 1 that measures the density of links inside a cluster or partition as compared to the links between communities (Fortunato & Barthelemy, 2007; Blondel, Guillaume, Lambiotte & Lefebvre, 2008; Fortunato, 2010).

Community detection methods are used to detect or partition static network or single snapshots, therefore, some algorithms can produce inconsistent data if they were used for evolving networks. Yet, Aynaud and Guillaume (2010) pointed out the suitability of Louvain Method for detecting communities in evolving networks (Aynaud & Guillaume, 2010). In addition, the

Louvain Method is well known for the high quality of its partitions and its speed (Leskovec, Lang, & Mahoney, 2010; Waltman, L., & van Eck, N. J. 2013). In Figure 38 we can see an example of the detected coordination cluster using Louvain method for the Day 2 (see Appendix B) response operation of Elbe River flood 2002.

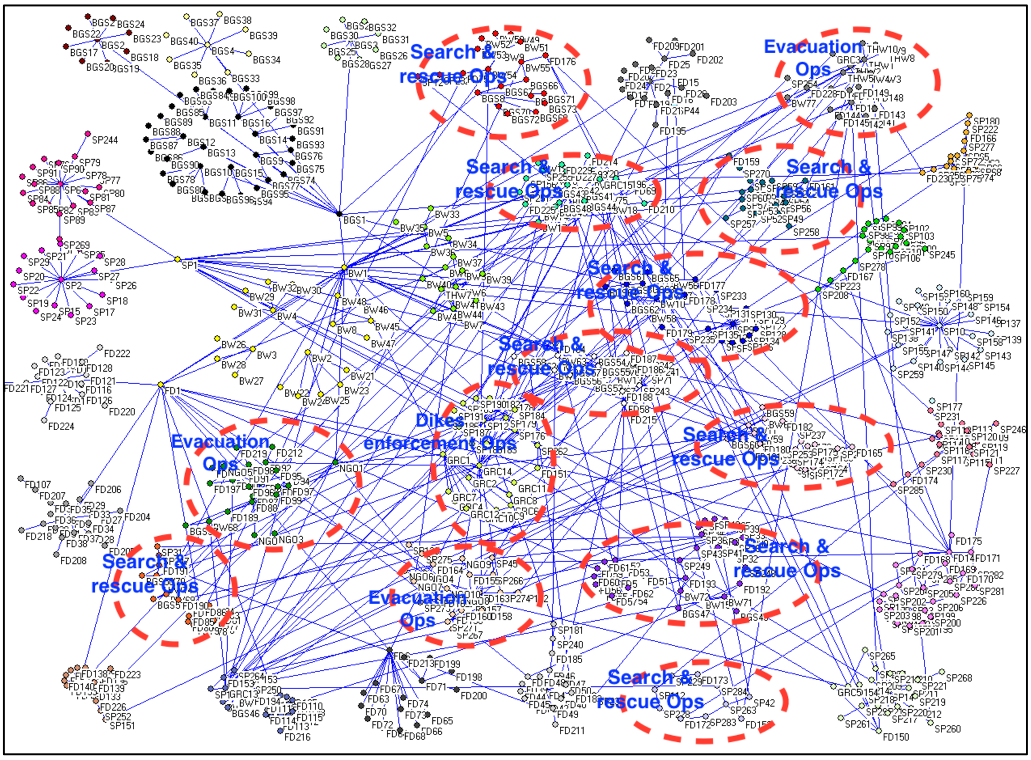

Figure 38. Coordination-clusters in Day 2 response network for Elbe River Flood 2002.

3.2.3 Stage 3 - Coordination in Emerging Disaster Response Networks

In Stage 3, the outcomes combination of Stage 1 and Stage 2 (i.e. Coordination matrix and coordination-clusters) to identify critical tasks that were carried out during the disaster response operations. The coordination theory was used to extract the qualitative details of coordination among multiple organizations such as actions, actors and resources. Data from the coordination matrix was used as an input to model the coordination processes in disaster response operations. Furthermore, the interactions between the actors and resources exchange are important to understand coordination flow in such operations. In Stage 3, a popular approach was adopted for modeling interacting processes, that is the Petri nets and its two derivatives, colored Petri nets and hierarchical colored Petri (Peterson, 1977; Bruno & Marchetto, 1986; Crowston, 1997; Holloway, Krogh, Giua, 1997; Dilmaghani, & Rao, 2009).

From the literature review, we have learned that Petri nets modeling was used to model processes and procedures in many areas including disaster and emergency management. Petri nets method was used as tool to evaluate different procedures and process flows in order to improve the disaster and emergency management systems (Bammidi & Moore; 1994; Dilmaghani & Rao; Karmakar & Dasgupta; 2011).

Despite the fact that Petri nets are useful graphical-tools to represent the complex elements of disaster response system, the classical method lacked the capacity to represent multiple resources and hierarchical processes. Such requirement was crucial to our model because response operations involved a variety of resources. Therefore, an extension of the classical Petri nets was adopted to help model the complex systems of coordination in response operations (Karmakar & Dasgupta, 2011). The colored and hierarchical Petri nets were used to describe the complex resources and simulate the different tasks carried out inside response operations. With such capacity to represent diversified resources and hierarchical operations, we were able to capture and simulate operations' flow on different levels of crisis management authorities (i.e. local level, regional level and national level). The models were used to simulate ongoing coordination processes.

On one hand, Petri nets provided a dynamic view of coordination processes flow. On the other hand, complex network analysis provided a view of "who" performing tasks, "how" resources are consumed by the teams. This combination facilitated the creation of an integrated perspective to the relationships forming and tasks performed by teams from the different organizations engaged in response operations.

In each case study, for constructing the model for disaster response operations, the coordination data of processes and resources were collected from the coordination matrices and coordination-clusters. After preparing the data, high-level abstraction of the response operations was mapped to the coordination flow of the top level. Then, overall operations were decomposed based on the functional clusters recoded from Stage 2 data to identify the sub-tasks and model the process flows of the lower level according of the response operations. This recursive procedure was followed until the basic service flow was identified. Examples of sub-tasks identified from the emerging coordination-clusters are (as shown in Figure 39);

- Search and rescue tasks.
- Security (roads, properties, public establishments).
- Installing temporary evacuation camps.
- Medical assistance.

Some of the tasks mentions above are in depended and some are dependent based on the involved actors and resources and the availability of those actors and resources at the time those tasks took place. Therefore, the modeling of the sub-tasks was dependent on the type of the disaster and complexity of the response operations. Yet, the high-level abstraction of the coordination flow in response operations was similar at different operations. In 2.1.2 - Figure 9 (Figure 39) we show an example of response operation of a fire incident.

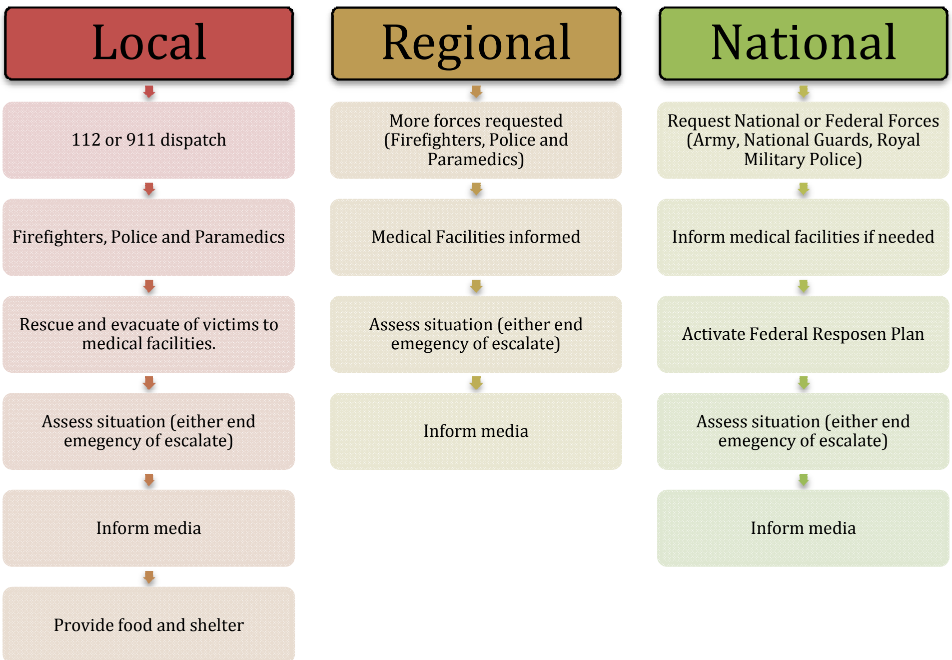

Figure 39. The different levels of disaster response operation for an average fire incident and activities required.

The distribution of response activities is done over 3 levels of authority and each level includes an *assessment process* that is followed by a decision either to escalate the operations, keep at the same level or halt the operations. Those three levels of authority and the escalation processes represent the high-level abstraction of the response operations. Beside those main processes, the procedure of decomposing the response operations to sub-tasks is more dependent on the scale and nature of the fire, but mainly sub-tasks can include alerting emergency response forces (i.e. Police, Fire Fighters and Paramedics). Next task can be providing medical support, evacuation, firefighting or building shelters beside other required actions.

As we mentioned in section 2.2.3.3 that colored and hierarchical Petri nets are supported by CPN-Tools software package (http://cpntools.org/) (Jensen, 1986; Jensen, 1990; Jensen, 1992; Jensen, 1997; Kristensen, Jørgensen, Jensen, 2004; Jensen, Kristensen, Wells, 2007; Girault & Valk, 2013). The CPN-Tool is a tool for editing, simulating and analyzing untimed and timed, hierarchical colored Petri nets. CPN Tool is the result of a research project, the CPN2000 project at the University of Aarhus, sponsored by the Danish National Centre for IT Research (CIT), George Mason University, Hewlett-Packard, Nokia, and Microsoft (Ratzer, Wells, Lassen, Laursen, Qvortrup, Stissing, Westergaard, Christensen, Jensen, 2003; Jensen, Kristensen, Wells, 2007).

The CPN-Tools was used to construct the Petri nets models for the disaster response operation associated with the case studies chosen in this research. In Figure 40, we show a Petri net model (created used CPN-Tools) for the example shown in Figure 39. The Petri net represents the high-level abstraction of the response operations. We can see the three levels of response operations (local, regional, and national) and the assessment processes associated with each level of authority.

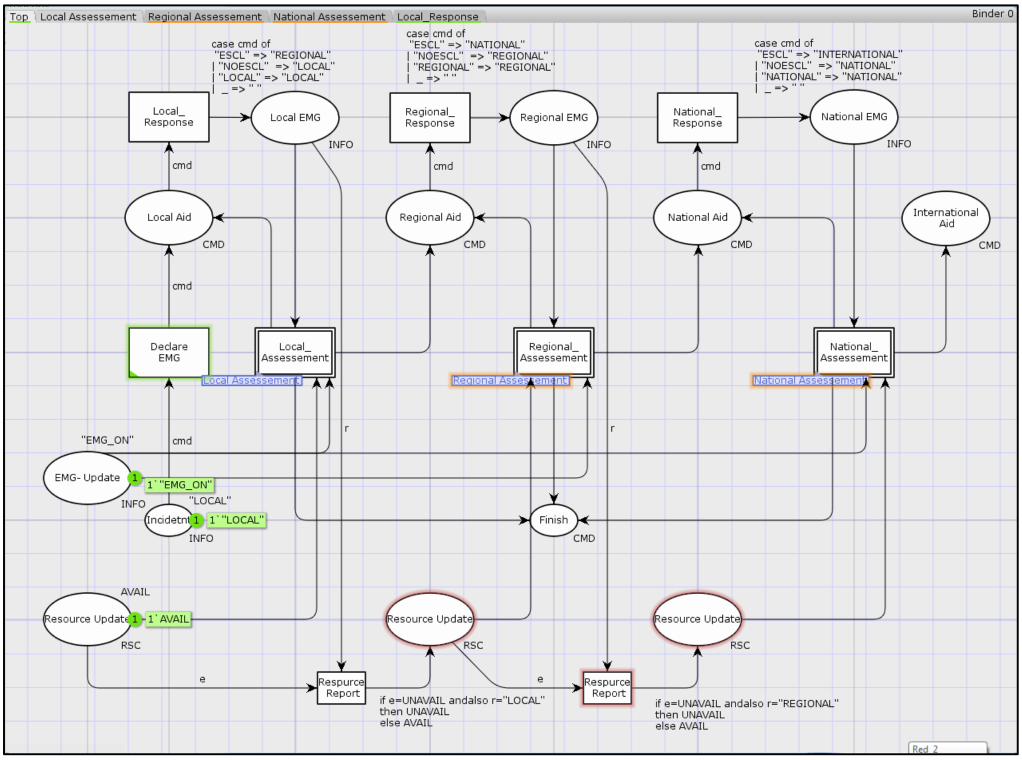

Figure 40. Petri Nets representation for the high-level abstraction of disaster response operations.

The CPN-Tools software package was a powerful tool to represent the sub-tasks for the decomposed response operations. In Figure 41 we show an example of a sub-task in the response operations, the assessment sub-tasks are repeated on each response level.

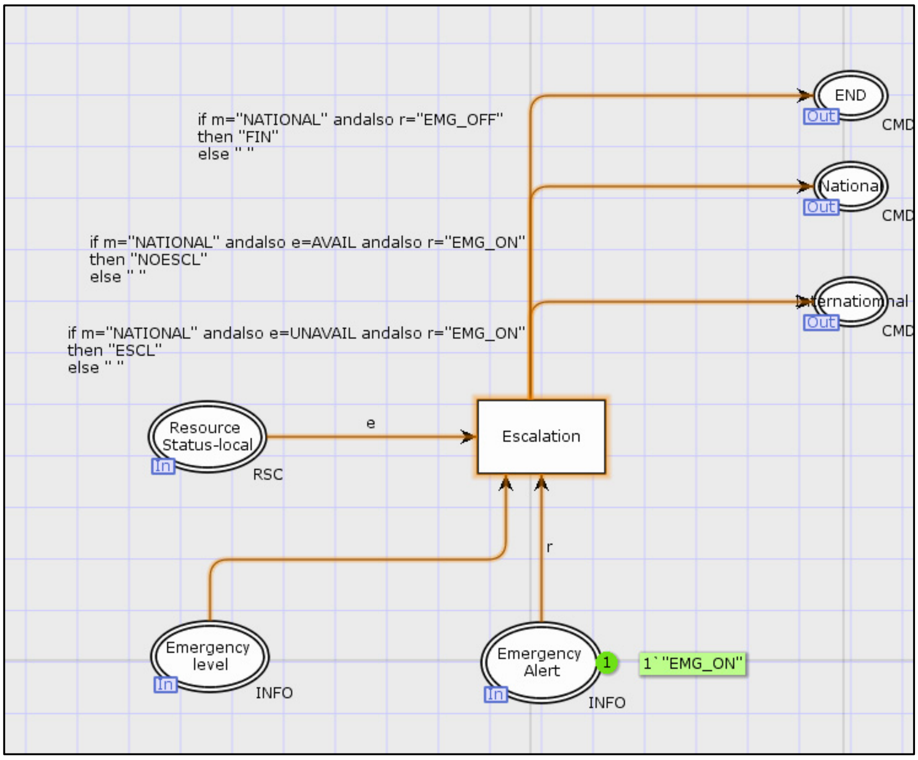

Figure 41. Petri Nets representation of the assessment process on the national level.

CPN-Tools also used to simulate different scenarios for the operations and the resource availability and disaster conditions to study the output of the network in different conditions. In Table 13, represents a sample of the different possibility of inputs to the assessment process and the expected outcomes.

The options for the resource update process on the different levels of the crisis management authorities are:

1. *Local level*, the information is reported directly by the local authorities to assess the situation.

2. *Regional level*, the information is reported (propagated) from local authorities to the regional level authorities that will trigger the regional assessment process. If resource are UNAVAIL, and EMG Level = LOCAL, then the unavailability will triggers the assessment process for higher level.

National level, the information is reported directly to the regional authorities to assess the situation. If resource are UNAVAIL, and EMG Level = REGIONAL, then the unavailability will triggers the assessment process for higher level

Response level	Resource availability	Emergency alert	Output
local	avail	on	NOESCL
local	avail	off	FIN
local	unavail	on	ESCL
local	unavail	off	FIN
Regional	avail	on	NOESCL
Regional	avail	off	FIN
Regional	unavail	on	ESCL
Regional	unavail	off	FIN
National	avail	on	NOESCL
National	avail	off	FIN
National	unavail	on	ESCL
National	unavail	off	FIN

Table 13. Possible options of the assessment operations inputs and outputs within different crisis management authorities.

Stage 3 represented the last part of the research design the analysis process for the data collected. The combination of the three stages provided us with a time-based perspective of the evolution of coordination in disaster response networks and a dynamic, event-based, perspective of the coordination flow in disaster response operations. The next section we are going to discuss the units of analysis and data selection.

3.3 Unit of analysis "Case selection"

Based on the various studies examined through the literature review process, the unit of analysis that has been adopted in this research is a disaster event where an ICS was officially activated, a C2C was established, an "Incident Commander" is appointed to orchestrate the response operations among the various organizations involved in the disaster response operations (Bigley & Roberts, 2001; Crichton, Lauche & Flin, 2005; Moynihan, 2009). The cases selected in this research represent two different types of response operations; a flood incident and a fire incident.

The reason behind that is to extract the commonalities in the high-level abstraction to create a universal dynamic framework (or model) for the overall response operations. Another reason is to examine different varieties of sub-tasks that can occur in different types of operations, which gave the framework a level or richness and validity.

3.4 Data collection

Based on the SNA and Coordination theory studies where case study method employed, data collection strategies always included multiple data source as recommended by Eisenhardt (1989) and Gerring (2007) and also to satisfy data triangulation principle. The following data sources were included:

1. Interviews with subject matter experts.
2. Official Incident reports provided by the Saxon Police Units in Dresden.
3. News clippings and media reports.
4. Official documents of disaster management plans.
5. Official websites of organizations involved in the response operations (i.e. Saxon Police, Fire Fighters in Germany, Homeland Security, Canadian Public Safety and other websites)

After collecting the data, a detailed descriptive profile was constructed for each case (see Appendix A for a profile example). The profile is detailing key events in the disaster main events, organizations involvement, resources used, collaboration actions, and critical collaboration incidents. Most important element was to create a time stamp for the key events and create a list of the key actors (individuals and organizations) involved in the response efforts. The data collected was used to construct the coordination matrices.

3.5 Summary

The goal of the research is understand the specifics of coordination dynamics in disaster response operations. The process involved examining networked-coordination and the patterns of coordination within such networked setting. In order to meet the goals, there was a need to develop a set of appropriate tools to examine the structures and processes involved. In addition, creating the links and aligning the different levels of actors across and within multiple response networks. Those actors and activities can exist around a core team, which is lead by the incident commander. However, the core team is connected to other actors in the response network. The relationship between organizations possesses unique properties that need to be understood. These “properties”, i.e. the “who communicates with whom, where, when and why, are fundamental to understanding the linkages that, when aligned and clearly coordinated, can make response operations successful. Such a wide spectrum of actors involved in emergency response operations, from macro institutions to micro individual creates a set of complex relationships that needs to be identified and their different contributions mapped and measured (Kapucu, 2005; O'Sullivan, et. al., 2013).

To achieve the goals of the research, we created a framework for examining coordination dynamics in disaster response operations. The framework comprises a set of the following methods: Coordination Theory (CT), Complex Networks Analysis, and Petri Nets. As it was explained in previous sections, coordination theory by Malone and Crowston (1990) and (1994) and its applications in computer science, business process design and economics (Bailetti & Callahan, 1993; Crowston et. al., 2006) was a normal fit for the research context of interorganizational coordination in disaster response networks. Applying the coordination theory lens to investigate tasks and dependencies in crisis response operations will provide the main constructs for the coordination framework in a crisis response network.

Further to coordination theory and in order to understand the structure of the formation of the temporary systems in disaster response operations, we used the complex network analysis and clustering techniques as a second tool to examine the different forms of relationships within disaster response networks. The outcome of the coordination matrix was used to construct PNs models for the response operations. The Petri Nets capability of representing hierarchical operations, we were able to capture the different levels of response operations.

4 Case Studies

An in-depth analysis was conducted to examine two disaster incidents that took place in two different European countries. The incidents differ in nature and scale, which allowed us to study patterns of emerging coordination-clusters and characteristics under different circumstances. The first incident is a large-scale one, the Elbe River Flood in Germany in 2002. The Elbe river flood was considered one of the major disasters in Europe and the response operations involved parties from different levels of authority (i.e. local, regional, national and international). The second incident is the Schiphol Tunnel Fire in the Netherlands in 2009. Unlike the Elbe flood, the Schiphol Tunnel fire was a minor incident that involved basic emergency response services (i.e. police, fire fighters and paramedics). The Elbe Flood and the Schiphol Fire provided a sample of response networks to help observe evolution of coordination-clusters in large-scale complex response operations versus small-scale minimal response operations. In this chapter we provide details regarding incidents' timelines, involved parties and response operations' details. The coordination matrices and SNA were used to construct and visualize the response networks for every case.

4.1 Elbe River Flood in 2002 in Germany

In August 2002, Germany and other parts of Europe experienced one of the worst flooding incidents within a century, the Elbe River flood. The Elbe flood was one of the worst natural disasters in Germany. For the proposes of this research, the Elbe flood case study was a good fit because it involved various types of interorganizational collaboration on different levels of authorities (i.e. local, regional, federal and international). The Elbe flood provided an illustration of positive and negative practices in interorganizational collaboration during disaster management.

The unit of analysis of the case study is the emerging organizational network during the course of the disaster response operations. Due to limitations associated with time and data access, we focus in this case study on the federal state of Saxony although the Elbe flood affected other parts of Germany. For each single day in the response operations, organizational networks were constructed and analyzed using the SNA method. Next step was to examine evolution patterns of coordination-clusters inside the response networks. In the upcoming sections we provide information about the topology of the Saxony State and describe the weather conditions over the period of incident. Such information will help to understand the circumstances and nature of the disaster at that time, and the response actions required for handling the flood incident.

The Elbe flood incident claimed 20 lives, 110 injured people in Saxony and, with nearly 100,000 people evacuated. Approximately 12000 commercial entities were affected and the estimated aftermath damages reached the amount of 6.2 billion Euros. The Saxon State capital, Dresden, suffered an approximate damage of 340 million Euros. Large numbers of schools were severely damaged and many hospitals were evacuated (Toothill, 2002).

The response operations lasted between August 12 and September 4 in some areas in Saxony. The operations involved the following entities: German Armed Forces (*Bundeswehr-BW*), Federal Police (*Bundespolizei or Bundesgrenzschutz- GBS*), Federal Agency of Technical Aid (*Bundesanstalt Technische Hilfswerk - THW*), Saxon Police (*Politzei Sachsen - SP*), Fire Departments (*Feuerwehr Sachsen - FD*), German Red Cross (Deutsches Rotes Kreuz - DRK) and other Non-Governmental Organizations (*Deutsche Lebensrettungs-Gesellschaft - DLRG, Arbeiter-Samariter-Bund – ASB, Johanniter-Unfall-Hilfe - JUH, Malteser Hilfsdienst - MHD*). In addition, an estimated 25,000 volunteers were involved in the disaster response operation.

Sources of information included press releases and peer-reviewed journals, however, the main sources of information used in examining the Elbe Flood case study are:

1. von Kirchbach, H.-P., S. Franke, H. Biele, L. Minnich, M. Epple, F. Schäfer, F. Unnasch and M. Schuster. (2002). "Bericht der Unabhängigen Kommission der Sächsischen Staatsregierung Flutkatastrophe 2002". The von Kirchbach report provided a comprehensive description of the environment conditions during the floods and the response action of the response operations in the state of Saxony. The report was authored to evaluate the disaster management operations during the floods in the Saxon State and makes recommendations to improve the efficiencies and effectiveness of the German disaster response systems.

2. Richter, S., Huber, R.K., and Lechner, U. (2002) The Elbe Flood 2002 – A Case Study on C2 Systems and Inter-organizational Coordination, *report prepared for the NATO Working Group SAS-065*, Universität der Bundeswehr München and IT IS eV, Munich. The report was authored as a contribution to the NATO SAS065 Research

Task Group to present and evaluate Command and Control (C2) Maturity Model aiming to de-centralized response task forces.

3. Situation Reports (Police department - Dresden). Detailed situation reports provided information and facts of the development of the disaster alerts in the region of Saxony and forces engaged in the response operations.

The upcoming sections of the Elbe Flood case study will cover information about (1) geographical nature of the affected areas, (2) sequence of events, (3) networks of organizations engaged in the response operations, and (4) interorganizational coordination and collaboration clusters.

4.1.1 The Elbe River Basin Description

The Elbe streams start flowing from the mountains in the north of the Czech Republic, traversing through Bohemia and Saxony before entering the German North Plain and ending in the North Sea (See Figure 42). In Figure 43, we can see the topographical nature of the Elbe basin in the Saxony region, where the southern region is rather mountainous in the Erzgebirge region and the northern parts are rather flat (the lowlands in Figure 43). The nature of the lands is rather steep and runs from southwest to northeast.

In addition, we can see in Figure 43, the connected network of rivers and streams running through the Saxony. In combination with the nature of the land, if there would be a heavy rain falls in the mountains, that would result a very quick rising in water levels that would almost give not time for alerting citizens or authorities. (Richter, et al, 2002; Spänhoff, B. Dimmer, R., Friese, H., Harnapp, S., Herbst, F., Jenemann, K., Mickel,A., Rohde, S., Schönherr, M., Ziegler, K., Kuhn, K., and Müller, U., 2012).

Figure 42. The Elbe River basin and the flood-affected areas.

*Adopted from Hochwasserkatastrophe im August 2002 – Bundeswehr
(http://www.bundeswehr.de/resource/resource/MzEzNTM4MmUzMzMyMmUzMTM1MzMy
ZTM2MzEzMDMwMzAzMDMwMzAzMDY3NmE2ODMzNzM3NDZhNmUyMDIwMjAy
MDIw/hochwasser.pdf)

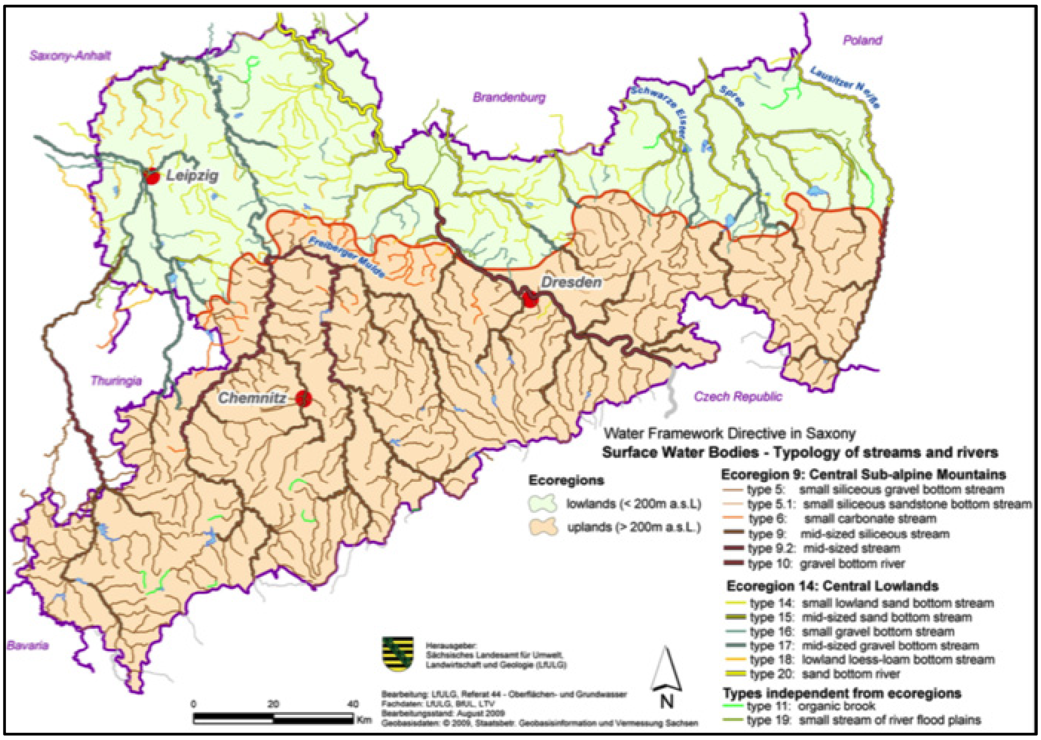

Figure 43. Province of Saxony, topographical map shows Elbe River basin

*Adopted from: Spänhoff, B., Dimmer, R., Friese, H., Harnapp, S., Herbst, F., Jenemann, K., ... & Kuhn, K. (2012). Ecological status of rivers and streams in Saxony (Germany) according to the water framework directive and prospects of improvement. *Water*, 4(4), 887-904.

4.1.2 Meteorological Conditions

The flood events were triggered by unusual, but not exceptional, meteorological conditions. Two weather systems crossed Europe in close succession during the first half of August. By August 6 and 8 the heavy storms system reached southern Germany and Austria, where heavy rainfall resulted. The system then moved eastwards along the southern side of the Alps, resulting in further heavy rainfall in Romania, The Czech Republic and the eastern coast of the Black Sea (Toothill, 2002; Mottram, Smith; 2003) In Figure 44, the track of the storms is shown along with the countries affected by flooding during passage of storms over the period of August 8th till August 13th. In Figure 45, it can be seen that the main concentrations of the rainfall were over Austria and the Czech Republic.

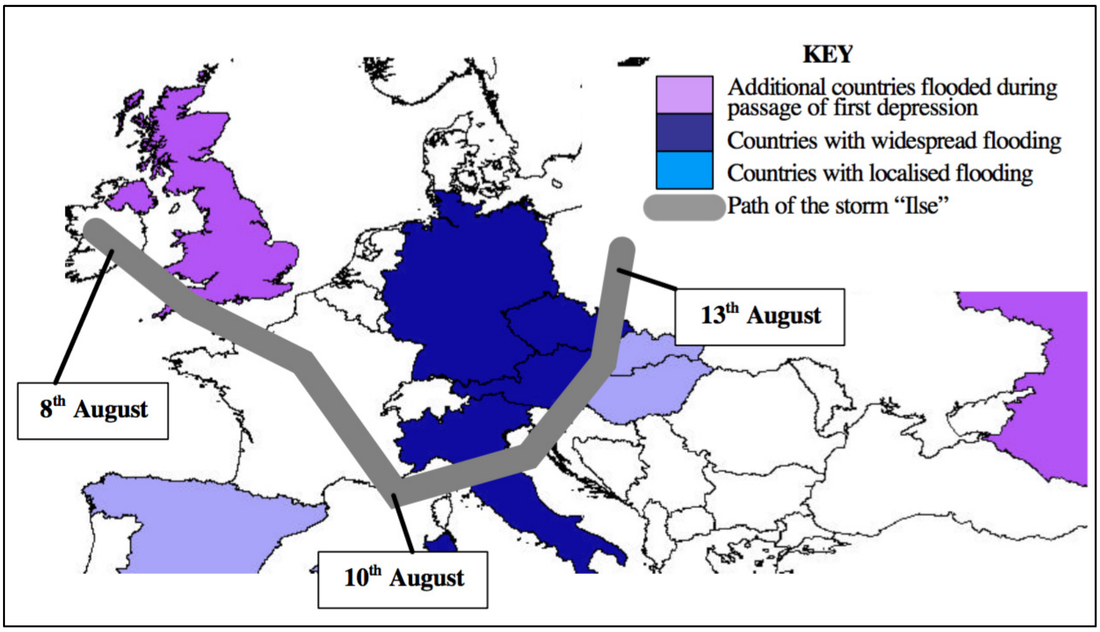

Figure 44. The path of the storm system from August 8 to August 13, 2002.
*Adopted from Toothill, J. (2002). Central European Flooding August 2002. ABS Consulting, Houston, TX, Tech. Rep. EQECAT

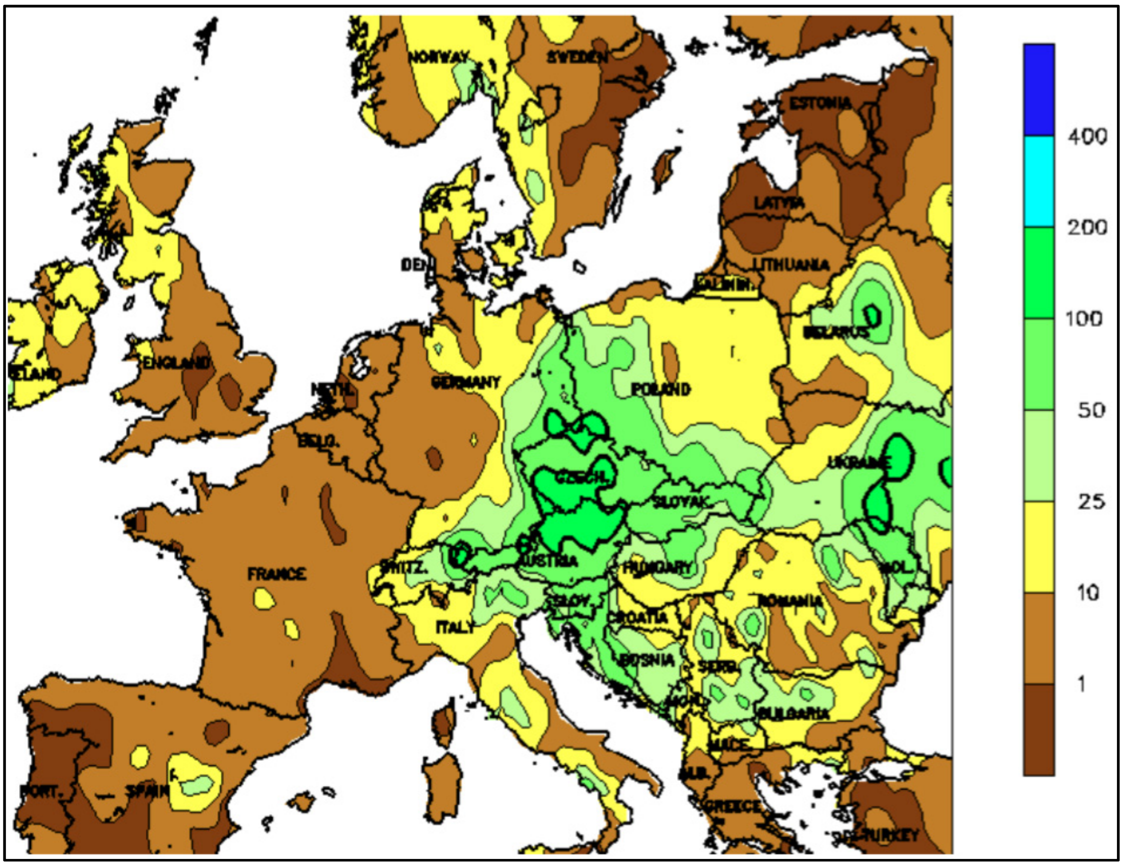

Figure 45. Cumulative rainfalls over Europe during the period 11th to 17th of August.
*Adopted from Toothill, J. (2002). Central European Flooding August 2002. ABS Consulting, Houston, TX, Tech. Rep. EQECAT

In Germany, the floodwater on the Elbe engulfed the city of Dresden, where several parts of the residential and commercial properties were submerged and many historical buildings in the city center were damaged. Figure 46 shows the water levels in meters at selected gauge stations along the Elbe River in Germany.

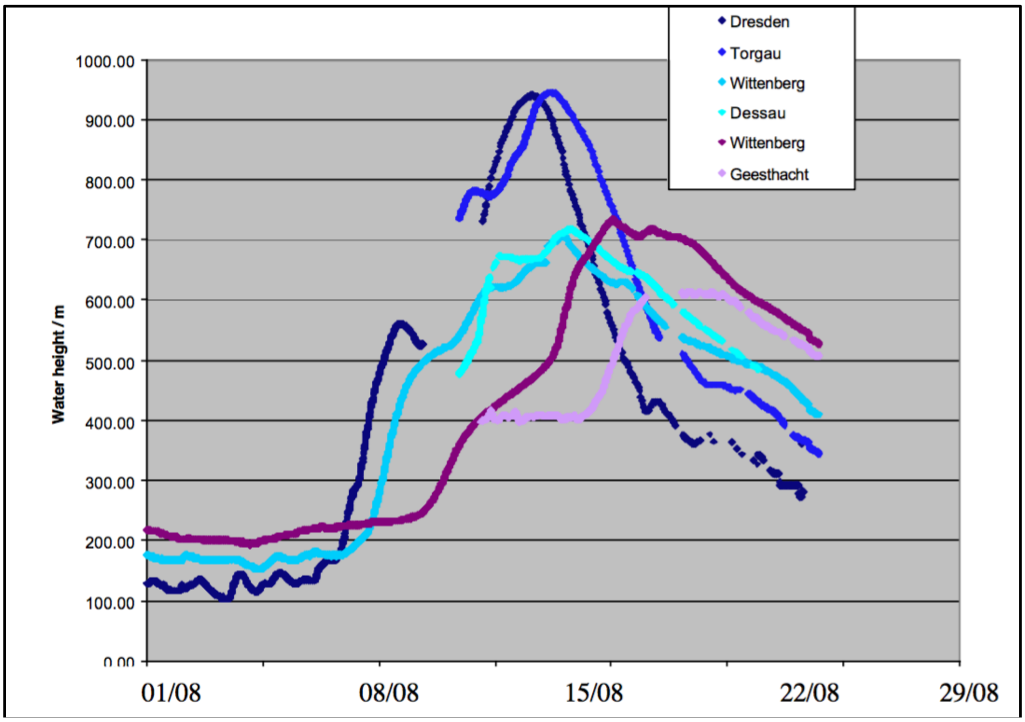

Figure 46. Water levels in meters at selected gauge stations along the Elbe River in Germany.
*Adopted from Toothill, J. (2002). Central European Flooding August 2002. ABS Consulting, Houston, TX, Tech. Rep. EQECAT

From the chart we can see that the flood reached its peak on August 13 and 18 in both Dresden and Torgau. On August 17, the highest water level reached in Dresden was 9.4 meters, exceeding the previously recorded high of 8.77 meters in 1845.

4.1.3 Flood Timeline

The flood timeline and the response operations details over the course of the disaster were extracted from the sources mentioned in section 4.1. The Elbe flood started on August 12 when alarms were raised in several locations in Saxony including the capital city, Dresden. The response operations and the state of emergency duration were different from one area to another depending on the severity of the damages. However, majority of the affected areas declared a state of emergency on August 12 and response operations lasted until September 24 at the most. Table 14 shows a sample timeline of the flood progress in Dresden with a time period of Tx= 1 day. The von Kirchbach report includes details of the flood timeline at various locations in the Saxon State. In the case of the Elbe River Flood we choose the time period Tx = 1 day due to several reasons. First is data sources provided details of the operations development based on daily bases. Second, it was difficult to obtain information with higher levels of granularity in such large-scale and complex response operations that involved other countries as well. Third, considering the duration of the disaster response operations (between 5 – 30 days or more), it would be time consuming to construct the networks on time slices less than Tx=1 day. Fourth, reconstructing response networks based on Tx=1 day provided a holistic view of the response operations which served a better purpose in examining the response operation on the macro-level than having uncompleted view on the micro-level.

Date	Description
August 12, 2002	Several second order rivers in Dresden and the city's outback strongly rise due to heavy rainfalls in the night between August 11 and August 12. In the morning flood warning level II (where IV is the highest) is proclaimed for the Elbe in Dresden. The water level is at that time 5.27 m (2 m is normal in August). Rain goes on with 150 l/m3 per day and the Elbe water level furthermore increases. Emergency alert is being proclaimed. The river Weißeritz brakes out of the new (artificial) riverbed and flows through the original one and floods parts of the city. Some of the parts were never flooded before in history.
August 13, 2002	Rain goes on and the Elbe water level is at 6.66 m. The Weißeritz heavily damages the city districts Löbtau, and Friedrichstadt. The Weißeritz floods Dresden main station. 1/6 of Dresden's homes are cut from electricity. The very famous picture gallery "Alte Meister" located in the Zwinger and the archive of the Saxon government are endangered by the flood. Further second order rivers as, e.g., the Lockwitzbach flood the city.
August 14, 2002	The rain stops and the Weißeritz returns in its riverbed. The level of the Elbe still rises.
August 15, 2002	The Elbe-level is higher than 8 m. The citizens of the city districts Niedergohlis, Altkaditz, Laubegast, Kleinschachwitz, Mickten, Trachau and Pieschen are evacuated.
August 16, 2002	In the morning the historical highest Elbe water level (1845 the Elbe-level was 8.77 m) is exceeded. In the evening the Elbe-level is 9.14 m. The Elbe rises slower than the Weißeritz and floods the center of Dresden. The famous palace Zwinger and the famous opera house Semperoper are flooded by the Elbe. Some large bridges are endangered and a more than 10 m long boat has to blown up such that it not rams Dresdens' bridge once it turns loose

Date	Description
August 17, 2002	The Elbe is at its highest level with 9.40 m. The water level sinks slowly but the groundwater-level rises about 3 m. The ground water floods a lot of cellars and damages a lot of houses. Note that it is difficult to draw water out of cellars because the stability of the houses becomes unsafe.
August 18, 2002	The Elbe-level sinks faster than expected. In the evening it is at 8.20 m.
August 26, 2002	Emergency state alert is halted.

Table 14. Flood timeline in Dresden, Saxony with Tx= 1 day.

*Adopted from Richter, S., Huber, R.K., and Lechner, U. (2002) The Elbe Flood 2002 – A Case Study on C2 Systems and Inter-organizational Coordination, report prepared for the NATO Working Group SAS-065, Universität der Bundeswehr München and IT IS eV, Munich.

4.1.4 The German Response System

Figure 47 and Figure 48 is adapted from Richter et al. (2002), show the different levels of the disaster management authorities and how these levels are linked to the different organizations involved in disaster management operations (i.e. BW, THW, DRK, etc.). The German Response System consists of three levels of authority:

- District level or the Lower disaster management authority
- Region level or the Higher disaster management authority
- State Level or the highest disaster management authority

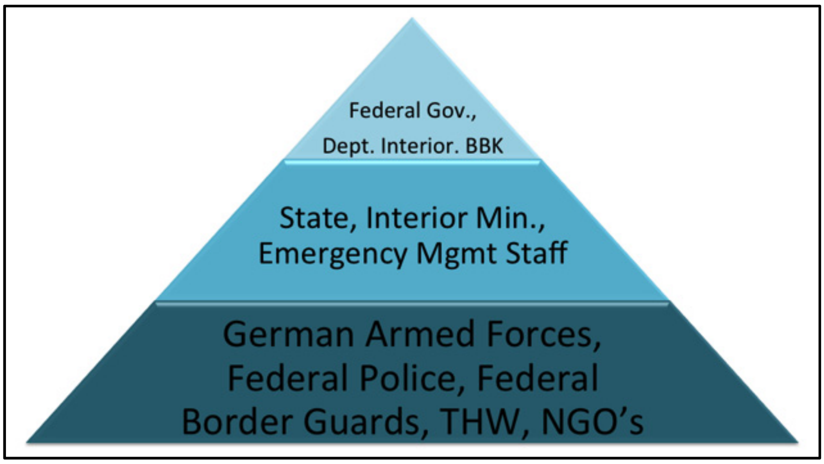

Figure 47. The hierarchy of the German response system. (Richter, et al., 2002)

The German disaster response divided into three phases, (1) preparations to control and reduce effects of a disaster; (2) management of disaster response operations; (3) repair of critical damage caused by disasters.

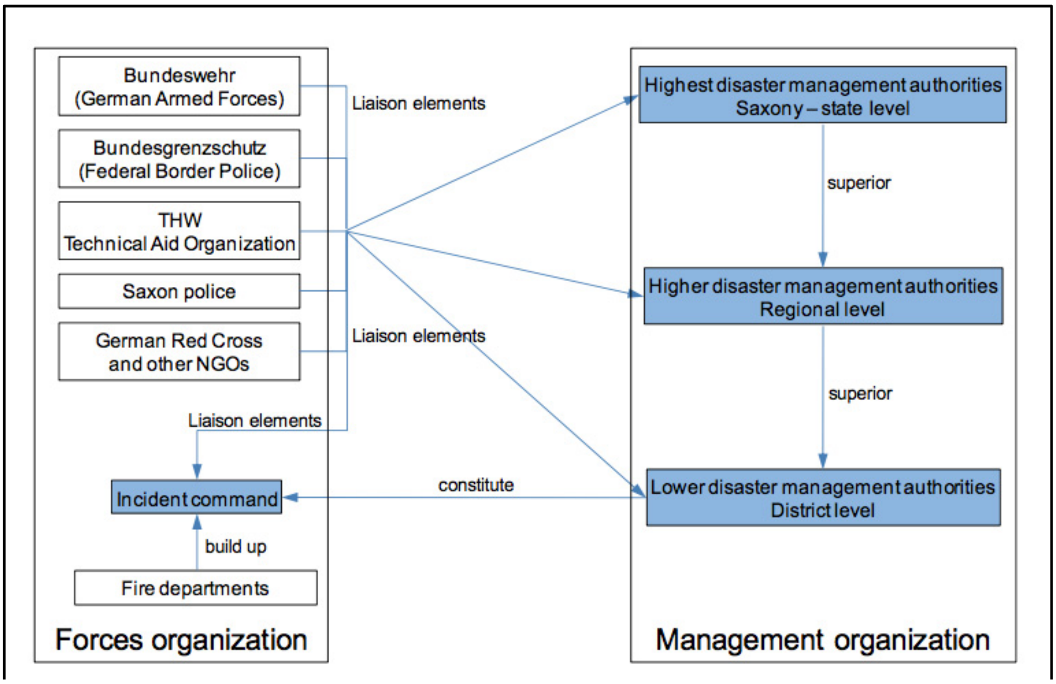

Figure 48. The organizational structure of the German response system. (Richter, et al., 2002)

4.1.5 The disaster response network and involved organizations

Table 15 shows the organizations that were involved in the flood crisis. The table is an adaptation from the Rechter et al. (2002) report.

Participating Organisations	From without Saxony	From within Saxony
German Armed Forces	15,500 (179 units) 15,500 soldiers	
Federal Border Police	2,200	
THW	2,835	
Police		1,600 – 4,000
Fire Fighters		20,000 – 23,000
NGOs (five accredited)	6,352	4,076
Unorganised volunteers	6,661	16,893
Total	33,548	42,569 – 47969

Table 15. Involved organizations in the Elbe River Flood response operations. (Richter, Huber, and Lechner, 2002)

Next step was constructing the initial response network based on the hierarchical structure of the involved organizations and the response network (based on data from the reports). Since it was difficult to retrieve precise information regarding the activities the individuals in each organization. We constructed the network based on divisions or units. We divided the numbers of persons mentioned in Table 15 to number of divisions (units, squads, groups or platoons).

Table 16, shows a list of the mapped numbers of the personnel involved to the corresponding divisions for each organization. The information regarding the average size of a *unit, group* or *platoon* is based on data extracted from the Richter, Huber, and Lechner (2002) report or publicly available information on the organization website. Appendix A and Appendix B include more details about the coding and visualization of the network graphs for each organization involved in the response operations.

Organization Name (Organization abbreviation)	Color code	Number of divisions (units, squads, or platoons
German Federal Forces (BW)	Green	155000 persons => 179 (from Richter, et al, 2002) BW1 - BW 178
Federal Border Police (BGS)	Black	2200 persons => 183 squads (Gruppe) *1 squad (Grp) = 12 persons BGS1 - BGS 182
Technisches Hilfswerk (THW)	Yellow	2935 persons => 28 units (from Richter, et al, 2002) *1 unit = 104 persons THW 1 - THW27
Saxon Police (SP)	Brown	12500 persons => 1041 squads *1 squad (Grp) = 12 persons SP1 – SP 1041
Fire Department (FD)	Red	23000 persons => 230 Units *1 unit = 100 persons FD1 – FD 230
German Red Cross (DRK)	Purple	7373 persons => 29 Platoons (From Richter, et al, 2002) DRK1 – DRK 29
Other NGO´s (NGO)	Blue	933 persons => 10 Platoons (From Richter, et al, 2002) NGO1 – NGO10
Unorganized Volunteers (UV)	_	VU was not included in the network

Table 16. Abbreviations, color codes and units (or divisions) mapping of organizations engaged in the response operations of the 2002 Elbe River Flood.

The next step after identifying and mapping the organizations involved in the disaster management forces, we construct a coordination matrix for the division involved in the disaster response operation based on the events development for the flood incident.

4.1.5.1 Response Network

After mapping the involved personnel to their correspondent number of divisions, we start constructing the "response network" based on the information gathered from von Kirchbach (2002) report, Richter et la. (2002) Report, police reports, press releases, and news clippings. The information that used to construct the networks is:

- Name of the organization
- Number of engaged units
- Description of work (tasks)
- Involved divisions

As it is shown in Table 17 another round of mapping the organization divisions to a corresponding task or function during the crisis response phase. For example, based in coordination matrix of Day 1 (see Appendix B), we have 79 units of the German Armed Forces (Bundeswehr - BW) were involved in the response operations. Main tasks of units engaged were establishing Command and Control (C2), transportation (maintaining roads and bridges), and search and rescue. At that stage we assumed the following:

BW1 is the Command and Control unit

BW1 ⇒ BW2 - BW20 units

BW2 - BW5==> Transport unit ==> 15 units

BW6 - BW9 ==> Engineering unit ==> 18 units

BW 10- BW20 ==> Search and Rescue ==> 31 units

That step produced the following network graph shown in Figure 49.

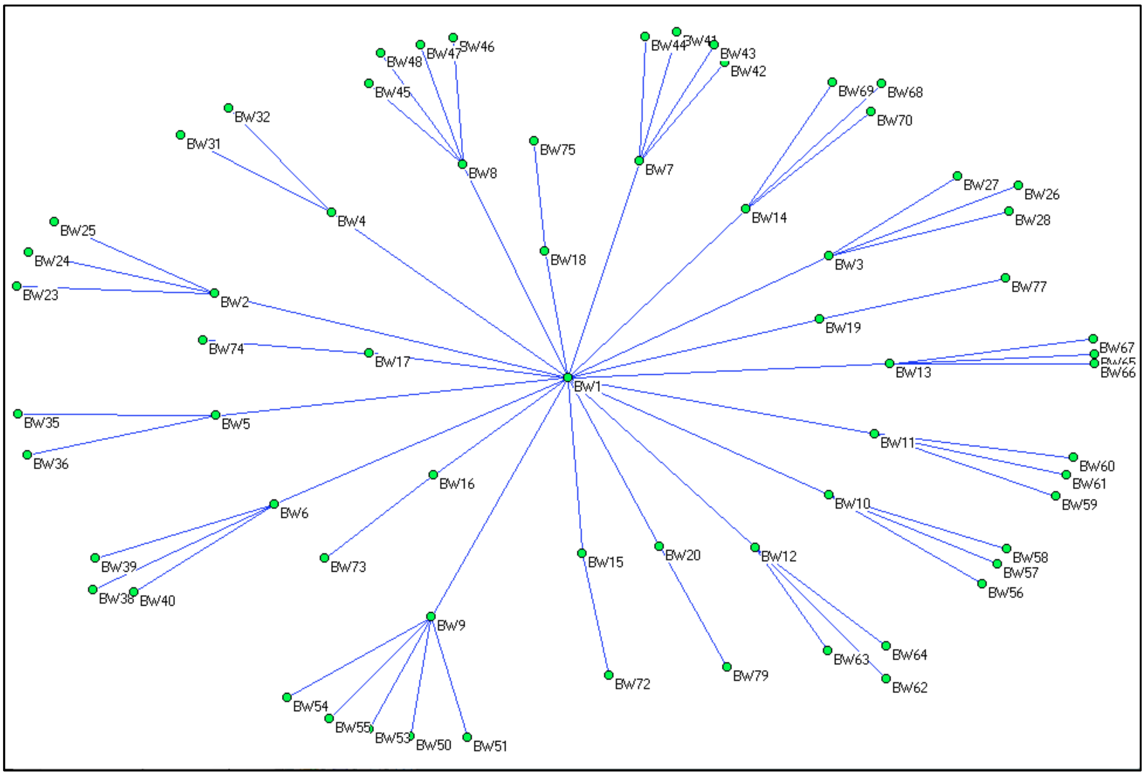

Figure 49. Bundeswehr-BW subnet for Day 1 with total of 79 nodes.

Table 17, shows the units' distribution for the initial disaster response network. Table 17 shows the mapping procedure that was carried out to map the units of the other organizations that were engaged in the response operations. The results of the previous step can be seen the network graph in Figure 50. Where we can see the star shape formations in our networks that reflects the hierarchies of each organization.

Organization	Total number of units	Subgroups and function
BW	79 Units	BW1 is the Command and Control unit BW1 ⇒ BW2 - BW20 units BW2 - BW5==> Transport unit ==> 15 units BW6 - BW9 ==> Engineering unit ==> 18 units BW 10- BW20 ==> Search and Rescue ==> 31 units
BGS	100 squads	GBS1 is Command and Control unit GBS1 ⇒ GBS2- GBS15 GBS2 - GBS8 ⇒ Search and Rescue ⇒ 45 units GBS9 - GBS12 ⇒ Transport support ⇒ 20 units GBS13-GBS15 ⇒ energy + water support ⇒ 20 units
THW	10 units	THW1 is the Command and Control unit THW1 ⇒ THW2 - THW10 THW2 - THW5 ⇒ Search and Rescue THW6 - THW7 ⇒ Clearing roads & bridges THW8 - THW10 ⇒ clearing hazardous material, cleaning wreckage
SP	285 squads	SP1 is the Command and Control unit SP1 ⇒ SP2 -SP 14 SP2- SP15 ⇒ Districts main stations (Saxony has 10 districts + 3 urban districts) Each SP squad between SP2-SP14 is connected to 15 SPx ⇒ each SPx is connected to the rest 76 (285-1-13-(13*15))
FD	230 units	FD1 is the Command and Control unit FD1 ⇒ FD2 - FD14 Incident command in Dresden region FD2-14 ==> is connected to 12 fire station FDx Each FDx ==> connected to the rest of the units
DRK	15 platoons	DRK is the Command and Control DRK ⇒ DRK2- DRK15
Other NGO's	10 platoons	NGO1 is the Command and Control NGO1 ⇒ NGO2- NGO10

Table 17. The units' distribution for Day 1

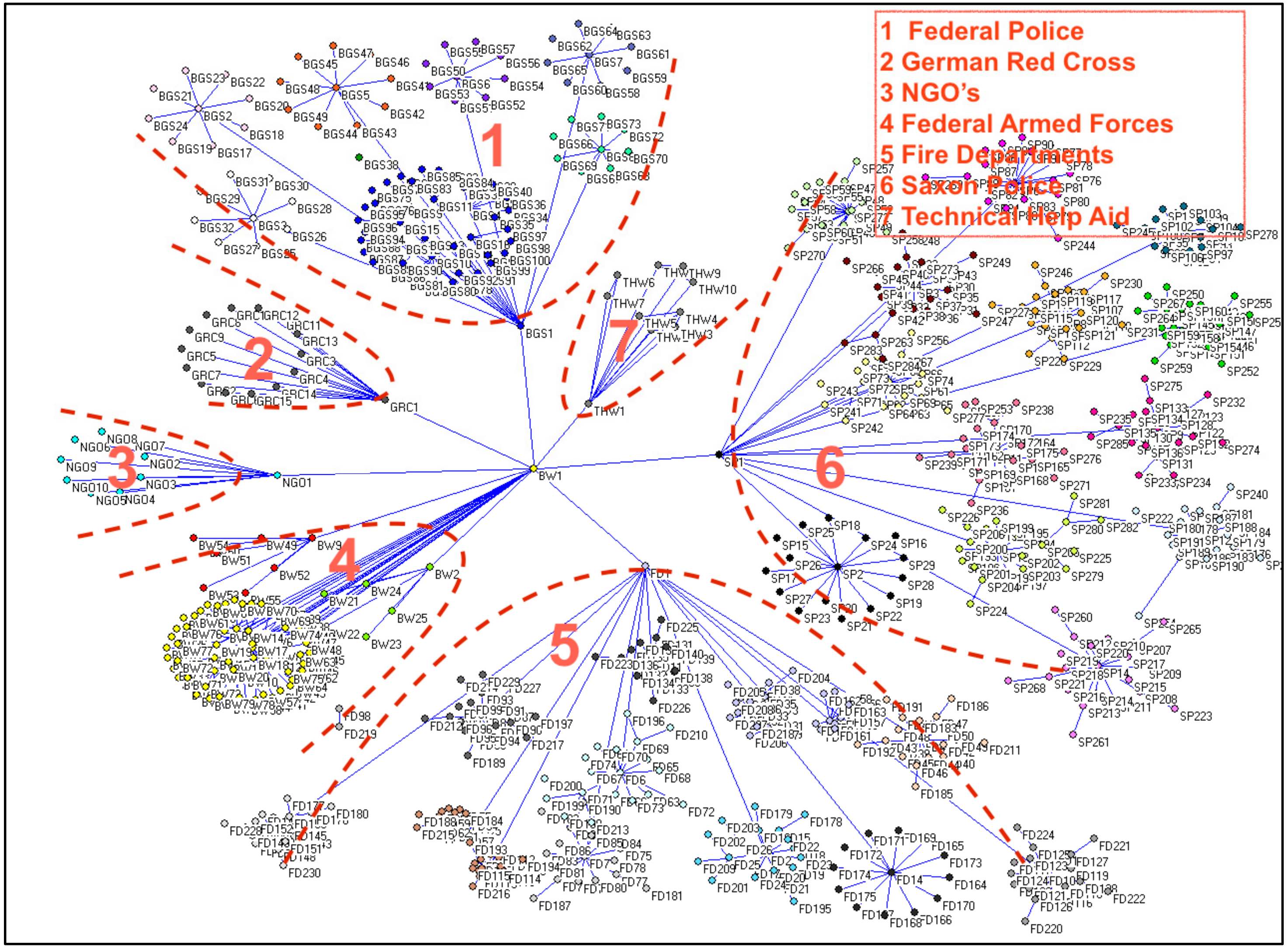

Figure 50. Hierarchical clusters of organizational networks engaged in the response operations.

4.1.5.2 Connecting the Dots

After preparing the initial response network based on the hierarchies, we start introducing some of the tasks performed during the response operations by assigning units from different organizations to these tasks. The assignments were made based information listed in Table 26 in Appendix A.

For example on August 13 (day 2 of the disaster) tasks like roads maintenance, medical care, search and rescue were required. In Tables 18 and 19 we have list estimates of organizations and number of units involved in performing some of those tasks.

Organization	Number of units involved
BW	31
BGS	45
THW	5
GRC	3
FD	55
SP	90

Table 18. Units involved in Search and Rescue task.

Organization	Number of units involved
BW	18
THW	5

Table 19. Units involved in road maintenance task.

Afterwards we apply the information from Tables 18 and 19 to the initial response network by creating organizational links between the units as shown in Tables 18 and 19. This procedure produced the network graph shown in Figure 51. In Figure 51, we can notice some parts that are still holding the initial hierarchical structure and others changed their structure totally due to the new links. This pattern reflects the different types of organizational coordination: inter-organizational and intra-organizational. The units (or nodes) that kept their initial hierarchy are units engaged in the operations but within the boundary of their own organizations. Also such pattern can be explained when units are not involved yet in the operations.

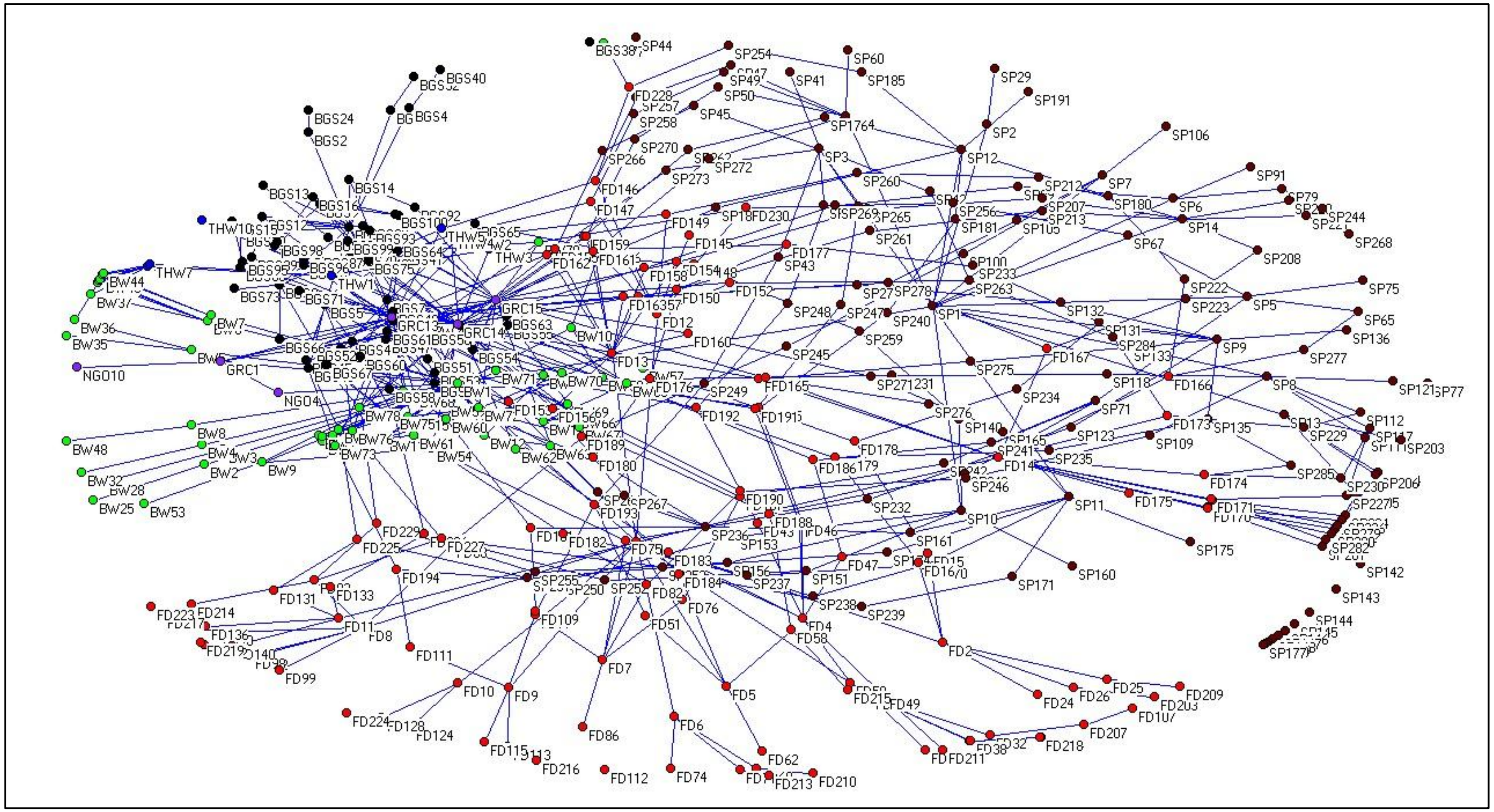

Figure 51. Response network of Elbe Flood response operations after adding tasks for road maintenance and search and rescue.

4.2 Schiphol Tunnel Fire in 2009 in The Netherlands

On Thursday, July 2nd, 2009 at about 17:30 hrs. a fire incident took place in the Amsterdam Airport Schiphol train tunnel. Due to an accumulation of dirt and other factors, a cable tray next to a railway track ignited by a spark released from the braking wheels of a passing train and started to smolder. The smoke resulting from the smoldering dirt was noticed by train drivers of trains passing through the tunnel. Together with reports of malfunctioning signals, the signs of fire were communicated to the Railway Traffic Controller, who responded by stopping the train traffic in the direction of Schiphol, requesting the Switching & Report Center to dispatch a technician, and preparing a possible evacuation of the tunnel. In Figure 52, is a map showing Schiphol tunnel highlighted in green and pointing-out the fire location.

Figure 52. Location of the Schiphol train platform and the suspected fire.

Meanwhile, the smoke and the smell of the fire were noticed by a train driver and a Schiphol employee at one of the platforms. The latter informed the Coordination Center Schiphol, which immediately began requesting several emergency services to dispatch. In addition, both the Royal Military Police and the National Railways received alarms from one of their employees. Triggered by these alarms, the emergency response was put in motion in a scattered fashion.

Several involved parties quickly started the evacuation of the platforms, but the decision to start evacuating the tunnels was delayed by uncertainties about the severity of the signs of the fire, the positions of the trains held in the tunnel tubes, and the fire fighters' intention to explore the tunnel. The fire turned out to be harmless, as it died out by itself. However, three trains full of passengers were held in the tunnel under fear- some circumstances, which would have had potential lethal consequences if the fire had posed an actual threat.

One important aspect of the tunnel at Schiphol Airport is that the authority above the ground and underground differs. The tunnels and overall rail traffic in the tunnel are the responsibility of ProRail, the body responsible for the rail infra- structure. Passenger trains in the tunnels and station are the responsibility of the National Railways (NS Rail), and safety concerns rest with the railway police, a specialized National Police unit. In addition, Schiphol Airport as an entity has a separate legal status, and its own fire service, while its police are a part of the border guarding Royal Military Police KMAR and are at the same time responsible for safety and security in the airport area. The Schiphol tunnel is located in Kennemerland region, which is generally responsible for emergency operations for sending additional capacity for all three emergency services fire fighters, medics, and police.

In this case, the process of executing the actions of alarming, dispatching, and decision-making involved six different organizational entities with their own safety and communication centers: ProRail, National Railways, Royal Military Police (KMAR), Railway Police, Safety Region Kennemerland, and Schiphol Airport Emergency Services. Figure 53, shows the official structure of communication lines (solid black) and the crucial connections for responders occurring during the incident (dotted blue). The red actors are the fire department, white are to ambulance services, blue to police and yellow are the railway organizations. The red/white-shaded actors in the middle are the dispatch rooms of safety region Kennemerland and Schiphol Airport. The Airport Fire Officer (AFO) has the authority over the fire department response on site. The AL is responsible for coordination between the railway actors.

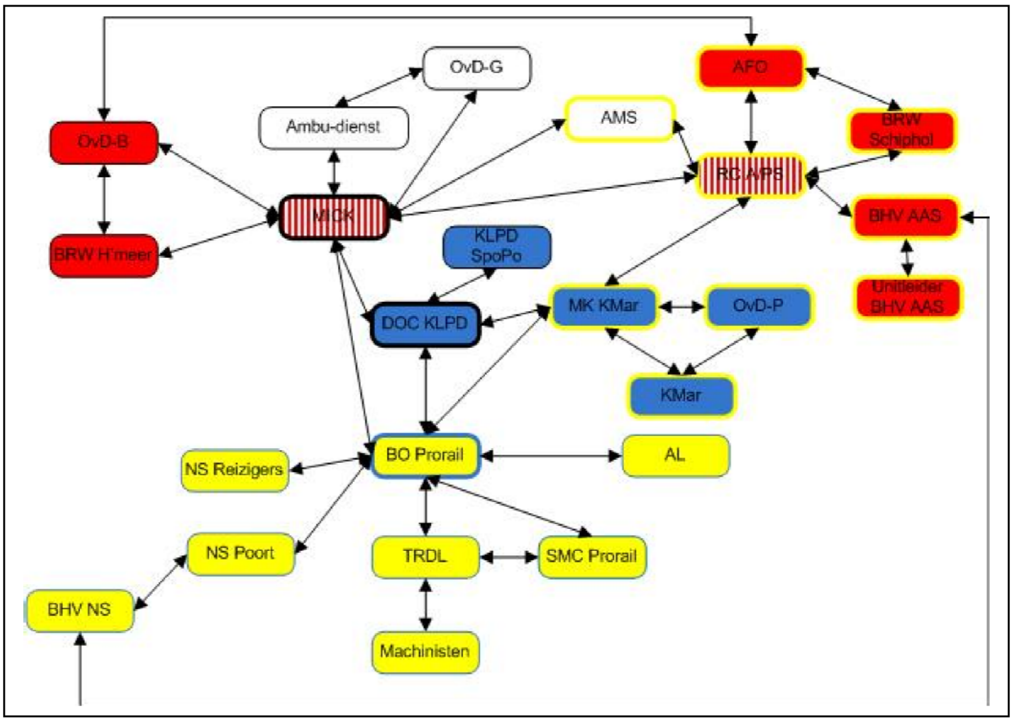

Figure 53. Official structure of communications between parties involved in Schiphol Tunnel (Inspectorate of Security and Justice, 2009, p. 62)

The Schiphol Tunnel fire case was selected for several reasons. First, it is an operation where the basic response forces were engaged (Police, Fire department and Medics). Due to the location of the incident, Schiphol Airport Authorities and Federal Police were involved too. The Schiphol fire case was good example to show clearly how coordination-clusters emerge. In addition, the incident time frame is well defined and documented. It starts first with detecting the fire and it ends with a sign "fire under control," all of which takes place within approximately 1 hour. Finally, during this period the interactions between the organizations are documented in detail in a public inquiry report (Inspectorate of Security and Justice, 2009) that describes the emergency response from three perspectives, which enhances the validity of the research.

4.2.1 The Crisis Response Network and Involved Organizations

The incident involved the following organizations and services:

- Rail Traffic System
  - ProRail (roadway provider, infrastructure manager, emergency organization rail)
  - NS Passengers (carrier, station staff)

- Rescue services
  - Fire
  - Police
  - GHOR / Ambulance Services
  - Amsterdam Airport Schiphol

Table 20, lists the different organizations and the corresponding units engaged in the response operations. The table also lists the Color Code and abbreviation of those units.

Organization	Color code	Unit	Abbreviation
Schiphol Airport	Yellow	Amsterdam Airport Schiphol Employees	AAS
Schiphol Airport	Yellow	Airport Fire Officer	AFO
Schiphol Airport	White	Airport Medical Services	AMS
Schiphol Airport	Orange	Coordination Center Schiphol	CCS
Region Kennemerland	Orange	Dispatch Center Safety, Region Kennemerland	DC_SR_K
Fire Services	Red	Fire engines	FE
Fire Service	Red	Fire Fighters Head Officer	FF_HO
Fire Service	Red	Fire fighters Officer	FF_O
Royal Mounted Police (RMP)	Blue	Royal Military Police, District Amsterdam	KMar
Royal Mounted Police (RMP)	Blue	Royal Military Police Control Room	Kmar_CR
Police	Blue	National Police Services Agency in Driebergen	NPSA
Railway Police	Blue	National Railway Police	NPSA_RP
NS Rail	Yellow	National Railway Command Center	NS_SC
NS Rail	Yellow	National Railway service personnel	NS_Service
Passengers	Yellow	Passengers	PSGR
ProRail	Yellow	ProRail Back Office	ProRail_BO
ProRail	Yellow	Emergency Operations Coordinator	ProRail_EOC
ProRail	Yellow	Rail Traffic Controller 1	RTC 1
ProRail	Yellow	Rail Traffic Controller 2	RTC2
ProRail	Yellow	Switching & Report Center	SRC
ProRail	Yellow	Switching & Report Center Technician	SRC_Technician
NS Rail	Yellow	Train driver(s)	CTxxxx

Table 20. Abbreviation and color code of participating organizations in the Schiphol Fire response operations.

ProRail

ProRail is responsible for the route control at Schiphol. The signalman is a control center station to Amsterdam and features the operating system process line. The dispatcher also has equipment that detects when trains are stopped in the tunnel. If a train stops for more than two minutes by the signalman and the nearest emergency exits are indicated. ProRail also manages the infrastructure and is responsible for the equipment in the tunnel.

Additionally, ProRail also is responsible for handling emergencies. In this emergency organization take all companies in the railway system part. The emergency services are not part of the railway system, but there are agreements and procedures designed to permit joint action. The operational management of each incident handling lies with the General Chief of ProRail Traffic Control. The General Chief coordinates and monitors the consistency and effectiveness and is the contact for the emergency services. General Chief of ProRail Traffic Control (RTC) is the coordinator in case of an emergency in the railway system.

NS Rail (NS Reizigers)

NS Passengers is the carrier of passenger trains in the Schiphol tunnel present at the time of the disaster and the employer of the staff (drivers and conductors) on the trains. It is the entity that runs the trains for the Schiphol tunnel area.

Station Staff

At the station Schiphol Airport is a division of NS Rail, Tickets & Service. This takes care of the ticket in the station of Schiphol Plaza. They also provide information to travelers in the hall as well as on the platforms. The staff belongs to the NS Rail Company.

Fire department (Brandweer)

In combating a disaster in the Schiphol railway tunnel is the operational management of the assistance in the chief officer of the fire brigade. He acts on behalf of the mayor and coordinates the efforts of all the emergency services. The Schiphol area and the Municipality of Haarlemmermeer have an agreement of shared responsibilities in the Schiphol area. This agreement is ensures that the performance of the fire services in the catchment 'Schiphol' is performed by (the airport fire brigade) Schiphol, under the ultimate responsibility of the municipality of Haarlemmermeer. The chief officer of the Fire Department responsibility is to coordinate with the other parties in case of a disaster in Schiphol. He acts on behalf of the mayor; therefore he coordinates the overall emergency response services.

Fire department – Schiphol Airport

Schiphol Airport fire department provides for the implementation of the fire mission two fire engines and its own Public Service. The Airport Fire Officer (AFO) is the command in charge of the airport fire brigade. In case of an event, the AFO is responsible for the resource control until the arrival of the Haarlemmermeer fire fighters. In case of emergency there are two sides involved:

- The Netherlands Schiphol Tunnel Authorities
- Haarlemmermeer Municipality and

Fire brigade of Haarlemmermeer

It provides support in case of incidents on the Schiphol area. Duty Offices and Chief Public Service are in charge of coordinating the efforts with other forces in case of incidents. This fire brigade provided one or more fire engine and support units.

Fire brigade of Schiphol Airport

The fire brigade of the Schiphol Airport provided 2 engines and support units. Airport Fire Officer (AFO) is responsible until the arrival of firefighting units from the Haarlemmermeer Brigade.

Police

KLPD (Division Railways)

The Railway Police is responsible for railway safety and on trains. In the context of disasters within and near the railway transport system would alert the monitoring center (DOC) of the KLPD to the emergency services.

In consultation with the regional police forces, the Railway Police is also responsible for policing at five so-called mega stations:

- Amsterdam Central Station
- Hague Central station
- Rotterdam Central Station
- Utrecht Central Station

The National Police Agency Division Railways can be the gatekeeper for the emergency services and the General Chief of ProRail. The KLPD is responsible for 5 stations and the railway police also responsible for safety near the railway system; they generate the alerts for the monitoring center (DOC) of KPLD. The Chief officer is the coordinator with the General Chief of ProRail

Royal Military Constabulary (KMar)

The Royal Military Police District Schiphol (KMarSpl) performs at Schiphol Airport. The KMarSpl's responsibilities for maintaining public order and assistance. In the event of disasters within the airport area, the control room of KMarSpl alerts departments and officials in accordance with the emergency plan.

GHOR / Ambulance Services

GHOR Kennemerland

The aim of the Medical Assistance in Accidents and Disasters (GHOR) is to realize that health care, under the direction of public administration can seamlessly scale up daily to scale (acute) care and that healthcare organizations involved might occur as cohesive care chain so that the victims of disasters and crisis optimum care can be provided. The ambulance services within the safety Kennemerland provide ambulance and emergency first aid in the region, including the service area of Schiphol.

Amsterdam Medical Services

Airport Medical Services (AMS) is a joint venture of KLM Airport Services BV and Schiphol Netherlands BV. The AMS includes both the Medical Service Schiphol and KLM Travel Clinic and they are located at Amsterdam Airport Schiphol. Core activities include emergency first aid and ambulance services. For this purpose, the AMS owns ambulances. Airport Medical Services (AMS) provide medical assistance for the area of the airport and in case of emergency in the Schiphol area too.

Amsterdam Airport

Control Center

The Control Center is involved in the event of disasters within the airport area. The control center is an operating division of Aviation / Passenger Services (A/PS). Under the service package includes activities such as handling calamities, fire alarms, emergency calls, etc. The control center job is to alert services and officials in case of an emergency. Control center of Aviation and passenger Services (A/ PS) it is responsible to respond in case of emergencies like fire alarms.

BHV AAS

Amsterdam Airport Schiphol has an emergency response organization, which may or may not coincide with the emergency response organizations of the various companies at Schiphol (called local BHV's) deployed to incidents. In total, the emergency response of AAS has about 400 BHV. About 100 of them are organized in six mobile teams. These teams are available 24 hours per day. Unit leaders control the BHV AAS. BHV Amsterdam Airport Schiphol (AAS) is an emergency response organization. It is organized in 6 teams of 100 people and with volunteers there are 400 available approximately.

4.2.2 The Fire Incident Timeline

The incident progress is listed in Table 21 with a time interval of T_x = 10 min. Table 21 also represents the coordination matrix of the incident. The table contains details about each time slot

T_x such as names of organizations engaged in the response operations during T_x. In addition to the names, the Table contains a list of the units involved from each organization and the actions taken during T_x.

Following the research method steps, the data from the coordination matrices were used to construct response networks for each T_x. A specialized software package, Pajek (http://vlado.fmf.uni-lj.si/pub/networks/pajek/), was used visualize the response networks and perform calculations of metrics like degree of centrality and community detection (using Louvain method). The series of Figures (54 – 60) shows the results from the previous step. The networks are based on the coordination matrix in Table 21 where T_x= 10min.

Finally, for both cases the Elbe flood and the Schiphol fire, we use the information form both coordination matrices and SNA into a modeling form that can describe the coordination flow in the response operations. In order to perform these operations, a software package, CPN Tools (http://cpntools.org/), was used to construct the model describing the flow in the response network. Those models will be presented in details in the upcoming the "Results" chapter.

Time	Organization	Unit(s)	Actions
T_{init} (Around 17:25)	/	/	• Due to accumulated dirt, a fire sparked in a cable duct inside the Schiphol Tunnel
T_0 (17:30-17:39)	NSs Rail ProRail	ProRail, TD3156, RTC1, RTC2	• Information exchange, train drivers and railway controllers regarding a burning smell in the tunnel.
T_1 (17:40 – 17:49)	NS Rail, ProRail, Schiphol Airport, Fire Department, RMP, Medical Services	CCS, DC_SR_K, Kmar_employee, KMar_CR, KMar_O, Schiphol_employee, AAS_DMS, AAS_BHV, AMS, AAS_HD, AFD, AFO, NS_Reizogers, ProRail_EOC, FE340, FE341, CT3963, RTCs, CT5763, RTC2, CT756, ProRail_BO, SRC, SRC_Technician	• Information exchange, ProRail Back Office NS Rail to report the event of smoke sensed inside the Schiphol Tunnel. • Information exchange, NS Rail report incident the RMP and Schiphol Airport Authorities. • Information exchange, NS Rail to report the incident to the Fire Department. • Platforms evacuation, RMP and Schiphol authorities to evacuate Schiphol platforms. • Train evacuation, ProRail and NS Travellers to warn public and evacuate trains from the tunnel. • Provide medical assistance, ambulance on site to inspect location of fire.
T_2 (17:50 – 17:59)	NS Rail, ProRail, Schiphol Airport, Fire Department, RMP, Medical Services	CCS, DC_SR_K, KMar_CR, KMar_O, NPSA_PR, NPSA_Driebergen, AAS_OM, AAS_BHV, FF_HO, FF_O, FE340, FE341, NS_Reizogers, ProRail_EOC, RTC2, CT3558, CT2169, CT756, ProRail_BO, SRC, SRC_Technician, Passengers	• Halt traffic and train evacuation, ProRail and NS Travellers to warn public and evacuate trains from the tunnel. • Coordination between Fire department and NS Passengers and ProRail to evacuate platforms. Fire fighters needed permission to enter the tunnel • Provide medical assistance, ambulance and inform hospitals in preparation for evacuation. • Information exchange, Schiphol Airport Authorities and ProRail regarding updates of the operations. • Technical assistance, ProRail technician were sent in to investigate area where the malfunction and burning smell were reported.
T_3 (18:00 – 18:09)	ProRail, Fire Department, RMP, Medical Services	DC_SR_K, AFO, FE340, FE341, FE344, AMS, ProRail_EOC, RTC2, SRC, SRC_Technician	• Information exchange, ProRail, Fire department, medical service to updated about the progress of the operations • Technical operations update, technicians investigate and

Time	Organization	Unit(s)	Actions
			report back to ProRail General Manager. • Train evacuation and platforms, coordination between ProRail Staff, ProRail Head Office, Control Center and Fire fighters to enter the tunnel and approach the trains to evacuate passengers.
T_4 (18:10 – 18:19)	NS Rail, ProRail, Schiphol Airport, Fire Department, Medical Services	DC_SR_K, AFO, , ProRail_EOC, ProRail_BO , RTC2, CT756, CT2169, CT3558	• Information exchange, Technician report that the fire was gone and tunnel safe to resume operations • Evacuation platforms and trains halt the operations and open the tunnels. • Restore service, ProRail to allow trains to leave the tunnel. • Passengers' evacuation, NS Rail operators handled the panicked crowds in the trains and at the platforms.
T_5 (18:20 – 18:29)	ProRail, Fire Department, and Schiphol Airport	DC_SR_K, AFO, FE344, FE341, ProRail_EOC, RTC2, CT756	• Information exchange, tunnels are safe and fire engines can clear the tunnels • Information exchange, ProRail to updated Schiphol Airport Authorities.
T_6 (18:30 – end)	Schiphol Airport, Fire Department, and control center	DC_SR_K, AFO, FE344, FE341	• Information exchange, report to RC that tunnels are clear and trains can operate now. • Information exchange, tunnels are free and ProRail can take back operations. • Information exchange, end the emergency and announce the end of the incident.

Table 21. Coordination matrix for the Schiphol Tunnel Fire incident with 10 min intervals.

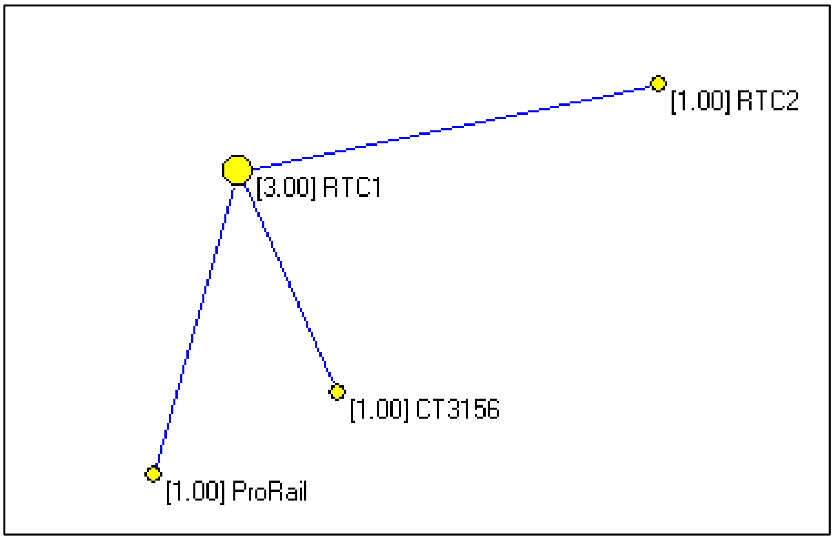

Figure 54. Response network at T_0 (17:30-17:39)

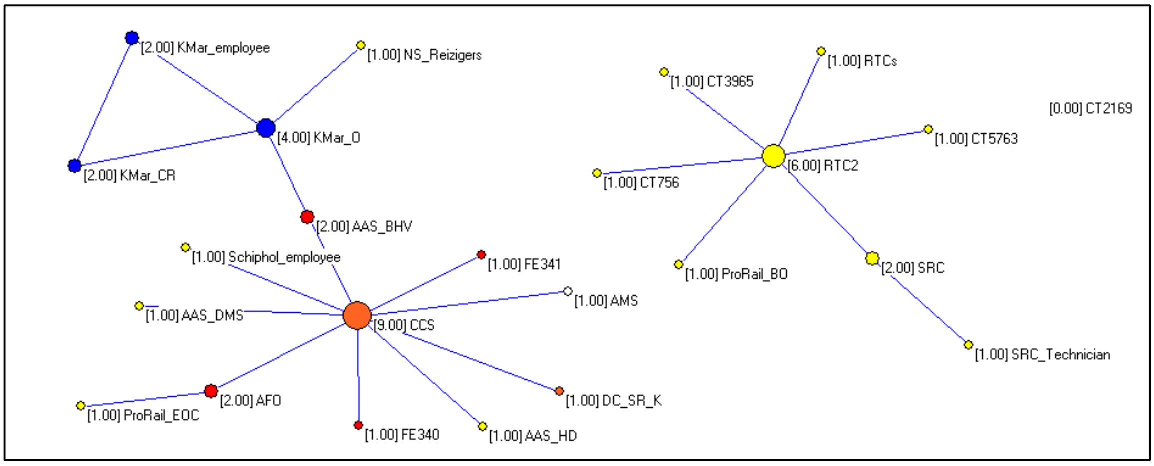

Figure 55. Response network at T_1 (17:40 – 17:49)

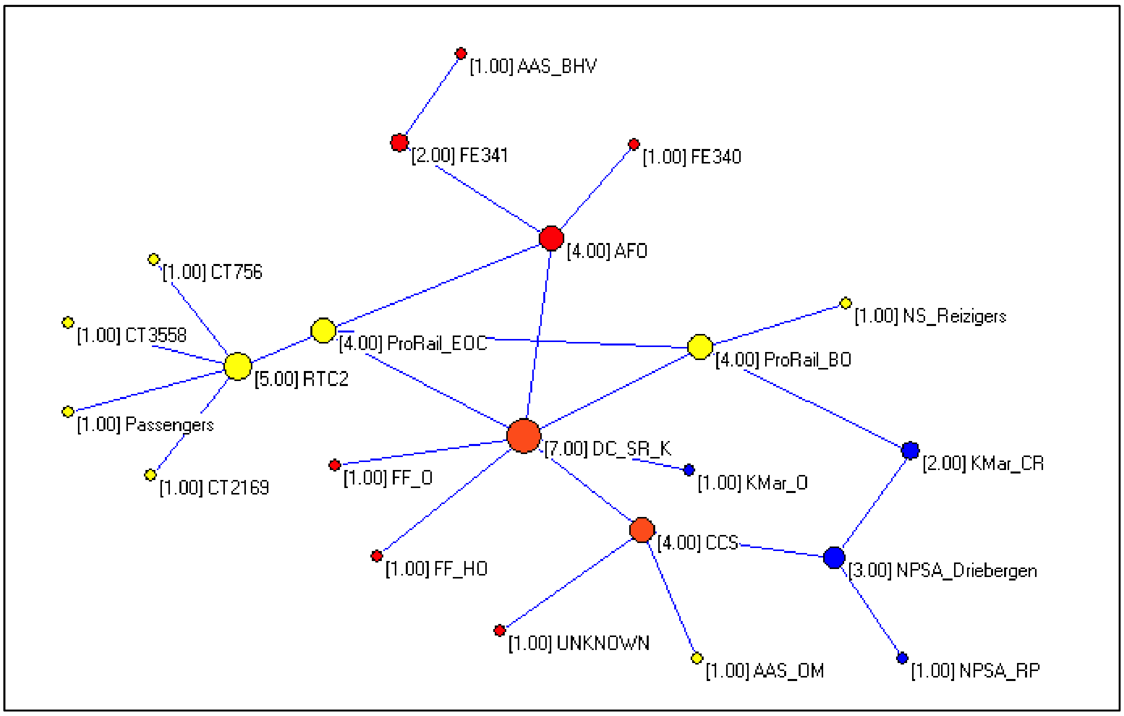

Figure 56. Response network at T_2 (17:50 – 17:59)

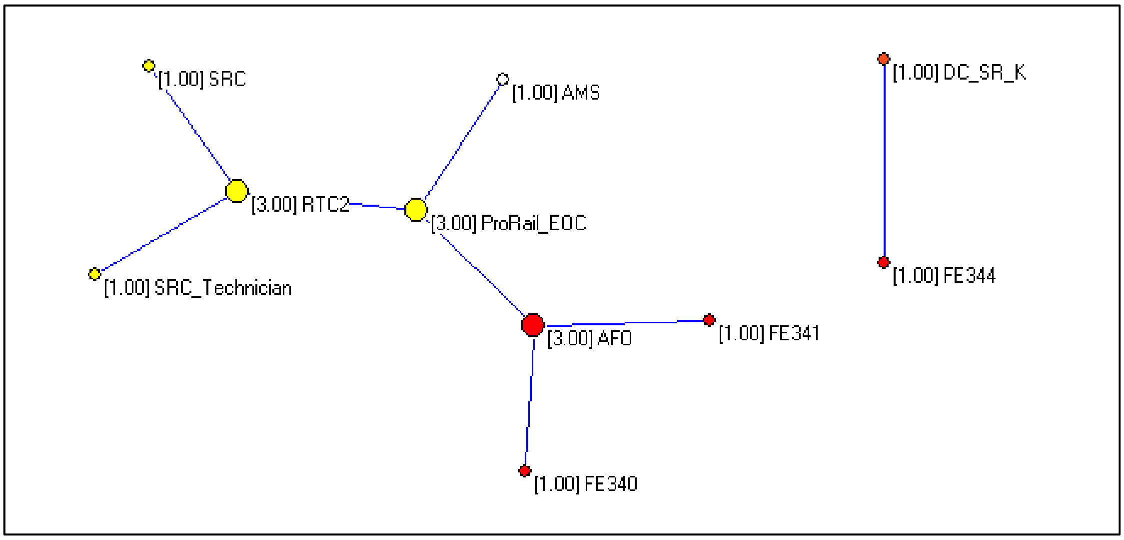

Figure 57. Response network at T_3 (18:00 – 18:09)

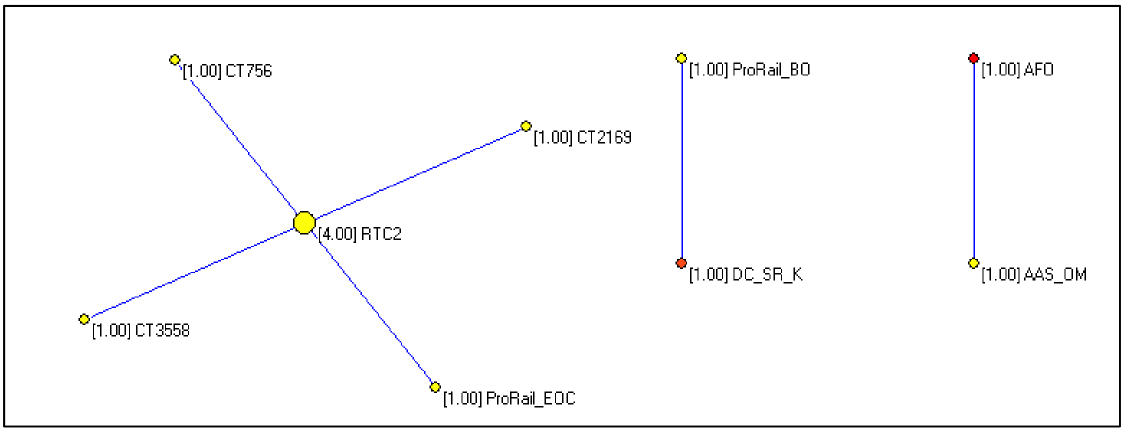

Figure 58. Response network at T_4 (18:10 – 18:19)

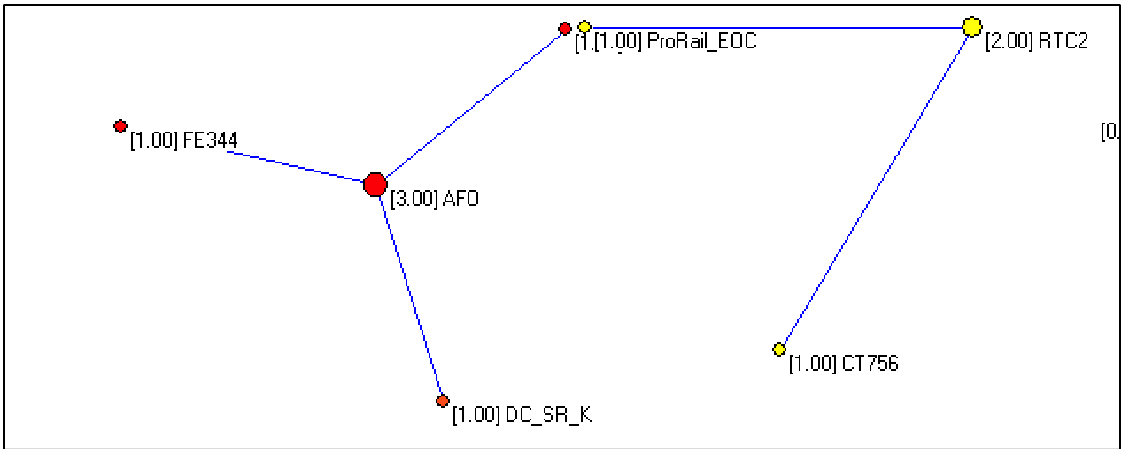

Figure 59. Response network at T_5 (18:20 – 18:29)

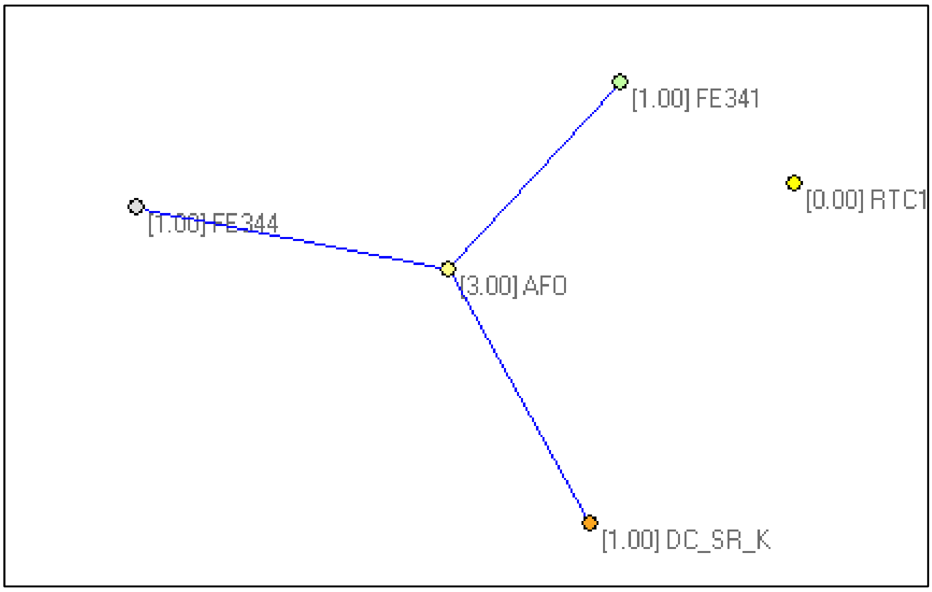

Figure 60. Response network at T_6 (18:30 – End of Incident)

4.3 Summary

The goal of the research is to propose a method for examining disaster response operations based on a network-governed structure. The Elbe River flood case study was chosen because it involved a diversified group of responders with different levels of authority. The Elbe River Flood case had a complex environment that involved a wide spectrum of intraorganizational and interorganizational relationships. The response operations ranged from activities around a core team lead by an incident commander to multilevel cross-organizational collaboration actions. Therefore, the case provided a rich environment for the research goals associated with interorganizational coordination in disaster response networks. The 2002 Elbe River Flood was a sample for analyzing response operations on the macro-level.

The 2009 Schiphol Tunnel Fire case study was chosen to examine the response operations on the micro-level where response operations involved merely a core team and basic 911 in North America (or 112 in Europe) responders. The case was a demonstration of the repetitive pattern associated of coordination-clusters formation in disaster response operations.

In summary, the two cases examined in this research provided fertile testing grounds to the novel approach proposed in this thesis. The Elbe Flood case tested the methods for its ability in handling operations with high levels of complexity and large numbers of actors. While, the Schiphol Tunnel Fire case tested the accuracy of the method in analyzing coordination dynamics in an operation associated with a small-scale incident. The results of the analysis will show the method’s capabilities in having a local view of coordination dynamics inside teams in relation to their global position in a response network.