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

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6 Discussion

In this chapter we seek to reflect upon the results found in this research in relation to the questions posed by the researcher. The main goal of the research was to understand the specifics of coordination in disaster response networks to examine coordination evolution in those networks. In order to fulfill this goal we uncovered an existing gap regarding the absence of sufficient tools to examine coordination in networked settings. As a result of those circumstances, the research led to developing a method to provide an integrated view of coordination evolution within networks. In the next sections we shed light on those findings and on the research limitations.

6.1 Interorganizational Coordination Dynamics in Emerging Response Networks

In this research we focus on addressing the phenomena of networked-coordination and emerging coordination-clusters in disaster response operations. This phenomenon is recognized by researchers in the disaster management field (Topper & Carley, 1999; Comfort & Haase, 2006; Butts, Acton & Marcum, 2012; Boersma, Passenier, Mollee & van der Wal, 2012; Boersma, Comfort, Groenendaal & Wolbers, 2014; Boersma, Fergusson, Groenewegen & Wolbers, 2014). Despite existing research, we still witness a gap between official disaster management systems and the reality of response operations. Such a gap resulted in the absence of disaster response plans that reflect the actual dynamics taking place inside response operations. The reason behind such a discrepancy is the insufficiency or almost absence of a methodology capable of analyzing the dynamics of networked-coordination in operations taking place in such high-risk and unstable disasters and emergencies environments. In order to address the research gap, we posed two questions:

RQ1: What are the patterns of interorganizational coordination in disaster response operations?

RQ2: How does networked coordination evolve in disaster response operations?

Due to the complex nature of the problem's context, we adopted a mixed methods approach to answer the research questions (Johnson & Onwuegbuzie, 2004; Johnson, Onwuegbuzie & Turner, 2007; Creswell, 2013). Using the mixed methods research enabled us to combine qualitative and quantitative techniques to address both research questions: (1) patterns of coordination and (2) dynamics of networked-coordination within uncertain and high-risk contexts. The combination of different methods provided a multi-dimensional analysis of coordination flow by showing how units or teams work together as a network during the disaster response operations.

In the previous chapters we (1) established the argument of a research gap in understanding coordination dynamics in disaster response networks; (2) developed a method to analyze coordination dynamics in disaster response networks; and (3) presented the results of applying our method to construct a network-based dynamic model describing coordination evolution in disaster response operations.

The first part of the findings comes in answer to RQ1 where we were able to understand the characteristics of emerging structures inside coordinative response networks during disaster response operations. The use of coordinating theory (Malone, 1987; Malone 1988; Malone & Crowston, 1990; Malone, Crowston, Lee, Pentland, Dellaroca, Wyner, Klein, 1999) in combination of SNA and community detection techniques (Fortunato & Barthelemy, 2007; Blondel, Guillaume, Lambiotte & Lefebvre, 2008; Lancichinetti, Fortunato, Radicchi, 2008; Fortunato, 2010; Aynaud & Guillaume, 2010; Lancichinetti; 2013) helped to uncover some of the coordination patterns in disaster response networks. Those patterns can be summarized as follows:

1. Coordination in response operations tends to shift away from the planned response systems towards function-based coordinative networks. Coordinative networks form based on tasks required during disaster response operations.

2. Coordination dynamics within those coordinative networks take the shape of what can be best described as a coordination-cluster. The coordination-clusters are structures formed by units performing various tasks during disaster response.

3. Coordination-clusters can take two forms:

    a. Homogenous clusters that reflect the intra-organizational coordination dynamics in a response network.

b. Heterogeneous clusters that reflect the inter-organizational coordination dynamics in a response network.

4. Coordination hubs or influencers appear and disappear inside the emerging coordination-clusters in response to tasks performed during the response operations. Their position inside the network depends on the evolution of disaster events rather than the planned ICS. Those hubs communicate information between the clusters and the network beyond communicating information inside the clusters themselves.

The second part of the findings comes in answer to RQ2 where we were able to formulate networked-coordination in disaster response operations. The resulting model described the dynamics of coordination in network settings. The process of formulating networked-coordination was made possible by using hierarchical CPN's (Kristensen, Christensen, Jensen, 1998; Jensen, Kristensen, Wells, 2007; van der Aalst, Stahl, Westergaard, 2013). The model completed the analysis by providing information about the transitions happening inside disaster response networks. Modeling coordination in disaster response networks captured some important features of networked-coordination that can be summarized as follows:

1. The hierarchical CPN model of both case studies showed that coordination is happening simultaneously at multiple levels. Coordination took place within two types of hierarchical CPN:

    a. A high-level CPN describing the coordination transactions that are taking place over the different levels of disaster management authorities. The high-level CPN served as a container by holding sub-models of ongoing operational tasks.

    b. A low-level CPN describing the coordination transactions that are taking place inside the emerging coordination-cluster in a disaster response operation. The CPN's modeled sub-processes of tasks carried out the actors of a disaster response network.

2. The two-tier CPN model described coordination dynamics within both administrative and operational contexts. Such a model was used to describe the seamless integration of sub-processes into a multi-layer response operation.

3. A multi-tier CPN model provided a flexible modeling canvas for testing different combinations of sub-processes and different scenarios of coordination flows.

4. CPN modeling enabled the tracking of resource consumption in the response network and the monitoring of conditional transitions in the operations over a multi-tier system. Such capabilities can provide trouble-shooting tools for existing disaster response systems.

5. The capacity of CPN modeling, which describes the global context of response operations helped to capture the lack of a common operational picture (COP) during response operations. Based on the model, the lack of COP was the result of having multiple information sources feeding the network in both global and local contexts.

6. The CPN model captured information transactions and actions that described coordination dynamics inside response networks. The network analysis could not present such transactions.

The research findings extended the capabilities of coordination theory in its application to disaster response operations and to networked-coordination. The outcome of the research was an expansion of previous work by other scholars who combined SNA techniques and some dynamic systems analysis (Topper & Carley, 1999; Comfort & Haase, 2006; Butts, Acton & Marcum, 2012; Boersma, Passenier, Mollee & van der Wal, 2012; Boersma, Comfort, Groenendaal & Wolbers, 2014; Boersma, Fergusson, Groenewegen & Wolbers, 2014). However, community-detection algorithms were not used efficiently in studying coordination in response networks. The final step to complete the analysis was using extensions of Petri-Nets to capture the various transactions, resources and hierarchies of disaster response networks.

While the main focus was the “response” phase at that stage of the research, a derivative of the method was applied to datasets from the “recovery” phase during 2004 Tsunami disaster in India. The method was adapted to accommodate the operational conditions for long-term relief operations (Weber & Noori, 2016). What was observed is that the network structures in both phases (response and recovery) followed similar patterns of response to events occurring during the execution of operations, such as forming the function-based clusters and witnessing change in the influencer nodes or hubs (i.e. degree of centrality per actor). The procedure followed in examining coordination dynamics in both phases of disaster management cycle. The conformity of the results in both cases helped in validating the proposed approach in analyzing coordination dynamics but not to withdraw general conclusion. The approach still need further testing as explained in the next section.

6.2 Limitations

In this research, we introduced a new approach to examining coordination dynamics in disaster response operations based on a combinations of DES modeling and complex networks. The analysis provided a complete picture of coordination dynamics in response operations along with linkages to coordination process flow and team formation in network-governed structures.

Despite the insights provided by the work presented in this thesis, we realize the need to validate the method against operations taking place within different types of disaster and within different political systems in order to learn and netter understand. Due to such limitations, we cannot generalize the outcomes to describe coordination dynamics in all types of disaster operations.

Other research limitations were the result of difficulties in accessing data related to disaster operations archived by official channels. Due to liability concerns, published reports and press releases do not document fully the behaviors of units involved the incidents were ICS's were circumvented. Unfortunately, it was difficult for the researcher become embedded in ongoing response operations due to lack of resources and budget constraints. Therefore, main sources or data were historical reports and past status reports, which already were publically available.

As a result of such limitation, relying solely on historical past reports can produce biased result or skewed towards ICS rather than emerging structures. Therefore, in order to fill in the gap, it is necessary to engage the researchers and academics in participatory field research.

One more limitation was the language factor since the researcher does not possess full knowledge of the language (German, Dutch) in the countries where case studies took place. Nevertheless, researcher spent a secondment period of 10 months at the German Armed Forces University / Universität der Bundeswehr München in Germany in order to overcome some of the limitations mentioned above.

Another issue that can be considered a limitation of the present work is community engagement. Despite the rowing role of communities in disaster management, the body of work in this thesis focuses mainly on the organization-to-organization rather than organization-to-community coordination dynamics. Despite the growing importance of local communities in disaster management, the role of local communities was outside the scope of our thesis due to two reasons:

1. The scope of the work that mainly focuses on inter-organizational coordination during disaster response operations. However, community-organization coordination dynamics are crucial to the execution of operations, especially given current advancements in information technology and social media.

2. The lack of well-documented reports of community engagements that were accessible for examination at the time. Language become another factor to be considered.

The second point highlight one of the shortcomings of using *past* reports to analyze disaster response operations where community role or use of social media is not captured.

Therefore, marginalization of the role of communities was not intentional. On the contrary, a preference was made to narrow and refine the scope of the research to an organization's engagement and not to provide a detailed examination of the role of local communities in disaster response.

Nevertheless, in the Weber & Noori (2016), the work examined the role of local NGO's and the local community engagement in long-term disaster recovery operations. When community-organization coordination was examined, a modification to the methodology was necessary in order to accommodate the complex nature of the communities, local NGO's and global organizations. Coordination theory was not applicable in this case because it didn't fit in the context. Instead, another approach was applied. Developed by (Weber, 2016) a combination of Actor-Network Theory and Critical Incidents were applied in order to extract the specifics of coordination dynamics in the network. The outcome of the Weber & Noori (2016) study showed the role of local NGO's and local communities in the success of recovery operations when obstacles were present during the execution of the rehabilitation projects.

7 Conclusion

In the previous chapters we presented a proposition of a novel methodology to analyze coordination dynamics in disaster response networks. We demonstrated the capabilities of the proposed method by examining two case studies of disaster events. The method included a combination of qualitative and quantitative research to examine the selected case studies and to build a replica of the response operations following a network-based approach. As the time factor is crucial to disaster management, time and event-based analyses were conducted in order to model the evolution of the response operations.

There are two folds to the research outcomes; *first* is discovering the patterns and modeling to the dynamics of networked-coordination in response operations, and *second* is developing a novel approach to studying the dynamic nature of coordination during disaster response networks. The ability to recognizing task-based coordination-cluster and homogeneity state of those clusters helped us to answer the research question regarding patterns of interorganizational coordination during disaster response operations. The combination of time-based network analysis and event-based analysis contributed to answering the research question on coordination dynamics and the evolution of disaster response networks.

The Elbe River Flood and the Schiphol Tunnel Fire case studies showed us examples of emergency situations where the first responders needed to act promptly to situations while disaster management authorities failed to respond at the same speed. The delay by disaster management authorities led to forming a response network that shifted away from the planned structure of the ICS. The response network evolution was based on the tasks needed for the response operations based on resource availability. One of the goals of the research was to provide a proof of existing patterns of new emerging hierarchies in response networks. The structure of those hierarchies is not simply chaos. The ICS help to provide a baseline for the newly spawning structure. Therefore, in understanding the patterns of such "chaos", we can integrate those patterns in the planning and execution in the modern disaster management operations. An example of that, becomes evident in the promotion of function-based planning. Understand the factors behind the formation of the coordination-clusters would help to update existing plans and provide better reasoning in decentralizing the operations.

Needless to say, disaster events are unique in their developments. One disaster model may not be applied to another. Therefore, actions executed during several response operations may produce different results depending on the needs and the reactions of other stakeholders in the network.

Network formation was not random but did not follow the planned hierarchy. In the task-based response network, we were able to recognize a multi-tier network of collaboration among the different parties that inherited the nature of organizations forming the clusters in the response network. Some clusters followed the organization hierarchy and others forget their own.

The results found in this research showed that hierarchies did not hold together in unstable environments such as disaster and emergencies. Sudden changes in environmental conditions caused pressure on the framework of the planned disaster response operations. This pressure turned the framework into an obstacle rather than a guideline to facilitate collaboration. Despite the fact that initial networks had higher scores in modularity, yet this score could be deceiving given the individual structure of a single organization not because of the overall network. Having lower modularity scores for the response network shows the failure of the hierarchical plans and the shift towards the task-based structure.

In addition, the purpose of studying coordination dynamics in response networks is to identify the deadlock, starvation conditions in response operations. The Petri Net model plays an important role to discover bottlenecks caused by lack of resources, occurrence critical incidents or competition. SNA and clustering helped in understanding the grouping dynamics, while the Petri Nets helped in examining the process flow and resources distribution. For example, the Petri Net model of the overall operations captured the common operational picture problem, while the network did not. Therefore, the optimization of process flow using the Petri Nets would help managing resource distribution and sharing. Yet, optimizing the Petri Nets was outside the scope of the work at that stage of the research. The process of optimizing the Petri Nets models would require further investigation to extract more information about the resources used and the tasks performed. Another consideration would be the timed Petri Nets because we would embed more details and extract performance measures from modeling different sub-tasks.

As mentioned earlier, we cannot generalize the results seen in this research for all types of disaster management systems (i.e. ICS) and for all types of disasters due to political and natural conditions. Therefore, there is a need to examine more cases within different political systems and other types of disasters in order to learn from them and understand more about the behavior of their organizations during disaster response operations. However, the proposed method can contribute towards creating a tool for academics and practitioners to help in the development and planning of crisis management systems. The research outcomes contribute to our understanding of how operations are conducted and how to improve existing systems and integrate new technologies, new strategies during future disaster response systems.

In the next sections we are shedding light on some theoretical and practical implications of this research. Finally we discuss some potential opportunities to expand the research in future.

7.1 Theoretical Implications for Disaster Management

We examined the emerging network-based coordination structure in disaster response operations and compared the structures to the existing ICS systems. The theoretical contribution of the research outcomes can be considered the first step to help us examine emerging interorganizational coordination in network-based structures. The proposed framework provides a dynamic perspective of coordination-clusters and coordination evolution in disaster response networks. The method can be considered a step forward to develop a standard scientific tool for analyzing coordination processes in network-based complex systems. The method can potentially contribute to broadening the empirical basis for planning and management of complex disaster response operations.

This research work contributes to the fields of *coordination science* by expanding coordination theory and its applications to the field of disaster management and to adapting the theory to study coordination in networks. In the field of social network analysis and complex networks, the research expanded on the Louvain method of community detection with a new application field (i.e. disaster management) and demonstrated the ability of the method to detect coordination-clusters in response operations. Another contribution is to the field of dynamic complex systems was the ability to use CPN in order to map task-based coordination-clusters into sub-models, which extended the capabilities of CPN's in modeling networked-coordination during responses networks.

Moreover, the outcomes contribute partially to the *operational research* field with the new approach for analyzing coordination dynamics. The ability to disassemble the operations into sub-tasks using network analysis while creating a dynamic model with Petri Nets provided a realistic and dynamic view of the ongoing operations. However, the methodology still needed more refinement n order to perform an optimization for processes and to examine different scenarios for finding best routes to execute different tasks.

However, in the crisis management context, the methodology proposed is considered a new approach to analyze ongoing dynamics in disaster management operations. The method was applied to operations taking place during a response phase. The method was extended in Noori Weber (2016) to operations during the recovery phase. The goal was to analyze the behavior of organizations in executing tasks during the recovery phase in long-term rehabilitation project. Yet the method needed some modification in order to fit with the environment of the analyzed operation.

In addition, the method was also applied in a different context, Product Development. The same method was applied to analyze processes related to mechanical parts design and product-line (Chahin, et al., 2016). In , another flavor of the method was applied to redesign processes related to product development and team organization in the organization.

Furthermore, the method holds another potential in innovation management for understanding communities especially in open source software development field and for analyzing innovation dynamics. However, the method will need altercations based on the context but also the core of using network analysis (i.e. clustering) and DES (i.e. Petri Nets) still essential to the process.

7.2 Practical Implications for Disaster Management

From the practical perspective of disaster management, it is assumed that disasters and emergencies can be contained and lives saved by applying a strict centralized command structure (Quarantelli & Dynes, 1977). The ICS hierarchical approach had proven insufficient to handling intensive disaster events (Dynes, 1994, Quarantelli, 1997; Comfort, 2007; Kapucu, 2009). The presented research provides insights of a clear transformation from such a strict centralized command structure to the emerging structures of coordination-networks in response operations.

The results showed a great deal of resilience in the emerging networks' behavior compared to the classical strict command and control systems. The proposed framework model can potentially serve as a planning support tool for practitioners in order to test different types and scales of disasters. The model permits parametric variations to test the effectiveness and efficiency of organizational and management options.

The ability of identifying roles of influential nodes in an emerging response network is an outcome that contributes to design a better coordination framework based on a flexible governance model in order to enable cross-organizational collaboration in crisis response networks. The envisioned research outcome should impact the future design of disaster response plans, which currently are manifested by the hierarchical ICS protocol.

7.3 Future Work

As mentioned in the limitation section, there are several potentials for improving and extending the work presented in this thesis. One venue of extending the current work is to include the human factors to examine coordination dynamics in disaster response networks. At earlier stages of the research, we considered following that path researching parts of the network as rational actors where human factors like trust, authority, and background knowledge are included as core to the analysis. However, in order to continue on this path, an approach would involve the utilizations of different methods for generating networks such as Agent Based Modeling and Neural Networks and in combination with clustering. However, generating a model based on those methods would be very sensitive to different factors and data accuracy is crucial. Therefore, the role of participatory field research become important to the accuracy of the results and data collected. Unlike depending on historical reports, the access to the field will lend an eye to the researcher to observe the dynamics in real-time and without any proxies.

Another extension to the current work is to develop the current model to automate the process of generating the coordination-networks using intelligent textual analysis and algorithms for generating hierarchical random network. Yet, this approach will need a rich data set to train the system in order to generate accurate networks.

In addition, the core method of network analysis and DEA has the potential for applying the method to other response operations with different types of disasters such as humanitarian disasters or malicious attacks. Another venue is to examine response system within different political systems to understand the effect of administrative and logistical factors on the behavior of organizations during disaster response operations.

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