Conclusions and reflections

6.1 INTRODUCTION

The aim of this thesis was to gain a better understanding of the coordination and communication challenges between the different control centres during the management of large-scale, complex disruptions. In the last couple of years there have been several 'out-of-control' situations when nobody really knew what was going on and what should be done, resulting in the uncoordinated management of large-scale, complex disruptions. While there has been a lot of academic research into supporting rescheduling activities during a disruption, far less attention has been paid to the difficulties encountered when coordinating these activities. This led to the following main research question of this dissertation: "*What explains the coordination breakdowns between the control centres in the Dutch railway system during the management of large-scale, complex disruptions?*" This thesis examined disruption management practices and associated coordination challenges in the Dutch railway system and compared it to four other European rail systems. In this final chapter, the research's main conclusions are presented and reflected upon. Section 6.2 will first provide a summary of the main findings of the four studies. Section 6.3 presents the overall conclusions on coordination practices in the Dutch railway system. Section 6.4 then focuses on the practical implications of the findings. Sections 6.5 and 6.6 offer a methodological and theoretical reflection. This chapter ends with some concluding remarks in Section 6.7.

6.2 SUMMARY OF THE MAIN FINDINGS

This section summarizes the main findings of the four studies in this dissertation.

6.2.1 Using DNA to investigate disruption management

In *Chapter 2* of this dissertation we sought to answer the following research question: "*How can DNA help to investigate coordination between the geographically distributed teams involved in the management of a railway disruption?*" Control centres must share up-to-date information in order to be able to quickly respond to disruptions and to align their activities. However, efficient and timely communication is not without its difficulties when operating in a dynamic and complex environment. A good understanding of the structure of the network of actors involved in the disruption management process and the flow of information between these actors can help to optimize the response to disruptions. Although Social Network Analysis is a proven technique for visualizing and analyzing networks, it only provides a static snapshot of a network. We therefore suggested Dynamic Network Analysis (DNA) as a valuable tool for taking the dynamics of the disruption management process into account and tested its use on a simulated case of a catenary failure.

First of all, the DNA has shown that the development of a collective understanding of the situation, as well as the formulation and implementation of a contingency plan leads to a considerable information flow between the different operators. *Secondly,* the DNA revealed that during the first phase of the disruption management process train dispatchers and regional traffic controllers play a central role in the lines of communication. The fact that they have to process and distribute a great deal of information, however, also makes them potentially weak points in the network due to the high task demands and the risk of information overload. This is especially problematic for the operators in the OCCR, as the DNA showed that they heavily rely on the information provided by these local operators.

Thirdly, the DNA also displayed that the network's structure is relatively sparse. This means that there are often no direct ties between actors and information therefore has to pass along many actors before reaching the intended recipient. While this reduces the coordination issues associated with unbridled direct mutual adjustment, it also slows down the dispersion of information in the network. This is challenging in a dynamic environment where conditions change fast. Actors thus often have to deal with inaccurate or outdated information. *Finally,* the inclusion of time in the network analysis revealed that operators actually start to manage disruptions without having the full details of the situation. This ties in with the perceived urgency of acting quickly in order to prevent the disruption from propagating. Overall, the first study has shown that DNA is a valuable tool for visualizing and analyzing the disruption management process and that the inclusion of time is important in order to capture the dynamics of the process. However, as the second study has shown, it is also important to look at the content of the information being shared. Simply sharing information does not mean that others will interpret it correctly and that actions will be coordinated.

6.2.2 A mixed-methods approach to understanding a coordination breakdown

The *third chapter* presents an in-depth case study of how a coordination breakdown between the different teams in the Dutch rail system led to the decision to stop the train service at two major stations during rush hour. In this study we wanted to understand: *what was the cause for this coordination breakdown and what explains the difference in response between the traffic control centres of both areas of control*? To answer this research question we combined Dynamic Network Analysis with theories of sensemaking. The mixed-methods approach addresses the need to study both the flows of information and the way this information is interpreted in order to understand the emergent behaviour that follows on from the complex interactions within the network of teams. The quantitative network analysis acted as a first stage in the research to identify key moments and actors in the process, and these served as important starting points for a more in-depth qualitative analysis of how actors made sense of this information.

The analysis showed how the term 'red flag' triggered the operators in the OCCR to frame the situation as a routine procedure, while the track team's aim was to find an improvised way of managing the process. This divergent framing of the situation accumulated over time, leading to inconsistent actions, incorrect assumptions and a lack of effective communication. The DNA showed how incorrect and incomplete information spread rapidly and uncoordinatedly through the network. As a result, actors and teams held different pieces of information and created fragmented accounts of the situation. The lack of a clear understanding of the situation and the following inconsistent actions of teams promoted uncertainty and negative emotions. This eventually resulted in a conflict between the track team and the train dispatchers in area A, when roles became under threat and were even debated. We observed two different responses to coping with the uncertainty: one whereby procedures were strictly followed and which eventually resulted in the decision to stop the train service (area A), and one in which safety concerns triggered improvisation (area B). This study highlighted the risk of blind spots that are the result of a commitment to taken-for-granted frames, such as procedures, labels and routines, which hinder adaptation. In the study we showed the difficulties of re-framing, as frames become reinforced over time and hence contradictory cues are overlooked or ignored. This seems to be of particular concern to distributed teams, as challenges of communication and interpretation are more salient there.

6.2.3 The role of MTS leadership during disruption management

Chapter 4 starts from the premise that there is a need for polycentric control to secure a system's adaptive capacity. Local control centres are needed to quickly respond to disruptions, while leader teams are necessary to synchronize the activities of the local control centres and to obtain system level goals. In this study we wanted to answer the following research question: *"How do leader teams in the OCCR provide leadership during the management of disruptions and which challenges affect their leadership?"* We looked at the role of the teams in the OCCR in preventing the system from falling into the three basic patterns of adaptive failure in complex systems: decompensation, working at cross-purposes, and outdated behaviours, or correcting these failures. The leadership behaviours of the teams in the OCCR were analyzed using the literature on functional leadership in Multiteam Systems. While studies have shown that effective leadership has a positive influence on inter-team coordination and system performance, the study in chapter 4 revealed some important challenges for leadership in a MTS.

First of all, we found that the operators in the OCCR often struggled to adequately monitor the performance of local operators in order to detect if they might need back-up and how this should be provided. But even when there were clear signals from local operators, these signals were not always recognized by the operators in the OCCR as a legitimate need for help. *Secondly,* local operators often did not ask for help or refused the help being offered by the operators in the OCCR. *Thirdly,* while the OCCR was intended as an information hub with an overall understanding of the situation, we found that the teams in the OCCR were quickly confronted with a degraded situation awareness due to inadequate lines of communication between the local control centres and the OCCR. Maintaining a shared situation awareness was further complicated by the pace at which conditions changed. This greatly reduced the possibilities of the teams in the OCCR to orchestrate the activities of the local control centres as the decisions made by these teams were often founded on already outdated information. *Finally,* we noticed a tension between the rescheduling activities of the local control centres and the wish of the teams in the OCCR to quickly implement a contingency plan based on an accurate situation assessment. It was shown that this could lead to an oversimplification of the situation by the teams in the OCCR, whereby contingency plans were implemented that did not match the operational conditions.

6.2.4 Differences and similarities in European railway disruption management

In *Chapter 5* we presented an international comparison of the disruption management structures and practices of five European countries (Germany, Denmark, Austria, Belgium and the Netherlands). A thorough literature search showed that there was no comparative research into the disruption management structures and practices of European railway systems. That's why we asked ourselves the following question: *"What different types of structures and practices of railway disruption management have been developed in European railway systems?"* The comparison focused on the trade-offs identified in the first chapter of this dissertation, that of centralized vs. decentralized structures and anticipation vs. resilience.

To compare the countries we derived several items from various strands of literature for both trade-offs. We began our comparison by describing the roles, structures and lines of communication in each country. This was followed by a description of each item, which revealed important differences between the countries. In order to show how each country performs on both trade-offs we assigned scores to each of the items and then took the average scores of all items to show how the countries compare in terms of how they perform on both trade-offs. We found two clusters of countries. First of all, Austria and the Netherlands are both moderately centralized and of the five countries, they rely the most on a formalized approach to deal with disruptions. Belgium and Denmark form the second cluster as they combine a centralized structure with an emphasis on resilience. Germany proved to be a bit of an outlier in our comparison due to its decentralized structure, which seems to relate to the size and complexity of the system.

Although rail systems are essentially quite similar in what they do (transporting passengers and goods) and how they do it, we nonetheless found important differences between the countries studied and therefore the study shows that there is not one best way in which to organize rail disruption management. Only by comparing practices does the range of possibilities become apparent. As such, comparative studies help rail infrastructure managers and train operating companies to reflect on their own practices, which have been shaped over a long period of time and become part of their daily routine. Moreover, the comparison also provides important insights into how each rail system has dealt with major developments in the rail sector, such as the growing competition on the rail market, which can have a huge impact on disruption management. At the same time these differences between the countries also make it difficult to make a direct comparison. First of all, a system's specific characteristics and the context in which it operates are not only important to understanding how disruption management has been organized, but also determine the possibilities for improvement and what can be learned from other countries. Secondly, the complexity of rail disruption management makes it impossible to look for a direct causal link between how disruption management is organized and the performance of a rail system. Hence, one should be cautious when comparing rail systems and doing so without taking the contextual details into account has proven to be of limited value.

6.3 GENERAL FINDINGS

We can now move beyond the findings of the individual studies and answer the main research question. The main research question of this dissertation is: "*What explains the coordination breakdowns between the control centres in the Dutch railway system during the management of large-scale, complex disruptions?*" From the findings in the four studies we can draw four main conclusions.

Conclusion 1: Situation awareness is often not shared during the management of large-scale, complex disruptions

One issue that appeared in all of the studies was the need to quickly share information between the different control centres in order to create and maintain a compatible understanding of the dynamic environment. This shared situation awareness is crucial to the control centres' ability to take rapid and decisive action in the event of a disruption and to effectively coordinate and adjust their actions during the management of a disruption (Uitdewilligen & Waller, 2012). Consequently, the way in which information is shared between the different control centres influences the system's adaptive performance. In this thesis it has been shown that sharing information between teams working in a dynamic and time pressed environment entails significant challenges.

The dynamic network analysis revealed that information processing and distribution is unevenly distributed among the actors during the first phase of the disruption management process. We identified train dispatchers and regional traffic controllers as potential weak points in the network, given the large amount of information they have to process and distribute, as well as the high number of tasks assigned to them. The third study confirmed the findings from the first study, as it found that these operators indeed struggled to keep others informed, especially during large-scale, complex disruptions as operators have to invest a lot of their cognitive capacity in rescheduling rail traffic in order to contain the disruption and avoid it propagating to other areas. During these moments of extreme high workload it is not only difficult to maintain a shared understanding of the operational environment among operators within a single team, but even more so between teams. We noticed that lateral communication between the regional control centres diminished, causing control centres to work at cross-purposes. But most of all, there was a steep decrease in regular information updates to the OCCR. This made it very difficult for the operators in the OCCR to maintain an overall understanding of the situation and to coordinate the activities of the regional control centres.

Maintaining a shared situation awareness is not only difficult because of the challenges of sharing information under pressure, but also because of the dynamics of the operational environment. Take, for example, the winter storm in the fourth chapter during which the number of malfunctions exponentially increased and the situation changed by the minute. In such a dynamic environment it is extremely difficult to keep each other up-to-date on the situation. As the DNA showed, information needs to be passed along many actors, which makes dispersion of information by phone rather slow. Consequently, information might already be outdated by the time it reaches its recipient. Of course there are other means of sharing information, such as the ISVL information system. The advantage of this system is that it makes it possible to quickly provide updates to all teams involved in the disruption management process via short text messages. However, when the work pressure rises this system suffers from the same limitations, as operators tend to neglect reading and updating the system. In fact, some operators see the communication system as an administrative burden, rather than a necessary tool to keep each other up-to-date. In sum, during large-scale, complex disruptions information is often scattered throughout the system and teams receive information at different moments in time.

Disruption management demands rapid and decisive action as trains can easily queue up. This makes it impossible to wait for information to become available and we have seen two ways in which the actors cope with this issue. First of all, operators will actively seek information. In the third chapter we used the term sensedemanding for this act of updating one's own situation awareness. The DNA in the third chapter has shown how these acts of sensedemanding actually caused a chain reaction of sensedemanding, which greatly increased the interactions in the network. Telephone lines quickly become clogged as everyone starts to phone everyone else. Moreover, operators get overloaded with information demands and are unable to attend to other tasks, such as making an accurate situation assessment. Secondly, operators often do not wait for the full details on a situation to become available. In the first study the DNA showed how operators pick up cues from overhearing their colleagues' phone calls and start managing the disruption before they have all the information. Operators anticipate that a situation will unfold according to earlier experiences and start managing the disruption '*in the spirit of*' the anticipated contingency plan. Hence, experience and assumptions play an important role when dealing with time pressure and uncertainty. Assumptions, however, may be very misleading if they do not correspond to the actual situation (cf. Stanton, Salmon, Walker, Salas, & Hancock, 2017), as the second study has shown.

Situation awareness in a system that operates a complex and dynamic environment thus seems to be distributed between teams rather than shared. According to the distributed situation awareness (DSA) perspective (Salmon et al., 2008; Stanton et al., 2017; Stanton et al., 2006) systems have a dynamic network of information upon which operators have their own unique view given their own specific goals, experience and tasks. Awareness will thus not be shared between actors, but should be compatible in order to hold the system together. Compatible situation awareness is acquired and maintained through transactions in awareness that arise from actors sharing information on the state of the environment. Poor information sharing can lead to inaccurate and conflicting assumptions and teams working at cross purposes. Once more, the winter storm case in the fourth chapter provides a good example. In this case the operators in the OCCR assumed that everything was relatively calm while local operators were increasingly struggling to keep the situation under control.

Conclusion 2: Collective sensemaking between teams is weakly developed

The second study of this dissertation demonstrated how the adaptive behaviour of one team can have a very negative effect on the system as a whole if it is not well coordinated with the other teams. As the track team deviated from formal procedures by giving an early warning to the OCCR, they caused confusion among the other teams in the rail system which eventually led to a complete coordination breakdown. This situation highlights the risks of deciding to work around standard procedures in a multiteam system. The case also revealed that coordinating this decision was made more difficult due to the fact that the teams in the Dutch railway system did not have compatible views on roles and responsibilities, procedures and the information needs of others. A good example of this is the track team's decision not to directly coordinate with the train dispatchers, but to first alarm the OCCR. It shows that the track team did not fully anticipate the impact of their decision on the train dispatchers' task of assuring the safe allocation of rail tracks and their differences in norms concerning safety. Similarly, contrary to the track team's expectations the OCCR felt no responsibility to inform the train dispatchers.

In response to this particular case, ProRail decided to improve both its procedures and the training given on following them. This is a logical response given the outcome of this particular decision to deviate from procedure. At the same time this research has shown that strictly following procedures actually hindered an effective response to the track team's workaround. The analysis of how actors made sense of the information revealed that the term 'red flag' triggered a routine response among the operators in the OCCR. This frame of a routine procedure was reinforced over time in the communication with the regional operators, in spite of the many contradictory signals that were ignored or simply missed. In fact, operators in the OCCR actively tried to restore standard procedures. Using the DNA we visualized how information uncoordinatedly spread through the network, leading to fragmented accounts of the situation and actions. The outcome of this particular case underscores the importance of quickly detecting a misunderstanding and repairing it. The detection of the misunderstanding was, however, hindered both by the operators' reliance on standard behaviour, rigid communication patterns and their incorrect expectations of other people's actions.

In the second study we emphasized the ability of operators and teams to update or switch frames when dealing with ambiguous situations as a perquisite for adaptive team performance. That is, they should be able to detect when a reliance on routine processing negatively impacts performance (Stachowski, Kaplan, & Waller, 2009). Instead of accepting taken-for-granted interpretations of events, ambiguous situations require extensive collective sensemaking (Uitdewilligen, Waller, & Zijlstra, 2010). Collective sensemaking means that actors jointly develop an understanding of the situation, challenge each other's assumptions and detect any potential loss of shared understanding on time. In the different studies we found that collective sensemaking between operators in the Dutch rail system is weakly developed. Operators often do not take the time to pose additional questions or do not feel free to cross-check information they receive. Moreover, when a situation becomes more ambiguous operators tend to reduce communication and hide behind their own interpretation of role boundaries and procedures. Finally, we have seen that the stress and growing frustration following the ambiguity and uncertainty of events negatively impacted operators' ability to make sense collectively. It even resulted in a conflict between teams and the decision to no longer cooperate.

So, shared procedural knowledge is important, as it enables teams to effectively coordinate their activities, but our research has shown that shared procedural knowledge alone is insufficient and may even lead to rigidity when dealing with non-routine events. The second study highlighted that teams will interpret situations differently, which triggers them to follow different and often incompatible procedures. Moreover, the study has also shown that the triggering of a specific procedural response can create blind spots to the need to reframe situations. Coordination thus should not only rely on being able to apply procedures, but also on the ability of actors to collectively make sense of events and to explicate different interpretations of situations (Faraj & Xiao, 2006). As Cooke et al. (2013) observed, it is important to have shared knowledge of tasks and teams, but if team members do not interact or fail to coordinate effectively, coordination will break down.

Conclusion 3: Contingency planning can lead to rigidity when responding to non-routine disruptions

Contingency planning is an important way of preparing the system for anticipated disruptions to rail services. These pre-established plans reduce workload during the management of a disruption as the solution to a disruption has already been developed in advance. Contingency planning also reduces coordination costs since the plans have been discussed and agreed upon in advance by the different parties involved, so that no consensus has to be reached during the management of the disruption. This makes it possible to quickly respond to a disruption. Moreover, the plans coordinate the rescheduling activities of the different control centres, as they indicate which trains or lines should be cancelled and where trains have to be short-turned. During our international comparison we observed significant differences between the countries we visited regarding the use and implementation of contingency plans. Some countries have only a small number of contingency plans or no plans at all, while in the Netherlands there are more than a thousand contingency plans for all kinds of disruptions. Moreover, while most countries use contingency plans as a reference framework, the Dutch rail system places emphasis on quickly choosing and implementing the predefined solutions of the contingency plans.

The Dutch railway system's reliance on contingency plans is understandable given its dense rail network and the intensive use. There is little time to develop an on-the-spot solution and there needs to be a quick response to prevent trains from queuing up and the disruption from cascading through the network. Moreover, contingency plans make the system less reliant on the expertise of the specific operators involved in managing the disruption and how they work together. The implementation of a contingency plan, however, is not without its difficulties. Choosing a plan (whether pre-defined or on-the-spot) requires an accurate assessment of the disruption and its impact on the available resources. In the third study we saw that it is very difficult for train dispatchers and traffic controllers to make a good situation assessment when faced with very dynamic and complex disruptions. Not only do they have to invest a lot of their cognitive capacity in controlling the traffic flows by quickly rescheduling trains, but these rescheduling activities also change the operational environment. Furthermore, information often only becomes available gradually.

This makes it very complicated to implement a contingency plan, as a great deal of communication is needed for enough knowledge on the situation to be shared between the regional and national control centres so that they can decide on a plan and make sure that it can be implemented. While situation assessment and the implementation of a contingency plan require a relatively stable situation, we have seen in the studies that the operational environment can be so dynamic that the understanding of the situation has to be updated continuously. Hence, disruption management cannot always follow a linear process: new rounds of situation assessment, communication and decision making are necessary to revise the plan. In the third study, however, we witnessed the opposite. Although the disruptions in the third study were far from routine, we still noticed a standard response to these disruptions with a step-by-step implementation of a contingency plan. This was illustrated by the fact that operators in the OCCR pushed for a quick implementation of a contingency plan on the basis of an already outdated and simplified assessment of the operational conditions to assert control over the situations and synchronize the activities of the regional control centres. Simplification helps decision makers to deal with the dynamics and complexity of the environment, as modifying a plan in progress poses many challenges in terms of communication and coordination between control centres (cf. Kontogiannis, 2010). However, if there is a failure to adapt to changing circumstances, the situation can quickly degrade and control over it may eventually be lost (Woods & Branlat, 2011a).

The findings of this study tie in with planning problems as identified by Weick & Sutcliffe (2007). According to these authors detailed plans discourage actors from recognizing and responding to the specific risks of events, as they focus people's attention on signals that are in line with the plan. Our research has shown that operators are not always aware that they are dealing with a much larger disruption than expected and that the conditions to implement the plan are thus no longer met or have significantly changed. Secondly, plans encourage a standardized response that discourages operators from improvising or thinking for themselves. Although the Dutch rail system has numerous contingency plans, there are even more conditions or combinations thereof that make every disruption unique and in need of a specific solution (cf. Golightly & Dadashi, 2017). We found in our international comparison that this is one of the main reasons why the other countries restrict the use of contingency plans or use them mainly as a reference framework. Conceptual plans offer more flexibility and encourage the development of a shared understanding of the specifics of each disruption and its potential risks.

Conclusion 4: Polycentric control requires effective teamwork between regional control centres and the teams in the national control centre

Another important coordination mechanism studied in this thesis is that of leadership. Regional control centres have their own goals, priorities and scope of responsibility. Consequently, local operators might make decisions that benefit the rail traffic in a specific region, while negatively impacting the traffic flows in other regions and the system as a whole. As was argued in chapter 4, leader teams are important to integrate the activities of the different control centres and manage resources in order to achieve the system's overall goals. In our international comparison we found that each country has its own way of integrating these multiple layers of control. Despite their differences, what all of these countries have in common is that authority is shared between national and regional control centres, with regional control centres often enjoying quite a lot of autonomy. Hence, although the national control centres are positioned hierarchically above the local control centres, their actual level of influence on the regional control centres is restricted. In the literature on these polycentric systems it is argued that it is necessary to find a dynamic balance between both layers of control that also corresponds to the operational conditions.

High Reliability Organizations are known for their ability to be both centralized and decentralized, as they can transfer from a centralized hierarchical structure during normal operating periods to a decentralized structure in the event of a crisis (Grabowski & Roberts, 1997). In the railway system the shift in authority is basically the other way around. During normal operations the system is decentralized, as rail traffic is controlled by regional control centres. During a large-scale disruption, a switch should be made to a more hierarchical structure in order to foster coordination and rapid decision making (Berthod et al., 2017). This thesis has shown that leader teams face important challenges in striking the right balance between centralized control to align the activities of the regional control centres and allow regional control centres enough flexibility to adapt to local conditions.

The transfer of authority between both layers of control has proven to be prone to ambiguity and disagreement (cf. Moynihan, 2009). Operators in the national control centres face the dilemma of having to decide on the right moment to intervene in local operations. Making this decision is often severely complicated by a lack of up-to-date information from the regional control centres and relies heavily on the expertise of operators in the national control centre to monitor their performance and correctly make sense of the incoming information to identify potential problems. At the same time, operators in the national control centre depend on the ability and willingness of local operators to notice in time when there is a workload issue, to call for help and to accept the help that is offered. We found that there is a great deal of variation in the perception among and between operators at both levels of control regarding how and when leadership should be exercised. This ambiguity concerning roles and responsibilities results in actors not meeting each other's expectations, impedes information sharing and may even lead to conflicts when roles are deemed to have been violated.

In the international comparison we found that Germany and Austria have tried to reduce this ambiguity by making the national control centres solely responsible for long-distance traffic. This separation of responsibilities is supported by detailed dispatching rules that guide the rescheduling of the local operators. Based on the findings of the third study, simply defining roles and responsibilities does not seem enough to support polycentric control. As mentioned in chapter 4, it cannot be expected that polycentric control will instantly occur by placing a leader team above the component teams. Leadership in a MTS requires effective teamwork between the component teams and the leader teams that follows from the acknowledgement of their mutual dependency.

Answering the overall research question

On the basis of the four conclusions, we can now give an answer to the main research question: *What explains the coordination breakdowns between the control centres in the Dutch railway system during the management of large-scale, complex disruptions?*

In order to align their activities, it is important that the different control centres involved in managing a disruption have an accurate and shared understanding of the operational environment. During large-scale, complex disruptions, however, it is a difficult and often time- consuming task to create an accurate understanding of the situation and given the dynamics of the operational environment this understanding can quickly become obsolete. In these ambiguous and dynamic situations it thus becomes especially important to continuously share and collectively make sense of information to maintain a congruent understanding of the operational environment. Paradoxically, the heavy workload that confronts operators during these large-scale, complex disruptions, as well as the limited communication channels, make it particularly difficult to keep each other up-to-date and to take the time to collectively make sense of this information. Consequently, operators and teams will have different or incomplete information and develop different and often incompatible accounts of the developing situation. Coordination mechanisms, such as procedures and plans that should hold the system together, not only prove to be brittle in these dynamic and complex environments, but they can actually obscure the need to adapt to changing conditions. In addition, centralized control is often severely hampered by the degraded situation awareness of operators in the OCCR and the slow decision making resulting from this. Consequently, regional operators make decisions without knowing whether they will impact the system as a whole.

6.4 IMPLICATIONS OF RESEARCH FINDINGS AND PRACTICAL RECOMMENDATIONS

At the start of our research project we were told that ProRail and NS were working on a new model for the management of disruptions after being confronted with several out-of-control situations. These out-of-control situations were a warning for ProRail, NS, and the government that despite the establishment of the OCCR, the rail system was still not fully capable of managing large-scale disruptions. Over the years we have seen how the initial ideas for this new traffic control model resulted in the development of a Centraal Monitor- en Beslisorgaan *(Central monitoring and decision making body, CMBO)*. The CMBO has been operational since early 2017[10] and forms a specific unit of ProRail's rail traffic control

10 Data collection for our research on the Dutch railway system was finalized before the CMBO was established.

within the OCCR. The CMBO is now the only party in the OCCR that monitors and decides on the adjustments made to the timetable in the event of a disruption. In the previous situation, as described in detail in this thesis, rail traffic was monitored by teams in the OCCR of both ProRail and NS and during a disruption they jointly decided on a contingency plan. In the new situation NS is solely responsible for the management of its own train crew and rolling stock and the rescheduling of these resources according to the alternative time table decided upon by the CMBO. It is expected that the removal of the overlap in tasks and responsibilities between ProRail and NS will lead to more rapid and decisive decision making.

Decision making is done by a team of national rail traffic controllers supervised by one duty officer. To support the traffic controllers of the CMBO in their decision making the various parties in the rail system have to provide regular updates on the status of their resources (rolling stock, train crew, infrastructure and traffic flows) and potential risks (weather-related issues or understaffing of local control centres) via new communication systems. To further secure the interest of the train operating companies, contingency plans will be improved and specified to increase the ease with which they can be implemented. Moreover, the decision making processes and outcomes will be jointly evaluated afterwards and contingency plans will be improved when necessary. What hasn't changed, at least not at the time of writing, is that rail traffic is still being monitored by the operators of ProRail in the regional control centres[11]. However, the manner in which operators in the CMBO monitor and can intervene in regional operations will be made more explicit. Moreover, there are plans to greatly reduce the number of regional control centres (ProRail) and even to fully centralize the rescheduling of train crew and rolling stock (NS).

Overall, the development of the CMBO should lead to 1) a command and control structure with clear role structures, supported by 2) improved contingency plans and 3) new information systems. The development of a more centralized form of decision making, clear division of roles, and improved planning is understandable given the coordination challenges encountered during the management of large-scale, complex disruptions. The decision to make one team or even person (duty officer) responsible for the decision making on the train service is in line with what we have seen in other countries and the reduced complexity of the structure could indeed speed-up decision making. However, in the first chapter of this thesis we highlighted the duality encountered when dealing with coordination issues in complex, dynamic and uncertain environments. A trade-off has to be made between an emphasis on centralization vs. decentralization and on anticipation vs. resilience. The current development will push the system towards greater centralization and anticipation, which could be beneficial when managing anticipated disruptions. At the

11 As of May 1st, 2018 the role of monitor in the regional operations centres of NS (*Monitor RBC)* does no longer exist

same time it could also make the system less able to handle unanticipated disruptions if these developments come at the expense of the adaptive capacity needed to quickly notice and effectively manage complex and non-routine disruptions. On the basis of the findings of this research, we will reflect on each of the three building blocks of the CMBO mentioned earlier and provide practical recommendations for each item.

6.4.1 Making more information available by means of improved information technology does not automatically lead to a shared understanding.

Improvements in information technology are regularly seen as a way in which to support coordination and decision making, as it allows for a fast dispersion of information that facilitates a shared understanding of the operational environment. However, there is a growing body of literature that points to the fact that making more information available does not automatically lead to improved situation awareness and decision making (Dadashi, Golightly, & Sharples, 2016; Marusich et al., 2016; Salmon et al., 2011). In fact, the volume of information available can overwhelm operators and lead to slower responses. As has been found in chapter 4, operators struggled to read and process all the information in the information systems and did not feed the system with new information as a consequence of high task demands. Moreover, an increase in the quantity and speed of information dispersion does not necessarily mean an increase in the quality of information. As each actor interprets the information in their own way, there is no guarantee that the information made available will be interpreted correctly by members of a different team, as we have seen in chapter 3. Information technology thus neglects the collective sensemaking process that is crucial for the enactment of coordination when dealing with uncertain or ambiguous situations (Wolbers & Boersma, 2013).

Recommendation 1: Underline the importance of collective sensemaking between teams and support this through training and the use of rich communication channels.

Does this render improvements to information technology obsolete? As Wolbers (2016) notices, information technology is not the final solution, but might still act as an important supporting platform that provides input for acts of collective sensemaking. Cooke and colleagues (2013) also stress the importance of applications that focus on facilitating interactions and the timely and adaptive sharing of information to support situation awareness as opposed to making more information available. So while information systems may facilitate a rapid dispersion of information, richer communication channels (e.g. telephone and conference calls) are still needed for the integration of information and negotiation on its relevance for the different teams (Uitdewilligen & Waller, 2012; Wolbers & Boersma, 2013). Besides improvements to information technology, it is thus also crucial to improve the way in which operators interact and share information in order to advance their collective sensemaking.

First of all, it is important that respectful interaction between operators is the norm. Having a diversity of perspectives can actually help to avoid blind spots and provide alternative solutions, as long as norms are in place to support the negotiation of different perspectives (Kellermanns, Floyd, Pearson, & Spencer, 2008; Wolbers & Boersma, 2013). In the studies we observed that this is not always the case and that emotions and conflicts negatively influenced collective sensemaking. Respectful interaction is crucial for people to be willing to share their interpretations with others, become aware of each other's point of view, and therefore to creating a compatible understanding of unforeseen situations (Sutcliffe, 2011). Secondly, in a multiteam system it is not just the quantity of communication that is important: even more important is the quality of the information being shared. More is not always better and people can easily be overloaded with details, as we have seen in the fourth chapter. Instead, information sharing should not only be on time by correctly anticipating the information needs of other teams; it must also be clear and concise so the intended recipient can more easily understand the message (Baker, Day, & Salas, 2006). Both communication norms and skills can be improved through training and regular assessment.

We do realize that the emphasis on collective sensemaking stands in sharp contrast to the need for speed felt by the operators and the high workload they experience during the management of disruptions. It is, however, important to regularly discuss the situation with the different control centres to see if everyone is still on the same page, especially during dynamic and non-routine situations when there is a high risk of false expectations. At NS we have seen that this is done by scheduling conference calls. Strangely enough, ProRail does not use these conference calls. Conference calls could facilitate the integration and interpretation of information between teams, as one-on-one communication by phone, have proven to be rather slow. Moreover, these conference calls are not only important during the management of a disruption, but can be especially useful in-between disruptions when workload is still low and potential risks can easily be shared between control centres. In addition, national traffic controllers can share system level goals and provide a framework for the regional control centres to adapt to situations. In the fourth chapter we have already seen how this can be done by distinguishing different modes of operation, each with their own specific goals and guidelines on how to achieve them. Shattuck & Woods (2000) call this the commander's or supervisor's intent. If these guidelines are provided prior to the management of a disruption, regional control centres will be more likely to pay attention to overall system goals and less communication will be required in the heat of the moment.

Recommendation 2: Reduce the risk of a communication overload among train dispatchers and regional traffic controllers.

In this study the train dispatchers and regional traffic controllers were marked as potential weak points in the communication network on the basis of the DNA. In the fourth chapter we found that during periods of high workload these operators struggled to share information. It is thus important to reduce the communication burden of the train dispatchers and regional traffic controllers. In the last years there have already been experiments with placing two train dispatchers behind one work station, one responsible for safety and one for logistics, to reduce the workload during disruptions. This experiment, however, showed an increased need for coordination between the two train dispatchers working at the same desk. Moreover, it does not solve the high workload of the regional traffic controllers. One way of reducing the communication burden of the regional traffic controllers is to give the team leaders a more central role in the lines of communication. Compared to the other countries studied, the team leaders at ProRail's regional control centres have a limited role with regard to communication. In the other countries visited, team leaders would manage the information in the control centre and share this information with the other regional control centres and the national control centre. In contrast, we noticed that there is often little communication between the team leaders of the regional control centres and the director (*regisseur)* in the OCCR; team leaders often lack a good understanding of the operational conditions and as we saw in the third chapter, team leaders are also not always on site.

6.4.2 Limits to command and control

The command and control paradigm is a powerful instrument for accomplishing tasks characterized by repetition and uniformity (Moynihan, 2009). Although the desire for command and control is understandable given the need for decisive decision making, it does not reflect the actual situation in which the CMBO only has partial control over the regional control centres. The latter would seem to be especially the case during large, non-routine disruptions when the regional operators are confronted with a high workload and tend to focus on their own tasks and goals. Successful disruption management thus relies on effective cooperation between the two levels of control, which needs to be fostered.

Recommendation 3: Train operators in the CMBO for multiteam leadership.

In the fourth chapter we have shown that there are important challenges to MTS leadership. Leadership of a multiteam system requires specific qualities that are different from those required in single teams. For example, leaders must integrate information from the different component teams and ask the right questions in order to create an overall understanding of the operational environment, be able to adequately detect and respond to workload issues, know how to distribute workload and provide assistance when needed, and adjust plans to unanticipated changes. These leader teams have to do this while being geographically separated from the other teams and often having to rely on already outdated information. Many of the operators in the OCCR have been hired on the basis of their long-term experience working in the rail sector and their expertise in terms of rail traffic, rolling stock and train crew management. Although this is very important knowledge, it does not mean that one also automatically has the requirements for a leadership role in a MTS. Such a leadership role and the associated behaviours require specific qualities in terms of communication and coordination that need to be actively trained. Moreover, MTS leadership qualities should also be an important criterion when hiring new operators to work in the CMBO.

Recommendation 4: Regularly train and evaluate the management of disruptions with multiple teams to foster the development of shared knowledge.

Training should not only be given to a single group of people or a team, as the training conducted with multiple teams is especially important. In the four years of doing research at ProRail we observed that this kind of training is very sparse. Most of the training is given within teams instead of between teams. Operators therefore do not receive training as a MTS, but as a single component team (Lacerenza, Rico, Salas, & Shuffler, 2014). This is strange, given the fact that good performance on the part of a single team does not necessarily entail good multiteam performance. Moreover, the training often focuses more on task skills or procedures and less on team work competencies. The evaluations of the disruption management processes, which are often conducted by the different control centres individually, also illustrated this. In the cases where different teams did meet each other to evaluate a disruption, I noticed that people were often meeting face-to-face for the first time, whereby they actively started to ask each other questions about their role, responsibilities, task requirements, and how they shared different viewpoints.

This knowledge of each other's roles and responsibilities is very important to ensure smooth coordination between teams (Marks et al., 2005). For example, Power (2017) argues that a poor understanding of roles can reduce cooperation as teams lack trust in other's abilities and impede coordination as they fail to share information and anticipate each other's actions. We have noticed that there is a particular lack of clarity between the regional and national control centres regarding their roles and responsibilities. Cross-training can help to make teams more able to anticipate each other's needs and actions (Wilson et al., 2007). The goal of cross-training is the development of shared knowledge on how the system functions and how tasks and responsibilities are interrelated by receiving information on other roles, observing other roles, or gaining first-hand experience of different roles (Gorman, Cooke, & Amazeen, 2010). As such, cross-training could help to make regional operators better aware of how their actions contribute to the overall goals of the system and how they could support the operators in the OCCR in their role of safeguarding these system level goals. At the same time it could help operators in the OCCR to better anticipate the needs of the regional operators.

6.4.3 The risks of relying on anticipation by planning

The Dutch rail system is very focused on the use of standard operating procedures. In response to the situation described in chapter 3, ProRail decided that new and better procedures, along with training people to apply them, should prevent situations like this from happening in the future. Unfortunately, this has not been the case as similar cases of coordination breakdown between teams, caused by misunderstandings, have occurred in the last couple of years. Similarly, the development of new and improved contingency plans can be seen as an attempt to be better able to anticipate events and guide the response to these events to reduce unwanted variation. However, contingency plans have their limitations and therefore it will not be enough just to prepare plans for all kinds of events. Reliable organizations acknowledge that surprising events occur and that it is necessary to deploy alternative solutions to problems (Branlat & Woods, 2010).

Recommendation 5: Train teams how to balance adhering to and deviating from procedures and plans.

Procedural training is aimed at following a standard response each time a specific event is encountered. This adherence to specific procedures should reduce the errors, unwanted variation, and waste resulting from human interaction and creative human involvement, and improve performance when working under stress and a high workload (Gorman et al., 2010; Gray, Butler, & Sharma, 2015). Training operators to follow an automatic response, however, prevents them from acquiring the skills needed to successfully deviate from procedures and adapt to the specific circumstances (Stachowski et al., 2009). Besides being good at applying procedures and plans it is thus also important that people are able to know when to abandon standard operating procedures and how to improvise in a coordinated manner. This requires operators to adopt a different mind-set, in which they are encouraged to confront ambiguity and uncertainty, look for weak signals, and be able to restructure their framing of a situation (Weick et al., 2008).

Hence, training should be aimed at increasing the range and richness of frames and improving operators' skills in noticing and diagnosing weak signals under stress (Klein, Phillips, Rall, & Peluso, 2007; Siegel, 2017). This could be done by including challenging and non-routine scenarios in training sessions to improve re-framing and coordination skills during surprise events. For instance, Gorman et al. (2010), have shown how perturbation training can be used to train teams in finding new solutions to coordination problems. Perturbation training introduces perturbations to standard coordination procedures (e.g. cutting of communication link) during skill acquisition to increase the flexibility and adaptability of teams. Perturbation training is thus focused on broadening a team's interaction repertoire instead of prescribing standard forms of coordination (ibid.).

6.5 METHODOLOGICAL REFLECTION AND LIMITATIONS

In this section I will reflect on the methodological choices made during the course of the PhD research, their implications, and the limits of this study.

6.5.1 Methodological reflection

The study of coordination in multiteam and/or interorganizational systems tasked with the time-critical response to disruptive events poses major challenges. Broadly speaking there are three main challenges: the unpredictable nature of the disruptive events, the geographical distribution of the teams under study and data collection during the actual management of the events. As a result, many studies focus on coordination in a single team, observe the response operation during a simulated exercise, or make use of retrospective interviews, surveys and event reports to reconstruct the response to an event. Although these decisions are understandable given the fact that research needs to be kept manageable and viable, they also limit our understanding of the complexity of multiteam coordination. In this study we have shown how recordings of telephone conversations in combination with the tools of Dynamic Network Analysis can act as a complexity-informed approach to understand coordination in complex systems (cf. Gerrits, 2012; Schipper & Spekkink, 2015; Teisman & Gerrits, 2014).

As far as we know, the tools of social network analysis have never before been used within the context of rail disruption management. In the first study, Dynamic Network Analysis turned out to be a very useful tool to efficiently describe and quantitatively assess the whole network of operators involved in the management of a disruption and the flows of information between them during the first phase of the process. It made it possible to assess not only the size and structure of the network, but also the position and tasks of the different actors within it. This was a first important step towards unravelling some of the complexity of the disruption management process. A true complexity informed method, however, includes the element of time to take into account the dynamic and emergent nature of disruption management. In this dissertation we have shown how the element of time can be included in social network analysis by chopping the process into time slices. This dynamic representation of the network provides a better understanding of how information flows and roles in the network change over time and thereby reduces the risk of misinterpreting data when looking only at aggregated networks.

One of the other drawbacks of social network analysis is that data collection has proven to be labour intensive and time-consuming when you want to model real-time communication between different teams during a disruption. The telephone recordings used in the second study yielded a huge amount of data that had to be hand-coded. This is why researchers have been developing ways of automating the collection of data and analysis of communication (e.g. Foltz & Martin, 2009; Gorman, Cooke, Amazeen, & Fouse, 2012;

Grimm et al., 2017; Kiekel, Gorman, & Cooke, 2004). Since communication between teams is mediated by information technology it is possible to collect data in real-time. For example, automatic speaker identification techniques are becoming better at detecting who is speaking to whom (Barth, Schraagen, & Schmettow, 2015). At the same time there are also attempts to automate the analysis of the data to quickly provide feedback on team performance. Algorithms and software have been developed to extract patterns in the specific timing and sequences of interactions that characterize a specific team performance or their situation awareness (Weil et al., 2008). Currently, the data used in the real-time monitoring of communication patterns is quite basic. As Weil et al. (2008) observe, a trade-off has to be made between ease of collecting and analyzing data, and the richness of the data. The problem is that these quantitative methods and tools abstract a great deal from the actual complexity of social systems (Schipper & Spekkink, 2015).

In this dissertation we have shown that rich qualitative data greatly contributes to a more complete understanding of real-time coordination. In the third study we made clear that it is not only important to look at the flows of information in a network or the timing of interactions, but that the interpretation of this information also plays a very important role in effective coordination. So instead of looking at the network structure to explain observed behaviour, we have combined a quantitative analysis of the communication patterns with a qualitative analysis of the communication content to gain a more in-depth understanding of the behaviour observed in this specific context. For example, this mixed-methods approach explained why the actors in the OCCR did not use their central positions in the network to provide others with crucial information, as they did not believe that it was their role. Mixing SNA with a qualitative analysis of the data makes it possible to reap the benefits of being able to visualize and investigate the structure of the network in which actors operate, while also gaining an in-depth understanding of the ties between actors that shape this network and the specific contextual details that would otherwise be lost.

A mixed-methods approach is not only valuable for researchers who mainly apply traditional quantitative SNA, but also for researchers who mainly use qualitative research methods and who write thick case descriptions, such as ethnographers. Howard (2002) and Berthod et al. (2017) have called for network ethnography to study the practices of distributed teams and interorganizational networks. Network ethnography uses SNA to select specific cases and sites for ethnographic field research. We have shown how DNA can be used as an important starting point for a more in-depth qualitative analysis by first abstracting and visualizing system-level patterns. Moreover, the network visualizations can also be used to collect additional qualitative data by discussing them with respondents (Schipper & Spekkink, 2015). For example, actors in the Dutch Railway system declared that they were unaware of their relatively central position in the network and thus their potential to steer the process.

A mixed-methods approach can thus help the researcher to structure data collection and analysis, but also to reflect on the result of both methods. Nonetheless, combining insights derived from both methods is not only complex, but as we have seen, the results of this combination might even be more clear to the researcher than their audience. Moreover, mixing methods is labour intensive and time consuming. So, despite the growing recognition that qualitative and quantitative approaches need to be integrated, researchers often opt for only one method. In this research we have shown that a mixed-methods approach does not only offer important benefits when studying distributed teams, but that it is also crucial to understanding multiteam performance as it emerges out of the interactions between the different teams.

6.5.2 Limitations of the study

This study also has some limitations that need to be discussed. First of all, there are limitations on the data used in the first study. The data for the DNA was collected by means of value stream mapping and not from a real disruption. Experts took several days to reconstruct the first phase of the disruption management process and very precisely describe the tasks and communication of every actor. This yielded a very detailed description of the disruption management process, which we could use for our DNA. Nonetheless, the data was not collected real-time and therefore the value stream might not represent the exact response during real-time operations. In addition, the aim of the value mapping was to reconstruct the disruption management process during a catenary failure, but did not involve the actual management of a disruption. Therefore we could not relate the network structure to a specific outcome.

Secondly, we should also point to a limitation concerning the scope of the research. In this study the focus has been on the first and, to a more limited extent, the second phase of the disruption management process. This is from the moment a disruption has been noticed until an alternative service plan has been implemented. Hence, no particular attention has been paid to the third phase of the disruption management process, during which the system has to return to normal operations. The decision to focus on the first and second phase was made from both a practical (limits on the data available in the first study) and theoretical point of view. The first phase of the disruption management process, or chaos phase as it is often called in the rail sector, is known for its dynamics, complexity, and high levels of uncertainty. This makes it a particularly interesting phase of the process in which to study the system's response. In contrast, during the recovery phase the system is relatively stable and more information and time is available for making decisions. The findings of this research, however, seem to indicate that the recovery phase forms a major bottleneck in the disruption management process, and deserves specific attention in future research.

Thirdly, there are also limitations regarding the use of telephone conversations to study real-time coordination. In the previous section I highlighted the benefits of coding and analyzing the content of recorded communication. Not only could we precisely follow the flows of information between operators, but we could also gain a good and detailed understanding of their collective sensemaking and team work behaviours, such as asking for help, providing back-up, and mutual performance monitoring. Naturally, information sharing is not confined to telephone calls. What the recordings do not reveal is how much information was actually available to the operators other than that shared through verbal communication. As Stanton (2017) rightfully observes, technological systems, such as ISVL and traffic management systems, have an important role in maintaining the operators' situation awareness. To deal with this issue, we carefully examined the loggings made in the ISVL communication system. Moreover, although it is not possible to get a complete picture of an operator's situation awareness, I do believe that this study has shown that it is possible to gain a good understanding of what the different operators and teams know and do not know by examining the content of the verbal communication.

Finally, the use of telephone recordings as the main source of data has placed an emphasis on the interactions between teams and the observable teamwork behaviours. At the same time there are also more implicit and difficult to capture affective, motivational and cognitive properties of teams that affect communication and coordination (Kozlowski & Ilgen, 2006). In the team literature these affective (trust, cohesion), motivational (collective efficacy) and cognitive properties (shared mental models and transactive memory) are seen as emergent states that characterize properties of teams and are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes (Marks et al., 2001). As chapter 3 has shown, this cohesion between teams can quickly crumble and even lead to a competitive orientation between groups when negative emotions spread within teams and conflicts arise. Team attitudes are thus very important to understanding the observable teamwork. Yet, in comparison to team communication and explicit coordination they are far more difficult to measure by means of communication analysis and thus for some part remain unknown (Wilson et al., 2007). We have, however, used interviews to allow operators to reflect on their own actions and behaviours in order to gain a better understanding of the attitudes and motivations underlying observed behaviours.

6.6 THEORETICAL REFLECTION AND IMPLICATIONS

In this section I will reflect on the theories and insights used from the different academic fields and the specific contributions made by this study to the literature.

One of the major contributions of this research is that we have studied a largely neglected issue in the disruption management literature, which is the coordination of the different rescheduling activities. Rail disruption management literature has mainly focused on the development of models and algorithms to provide decision support tools for the rescheduling of time-tables, rolling stock and train crew. The focus in rail disruption literature on algorithms and models has pushed the role of operators to the background. In this study we have shown the importance of gaining a better understanding of the complexity of disruption management and the inter-team communication and coordination challenges. Since there are almost no studies on this specific topic, we used and combined theories and insights from many different fields, including resilience engineering, organizational studies, human factors, applied psychology and emergency management. Most of the literature found in the different academic fields, however, focuses on teams as isolated entities or uses the aggregated system as its level of analysis.

This is why we turned to the literature on Multiteam Systems to better understand not only what happens within teams, but also within this network of heterogeneous teams. MTS is a relatively new field, but there is a growing interest in it and during our research a great number of new articles on MTS were published. Most of these articles are, however, conceptual and focus on theory building. Similar to the literature on single teams, theory testing is mostly done via simulation-based, modelling or laboratory settings under tightly controlled conditions. Moreover, students often play a crucial role in these experiments and simulations. Hence, the essential contextual details, task dynamics, and the expertise of operators is lost in these studies, which raise doubt as to whether the findings of these studies can be generalized to natural settings (Byrne & Callaghan, 2013; Gerrits, 2012; Klein & Wright, 2016). The number of actual field studies is still very limited and it is therefore time that the current theory on MTS is tested in field studies. This thesis already makes a contribution to the literature on MTS with the study of real life cases of coordination during the management of rail disruptions. In the third study we have, for instance, found that theoretical ideas on MTS leadership might not always be so easy to accomplish in real life, given the complexities in which MTSs operate.

In addition, as Shuffler et al. (2017) observe, most research on MTS has followed traditional variable-centric approaches to understanding MTS performance, i.e. identifying and isolating important constructs relevant for MTS performance and then studying how these variables influence performance. This variable-centric approach relies on simplifying the complexity inherent to MTS, such as assuming that intra-team properties are homogenous across teams and team members, and that they are static. By isolating general mechanisms we do not truly account for the behaviour that we encounter in complex social systems (Morçöl, 2012). For instance, it does not take into account how different properties manifest simultaneously, how these properties influence each other, and how they vary between teams. So although variable centred approaches can help to advance the theory on MTS, they do not in themselves explain MTS performance. Instead, it is necessary to study the dynamic interactions between the different actors and teams in order to understand the resultant emergent and non-linear outcome at the system level (Gerrits, 2012). As we have shown in chapter 3, it takes the entirety of interactions and activities of actors and teams to explain a coordination breakdown. In addition, the case has shown that the specific context in which the operator works is explanatory for which mechanisms are triggered and which are not (Teisman & Gerrits, 2014).

This is why researchers advocate taking a process approach in order to understand team performance in real-life settings (Cooke, 2015; Klein & Wright, 2016). For example, Interactive Team Cognition (ITC) theory (Cooke et al., 2013; Cooke, 2015) sees team cognition as a process of team members interacting to complete a cognitive task, rather than static knowledge held by the team. Instead of seeing situation awareness as the static shared knowledge on a situation, ITC considers situation awareness as the timely and adaptive responding of a team through interactions among team members. In this dissertation we have shown how DNA can be combined with a qualitative analysis of the content of communication in order to gain insights into the process of collective sensemaking not only within teams, but also between teams. DNA does not only capture the dynamics of the interactions between actors, but also shows how the behaviours of individuals are constrained by the network they are embedded in. As such, it is an example of a process approach that takes the specific dynamics and contextual constraints into account for a more fine-grained perspective on the complexities of multiteam performance. This can help to better specify MTS theory and create more advanced interventions and tools (Shuffler et al., 2017).

The findings of this dissertation also contribute to the literature on critical infrastructures providing public services. Most of the train operating companies and infrastructure managers in Europe are still state owned and basically fulfil a public service. In the introduction I have pointed to the fact that much has been written on restructuring policies in the rail industry, but that these studies have mostly paid attention to the actual policies, their implementation, and their outcome in terms of performance. Far less attention has been paid to the effects of these policies on the daily operations of the operators managing the railway system. This is quite strange, as these restructuring policies have had a major impact on the rail system's ability to provide reliable services, changing it from a primarily intra-organizational task to an inter-organizational task (De Bruijne, 2006).

As Berthod and colleagues (2017) also point out, research on whether and how public networks organize to provide reliable service delivery is absent from the literature, despite the challenges inherent to such networks as an organizational form. Much remains unclear on how these networks are structured, managed and controlled. In this dissertation we have made an international comparison of how the different rail systems have organized their disruption management process. This comparison has also provided insights into how the different extents of open market access and unbundling of rail operations and infrastructure management influence how disruption management has been organized.

6.7 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the findings and limitations of this study, I will also propose some avenues for future research

Recommendation 1: Further explore how dynamic network analysis can be used in a mixed-methods approach.

In this study we have advocated taking a more qualitative approach to social network analysis and have demonstrated how this can be done by combining a quantitative analysis of the communication flows with a qualitative analysis of how actors made sense of the information shared. In our research we made use of qualitative data for both the quantitative and qualitative methods of analysis and used the outcomes of the DNA as a starting point for the qualitative analysis. As mentioned earlier, combining methods is labour intensive and complex. Hence, many researchers will opt for either a quantitative or qualitative approach. Given the results of this research, however, I would not only urge more network researchers to adopt a mixed-method research design, but also to explore new and maybe even better ways of balancing the qualitative and quantitative approaches. As Edwards (2010) rightfully observes there is no one best way to integrate quantitative and qualitative methods in SNA and so there is definitely room for methodological development. It would be interesting to explore the different ways in which quantitative and qualitative approaches can be balanced, both in terms of data collection and analyses, and to also examine the advantages and limitations of these different approaches.

Recommendation 2: More research on coordination challenges in rail disruption management is needed.

This study has addressed a largely neglected issue in the disruption management literature, that of coordinating actions and information between the different teams managing the disruption. As we are one of the first to explore this topic in this specific context, additional research is needed. Future research should not only study the management of more and different kinds of disruptions to expand our knowledge on this topic, but should also provide insights into how the specific characteristics of the disruption (e.g. cause and timing) influence the communication and coordination challenges encountered (cf. Golightly & Dadashi, 2017). Secondly, the international comparison of rail disruption management could be expanded and improved by including more countries in the comparison and by providing a more empirical grounding of the items used. Moreover, an important step would also be to relate the trade-offs found in the international comparison to the effectiveness of the disruption management process. We have taken a first step towards expanding and enriching the international comparison during a one-year postdoctoral research project. Thirdly, future research should not only pay attention to the initial response to a disruption in order to bring the system into a relatively stable state, but also to its ability to fully recover from a disrupting event and the associated coordination challenges. Finally, the wider network of actors involved in the management of rail disruptions, such as contractors and emergency services, should be included in future research to also take into account the role of those managing the specific incident and how their activities impact the disruption management process.

Recommendation 3: Further explore the role and challenges to MTS leadership.

In the fourth chapter we have shown that there are some major challenges to MTS. Leadership is very important to integrate the activities of the different component teams in a MTS. This is why it is important to further explore the role of MTS leadership in different settings. Future research should not only look at the behaviours and qualities of leaders, but also at how these leader teams are embedded in the wider system. For example, Davison and colleagues (2012) argue that lateral coordination between component teams combined with hierarchical integration through leader teams constrains MTS performance. In the fourth chapter we have indeed seen how lateral coordination between the regional traffic control centres can negatively impact vertical coordination. At the same time this research has shown that both lateral and hierarchical integration is possible and even necessary in railway systems as component teams need to quickly respond to disruptions in a coordinated manner. Our international comparison has shown that there are different ways in which hierarchical and lateral integration have been combined. Future research should focus on the conditions that support both lateral and hierarchical coordination between teams.

Recommendation 4: Compare the disruption management practices of different critical infrastructure systems.

Railway systems are not the only critical infrastructure systems in which control centres are tasked with the reliable provision of services and that are very vulnerable to disruptions. Other such systems include road, electricity and telecommunication networks. Some of these infrastructures have also experienced the unbundling of the monopolies that used to manage them (cf. De Bruijne, 2006). In this study we have already seen that there are similarities, but also major differences in how the different rail systems have organized their disruption management process. It would therefore be interesting to explore how disruption management has been organized in other critical infrastructures and how these systems deal with the trade-offs identified in the first chapter.

6.8 CLOSING REMARKS

In this thesis we have looked at the management of large-scale, complex disruptions. We have seen that disruption management is a very complex matter that requires the coordinated action of many different operators and teams involved in the process. Communication and coordination problems become especially pressing during major and unique disruptions, when there is a real risk that control over the system will be lost. Perhaps the results of this thesis will not immediately contribute to giving the railway system a more positive image and might even strengthen people's conviction that travelling by car is by far the best option. We must, however, also look at the other side of the coin. NS and ProRail recently released an international benchmark in which they compare their performance with peers in six other European countries (ProRail & NS, 2017). Although we know on the basis of the fourth study that it is very difficult to directly compare countries, the results of the international benchmark revealed that the performance of NS and ProRail is actually quite good. Especially given the fact that the Dutch rail network is the busiest in Europe. Overall, the punctuality of passenger trains is one of the best in Europe and there are relatively few 'black days' (days when the total punctuality falls below 85 percent). This does not however, mean that there is no room for improvement in both the overall performance of the rail system and more specifically the management of disruptions. These improvements are of major importance in order to increase the overall reliability of the system and to accommodate the desired growth in rail traffic on the already congested rail network.

Process improvements could make an important contribution to the Dutch railway system's ability to quickly respond to disruptions and return to normal operations. At the same time we must also point out that there are limitations to what can be achieved by improving coordination and communication between teams. Improved coordination and communication between teams may expand the system's adaptive capacity, but there are many factors that influence the overall success of managing rail disruptions. For example, in this thesis we have seen that the rescheduling of train crews forms a serious issue during the management of disruptions and may even trigger an out-of-control situation. Despite new innovations there are limits to the number of trains that can be rescheduled and during large-scale disruptions this capacity is often insufficient. The rescheduling capacity is closely linked to how crew schedules have been planned. In this planning process a trade-off must be made between conflicting goals such as punctuality, costs, rescheduling capacity and variation in crew schedules. The system's adaptive capacity is thus bounded and highly depends upon the strategic choices made in the planning phase.

As this thesis has shown there is not one optimal model for organizing rail disruption management. Railway systems are complex systems in which important trade-offs have to be made that bound their performance (Woods & Branlat, 2011). Problems during the management of disruptions can't simply be blamed on the unbundling of the rail system nor will a merger between ProRail and NS solve all the issues. It is important to gain a better understanding of the complexity of rail systems in general, and rail disruption management in particular. Although many people have an opinion on how the rail system should work, only a few have any idea of how it actually functions. I hope that this thesis will make a contribution to the general knowledge on rail disruption management and that it will also make people feel more at ease when stranded at a train station, knowing how many people are working extremely hard to solve the disruption as soon as possible.