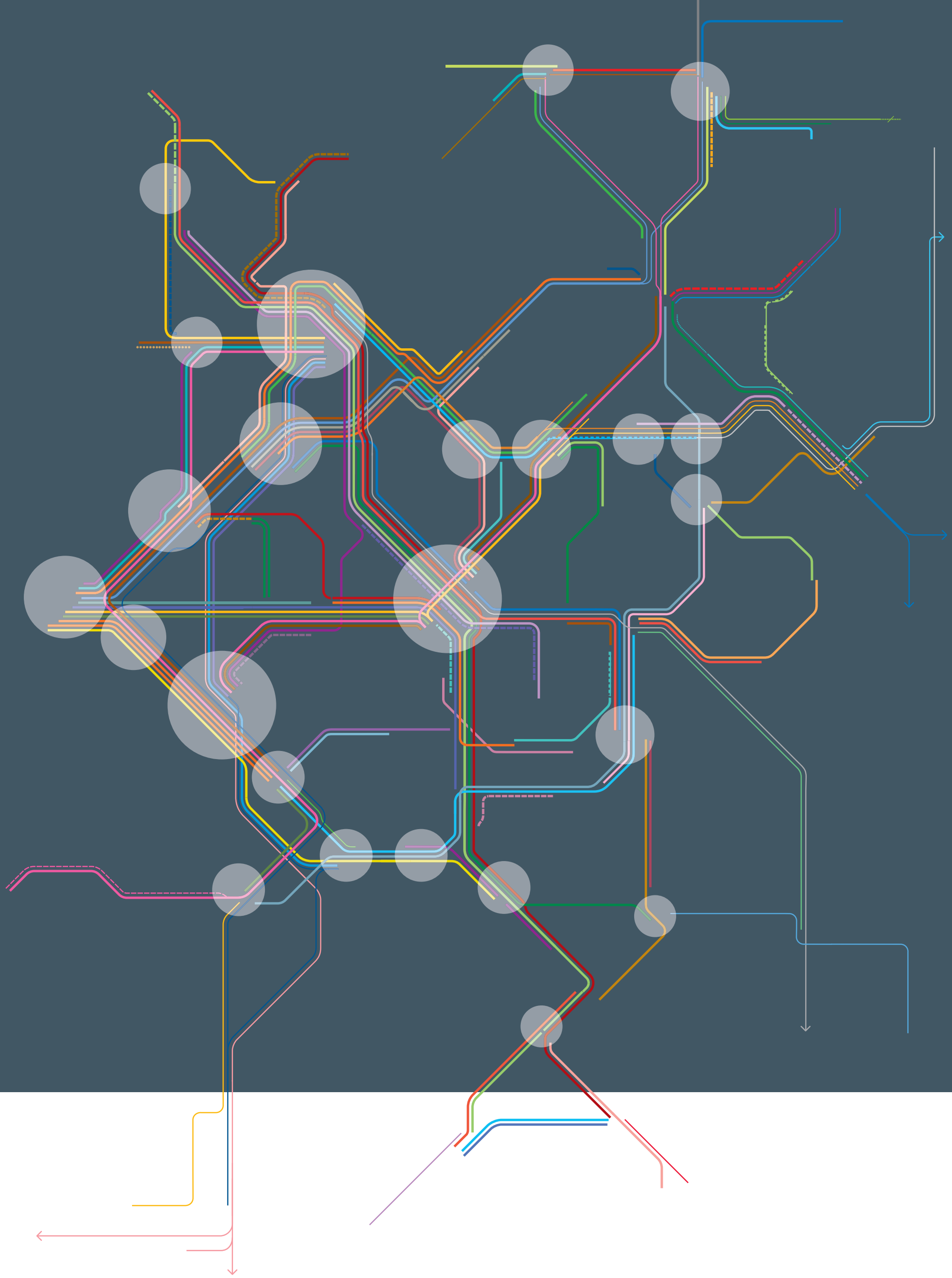

MANAGING RAILWAY DISRUPTIONS

The role of inter-team coordination during rail disruption management

DANNY SCHIPPER

Managing Railway Disruptions

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Managing Railway Disruptions

The role of inter-team coordination during rail disruption management

Managen van verstoringen op het spoor

De rol van coördinatie tussen teams tijdens verstoringsmanagement op het spoor

Proefschrift

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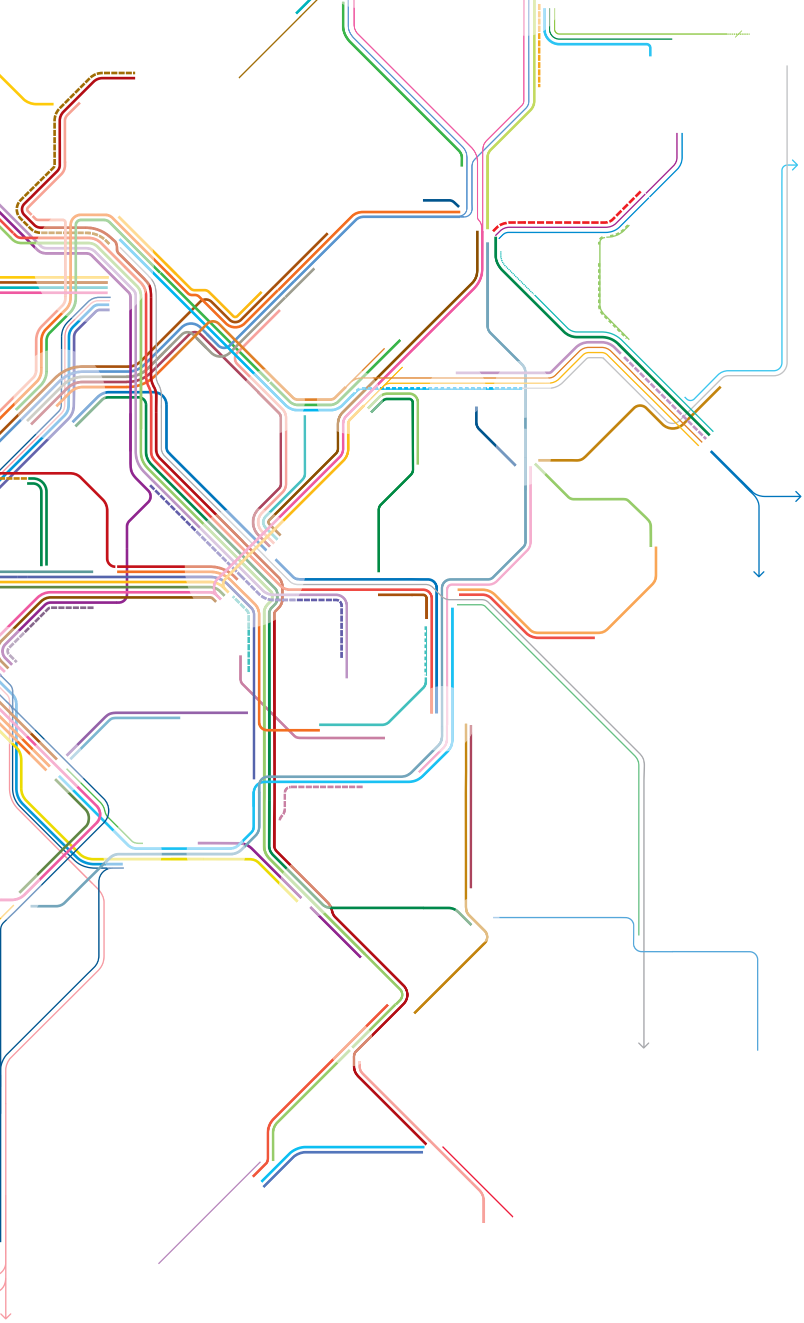


CHAPTER 1

General Introduction

1.1 INTRODUCTION

Everyone who travels by train in the Netherlands knows that they have to take potential delays into account. For example, there might be problems with the barrier arms at a level crossing, forcing trains to approach it slowly. Such disturbances are annoying as they may mean missed connections or increased waiting times. Major disruptions, however, such as broken overhead wires, cause such substantial deviations from planned operations that these plans have to be significantly revised (Nielsen, 2011). This rescheduling is done by controllers working in control centres. Controllers are confronted with all sorts of unique and challenging disruptions on a daily basis as their job is to ensure that operations are adapted to contain and minimize the impact of disruptions (Golightly & Dadashi, 2017).

While in most cases operators are able to adequately manage disruptions, the past few years have seen a number of instances in which the system span out of control. This occurred during the snowstorms of 2010, 2011 and 2012, but also more recently with power supply and ICT failures in 2015 and 2017. On all of these occasions, there was relatively little or no rail traffic in large parts of the country. Images of crowded train stations, passengers staring at blank departure boards, and crammed trains dominated the media. In response, politicians have repeatedly expressed their concerns about the poor performance of the Dutch railway system. In 2011 the minister even judged the system to be too complex to adequately anticipate and recover from large-scale disruptions (Ministerie van Infrastructuur en Milieu, 2011). These major disruptions have been extremely detrimental to the Dutch rail system's image, even though overall performance in terms of punctuality has been good over the years. Many politicians have called for radical changes, such as placing ProRail under direct state control. Improving disruption management is thus a very important challenge, one that is vital to restoring the trust of both passengers and politicians.

While these large-scale disruptions form a serious problem to the economy and society[1], we must not forget that managing the Dutch railway system reliably poses significant challenges. First of all, the Dutch railway network is one of the busiest of Europe in terms of passenger kilometres per kilometre of railway track (Ramaekers, de Wit, & Pouwels, 2009). Accommodating all the different train services on this relatively small rail network makes it difficult to run according to schedule. Moreover, with such a tight schedule, delays will have knock-on-effects causing problems to spread to other parts of the network. Secondly, the railway system has been developed over decades and therefore its components are of varying ages, designs and performance characteristics (Schulman & Roe, 2007b). For example, the Dutch railway system has more than 7,500 switches and 10,000 signals of various types and ages. Over the years the system has also become more complex as new

1 KiM (2017) calculated that the social costs caused by rail delays and disruptions ranged between 400 and 500 million euros in 2016.

communication, control and information technologies have been introduced to automate and centralize rail traffic control. For instance, signalling control has shifted from lever frames and control panels to computer-based control. Research by Perrow (1999) has shown that these systems with their complex collections of interacting components are prone to multiple and unexpected failures that can easily cascade. In the last couple of years ProRail has experienced several traffic management system failures which made it impossible to operate signals and switches so that rail traffic had to be stopped. Finally, the rail network is a large *open* system more than 3,000 kilometres in length that is exposed to all sorts of risks, such as extreme weather, suicide attempts and animals on the tracks.

De Bruijne and Van Eeten (2007) point to another important challenge for the reliable management of infrastructure systems like the Dutch railway system, which is the fragmentation of organizations that operate, manage and oversee these systems. Restructuring policies, including privatization, liberalization and deregulation, have changed infrastructure systems from large-scale integrated monopolies into networked systems consisting of multiple private and public organizations with competing goals and interests. Of course, the split-up of Netherlands Railways (NS) in the mid-nineties into the train operating company NS and the infrastructure manager ProRail is a prime example of this development. Another example is the outsourcing of the maintenance of the railway infrastructure to private contractors. Hence, the provision of reliable services has changed from being a primarily intra-organizational task to being an inter-organizational challenge (ibid.). While much has been written in the academic literature on railway unbundling and privatization (cf. Asmild, Holvad, Hougaard, & Kronborg, 2009; Finger, 2014; Gómez-Ibáñez & de Rus, 2006), most of these studies look at the reform policies, their implementation or the outcome in terms of performance. Far less attention has been paid to the effects that these policies have on the daily operations of controllers tasked with managing rail traffic and disruptions (see Steenhuisen & De Bruijne, 2009 for an exception to the rule).

With the unbundling of the rail system, rail traffic operators who used to work in one control centre were forced to work in separate control centres. Currently the rail traffic of all train operating companies (around 40 cargo and passenger service operators) is monitored and controlled by ProRail's controllers working in 13 control centres spread throughout the country. NS has five control centres to monitor its own operations, a significant share of which involves managing train crew and rolling stock. Although both processes have been separated, there is still a massive interdependence, especially when dealing with disruptions. This means that operators working in the different control centres of both companies have to work together closely and share a great deal of information by phone or via information systems. In practice, however, situations during a disruption often changed faster than the parties could communicate and the decentralized control made it difficult to manage disruptions with a national impact. This is why ProRail and NS decided to develop a joint control centre, called the Operational Control Centre Rail (OCCR).

In the OCCR many of the parties involved in the management of the railway system are co-located. These parties not only include ProRail's traffic control and NS' operations control, but also the teams responsible for Incident Management, Asset Management and contractors. The co-location of all these parties is intended to lead to improved information sharing, a better understanding of each other's roles, procedures and processes, and as a result, better decision making during disruptions (Goodwin, Essens, & Smith, 2012). Inside the OCCR, ProRail and NS monitor railway traffic at a national level and can intervene in regional operations when necessary. Despite the establishment of the OCCR, however, there have been several large-scale disruptions in the last couple of years where the situation span 'out-of-control'. One prime example of such an out-of-control situation was during a snowstorm on the third of February in 2012. Snowfall caused multiple malfunctions to the rail infrastructure and rolling stock. As a result, there were little or no train services in large parts of the country. An evaluation of this day by ProRail and NS revealed that the out-of-control situation had not been caused by the snow, but by the way in which the disruptions had been managed (Nederlandse Spoorwegen, ProRail, & Ministerie van Infrastructuur en Milieu, 2012). Poor communication and slow, ill-informed decision making meant that people were unaware of what was really going on and what should be done. Due to the lack of efficient coordination[2], control centres were working at cross-purposes and local decision making was encouraged. This had a negative impact on the train service as a whole and the management of disruptions in neighbouring control areas.

1.2 RESEARCH AIM AND RESEARCH QUESTION

As the previous section has made clear, the introduction of the OCCR as a boundary-spanning platform for the rail sector did not solve all the coordination issues in the Dutch rail system. In fact, one could say that it might have even made things more complicated by introducing another layer on top of the already complex network of control centres. The introduction of the OCCR created a multi-level networked system consisting of multiple semi-autonomous control centres, who pursue their own sub-goals within their own scope of action. At the same time they need to work together towards one overarching goal: restoring normal operations as soon as possible after a disruption. Achieving this overarching goal requires the coordinated efforts of all the control centres. As the previous section made clear, this is no easy task when working in a dynamic and time-pressured operational environment. The aim of this research is to gain a better understanding of the coordination and communication challenges *between* the different control centres during the management of

2 Following Faraj & Xiao (2006), we define coordination as the integration of organizational work under conditions of task interdependence and uncertainty.

large-scale, complex disruptions. This means that the disruption management process must be studied at the level of the system as a whole. We will analyze the management of several large-scale disruptions in the Dutch railway system and compare Dutch structures and practices for dealing with disruption management with those found in other European railway systems. The main research question is as follows:

> *"What explains the coordination breakdowns between the control centres in the Dutch railway system during the management of large-scale, complex disruptions?"*

In this study we specifically look at how the control centres jointly cope with the disruptions that *do* occur, although we acknowledge that it is also important to try to prevent disruptions from happening in the first place. For example, over the years ProRail has greatly reduced the number of switches in order to reduce the risk of malfunctions. It has even started to place sensors on switches to measure temperature, power usage and vibrations in order to predict faults. Despite these great efforts, it remains impossible to anticipate all events (Golightly & Dadashi, 2017). Hence, it is still very important to improve disruption management practices. The results of this thesis should therefore contribute to the improvement of the disruption management process in the Dutch rail system. Also provide valuable insights other rail systems and large critical infrastructure systems in general. Strangely enough, research on how public networks organize for a reliable service delivery is almost absent from the literature (Berthod, Grothe-Hammer, Müller-Seitz, Raab, & Sydow, 2017). Academic research on railway disruption management, particularly on the coordination of these rescheduling activities, is still very limited (also see section 1.3). With this thesis we want to contribute to the literature on railway disruption management by addressing these coordination challenges.

This thesis also aims to contribute to the Whole System Performance of the Dutch railway system. ProRail and the Dutch Research Council (NWO) initiated the Whole System Performance research programme[3] (2012-2018) to improve cooperation between the many different stakeholders in the rail system and to advance its asset and disruption management. A total of four research projects contributed to this research programme. I was part of the research project called Managing Complex System Disruptions (MaCSyD). In this project researchers from VU University Amsterdam, Delft University of Technology, and Erasmus University Rotterdam jointly studied communication and coordination practices during the management of rail disruptions. This has, for example, resulted in a joint article on collective

3 See http://explorail.verdus.nl/1334 for an English summary.

sensemaking among operators in the OCCR during an autumn storm[4], which is not part of this dissertation. This dissertation is one of the project's end products and offers a systems perspective on disruption management by looking at the joint efforts made by the control centres to manage disruptions. Another end product is the dissertation of a PhD candidate from VU University Amsterdam (Willems, 2018). As an organizational ethnographer this candidate observed the daily practices of the different parties involved in the management of disruptions to gain a deeper understanding of these practices. The micro-perspective of the ethnographic study and the systems perspective of this study aimed to complement each other in order to gain a comprehensive understanding of rail disruption management.

In the next section we will take a closer look at the management of complex socio-technical systems in general and the literature on railway disruption management in particular. In section 1.4 Dynamic Network Analysis is introduced as a method to analyze coordination between actors in a complex system. Section 1.5 addresses the methodological challenges of studying disruption management and the outline of the dissertation is presented in section 1.6.

1.3 SCIENTIFIC POSITIONING AND RELEVANCE TO THE LITERATURE

1.3.1 Disruption management in railway systems

Operations Researchers dealing with disruption management focus on how to assist operators with rescheduling activities by developing algorithms and recovery models and implementing them in decision support systems. Disruption management deals with topics such as coping with disruptions, minimizing negative effects and how to minimize deviation costs while solving disruptions (Yu & Qi, 2004). There is extensive literature on disruption management and its techniques have been applied in several areas, including project management (Howick & Eden, 2001; Williams, Ackermann, & Eden, 2003), supply chain coordination (Huang, Yu, Wang, & Wang, 2006; Qi, Bard, & Yu, 2004), and airline operations (Clausen, Larsen, Larsen, & Rezanova, 2010; Kohl, Larsen, Larsen, Ross, & Tiourine, 2007; Rosenberger, Johnson, & Nemhauser, 2003). Disruption management for railway systems is, however, still relatively unexplored in comparison to, for example, the airline industry. Moreover, most of the models and algorithms developed for railway disruption management only cover a small part of the disruption management process, as they tend to focus on a specific type of disruption, a phase in the disruption management process, or the rescheduling of a specific resource (rolling stock, timetable, train crew) (see Cacchiani

4 Merkus, S, Willems, TAH, Schipper, D, van Marrewijk, AH, Koppenjan, JFM, Veenswijk, M, & Bakker, HLM (2017). A storm is coming? Collective sensemaking and ambiguity in an inter-organizational team managing railway system disruptions. *Journal of Change Management*, 17(3), 228-248.

et al., 2014 for an overview). However, the interdependence between tasks and resources is a key challenge during the management of a disruption. So far, these systems have not been implemented much in practice due to the lack of integrated and dynamic models and tools (Quaglietta, Corman, & Goverde, 2013).

While Operations Research has paid a great deal of attention to the support given to rescheduling activities, less attention has been paid to the coordination of these closely-linked activities. One of the exceptions is the work of Corman and colleagues (2012; 2014), who assessed the performance of centralized and decentralized rescheduling approaches and developed algorithms to support coordination. Models are, however, simplified forms of reality or may even be normative, and therefore they cannot always deal with the uncertainty and dynamics of the disruption management process (Golightly et al., 2013). In addition, although there has been a lot of development in terms of supporting tools, most of the rescheduling is still done by the different dispatchers on the basis of predefined rules and experience. Decisions made by individual operators or control centres are not necessarily optimal and might even lead to new conflicts (Kecman, Corman, D'ariano, Rob, & Goverde, 2013).

It is therefore important to take into account the uncertainty associated with human behaviour. In order to understand disruption management in the Dutch railway system it is vital to look at real-world cases of how the different control centres jointly respond to a disruption and the unexpected consequences of this adaptation process. Communication and coordination play a crucial role in this process, which is facilitated by technology. Hence, the Dutch railway system can be seen as a complex socio-technical system that is characterized by the interdependence between social and technical elements and the resultant behaviour that emerges from their interactions (Walker, Stanton, Salmon, & Jenkins, 2008).

1.3.2 The reliable management of complex socio-technical systems

In recent decades there has been a growing interest among organizational scholars in the conditions that influence organizations' ability to reliably manage large-scale, complex socio-technical systems under a variety of dynamic conditions, i.e. an organization's ability to both plan for incidents and to absorb and rebound from them in order to provide safe and continuous service delivery (cf. Hollnagel, Paries, David, & Wreathall, 2011; La Porte, 1996; Perrow, 1984; Weick & Sutcliffe, 2007). The best known examples are the studies on High Reliability Organizations (HRO) (La Porte, 1994; Rochlin, La Porte, & Roberts, 1987; Rochlin, 1999). Studies on nuclear power plants and aircraft carriers have shown how these organizations were able to operate relatively closed complex systems safely and reliably over long periods of time and under trying conditions by creating appropriate structures, attitudes and behaviours. On the other side of the spectrum is Perrow's (1984; 1999) Normal Accident Theory (NAT).

As stated by Perrow, large-scale complex systems are actually prone to failure. In his studies he showed how one failure can trigger other failures and how these failures can spread and cascade in a way not anticipated by either the system's designers or those operating it. This may cause small-scale disturbances to develop into large-scale problems that are difficult to stop and may even lead to system failure. Despite their differences, both NAT and HRO point to the importance of the social and organizational underpinnings of a system's reliability (Sutcliffe, 2011). Many studies address the limitations of traditional hierarchical systems in effectively coping within complex, ambiguous and unstable task environments (Bigley & Roberts, 2001; Woods & Branlat, 2011a). The core assets of these systems standardization, formalization and hierarchy severely limit the flexibility needed to operate in these environments. Within the organizational literature two important trade-offs can be identified in the reliable management of these systems: a) decentralized versus centralized structures and b) anticipation versus resilience.

According to Perrow (1984; 1999), complex and tightly-coupled systems must simultaneously be centralized and decentralized, which he deemed an unsolvable problem. Highly-centralized authority structures are needed to facilitate rapid and decisive coordinated action, given the tight coupling of systems and the risk of cascading failures. Decentralized systems are too slow to handle cascading failures. The latter is also a problem in the Dutch railway system. For example, evaluations of two large-scale disruptions during the winter of 2012 showed that situations would often change faster than operators could coordinate and deal with (Nederlandse Spoorwegen et al., 2012). Moreover, the system's decentralized nature led to local optimization, as local problems were unintentionally spread to other control areas. Nevertheless, decentralized decision-making remains necessary in order to deal with the interactive complexity of systems and the unpredictable problems resulting from this complexity. Decentralized units are better able to manage these non-routine situations given their local expertise and more direct control over resources (Perrow, 1999). For example, train dispatchers' detailed knowledge of the rail network helps them to find improvised solutions in order to reroute trains.

Other researchers provide an alternative view on the tension between centralization and decentralization (cf. Bigley & Roberts, 2001; Branlat & Woods, 2010; Gauthereau & Hollnagel, 2005; Weick & Sutcliffe, 2007). For instance, Gauthereau & Hollnagel (2005) state that centralized structures do not always need to limit organizational flexibility and that both decentralized and centralized forms of governance must be present at the same time. They showed how central planning offered a framework that supported the coordination of local adaptation. This kind of control is also known as polycentric control (Branlat & Woods, 2010; Woods & Branlat, 2010). Polycentric control seeks to sustain a dynamic balance between the two layers of control, i.e. those closer to the basic processes and with a narrower field of view and scope (e.g. regional control centres) and those farther removed, which have a wider field of view and scope (e.g. the OCCR), as situations evolve and priorities change. So instead of being centralized or decentralized, autonomy and authority should be adapted to the pace of operation. Nevertheless, much remains unclear about polycentric systems and the coordination challenges that follow from this dynamic form of governance.

Another important tension is that between anticipation and resilience (Roe & Schulman, 2008; Wildavsky, 1988). According to the *anticipation* approach a system's reliability stems from constant and predictable performance. The anticipation approach involves predicting potential failures or disruptions in order to plan ahead (Stephenson, 2010). Designed coordination mechanisms, such as protocols, rules and contingency plans, prescribe what operators should do in the event of a disruption and how they should work together. This is intended to increase the system's responsiveness as it reduces coordination issues between actors. However, it has been shown that it is extremely difficult to anticipate every contingency, as the type, timing and location of an incident make disruption management very unpredictable (Golightly & Dadashi, 2017). An over-reliance on anticipation can thus cause a loss of capacity to adapt to unanticipated situations. Hence, Woods & Wreathall (2008) distinguish two types of adaptive capacity: first order and second order. First order adaptive capacity involves responding to anticipated events according to predefined procedures, plans and roles, while second order adaptive capacity emerges when operators dynamically respond to non-anticipated situations by means of, for example, mutual adjustment, informal communication, and improvisation.

The second order adaptive capacity or *resilience* approach to reliability substitutes foresight for the reactive capacity of systems to recognize and adapt to changing conditions in order to maintain control (Vogus & Sutcliffe, 2007). In other words, there needs to be discretionary room for operators to respond to the specific situation through mutual adjustment and improvisation (Faraj & Xiao, 2006). However, this does not mean that formal modes of coordination can just be abandoned. As Kendra & Wachtendorf (2003) observe, anticipation is an integral dimension of resilience, as planning and formalizing response arrangements help actors to make sense of a particular situation and facilitate a rapid and flexible response. This means that anticipation and resilience are not mutually exclusive and that both approaches need to coexist.

Organizations operating in a dynamic and complex environment thus paradoxically emphasize both formal and improvised forms of coordination (Faraj & Xiao, 2006). Operators working in control centres are confronted by these trade-offs on a daily basis. They have to decide between following design principles and relying on improvisation and between hierarchical and on-the-spot decision making (Schulman & Roe, 2011). Operators not only have to deal with often unique disruptions, but these disruptions also tend to be very dynamic as conditions often change fast. This makes it difficult to create a good understanding of the situation, since information is often ambiguous, quickly outdated, and only becomes available gradually (Nielsen, 2011). For example, in the case of a broken catenary a repair crew has to go on site to make an accurate estimation of the damage and the repair time. An effective and timely response to a disruption depends on the operators' ability to quickly create an understanding of the evolving situation (Waller & Uitdewilligen, 2008). This process is called sensemaking and involves the creation of a plausible understanding of a situation and the continuous updating and revising of this understanding to deal with uncertainty and the dynamics of the environment (Weick, Sutcliffe, & Obstfeld, 2005).

Operators thus not only need to coordinate their activities, but must also do this in an adaptive fashion (Burke, Stagl, Salas, Pierce, & Kendall, 2006). Most research has focused on these coordination and adaptation challenges in complex, dynamic and time-pressured environments from the point of view of co-located teams (Ren, Kiesler, & Fussell, 2008). In this thesis, however, the focus is on the network of control centres, separated by geographical and organizational boundaries. There is limited knowledge on the challenges of coordinating activities between distributed teams, despite the fact that these teams have to deal with unique communication and coordination challenges that must be managed properly (Fiore, Salas, Cuevas, & Bowers, 2003). For instance, geographically distributed teams have to rely on technology (phone, computer, and video) to communicate instead of being able to talk face-to-face like co-located teams. The use of technology has an important impact on the sharing and interpretation of information (Vlaar, van Fenema, & Tiwari, 2008). In the next section I will elaborate more on these specific challenges by turning to the literature on Multiteam Systems.

1.3.3 The Dutch railway system as a multiteam system

Each control centre can be seen as a team pursuing their own sub-goals and tasks (managing train crew or optimizing rail traffic flows). These individual teams are tied together by a collective goal, which in this thesis is the management of a disruption. This tightly-coupled network of control centres forms a Multiteam System (MTS). Multiteam systems have been defined as two or more teams that interface directly and interdependently in response to environmental contingencies in order to accomplish collective goals (Mathieu, Marks, & Zaccaro, 2001). Multiteam systems differ from most other organizational forms in that they work in highly dynamic and complex environments and thus must be able to respond rapidly to changing circumstances under high time-pressure. This places a premium on the teams' ability to bring together their skills and knowledge to tackle novel and surprising events (Zaccaro, Marks, & DeChurch, 2012). Moreover, as in the Dutch railway system, MTSs are often made up of teams from different organizations.

As Mathieu and colleagues (2001) state, the high interdependency between teams makes MTS more than just the sum of individual team activities. It is therefore necessary to examine the teams' joint efforts in order to understand the workings of the system as a whole. As such, MTSs form a new and unique level of analysis with their own unique challenges, which might not be fully explained by traditional team or organizational research literature. As Lanaj et al. (2013) observe, factors that contribute to processes within teams might hinder processes between teams and therefore well-accepted theories on stand-alone teams (e.g. on leadership, communication, and coordination) might not apply to MTS. For instance, while HRO literature stresses the importance of a free flow of information between operators to coordinate activities and pick up warning signs, research has shown that geographically separated teams experience difficulties in distributing information evenly, accurately and on time (Hinds & McGrath, 2006). Moreover, a system with different specialized component teams may also lead to diverging definitions of shared problems and a focus on in-group goals at the expense of collective goals (Davison, Hollenbeck, Barnes, Sleesman, & Ilgen, 2012).

While MTS might have been around for decades, team researchers only defined the construct at the beginning of this century and therefore MTS research is a relatively new field. Initial research adopted a grounded approach to study this organizational form in practice, but much of the subsequent work has either been done in laboratory settings or is theoretical (Shuffler, Rico, & Salas, 2014). Although MTSs operate in turbulent environments, not much research has focused on how these systems adapt or fail to adapt to contingencies (Shuffler, Jiménez-Rodríguez, & Kramer, 2015). Hence, there is still much to learn about the unique properties and challenges of MTS in a real-world context.

As has been mentioned in the previous section, an effective and timely response to a disruption requires a thorough understanding of the situation. In the Dutch railway system multiple teams adapt to changes in the environment. This means that sensemaking is not only distributed over multiple roles, but also over multiple control centres. Consequently, operators and teams need to share important information on their understanding of the dynamic environment in order to align their activities. This understanding of a complex and dynamic situation is called situation awareness (Uitdewilligen, 2011). For example, while it might be beneficial for one team to deviate from procedures, this decision could result in a great deal of confusion among the other teams and have a negative effect on the system's overall performance if it is made in isolation (Woods & Shattuck, 2000). Effective disruption management thus not only depends on the capabilities of single teams to create a good understanding of the situation and decide on an appropriate response, but also on how these decisions are coordinated with other teams. In this thesis we will zoom in on the role of sensemaking and the difficulties inherent to creating and maintaining a shared understanding between distributed teams.

In terms of the second trade-off, the need for both centralized and decentralized forms of control places an emphasis on the capacity of *supervisory* or *leader* teams (cf. Davison et al., 2012; DeChurch & Marks, 2006; DeChurch et al., 2011) to balance autonomy and authority between local and central control centres (Shattuck & Woods, 2000). Too much autonomy for local teams when adapting to local situations could lead to a fragmented response to a disruption, while centralized control through centralized decision-making and planning might be too rigid to deal with unanticipated situations. Leader teams thus need to balance the risk of teams working at cross-purposes against that of implementing an inadequate response to changing conditions. Making this trade-off is not only difficult for leaders in single teams, but is especially difficult for remote leader teams as they have to make sense of the situation from a distance. In this thesis we will look at the challenges that leader teams encounter when balancing this trade-off and compare five European rail systems on how they structure the relationship between local and centralized control.

1.4 INVESTIGATING A COMPLEX MULTITEAM SYSTEM USING SOCIAL NETWORK ANALYSIS

Examining a complex multiteam system does not only provide a unique level of analysis, but also presents the unique challenges of studying such a system. The large size of a MTS, along with the specialized nature of the task and goals of the operators and teams, makes it difficult to analyze complex socio-technical systems. As mentioned earlier, MTSs, like any other complex system, are more than the sum of individual team efforts. The different teams need to maintain a shared situation awareness in order to coordinate their activities. They do this by exchanging information. Hence, it is important to study the interactions between the different teams and the resultant emergent behaviour (Stanton, 2014). One of the methods commonly used to study flows of information is Social Network Analysis (SNA). SNA has been used to study coordination in a wide variety of fields, such as emergency response management (e.g. Kapucu, 2005; Salmon, Stanton, Jenkins, & Walker, 2011) and hospitals (e.g. Hossain, Guan, & Chun, 2012). SNA is seen as a valuable tool for studying coordination, but as far as I know it has not been applied to studies on railway disruption management. That is why in this thesis it is argued and shown how SNA can be applied to study railway disruption management.

The way in which information is communicated and distributed affects team performance (Parush et al., 2011). This makes it important to understand how information is shared between teams and how this affects team dynamics. SNA makes it possible to obtain a systematic overview of the network of control centres and their relationships (linkages) as they respond to a disruption. These linkages affect the kind of information that is being exchanged, between whom and to what extent (Haythornthwaite, 1996). SNA is not only a method for visualizing networks, but also for quantitatively assessing the communication patterns and the role of actors within a network. This makes it possible to investigate the involvement of a specific actor or how flows of information deviate from formal procedures. This renders SNA especially suitable for studying coordination in a distributed setting as these kinds of insights may help to identify problems that are inhibiting coordination (Hossain & Kuti, 2010).

SNA, however, has its limitations (cf. Schipper & Spekkink, 2015). It focuses on mapping networks and measuring their characteristics. This emphasis on the structure of networks has mostly resulted in static representations of networks to understand how these structural properties affect certain outcomes. In this chapter we have repeatedly argued that disruption management is an emergent and dynamic process. Hence, the changing patterns of communication and roles of actors or teams within the network are lost when only a snapshot of the network at one point in time is provided. We will show in chapter 2 how the role of time can be included to capture the network's dynamics during the management of disruptions. A better understanding of these network dynamics can help improve coordination between the teams (Abbasi & Kapucu, 2012).

Secondly, although network analysis is a great method for revealing and quantitatively assessing communication patterns, it is largely blind to the content of the information being shared, how the information is communicated, and how actors respond to this information. Each actor interprets and uses the information in their own way based on their roles, tasks, and experience (Salmon et al., 2008). This is why actors have to collectively make sense of the information being shared. Hence, a quantitative analysis of the information flows should be combined with a qualitative analysis of the interactions (e.g. communication content and style) between actors. In the last couple of years there have been increased calls for a more qualitative approach to SNA (e.g. Crossley, 2010; Edwards & Crossley, 2009; Heath, Fuller, & Johnston, 2009). Nevertheless, the number of studies providing such a mixed-method approach is limited. In this thesis it is shown how dynamic network analysis can be combined with a qualitative analysis of how actors made sense of the information being shared.

1.5 METHODOLOGICAL CHALLENGES IN STUDYING DISRUPTION MANAGEMENT

To assess a system's adaptive capacity, a common practice is to look at how it responds to disruptions (Woods & Cook, 2006). Such an analysis provides information on how well the system copes with increasing demands and reveals important coordination patterns and challenges. Disruptions that push the system near the limits of its performance boundaries are especially important, as they provide insight into both hidden sources of adaptiveness and a system's capacity limits (ibid). Large-scale, non-routine disruptions are thus particularly suitable for revealing these boundary conditions, as effective coordination becomes especially important and difficult to maintain during these situations (Uitdewilligen, 2011). The analysis of disruption management fits within a Naturalistic Decision Making (NDM) or Macrocognition approach (cf. Klein & Wright, 2016; Schraagen, Klein, & Hoffman, 2008). Macrocognition is concerned with cognitive processes, such as sensemaking, coordination, adaptation, planning and replanning, by experts in complex real-world settings under time pressure and uncertainty, as opposed to often applied controlled laboratory studies of isolated cognitive functions. Macrocognitive research thus tries to better understand how teams work together and adapt to situations in natural settings.

Studying disruption management in practice poses certain methodological challenges, given the unexpected nature of disruptions and the difficulties in collecting data. One of the most commonly used methodological approaches to collecting data on operators' activities is direct observation (Branlat, Fern, Voshell, & Trent, 2009). While observations are valuable for collecting data on the behaviour of one operator or a small group of operators working in close proximity, it is far more challenging to observe the work of operators who are geographically separated. It is difficult to plan these observations given the uncertainty of when and where a disruption will occur. As such, direct observation requires several trained researchers to spend a lot of time at the various control centres. This is a problem given the limited amount of resources available. Another well-known method of data collection is the use of retrospective interviews. Nevertheless, as we noticed during our research and as has been shown in other studies, people working under stress tend to find it more difficult to recall details accurately. As Aiken & Hanges (2012) observe, the pressure of the moment might override rational thought and response. This makes it difficult to ask respondents to reconstruct specific events or apply self-report measurements, and even more difficult to try to reconstruct flows of information solely on the basis of interviews or surveys.

Luckily, after a year we were granted restricted access to recordings of telephone conversations between ProRail operators. Unfortunately, NS could not make their recordings available. The telephone conversations had been recorded for legal (safety critical communication) and training purposes. For my research they were a crucial source of data that enabled me to study the flows and content of the communication between operators working at different control rooms and to understand how they collectively made sense of this information. Nevertheless, studying the communication between operators in the Dutch rail system proved to be a challenge on its own. The rail system is known for its use of jargon, speaking in terms of train numbers and an excessive use of abbreviations. For operators this jargon is part of their identity and even a way to exclude outsiders. This meant that I had to quickly learn the language used in the Dutch rail system.

Another challenge when studying a multi-team system is that people can perfectly explain their own role in a process, but are only able to give a very general overview of how the entire system works. This meant that I had to become familiar with the different roles and teams within the system in order to understand what they do and how they work together. I also had to familiarize myself with the technological systems they use, as these systems are critical in their daily work. This is why, in addition to analyzing large-scale disruptions, I also made several site visits to the various control centres of both ProRail and

NS, spent numerous hours observing and interviewing operators during their daily work and attended their training sessions.

ProRail granted us unrestricted access to the OCCR and appointed a research coach who showed us around and quickly made us familiar with the different parties located in the national control centre. Our research coach also played an important role in updating us on important developments in the rail system and helping us to get in contact with people. The OCCR proved to be a great site to learn a lot about disruption management and to talk with operators from the different teams involved in the process. At this early stage in the research interviews were often open and informal. I asked operators to tell me about their role in general and more specifically during the management of a disruption. Another important topic concerned the difficulties encountered when managing disruptions and the relationship with the other teams involved in the process. Detailed notes were made of the interviews and observations. Sometimes I would observe and interview an operator during his or her shift, which could start early in the morning (7 am to 3 pm) or late in the afternoon (3 pm to 11 pm). There were also days in which I would switch between operators or teams. Later on I arranged site visits to the regional control centres of both ProRail and NS. I usually met with the team or shift leader at the beginning of their shift. After I had carefully explained the reason for my visit, they would show me around, introduce the different roles in the control centres, and made it possible for me to observe and interview different operators.

The unpredictable nature of disruptions also poses some interesting challenges when selecting disruptions to investigate. Large-scale disruptions do not happen that often (although some passengers might think otherwise) and are therefore easy to miss. As I was not always present at the OCCR, I had to rely on other sources for information on disruptions that had occurred. I found that the mass media could be used as a source of information on major disruptions. To gain more details on the disruptions our research coach put me on a mailing list to receive OCCR shift reports four times a day, management reports on large-scale disruptions, and management text messages. Of course, our research coach was also an important source of information on disruptions and he helped me to contact the people involved in the management of the disruption. These sources helped me to select cases to investigate further.

Despite having access to recordings of telephone conversations, interviews remained important as they allowed the operators to reflect on the course of events and provide clarification on matters. As mentioned before, it is difficult for operators who work under stress to provide detailed accounts of events, especially when they have to deal with multiple disruptions on a daily basis. Hence, it was crucial to approach respondents soon after a disruption had occurred. This meant that disruptions which occurred a considerable time ago were less suitable cases for investigation. Understanding disruption management from a multiteam system perspective, i.e. how multiple teams function, also contributed to the difficulties of collecting data. For example, access to the recordings of the telephone conversations and respondents depended on the willingness of the managers of each control centre to cooperate with the research.

1.6 OUTLINE OF THE DISSERTATION

This thesis is article-based. This means that the four empirical chapters of this dissertation are based on articles which have been submitted to international peer-reviewed journals. The four articles have been published in the following journals: European Journal of Transport and Infrastructure Research; Complexity, Governance & Networks; Cognition, Technology & Work, and Journal of Rail Transport Planning & Management. Three out of the four articles have been co-authored, but as the first author I took the lead in the data collection, analysis, and writing of the manuscript. In one of the articles I am the single author. The articles stand alone and thus the chapters can be read independently, but each article builds on previous publications.

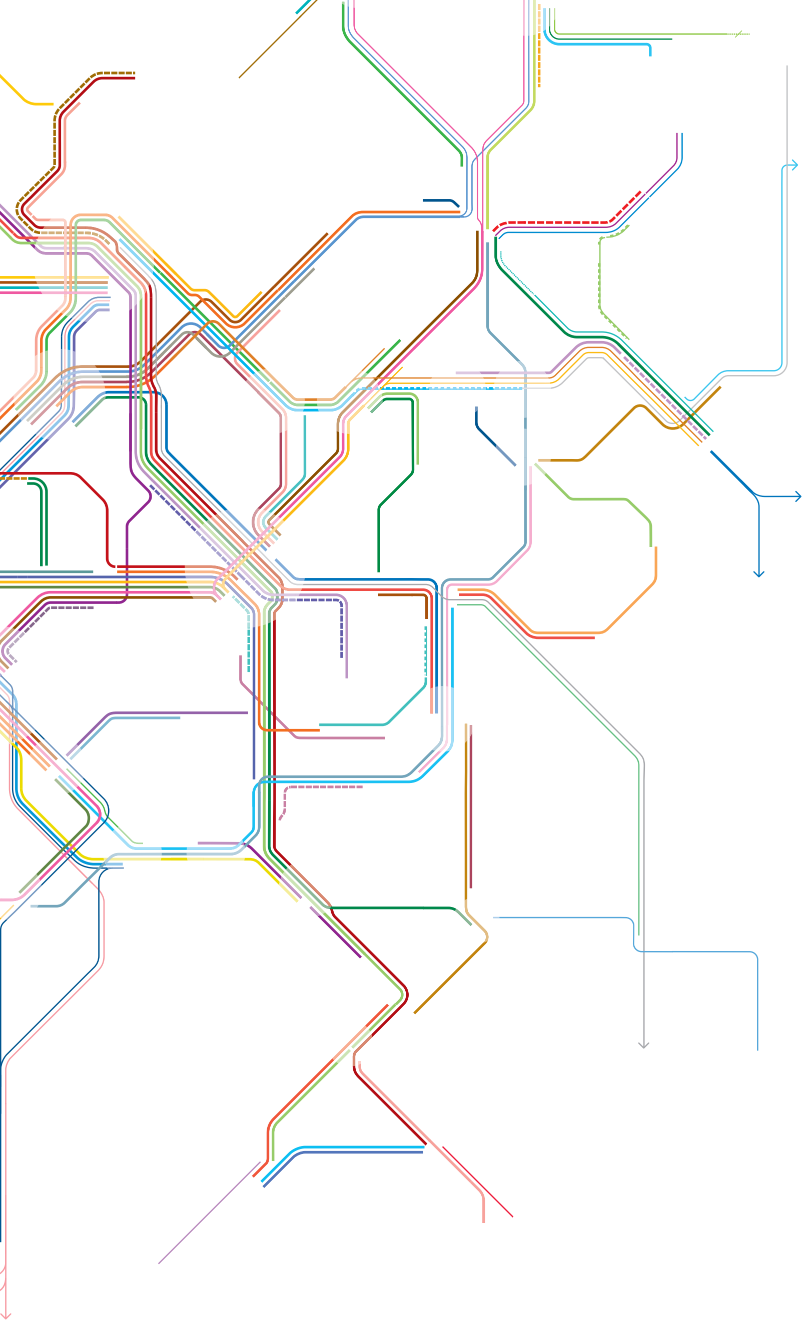
Chapter 2 starts with the first empirical study in which we will demonstrate the tools of Dynamic Network Analysis (DNA) to study the flows of information during a minor disruption. DNA makes it possible to include the element of time in SNA and thus to take the dynamics of the information flows and the positions of actors in the network into account. We will use DNA to visualize and analyze the communication patterns between operators involved in the disruption management process and to identify potential coordination issues.

Chapter 3 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 apply a mixed-methods approach to explain this coordination breakdown by looking at both the flows of information between actors using DNA, as well as how actors collectively make sense of the information being shared. This study shows how teams, by deviating from standard procedures, create ambiguity for the other teams in the network and how they have to collectively make sense of the new situation in order to create a congruent understanding. In this study we will illustrate how specific labels and the procedures they trigger may actually hinder the development of a sufficiently-shared understanding between teams.

Chapter 4 addresses the need for polycentric control in order to secure a system's adaptive capacity. Regional control centres are needed to quickly respond to disruptions, while leader teams are necessary to synchronize the activities of the regional control centres and to secure system level goals. In this study we will look at how operators in the OCCR provide leadership during the management of two large-scale, complex disruptions and the main challenges these leader teams encounter when providing leadership in a multiteam system.

In *Chapter 5* we will make a comparison of how disruption management is organized in Austria, Belgium, Denmark, Germany and the Netherlands. This comparison is structured around the two trade-offs identified in this chapter: centralized versus decentralized and anticipation versus resilience. In this study we will show the differences and similarities in how the different rail systems have dealt with these trade-offs.

Finally, in the concluding chapter of this dissertation (*Chapter 6*), an answer will be provided to the main research question on the basis of the main findings of this study. We will also discuss the practical, methodological and theoretical implications of this research, along with suggestions for future research.



CHAPTER 2

A Dynamic Network Analysis of rail disruption management

This chapter is published as:
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ABSTRACT

Railway systems experience disruptions on a daily basis. We test the use of Dynamic Network Analysis as a methodological tool in order to investigate the communication patterns during the dynamic process of disruption management. The tool was applied to a simulated case of a catenary failure in the Dutch railway system. DNA provides a systematic overview of the communication patterns and tasks associated with the disruption management process. Key actors were identified and the overall structure of the network analyzed. The dynamic component to our network analysis revealed that information is being shared within disconnected parts of the network during the first few minutes, without those parts having a direct link to the source of the information. These findings show that employing only static analysis of networks obscures the real dynamics of information sharing during railway disruptions and potential coordination problems. DNA therefore can be an important method and tool to reveal issues that need to be resolved.

2.1 INTRODUCTION

The Dutch railway network is the busiest of Europe in terms of passenger kilometers per kilometer of railway track (Ramaekers et al., 2009). Accommodating all the different train services on the relatively small rail network makes it difficult to run according to schedule and delays can easily have knock-on-effects causing problems to spread to other parts of the network. This makes the Dutch railway system highly vulnerable to disruptions, i.e. an event or a series of events that leads to substantial deviations from planned operations (Nielsen, 2011). Nevertheless, the overall performance of the railway system in terms of punctuality has been good in the previous years. However, as the winter seasons often demonstrate: when things go wrong they tend to go wrong on a large-scale, leading to loss of control and long recovery phases.

These major disruptions lead to dissatisfaction among travelers, extra expenses, and revenue losses. In response, train operating companies (TOCs), infrastructure provider ProRail, and the Dutch government have sought ways to improve operational performance. As the possibilities to expand the infrastructure capacity are limited, due to financial and environmental constraints, most of these resources have been aimed at reducing the system's vulnerability, i.e. increasing its robustness to absorb shocks and to improve its capacity to recover from disruptions. Simplification of the infrastructure (unbundling of nodes, reducing the number of switches), time table and logistics is considered to contribute to the robustness of the system (Ministerie van Infrastructuur en Milieu, 2011). One major vulnerability is the coordination between the different parties involved in managing disruptions (Ministerie van Infrastructuur en Milieu, 2011). This process has become so complex that that it is considered unsuitable to anticipate and recover from disturbances (ibid.). A possible solution would be to reduce the number of actors involved and to introduce stricter procedures in an attempt to bring down the diversity in possible behavioral responses (Sutcliffe & Vogus, 2003). While this may help in coping with most of the common disruptions, research shows that optimization of existing systems has a limited impact, there is a trade-off between optimization and brittleness in the face of novel events and uncertainties (cf. Csete & Doyle, 2002; Hoffman & Woods, 2011; Woods & Branlat, 2011a).

We understand the railway system as being a complex socio-technical system (cf. Comfort, 2005; Walker et al., 2008) that consists of several social subsystems, each with particular goals, perceptions, tasks and resources. These geographically separated subsystems have to coordinate their activities during a disruption in order to return to the original operational plan as quickly as possible (Bharosa, Lee, & Janssen, 2010). Coordination relies on effective communication in such complex systems (Faraj & Xiao, 2006; Gittell, 2011; Ren et al., 2008). While most policies and research focus on reducing this complexity, fewer (empirical) studies have focused on understanding and harnessing the complexity of disruption management. A comprehensive overview of who does what during a disruption and of how information is being shared between actors in the Dutch railway system is therefore still missing.

In this article we want to propose and demonstrate a method with which such a comprehensive understanding of the complex communication patterns during disruption management can be mapped and analyzed. Visualizing and analyzing network structures can reveal properties of the operation of the railway system that might not be obvious from standards operating procedures (Houghton et al., 2006). Naturally, that requires collecting, structuring and analyzing a considerable amount of data. We propose Dynamic Network Analysis (DNA) as a promising method and tool for such an endeavor because it allows capturing the irregular flows of information during a disruption, in contrast to the more static tools of traditional social network analysis. However, to our knowledge DNA (or even SNA) has not been applied to studies on railway disruptions. These considerations lead to us to the following research question: How can DNA help to investigate coordination between the geographically distributed teams involved in the management of a railway disruption? We will use an example of a failing catenary to demonstrate the various aspects of DNA.

We will first discuss the properties that make disruption management so complex and the need for DNA (section 2.2). Next, DNA will be presented (section 2.3), followed by the research methodology (section 2.4). A short overview of how disruptions are managed in the Dutch railway system is provided in section 2.5. The results of applying DNA to the catenary failure are presented in section 2.6 followed by a discussion (section 2.7), and the conclusions (section 2.8).

2.2 THE COMPLEXITY OF MANAGING RAILWAY DISRUPTIONS

There is a growing interest among theorist in conditions that influence organizations to reliably manage large and complex technical systems (cf. Hollnagel et al., 2011; La Porte, 1994; Leveson, Dulac, Marais, & Carroll, 2009; Perrow, 1999; Rochlin et al., 1987; Weick, Sutcliffe, & Obstfeld, 2008). A breakdown of the services that such systems provide can cause very serious problems to the economy and society (De Bruijne & Van Eeten, 2007). Consequently, protecting these systems against failures, or making sure that they can be rapidly restored, has become an important objective. Paradoxically, while there is a growing demand for high-reliable services, we have witnessed the dismantling of the organizations operating these systems (Schulman, Roe, Eeten, & Bruijne, 2004). Under the influence of restructuring policies, the provision of reliable services has shifted from a primarily intra-organizational task to an inter-organizational challenge (De Bruijne & Van Eeten, 2007).

These now multi-layered networked systems, such as the one this chapter focuses on, have to deal with dispersed authority, information asymmetry and consist of organizations with diverging goals and specialized tasks, which may be mutually conflicting (Branlat & Woods, 2010; De Bruijne, 2006; Ren et al., 2008; Woods & Branlat, 2010). Providing reliable services therefore requires multiple teams who are separated by organizational and geographical boundaries, to align their goals and activities. However, as De Bruijne (2006) notes, a thorough understanding of how *networks* of organizations operate and coordinate their actions to reliably operate complex technological systems is still lacking.

The volatility and complexity of the networked system means that operators will increasingly have to deal with unexpected conditions. In these cases they cannot always rely on predefined protocols or contingency plans. Schulman et al. (2004) & De Bruijne & Van Eeten (2007) point to the increasing importance of flexible response capabilities to maintain reliable services in complex networked systems. This means that operations move from long-term planning to real-time operations, with a central role for dispatchers and operators, who need to make constant adjustments to the planned operations.

Adaptation in networked systems however has it challenges. Each disruption is somehow unique and how it propagates is difficult to predict (Törnquist, 2007). A disruption is a developing situation where the knowledge of the state of the system only gradually becomes available (Nielsen, 2011). This means that adaptation is done under pressure in a dynamic environment, which affects the solution options available (Kohl et al., 2007; Nielsen, 2011). There is a considerable tension between fast decision-making and gathering the right information to make an informed decision. Decision-making therefore takes place under conditions of uncertainty, stress and imperfect information, which is also spread among the different organizations (Grabowski & Roberts, 1997).

Besides, there is the complication of subsystems being *simultaneously* autonomous and interdependent (Grabowski & Roberts, 1999). Subsystems operate independently of other subsystems. However, they do this in the context of networks of interdependencies with other subsystems and cross-scale interactions, which will have implications at the system level (Branlat & Woods, 2010). The thirteen traffic control centres of ProRail are a prime example of this. As each control centre has its own bounded geographical area for which it is responsible, traffic controllers will make decisions based on local information. However, most trains cross several control areas, so decisions made by one traffic controller will impact train traffic in another area. Each individual action may affect the ability of others to manage the system reliably (De Bruijne, 2006).

In addition, given the many subsystems and the complex relations between these interacting subsystems (Perrow, 1984; 1999), local failures can easily cascade and reinforce through the system, e.g. local problems in one control area can be amplified unintentionally by the traffic controller in the next area, thereby creating a cascade of failures and corrective measures (Nederlandse Spoorwegen et al., 2012). This explains the non-linear effect where two or more small disturbances can lead to a system breakdown, such as often occur during winter seasons, when initial disturbances are aggravated because the complex interactions and ambiguous couplings reinforce the non-linear relationship between local actions and the systemic whole (Leveson et al., 2009).

The uncertainty, time pressure and the interdependence of activities during a disruption increases the need for coordination and thus the exchange of up-to-date information between the different actors in order to return to normal operation as soon as possible (Faraj & Xiao, 2006; Ren et al., 2008). However, sharing information in complex and dynamic situations has proven to be difficult (cf. Bharosa et al., 2010; Faraj & Xiao, 2006; Kapucu, 2006). These difficulties are reinforced by the poor communications endemic to those across organizational boundaries and between distributed teams (Pidgeon & O'Leary, 2000). Distributed teams are known for having difficulties in sharing information evenly, accurately, and when needed (Hinds & McGrath, 2006).

It is necessary to understand how actors connect and share information during a disruption. As Ren et al. (2008) mention, most research focuses on the processes from the point of view of one focal actor or a co-located group to understand information exchange. Only a few studies have taken the whole network as their unit of analysis (cf. Hossain & Kuti, 2010; Provan, Fish, & Sydow, 2007; Provan & Kenis, 2008). Following Hinds & McGrath (2006) and Hosain & Kuti (2010), we believe that the whole network needs to be studied in order to gain insights into how the communication structure affects its capacity to coordinate. We will introduce Dynamic Network Analysis as a method that allows such an analysis of the network. Not only does it enhance our understanding of the communication patterns and interdependencies of the network, but it also shows its dynamics during the process of disruption management.

2.3 DYNAMIC NETWORK ANALYSIS

Dynamic Network Analysis or DNA, is rooted in Social Network Analysis or SNA. SNA was developed to highlight and analyze formal and informal relationships. It helps to collect and analyze data from multiple interacting individuals or organizations (Provan, Veazie, Staten, & Teufel-Shone, 2005). SNA focuses on relationships between actors instead of the attributes of individuals. As such, it emphasizes the importance of relationships for the exchange of resources like information (Wasserman & Faust, 1994). It is these patterns of relationships (linkages) between actors (nodes) that affect the kind of information that is being exchanged, between whom and to what extent (Haythornthwaite, 1996). The patterns of information flows through time and space can then be quantitatively analyzed. To this aim, several metrics have been developed for both the node level and the network level (Kim, Choi, Yan, & Dooley, 2011). Using these metrics makes it possible to quantitatively assess how the general network structure and the positioning of each organization within the network influence the information that is conveyed through the network (Provan et al., 2007).

Traditionally, SNA work is a strongly quantitative method focused on small, bounded networks, with a focus on one type of relation and a single type of node (Carley, 2005). DNA varies from SNA in that it can handle large dynamic, multi-mode, multi-link networks with varying levels of uncertainty (Carley, 2003). Multi-mode means that the socio-technical systems being analyzed can consist of a plurality of node types, such as people, organizations, resources and tasks. Any two nodes can have various types of connections; DNA is therefore well-suited to analyze the multi-link relations of socio-technical system (Carley, Diesner, Reminga, & Tsvetovat, 2007). Such systems can be represented by these many different networks, e.g. a social network (actor by actor) or a task network (actor by task). The collection of these networks is referred to as a meta-matrix (Tsvetovat & Carley, 2004). The added value of a 'network of networks' approach has also been acknowledged by others (cf. Salmon et al., 2011). The meta-matrix framework represents the network of relations connecting node entities (see Table 2.1). It is used to analyze the properties of the socio-technical system and its interactive complexity.

Table 2.1 The meta-matrix framework

	People	**Task**
People	Social network Who talks to whom?	Assignment network Who is assigned to which task?
Task		Dependencies Which tasks are related to which?

Source: Carley and Remminga, 2004 (edited by authors)

Another important attribute of DNA is that it is able to deal with longitudinal data series. As the previous sections have shown, disruption management is a dynamic process. Here, networks are not static but continuously changing through interactions among its nodes (Knoke & Yang, 2008). What is needed is an understanding of how information flows are structured and how these structures change over time (Wolbers, Groenewegen, Mollee, & Bím, 2013). This makes traditional SNA less suitable to model communication during disruption management as it only provides one static snapshot (Effken et al., 2011). We can add time stamps to the data and groups these to create time slices (Wolbers et al., 2013). Time slices show the frequencies of information exchange in the network as it develops over time. The flow of information can then be analyzed by comparing these time slices.

2.4 DATA COLLECTION AND STRUCTURING

Gathering complete network data for inter-organizational networks is challenging (Hossain & Kuti, 2010). Obtaining real-time data on the response network to a disruption requires several knowledgeable researchers, to be at different locations in the network at the right moment. Disruptions also occur unpredictably, so gathering real-time data can be quite time consuming and costly. ProRail has therefore utilized value stream mapping to determine what happens from the moment a train driver notices a damaged catenary, until a contingency plan is implemented. With the help of a complete team of representatives involved in the process a map was created, using pen and paper, showing every step as it happens in reality. The process was broken down in to specific tasks and the flows of information were included in the map[5]. Creating the value stream map took several days for which a safe environment was created, so participants would feel free to provide as much detail as possible. ProRail gave us the permission to use the data from this value stream map for our DNA.

The data was converted into an edge list. Each row in an edge list represents a single tie in the network and it is possible to attach variables (such as the time of occurrence) to the ties. Every edge represents an actor x actor (who shares information with whom?), actor x task (who does what task?) or task x task (how are tasks related?) tie. Since the actor x actor ties represent the flow of information between actors, the edges are directed and valued, meaning that the information flows in a certain direction and that there might be multiple interactions between two actors. We have chosen to focus our analysis on the actors who check and implement the contingency plan. Consequently, the tasks related to the repair of the catenary and those on providing travel information are not included. The edge list was then imported into ORA[6]. ORA generated series of reports that contain multiple metrics, both on a node- and whole network level (Carley et al., 2007; Carley & Pfeffer, 2012).

Given the properties of disruption management in the Netherlands, we are interested in the *centrality* of actors. Centrality is fundamental to node-level metrics and reflects the relative importance of individual nodes (Kim et al., 2011). It is used to capture the flow of information in a network and estimate potential levels of coordination (Hossain, Wu, & Chung, 2006). Freeman (1979) identified three distinct facets of network centrality: degree, betweenness and closeness, with each of these measures having different implications for coordination. The three measures are conceptually operationalized in in Table 2.2.

Degree centrality allows us to measure the activity in communication of every node. Nodes that process and distribute a high amount of information feature a high in- and out-degree centrality. By combining the degree centrality of nodes with the actor by task

5 ProRail initiated the so-called ‘Lean Transformatie’ program as a concerted effort to improve its operational performance and (as a result) to improve its customer relations. The mapping of a catenary failure was part of this program and aimed to identify the number and quality of interactions following when staff develops a solution to such a failure. A better understanding of these interactions should then be used to implement a Kaizen-like way of working.

6 ORA is a dynamic meta-network assessment and analysis tool developed by CASOS at Carnegie Mellon University, Pittsburg (PA). This user-friendly software tool allows researchers to visualize and analyze networks over time.

Table 2.2 Node-level metrics and their conceptual definition

Node-level metrics	Measurement	Conceptual definition
Degree centrality	Measures the number of direct ties a given node has. The larger the number of direct ties an actor has the higher its degree centrality. In directed networks (networks that show the direction of information flowing), a distinction can be made between in-degree (information flowing to a node) and out-degree centrality (information flowing from the node).	The more central an actor is, the more potential it has for activity in communication (Mullen et al., 1991).
Betweenness centrality	Measures the extent to which a particular node lies in between the other nodes of the network	The more central an actor is, the more control or capacity it has to interrupt information flowing through the network. Betweenness reveals bottlenecks and structural weak points in information flows (Hossain & Kuti, 2010), but also influential nodes that can coordinate group processes (Mullen et al., 1991; Hossain et al., 2006)
Closeness centrality	Measures the sum of distances from one node to all others, so closeness refers to the extent a node is close to all other nodes in the network.	The more central an actor is the more independence the actor has and the easier it can distribute messages in a minimal amount of time (Mullen, Johnson, & Salas, 1991).

relationships, we can get an indication on the workload of every node. Betweenness centrality shows which nodes will most likely have to pass along information for information to traverse disparate parts of the network. These nodes can become weak points in the process when they (unknowingly) distort information or are no longer able to process it. Finally, with closeness centrality we can assess whether the nodes that distribute the most information can actually do this within the least amount of time, given their position in the network.

Network level metrics are used in order to define the overall structure of the network. For these measures we turn to the work of Stanton et al. (2012) & Walker (2009), who showed that the following network-level metrics can be used to define a network of organizations: network density (distribution of information), diameter (patterns of interaction), and centralization (allocation of decision rights). Table 2.3 shows the conceptual definition of these three measures. Density measures how fragmented (or sparse) the network is, i.e. what the influence is of the indirect communication on the distribution of information through the network. The diameter of the network measures the maximum number of steps needed to travel from one node to another. Information will need to traverse a lot of actors in fragmented networks. Centralization calculates whether the network is centralized or decentralized.

Table 2.3 Network-level metrics and their conceptual definition

Network-level metrics	Measurement	Conceptual definition
Network density	Measures the actual number of ties as a ratio to the maximum number of ties possible, ranging from 0 (no nodes are connected) to 1 (every node is connected to every other node).	Density measures how well connected a network is. This gives information about the rate of flow of information among nodes (Chung & Hossain, 2009). The denser a network is, the broader the dissemination of information will be possible, since there are more direct pathways between sender and receiver (Stanton et al., 2012).
Network diameter	Measures the largest number of nodes that have to be traversed when traveling from one node to another.	The higher the diameter of the network the more actors there are on the lines of communication (Stanton et al., 2012). Networks with a high diameter will need more steps to distribute information.
Network centralization	Measures the extent to which the overall connectedness is organized around particular nodes in a network.	Network centralization and network density are complementary. Whereas density is concerned with the cohesiveness of the network, centralization reflects distribution of power or control across the network (Kim et al., 2011). Highly centralized networks have a few influential nodes, while in decentralized networks power is more distributed.

2.5 DISRUPTION MANAGEMENT IN THE DUTCH RAILWAY SYSTEM

It is essential to first give a brief overview of the nature of disruption management in the Dutch railway system in order to understand its complexity before discussing the analysis. Until the mid-1990s, NS used to manage the railway traffic. This unit was then split-off from the commercial passenger services into ProRail. ProRail controls and monitors all the train movements and its traffic controllers assign paths to all TOCs. During disruptions, these traffic controllers have to manage the overtaking, re-routing, short turning, or canceling of trains (Jespersen-Groth et al., 2009).

There are several companies that offer passenger and cargo services. NS is by far the largest provider of passenger services and operates all main railway lines. During a disruption the TOCs will have to guarantee that rolling stock is available and that crew schedules are adjusted. Infrastructure, rolling stock and train crew are highly interrelated in practice, which presents a complex puzzle that needs to be solved in a coordinated manner. Given the dominant position of NS and the historical bond between ProRail and NS, we will focus on how these two companies manage disruptions.

Besides the organizational divide between ProRail and NS, there is also a divide between the national level, and the regional level (Figure 2.1). ProRail has thirteen regional traffic control centres that are responsible for the railway traffic in specified geographical areas. Regional traffic controllers monitor the railway traffic in the designated areas and optimize traffic flows. In addition, train dispatchers are responsible for securing safe railway opera-

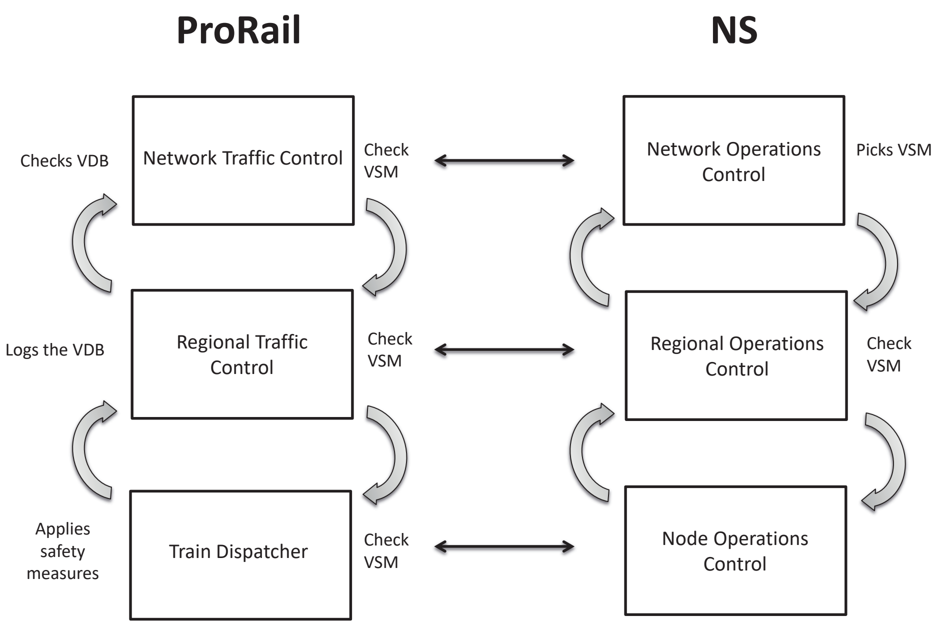


Figure 2.1 Communication flows during a disruption between ProRail and NS

tions on the sections assigned to them. Train dispatchers control the train traffic through switches and signals. This is mostly an automated process. Similarly, NS has five regional control centres where the railway traffic is monitored and where crew and rolling stock are managed. Coordinators have been assigned to important nodes (mostly large stations) to manage the shunting process and to inform employees on the platforms. Not only do these regional centres of ProRail and NS monitor *different* geographical areas, but this is also done from *different* locations or rooms. This means that information on the availability of infrastructure and rolling stock & crew has to be shared by phone or data links.

In 2010, ProRail and NS established a joint Operational Control Centre Rail (OCCR). The OCCR is to serve as a boundary spanning platform that should encourage mutual communication, coordination and learning in order to reduce recovery time during disruptions. In the OCCR ProRail and NS monitor the railway traffic on a national level and intervene when necessary. For instance, network traffic controllers can overrule decisions made by regional traffic controllers, if the decisions made by these regional traffic controllers are conflicting. As such, the management of disruptions is done by two different organizations and each organization has its subsystems that have different responsibilities both in terms of tasks and geographical areas. The OCCR is meant to overcome some of the organizational divides.

We will now have a closer look at the process of disruption management as designed by ProRail and NS. In most cases, train drivers are the first who are confronted with a disruption. They will have to inform the train dispatcher about the situation, who will apply the necessary safety measures. The train dispatcher will then alarm other actors according to a decision tree. Next, the train dispatcher and the regional traffic controller (RTC) assess the impact of the disruption on the traffic and decide to what extent services can continue on the affected section. The RTC will then log the decision concerning the new distribution of the capacity (VDB), which is then checked by the network traffic controller (NTC) to see if the chosen distribution does not conflict on a national level. The network operations controller (NOC) of NS will then select a contingency plan (VSM). These are predefined plans for the most common disruptions. The NTC can adjust these contingency plans within the limitations set by the RTC in the VDB. Implementation of the VSM is done at the regional level, where it first has to be checked in terms of feasibility, e.g. whether train drivers are available to operate trains.

Defining, checking and implementing a contingency plan during disruptions leads to considerable information flows through the system as is illustrated by Figure 2.1. It shows there is a vertical two-way flow of information within both of the organizations (left column ProRail, right column NS), as well as horizontal flows of information between the different subsystems of ProRail and NS, as indicated by the black arrows. Diagonal communication has been reduced to a minimum in order to avoid misunderstandings. So, each division of ProRail should only communicate with its counterpart of NS in terms of geographical responsibility.

2.6 USING DNA TO ANALYZE AND VISUALIZE A CATENARY FAILURE

The network shown in Figure 2.2 features all the actors (red round nodes) involved in the management of the disrupted catenary, i.e. the process leading up to the implementation of the contingency plan, and the tasks (blue triangular nodes) that these actors need to perform in this process (see appendix for the full name of the abbreviations). The dotted lines indicate task by task relationships. A first observation concerns the large number of actors that are involved in the process, something that is not surprising given the situation in the Dutch railway system. Besides the actors mentioned in Figure 2.1, there are numerous others that perform specific tasks (24 actors and 35 tasks), which results in a complex network of interdependent actors and tasks. The graph also shows that there is an asymmetrical distribution of the tasks and communication activity among the nodes.

Table 2.4 shows the centrality measures applied to the nodes in the network. The nodes with an asterisk have a higher than normal value, meaning the value is more than one standard deviation above the mean. Since this is a directed graph we calculated both the indegree (number of ties directed to the node) and outdegree (the number of outgoing ties of a node). The links have been inverted (1/w) when measuring betweenness and closeness centrality to take into account the valued data. This was necessary because ORA treats

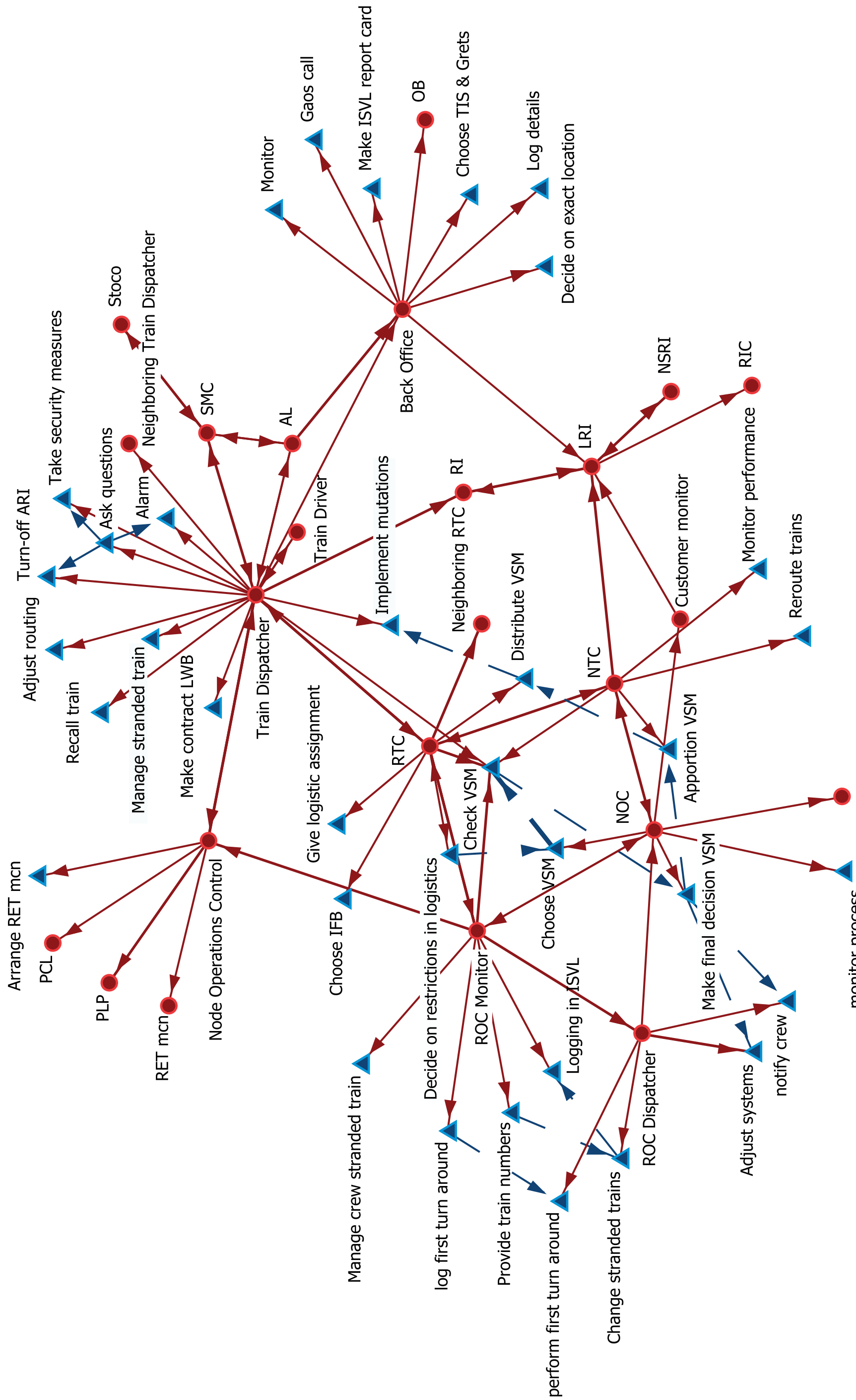


Figure 2.2 Overview of the overall network of actors and tasks during the management of damaged catenary.

Table 2.4 The most central nodes based on degree, closeness and betweenness centrality measures

	Total degree centrality	Indegree centrality	Outdegree centrality	Closeness centrality	Betweenness centrality
1	Train Dispatcher (20)*	LRI (8)*	Train Dispatcher (12)*	Train Dispatcher (0,236)*	Train Dispatcher (0,259)*
2	RTC (15)*	Train Dispatcher (8)*	RTC (9)*	RTC (0.241)*	RTC (0,156)*
3	LRI (12)*	RTC (6)*	Node Operations Control (7)*	ROC Monitor (0,211)*	ROC Monitor (0,116)*
4	Node Operations Control (11)*	SMC (5)*	ROC Monitor (7)*	Node Operations Control (0,206)*	NOC (0,079)
5	ROC Monitor (11)*	NTC (4)	NOC (5)	SMC (0,204)*	Node Operations Control (0,079)

line weight as distance while we treat it as the number of interaction between nodes. Tie strength therefore indicates a possibility of information to pass along. By inverting the links we can keep the interpretation of line weights as similarity information.

The train dispatcher has the highest centrality score for all measures, except for that of indegree centrality, followed by the regional traffic controller. The train dispatcher (total degree score 20) is the actor that communicates most frequently with other actors. The large number of outgoing ties of the train dispatcher illustrates its central role in distributing the information in the network. The high closeness centrality score supports this role, as the central position of the train dispatcher makes it possible to distribute the information within the least amount of time. The high betweenness centrality score of the train dispatcher shows that the train dispatcher acts as a hub in transmitting information between disparate parts of the network. These findings confirm the specialized role of the train dispatcher in disruption management as he or she is solely responsible for safe railway operations.

Table 2.5 shows the scores for the whole network measures. Density assesses the interdependency of actors. The diagram shows that there is no diagonal communication between the actors, exactly as was designed in order to avoid miscommunication. This also influences the rate of flow of information, as in more sparse networks there will be less communication linkages. Because there are often no direct ties between nodes, multiple steps are necessary for information to flow through the network. The network is indeed sparse (density 0.08) indicating that the actual number of ties are a low percentage of the potential maximum number of ties. The diameter score of 13 shows that there are many nodes on the line of communication between the two most separated nodes, given the theoretically maximum diameter of 23 (number of nodes minus 1).

Table 2.5 The results of the network-level metrics

Network-level metrics	Results
Network density	0,08
Network diameter	13
Centralization, Indegree	0,078
Centralization, Outdegree	0,139
Centralization, Betweenness	0,242
Centralization, Closeness	0,373

The centrality scores indicate how tight the network is organized around the most central node, the train dispatcher. The degree centralization scores are relatively low so there isn't a particular node dominant in the network, i.e. the network is loosely coupled with information distribution (out-degree) being more dominated by a few nodes than information receiving (in-degree). The betweenness centralization is a bit higher, but there isn't a dominant node that controls the flow of information. Closeness has the highest centralization score. Still the overall accessibility of information is moderately low.

We have visualized and described the whole network and the role of specific nodes within. However, the importance of a node in a network cannot be determined without reference to the dynamic patterns of communication during the different phases of the disruption management process (Borgatti, 2005; Wolbers et al., 2013), as described in section 2.3. Therefore we have created six time slices to see how the network develops over time and how the position of nodes changes (see Figures 2.3 to 2.8).

The first time slice shows the train driver alarming the train dispatcher about the damaged catenary. The train dispatcher subsequently applies the safety measures. At this initial stage, it is crucial that the train dispatcher collects accurate and detailed information about the situation from the train driver because other actors will use this information for their decisions and actions. It is therefore remarkable to see three isolated networks during time slice 1. It highlights actors acting without having a direct link to the train dispatcher (their official source of information). This is the result of the co-location of the RTC, the travel informant (RI) and the train dispatcher, which makes it possible for them to overhear the phone call of the train dispatcher with the train driver. So without having the full details on the situation, the RI and the RTC already start making preparations. After the official notification by the train dispatcher, information is quickly exchanged throughout the network in order to determine the consequences of the damaged catenary and to work towards the contingency plan (time slices 2 to 4). The network becomes fragmented again, when the plan for the disruption has been defined and checked and actors focus on their own specific task in the implementation phase. Apparently, this can be done in isolation from the other actors (time slices 5 and 6).

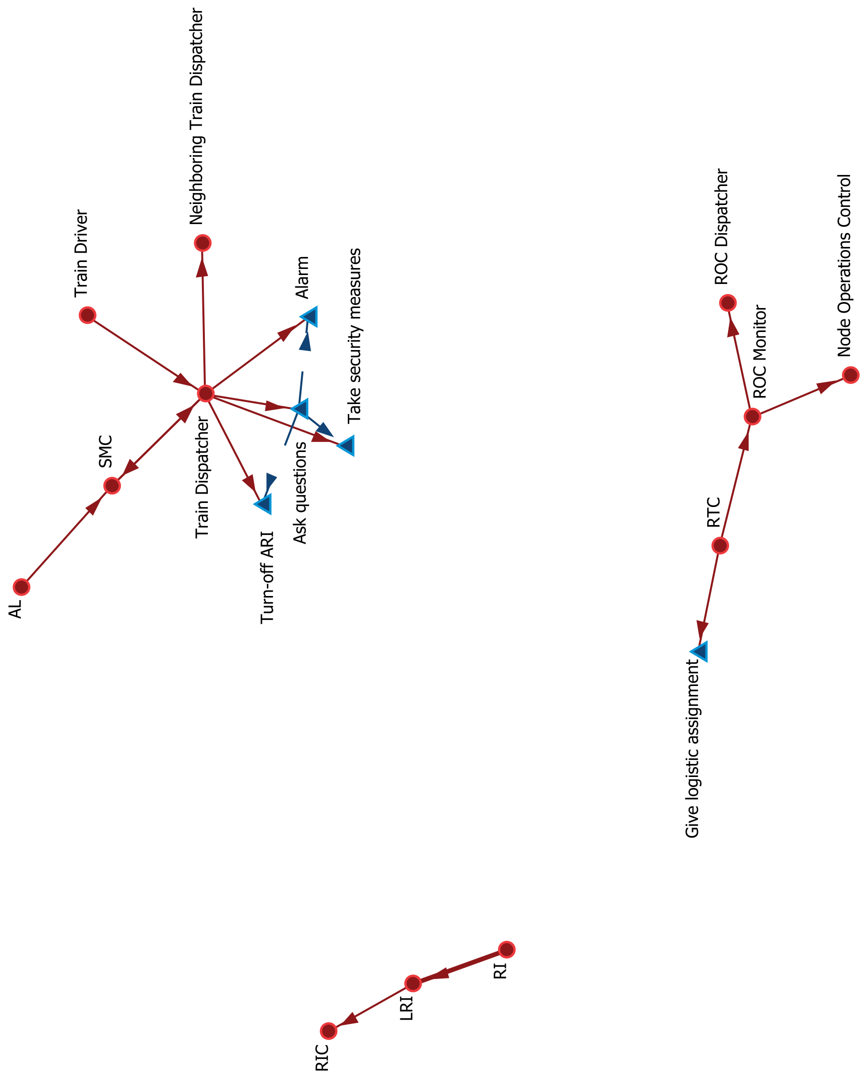


Figure 2.3 Time slice 1

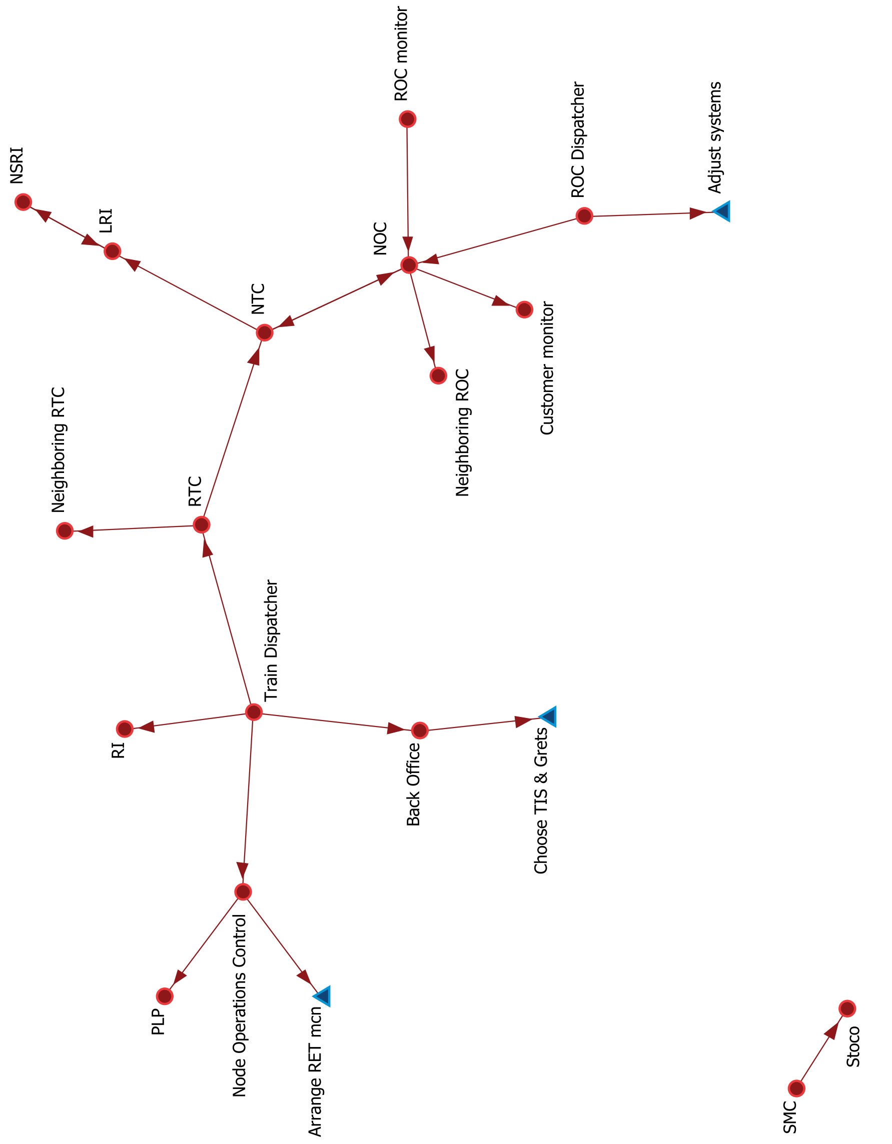


Figure 2.4 Time slice 2

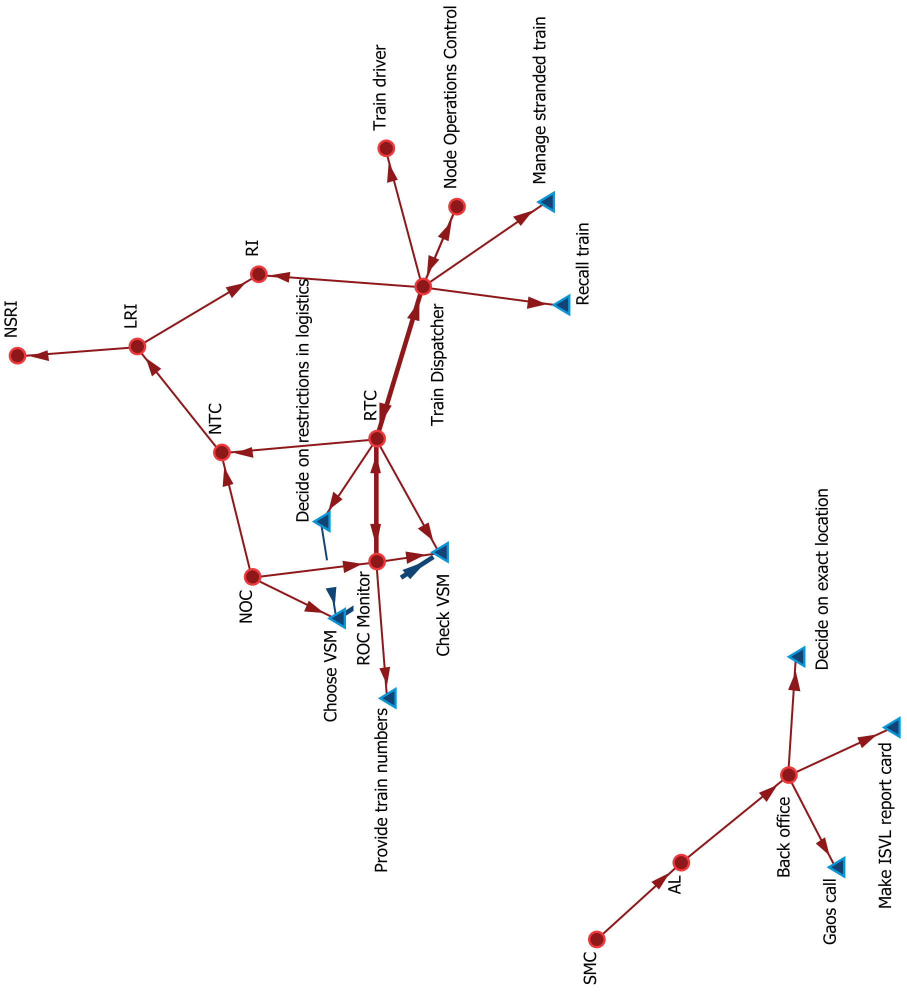


Figure 2.5 Time slice 3

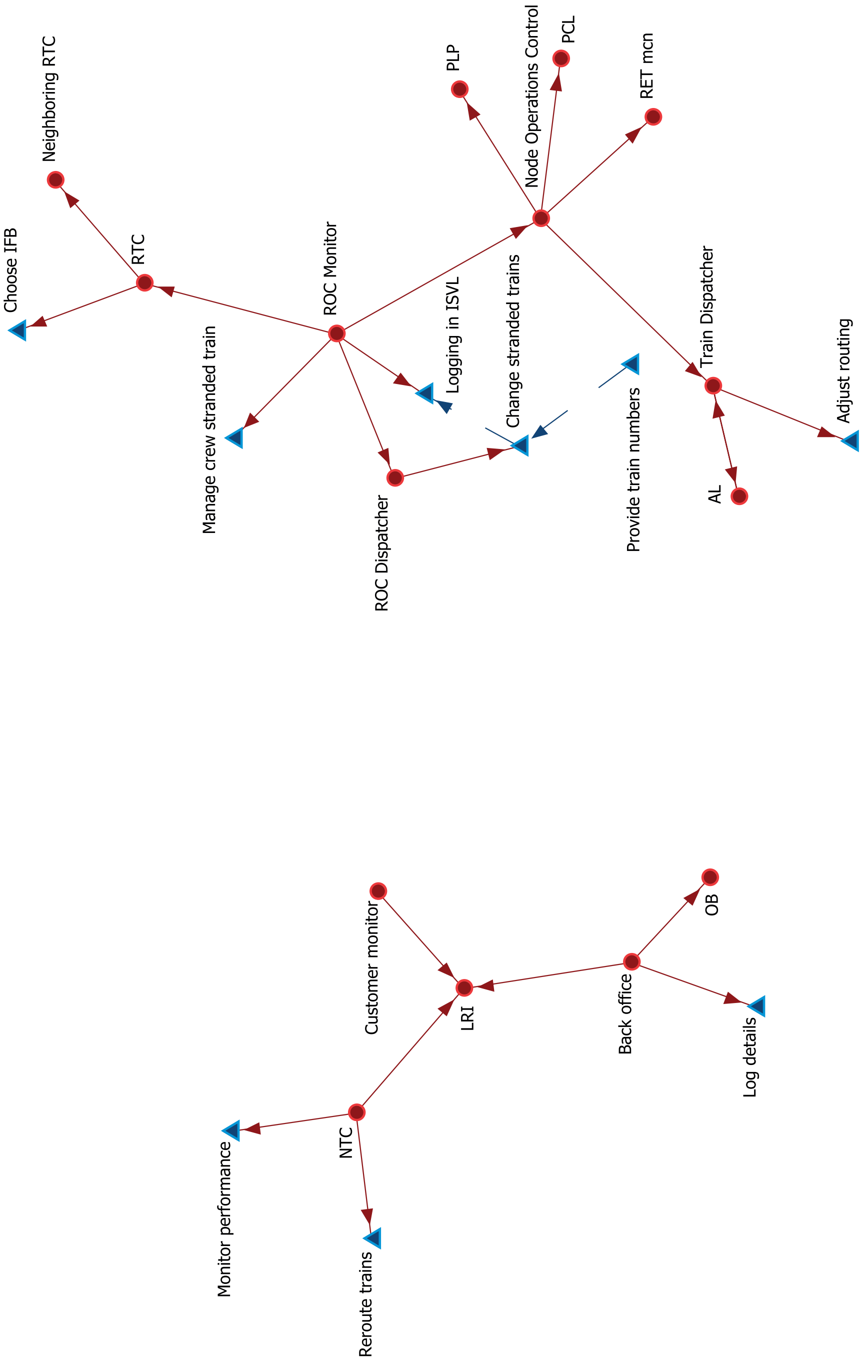


Figure 2.6 Time slice 4

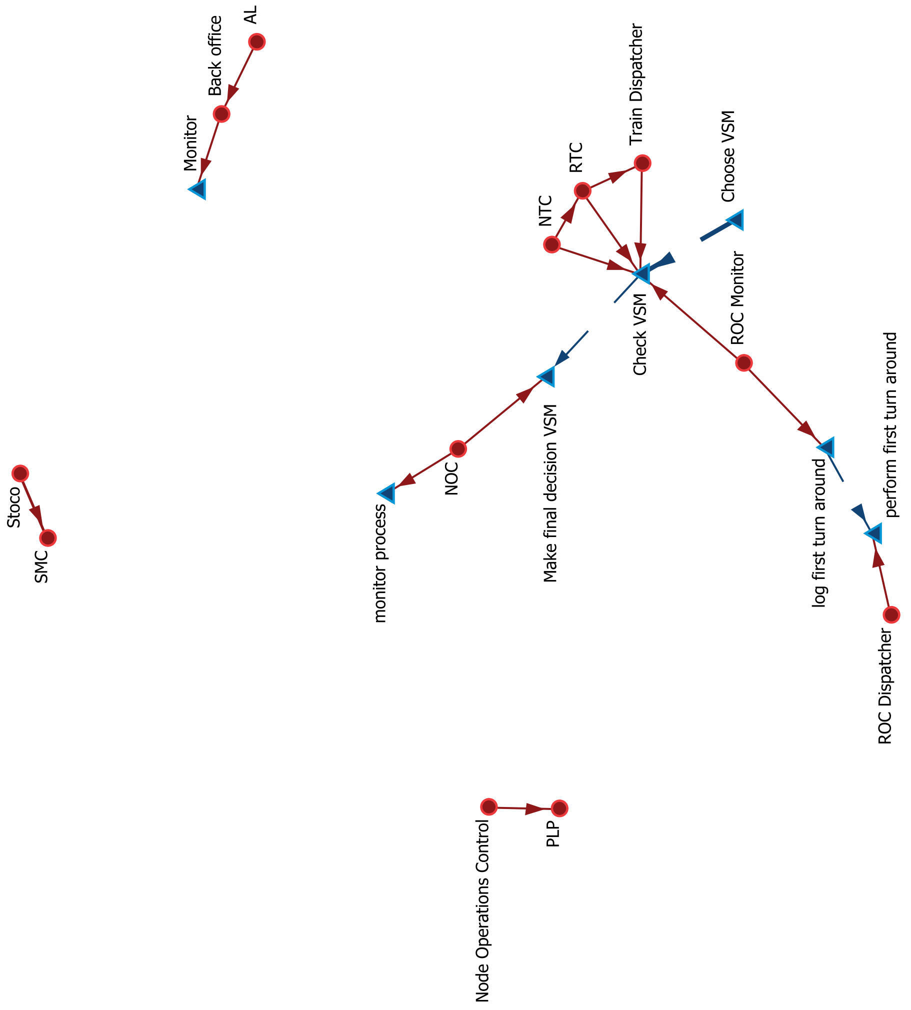


Figure 2.7 Time slice 5

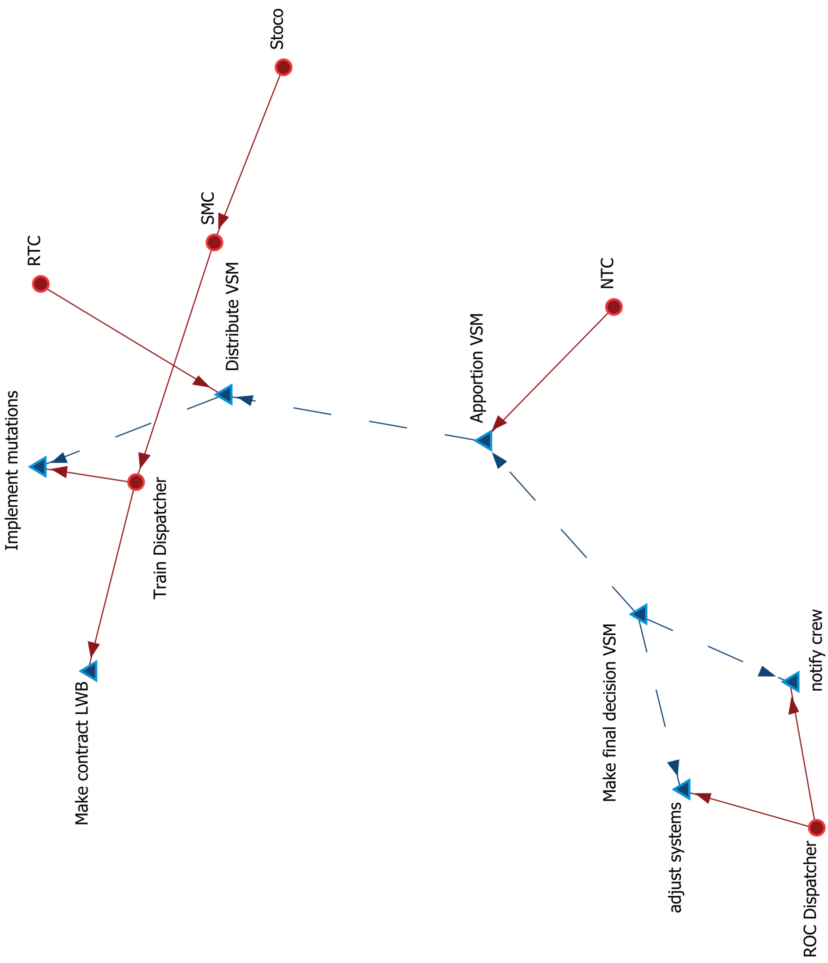


Figure 2.8 Time slice 6

Table 2.6 shows the most central actor for each time slice in terms of degree-centrality and betweenness-centrality. Closeness centrality is not calculated as in most time slices the networks are disconnected, rendering closeness centrality problematic to calculate (Borgatti, Everett, & Johnson, 2013). There is a high correlation between both measures, but both show that the most central actor varies considerably in each time slice. This confirms the decentralized and fragmented nature of the network. The various (disconnected) sub-networks act rather autonomously in managing the disruption, without there being a central core (Wolbers et al., 2013).

Table 2.6 Most central actors per time slice

Time	Nodes (Actors)	Nodes (Tasks)	Ties (Actor x Actor)	Total degree centraltity	Betweenness centrality
T1	12	5	10	Train Dispatcher	Train Dispatcher
T2	17	3	17	NOC	NOC/NTC
T3	13	9	16	RTC/ Train Dispatcher	RTC/ Train Dispatcher
T4	15	9	14	Node Operations Control	Node Operations Control
T5	12	7	5	RTC, SMC, Stoco	RTC
T6	6	7	2	SMC	SMC

2.7 DISCUSSION

Three centrality measures (degree, betweenness and closeness) were used to assess the role of the actors in the disruption management process. For all measures, except indegree, the train dispatcher and RTC were the highest in centrality. This shows their importance in the processing and distribution of information. However, this important role is simultaneously a potential weak point in the flow of information. Given their hub functions, it is crucial that the train dispatcher and the RTC provide others with timely and accurate information. However sharing the right information can be difficult when confronted with an information-overload under high workload. Especially the train dispatcher can become a bottleneck instead of an efficient hub, because the train dispatcher also has the most tasks assigned to him or her (10).

The first priority of a train dispatcher during the first minutes of a disruption is to take all necessary safety measures and, secondly, to provide the other actors with detailed information about the situation. During a severe disruption the workload of a train dispatcher influences its capacities to share information. In such situations they are often no longer able to rely on the automated traffic control system and thus have to solve the situation manually. It then becomes very challenging to perform an efficient control of the traffic (Kauppi, Wikström, Sandblad, & Andersson, 2006). The high workload in terms of manual control and oral communication makes it difficult to keep the other actors up-to-date on the situation in order to create a shared understanding, in particular in a dynamic situation that requires constant adjustments. As Comfort et al. (2004) explain, when the information requirements for coordination increases, the cognitive capacity of human decision-makers to process the expanding amounts of information decreases. Under high workloads, actors are confronted with an information-overload in which it is difficult to determine what should be shared. Consequently actors limit themselves to their formal tasks and important but non-formalized information is no longer properly communicated (Bharosa et al., 2010; Steenhuisen, 2009; Sutcliffe & Vogus, 2003). With components stretched to their performance limits, the system's overall control of the situation can collapse abruptly (Branlat & Woods, 2010; Woods & Branlat, 2011a).

Another interesting finding, related to the previous one, is the low centrality scores for the actors in the OCCR (NTC and NOC). Closeness centrality can also be seen as indicating the independence of nodes. Nodes with a high closeness centrality can act autonomously and navigate freely across the network to access information in a timely manner (Kim et al., 2011). As a centralized monitoring centre we would expect the OCCR to be within close reach of the other actors in the network. The low closeness centrality scores (NTC, 0.170; NOC, 0.161) show that this is not the case, which means that the OCCR is heavily dependent on the information it receives from the regional control and operating centres. The actors in the OCCR often need to actively collect the information from the regional centres. This can turn the OCCR in a bottleneck in the decision-making process when considerable exchanges of information are required and channels for this exchange are difficult to maintain (Branlat & Woods, 2010). An often heard complaint is that the OCCR makes decisions based on outdated information of local situations. The low centrality scores of the NTC and NOC in this particular case might however also have to do with the nature of this (small-scale) disruption.

In addition, we calculated the density, diameter and centralization in order to define the overall network structure. The low density score and high diameter of the network show that it is relatively loosely coupled. As there are often no direct ties between nodes, information will have to pass along many actors before reaching the intended recipient and actors will therefore have limited access to information. Given the large amount of nodes on the line of communication there is a high chance that information gets distorted, as errors typically accumulate in retellings. In addition the network might prove less efficient than a dense communication structure, as information might not reach actors in time. It is however difficult to decide upon the right amount of integration of a network, as more ties between nodes will also lead to a higher complexity and thus higher coordination needs (Carroll & Burton, 2000). For instance, Hinds & McGrath (2006), found that dense communication between distributed teams was associated with more coordination problems, while hierarchy of communication led to smoother coordination.

Finally, the time slices revealed that information is being shared within disconnected parts of the network during the first few minutes, without those parts having a direct link to the source of the information. We know from our observations that operators frequently make decisions based on experience. They anticipate that a situation will unfold itself according to earlier experiences and already start to manage the disruption without having full knowledge on the situation. This ties in with the tension between fast-decision making and gathering the complete information to make an informed decision mentioned before. Inevitably, decisions based on incomplete information could also lead to ineffective or counterproductive solutions (Quaglietta, Corman, & Goverde, 2013).

2.8 CONCLUSIONS

We set out to test the utility of Dynamic Network Analysis (DNA) as a network tool in order to investigate the communication patterns during the management of a disruption in the Dutch railway system and how this structure might influence coordination. The Dutch railway system is a networked system in which several organizations and teams, separated by geographic and organizational boundaries, manage disruptions. It is therefore important to understand how these actors connect and share information during a disruption. DNA makes it possible to capture the irregular flows of information during a disruption. The tool was applied to a simulated case of a catenary failure to visualize and analyze the network of interdependent actors and tasks over time.

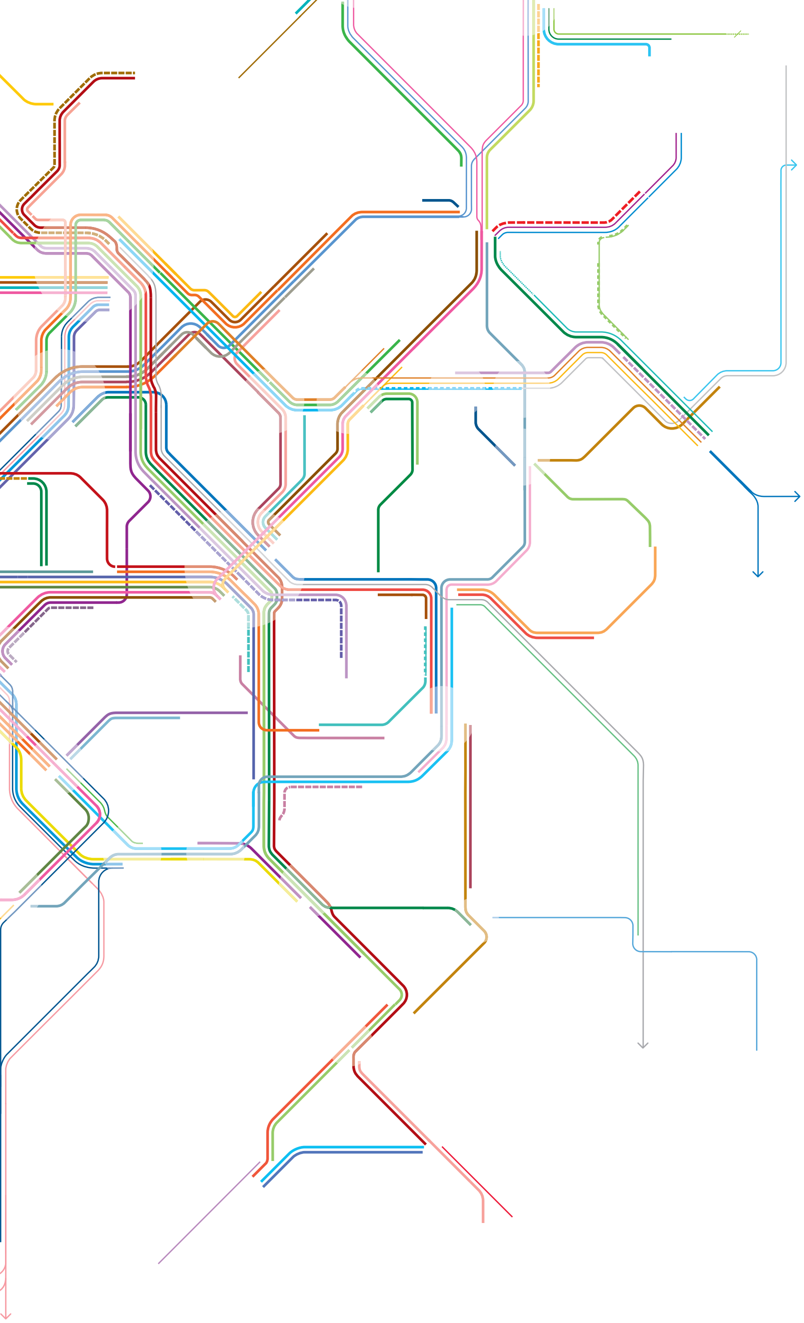
Our research question was: how can DNA help to investigate coordination between the geographically distributed teams involved in the management of a railway disruption? DNA as a method seems to perform well in describing and structuring the complex information flows during disruption management. Even the first, still static, overview of the overall network has given a systematic overview of the communication patterns and tasks during the development of a solution for the catenary failure. Key actors could be defined using the centrality values and the overall structure was described using network-level measures. This revealed the central roles of the train dispatcher and regional traffic controller, and the decentralized structure of the network along with the long lines of communication.

The dynamic nature of disruption management is captured through the time slices. The network changes shape over time and to understand this change requires such time slices. The analysis showed that there is a considerable variation in the centrality of actors per time slice. For instance, the train dispatcher is mostly active communicating in the first minutes of the disruption (T1 and T3). The time slices also showed the emergent character of the network. In the first time slices the network quickly becomes highly connected as information on the disruption is shared between the different teams, but the network quickly becomes more fragmented as actors return to their own specific task. Time slices revealed that information is being shared within disconnected parts of the network during the first few minutes, without those parts having a direct link to the source of the information. These dynamics do not appear in the static image of the network with which we started. However, it forms an essential link between the different parts of the network. This aspect confirms Wolbers et al. (2013) finding that employing only static analysis of networks obscures the real dynamics of communication and potential coordination problems. DNA therefore makes it possible to discover issues that can be resolved (cf. Hossain & Kuti, 2010).

For the sake of a fair evaluation, we should also point to a limitation of DNA such as we encountered during the case analysis. While DNA allowed us to structure the information flows, we were unable to say anything about the content of the information that flows through the ties, or how actors respond to this information because it would be difficult to incorporate this in analysis and it would require an enormous amount of data. DNA reduces the ties between actors to being either present or absent, which in our case means information is flowing between actors or not. It is possible to classify the ties between actors by adding an attribute, i.e. information quality, but this mainly makes a contribution in terms of visualization and not for the analysis. For a comprehensive analysis of such disruptions, it would be necessary to combine a DNA with a qualitative analysis (Crossley, 2010).

Naturally, there are limitations on the data we used for this analysis and how the data was collected. The process mapping was focused on the first phase, directly after the catenary failure, and not on the return to the normal state after the disruption. We therefore cannot relate the findings from the network analysis to the performance of the network in terms of coordination outcomes. Secondly, process mapping might not give an exact representation of how actors behave during real-time operations, although it can be observed that actors have indicated that they deviate from procedures. Process mapping however makes it possible to create a detailed representation of the process and the information flows, which is supported by the whole team of representatives. Finally, the chosen case shows quite some resemblance with the standard operating procedures. Although many actors are involved, the case is relatively low in complexity. As such, solving it requires a great of deal of routine tasks. It can be expected that non-standardized disruptions force actors to deviate from their routines and procedures, which will most likely result in different network structures and information flows.

Given these considerations, we recommend applying DNA to larger and more complex disruptions and to combine DNA with qualitative data such as records of telephone conversations, when attempting to understand how and with what results actors in the railway network coordinate their activities to get the system back to a normal state. Of course, DNA could be used in other networked infrastructures to make operations visible and to identify coordination issues.



CHAPTER 3

Communication and Sensemaking in the Dutch railway system: Explaining coordination failure between teams using a mixed-methods approach

This chapter is published as:

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ABSTRACT

Early in 2014, the Dutch railway system spiralled out of control after traffic management was confronted with the decision to take four double switches and two rail tracks out of service. A lack of coordination between the responsible teams resulted in the decision to stop all traffic in one of the busiest parts of the network during the rush hour. In this study we aim to understand why the teams in the Dutch railway system were not able to adopt a coordinated approach to reschedule rail services. To answer this question, we used a mixed-methods approach by combining dynamic network analysis (DNA) with sensemaking. Our analyses show that a diverging framing of the situation accumulated over time, leading to inconsistent actions, incorrect assumptions and a lack of effective communication. Informal and indirect communication spurred uncertainty and promoted negative emotions, which eventually resulted in a conflict between the actors. We discuss the difficulties of managing ambiguous events in multiteam systems.

3.1 INTRODUCTION

Early in 2014 the Dutch railway system spiralled out of control after the rail infrastructure manager decided to take four double switches and two rail tracks out of service. This decision was taken early in the afternoon by the responsible track team who thought that the equipment no longer met the authority's safety standards. These switches and tracks are located at three of the busiest train stations in the Netherlands in two different rail traffic control areas (from here on: areas A and B). Since their decision would have a huge impact on the train service, the track team decided to give the other teams several hours of preparation time. Regardless, what should have been a coordinated procedure, resulted in a loss of control. While the train dispatchers in area B managed the process adequately, train dispatchers in area A decided to stop the entire service during peak hours. Many passengers were stranded, which drew negative attention from the media and politicians. We aim to answer the following research questions: Why were the actors in the railway system unable to adopt a coordinated approach in order to adjust operations, and what explains the difference in response between the traffic control centres of areas A and B?

Like many other critical infrastructures (CIs) in Europe, the Dutch railway system has undergone major changes over the past decades under the influence of EU and national policies. The Dutch railway system has changed from a mostly large-scale integrated monopoly into a networked system consisting of multiple private and public organizations with diverging goals and specialized tasks, which may be conflicting (De Bruijne & Van Eeten, 2007; Schulman et al., 2004). Providing reliable services therefore requires multiple teams, who are separated by organizational and geographical boundaries, to continuously negotiate and renegotiate issues related to reliability (De Bruijne, 2006). However, this network of teams poses additional challenges in terms of coordination and communication. For example, studies have found that geographically dispersed teams have difficulties in distributing information evenly, accurately, and in time (Hinds & McGrath, 2006). We are therefore interested in how actors in such networks communicate. To study the flows of information, we use social network analysis tools, more specifically Dynamic Network Analysis (DNA).

The premise for this research is that coordination problems are not just the result of deficiencies in the quantity of information flows. Given the contextual differences in which people are working and their differences with regard to knowledge, goals and expertise, there is a considerable chance that information will be interpreted differently (Vlaar et al., 2008). This could lead to different understandings of specific situations and therefore to potential conflicts regarding the course of actions to be followed. Successful coordination stems from a congruent framing of a situation (Cornelissen, Mantere, & Vaara, 2014). Consequently, the structural dimensions of communication need to be studied in conjunction with the attribution of meaning in order to understand coordination in a network of diverse teams. In this study we therefore combine DNA with theories of sensemaking to understand how information is processed within and among actors in order to understand how their actions made sense to them at that time (Muhren, Eede, & Van de Walle, 2008).

This research contributes to the literature in three areas. First, we extend coordination beyond individual actors or co-located groups and look at coordination on the level of the whole network of geographically and organizationally separated teams, something which has received little attention (Gittell & Weiss, 2004; Zaccaro et al., 2012). Second, we use a mixed-methods approach by combining Dynamic Network Analysis with an analysis of sensemaking. Third, we answer the call for the integration of time dynamics into network studies using DNA, to see how the structure of the inter-organizational network changes over time and how the relative importance of actors within the network changes (Abbasi & Kapucu, 2012; Wolbers et al., 2013).

The remainder of the paper is structured as follows. We will discuss the dynamics of communication and sensemaking in network coordination in section 3.2. The mixed methodology is explained in Section 3.3 followed by an introduction to the case in Section 3.4 We will identify key moments and actors by looking at communication patterns in Section 3.5. The case is analyzed in Section 3.6 The discussion and conclusions are presented in sections 3.7 and 3.8

3.2 COORDINATION AND SENSEMAKING BETWEEN TEAMS

Coordination can be achieved through pre-defined plans and procedures, but these formal modes of coordination are not always able to deal with the dynamics and uncertainty of specific situations and may severely limit the flexibility of organizations (Bigley & Roberts, 2001; Johansson & Hollnagel, 2007). Adjusting to uncertain situations requires actors to mutually adapt and collectively improvise (Cornelissen et al., 2014). Communication plays a crucial role in the coordination of actions. Especially rich informal communication has been identified as one of the most important sources of resilient system performance (Roe & Schulman, 2008). Regular information updates to other team members help to create and maintain a shared understanding of problems and the actions needed to tackle them (Kontogiannis & Malakis, 2013). Thus, accurate information updates should be provided regularly and on time (Gittell & Weiss, 2004).

While previous researchers emphasized the importance of effective communication for successful coordination, they also found that geographically distributed teams face greater obstacles in sharing information effectively. Since communication between distributed teams is often technology-mediated, the information flows in these processes are restricted (e.g. number of communication lines) and the updating of information suffers from delays (Salas, Burke, & Samman, 2001). As Hinds & McGrath (2008) describe, distributed work settings lead to less informal and spontaneous communication in comparison to teams that are co-located People working at different locations will also have different information assumptions, preferences and constraints (Vlaar et al., 2008). Consequently, information is often distributed unevenly and communication patterns can be quite unpredictable (Powell, Piccoli, & Ives, 2004). Moreover, since information flows and format are mediated by technology, important visual and social cues associated with traditional face-to-face interaction methods that help to interpret communication and team members' actions are absent (Fiore et al., 2003). In short, challenges of understanding and communication are more salient in a network of diverse teams, which could result in the development of a different framing of situations.

It is therefore important that the communicating parties can reach at least a congruent or compatible shared understanding during non-routine situations, (Fiore et al., 2003). Following Wolbers & Boersma (2013), we see this act of creating a sufficiently shared understanding as a *process of sensemaking*. Sensemaking means that actors try to understand events that are novel, ambiguous or contrary to expectations. They deal with this ambiguity or uncertainty by creating plausible interpretations of reality through the extraction of cues from their environment to create an initial sense of the situation (Maitlis, 2005; Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2014; Weick et al., 2005). Cues trigger sensemaking as they indicate a discrepancy in the ongoing flow of events, which creates uncertainty about how to act. Actors then try to interpret and explain these surprising events by placing these cues in a mental model or frames of roles, rules, procedures and authority relations (Weick, 1993). These frames thus play an important role in terms of coordination as they trigger specific activities and expectations regarding the behaviour of others (Cornelissen et al., 2014). Finally, the sense made of the situation has to be put into action, to see whether it restores the interrupted event or if it is necessary to revise the interpretation. Sensemaking is therefore essentially an *episodic* process that occurs from the moment organizational activities are interrupted until they are restored or permanently interrupted and contains three recurrent steps: noticing and bracketing cues from the environment, creating interpretations and action taking (Maitlis & Christianson, 2014; Sandberg & Tsoukas, 2014).

Sensemaking is a social process because actors interpret their environment in and through interactions with each other, thereby constructing shared accounts that allow them to comprehend the world and act collectively (Maitlis, 2005). Actors can therefore influence the sensemaking and meaning construction of others, a process that is called *sensegiving* (Gioia & Chittipeddi, 1991). Actors can also actively demand information and clarification, which is called *sensedemanding* (Vlaar et al., 2008). As Cornelissen et al. (2014) put it, successful or failed coordination depends on how actors individually and collectively frame and reframe situations as a basis for action. These accounts do not have to be completely overlapping, but they should be equivalent enough to allow coordinated action (Maitlis & Christianson, 2014). However, the creation of a shared understanding is a difficult task that requires much effort and interaction (Bechky, 2003). The responses to violated expectations or ambiguous events depend on a variety of factors, e.g. individual, social, or organizational identity and personal and strategic goals (Maitlis & Christianson, 2014). This means that sensemaking is tied to individuals and that meaning in organizations is often contested because of the different positions, interests and backgrounds of actors (Brown, Stacey, & Nandhakumar, 2008).

To sum up, coordination in a network of diverse teams requires both effective information sharing and acts of collective sensemaking in order to create a sufficient shared understanding of the task situation. In this study we therefore combine Dynamic Network Analysis to capture the flows of information with a qualitative analysis of how this information is processed by the actors. In the next section we will explain how we gathered and analyzed the data for both the DNA and the sensemaking process and how we combined both methods.

3.3 RESEARCH METHODOLOGY

We obtained recordings of all telephone conversations between all actors involved in the disruption. From these recordings, we selected the calls in which information on the switches and tracks was shared between actors. These recordings were transcribed (156 telephone calls in total). In addition, we carried out 9 in–depth interviews with actors involved in the case. Respondents were selected on the basis of their different roles and their geographically different locations. The interviews were used to reconstruct the events of the day from their respective locations. All interviews were transcribed. We also studied all relevant written documents, such as shift reports, e-mail conversations and logs. Finally, we attended a meeting during which actors reconstructed the day and shared their perspectives on the events. We observed this meeting and took detailed notes.

In order to reconstruct the network, it is necessary to know “who talks to whom and at what time”. The telephone recordings offer rich and complete network data. Most of the files included information on the specific actors communicating and the time of communication. We transcribed the recordings and then translated them into numerical data. Using these data, we created an edge list containing the sources and targets of information flows and the time of communication. The telephone conversations don’t cover the communication between actors located in the same room. The interviews and documents fill in this data-gap.

Next, we created six time slices, each lasting half an hour, following the example of Wolbers et al. (2013). Comparison of the different time slices shows how the network evolved over time. We found that a thirty-minute time interval offered us enough detail to show the general communication dynamics. We also created a two-mode network that shows which actors (mode 1) were involved during certain time periods (mode 2) of the process. The two-mode network was recorded as an incidence matrix, marking the presence (1) or absence (0) of actors in the different time periods (seen as events). The relationship between the two modes shows how many actors were actively communicating during each specific period of time. To show the relative importance of a time slice, we divided the number of actors in a time slice by the maximum number of actors (Borgatti & Halgin, 2011). This two-mode analysis required us to use time slices of fifteen minutes in order to obtain a more detailed picture of the network development. We used the software package ORA to structure the data.

The metrics from the DNA form the backbone for the analysis of the sensemaking process. To this end, we performed a qualitative analysis of the telephone conversations. This allowed us to identify which frames emerged, persisted or disappeared throughout the day, and how that was caused by both sensegiving and sensedemanding activities. First, we coded cues or occurrences that interrupted the expectations of actors regarding normal work practices. This is where actors collect and bracket information to get an initial sense of the interrupted situation (Sandberg & Tsoukas, 2014). We then focused on how these events were categorized as interruptions to define a specific situation. Following Cornelissen et al (2014), we coded words and expressions within communication that cued or prompted a cognitive or schema of interpretation. In this step we also looked for the factors influencing sensemaking as mentioned in the literature, i.e. identity and emotions. In the final step, we identified the actions taken by actors based on the framing of the interrupted situation and how this fed into the next phase. This allowed us to detect whether and how frames are updated with the help of new information.

3.4 INTRODUCTION TO THE CASE

The Dutch railway system is managed by the government-owned organization ProRail, which manages the maintenance of the railway network, assigns capacity to the train operating companies (TOC) and monitors and controls all train movements. Maintenance has been outsourced to contractors, but is monitored by ProRail's track managers and track inspectors. Railway traffic is controlled by thirteen regional traffic control centres. Regional traffic controllers optimize traffic flows within their own region and train dispatchers are responsible for safe rail traffic on the sections assigned to them. The management of the railway system is decentralized, with considerable local autonomy. Over the years, this has led to problems with local optimization and working at cross-purposes. A national control room, the Operational Control Centre Rail (OCCR), was established in 2010 to overcome such problems. In the OCCR, ProRail and NS (by far the largest TOC in the Netherlands) monitor the railway system at the national level. We present the main actors in the Dutch railway system in Table 3.1.

Table 3.1. The main actors involved in the case and a description of their role

Role	Abbreviation	Role description
Track Manager	WD 2 AM	Is responsible for the quality of the railway infrastructure in order to assure safe usage
Track Inspector	-	Supports the track manager by monitoring deviations and consulting him on corrective measures
Regional Traffic Controller	Traffic Control	Is responsible for the optimization of rail traffic flows in specific geographical areas.
Train Dispatcher	-	Is responsible for the safe allocation of railway tracks to trains, primarily by using signalling and controlling switches
National Asset Manager Coordinator	RIIB	Monitors incidents, malfunctions and maintenance work and their impact on railway traffic at national level in the OCCR
National Traffic Coordinator	RLVL	Manages railway traffic at national level in the OCCR
National Traffic Controller	LVL	Monitors the railway traffic on the main corridors of the railway system in the OCCR
Power switching and monitoring centre	SMC	Takes calls on malfunctioning infrastructure and reports them to the contractors
National Train Operating Coordinator	LBC	Manages the train operations for NS at national level in the OCCR.
Team Leader	TL	Team leader of the regional traffic control centres
Node Coordinator	NC	Manages the shunting of trains at the large stations

We begin our study with a regular inspection by the contractor in area A on February 19th, 2014. The contractor noticed that two rail tracks did not meet the safety standards defined by ProRail. This did not mean that there was an immediately unsafe situation, but action was required to assess the situation. The contractor informed the track inspector about these deviations at 8:30. At the same moment the track inspector was reading his monthly reports on four double switches (2 in area A and 2 in area B), which had been showing deviations from safety standards for some time. These switches were being monitored on a monthly basis. Large-scale renewal of switches had been scheduled for some years, but they had been postponed due to a lack of funds. Subsequently, the track team started to deviate from their own safety rules and had to increasingly rely on their own expert judgments. Audits conducted by the Human Environment and Transport Inspectorate, in which they rebuked the maintenance team for not following their own rules, served as a wake-up call. This made the team aware of their own behaviour and changed their perspective on how to apply safety standards. Consequently, the track inspector and track manager decided that the switches and tracks should immediately be taken out of service and that large-scale renewal was the only viable option left.

The formal procedures prescribe that train dispatchers should be notified immediately in the event that rail infrastructure is no longer safe to be used. This allows them to immediately take the required safety measures to prevent trains from running over the designated switches and tracks. The SMC should provide the train dispatchers with a specific reference number (RVO number), which is also used by the contractor. In view of the huge impact of their decision on the train service, the track inspector and track manager decided that the switches and tracks could be used until 18:00 to give themselves and others some preparation time. Hence, they decided to issue an early warning to the OCCR, to let them coordinate the whole process. As the track inspector explained: “In my opinion when you call the OCCR, which is our big institute, the coordination centre, they will manage things. They will make sure that the loop is closed and the train dispatchers are informed.”

However, the train dispatchers were not officially informed about the switches and tracks until just half an hour before the 18:00 deadline. Minutes before the deadline, the train dispatcher in area A deemed it necessary to suspend all rail traffic in the middle of rush hour. We will analyze the events leading up to this decision.

3.5 IDENTIFYING KEY MOMENTS AND ACTORS IN THE PROCESS

We start our analysis by making a reconstruction of the flows of information between the different teams and organizations leading up to the decision. The quantitative network analysis acts as a first stage in our research to identify key moments and actors in the process, which serve as important starting points for a more in-depth qualitative analysis of how the information was processed. We identified a total of 156 instances of information sharing among 40 actors. To grasp the dynamics in the spreading of information we created six time slices of half an hour each (from 15:15 until 18:15). Each time slice shows all the information exchanges between actors or nodes in that period. Network graphs of each time slice, showing the development of the communication network over time, are presented in Figures 3.4 through 3.9. In the figures each node represents an individual performing a specific role in the process. The round nodes are actors of traffic management, the square nodes are asset management, triangular nodes are NS and the diamond-shaped nodes are contractors. The arrows show who provided whom with information during that specific time period.

We then used several network metrics to quantitatively assess the development of the network over time. As Figure 3.1 shows, the number of actors involved and interactions fluctuated throughout the process, with a peak in the number of interactions at time slice 6 (17:45-18:14). The spike in the number of actors involved and information exchange between time slices 2 and 3 (15:45-16:44), as well as the sudden drop at T4 (16:45-17:14), are especially remarkable and need further investigation.

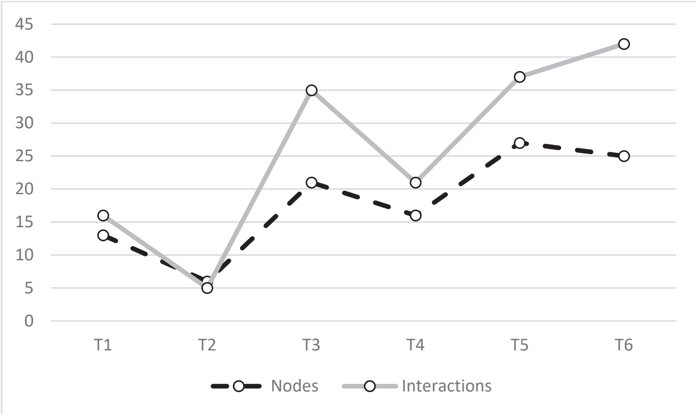


Figure 3.1 Number of actors and interactions throughout the process.

Figure 3.2 shows the density and betweenness centralization scores of the networks. Density describes the number of links between nodes as opposed to the maximum number of linkages possible. A dense communication structure enables a free flow of information between actors and can therefore facilitate coordination. Furthermore, a dense network also gives actors more opportunities to engage in sensemaking dialogue with others. As Figure 3.2 illustrates, density increased slightly during T1 – T2, but then fell to five percent at T5. Overall, the density is very low, which shows that many actors were not directly communicating with each other, i.e. the network was rather sparse, resulting in long communication lines. Betweenness centrality measures the extent to which a particular node lies in-between the other nodes in the network. The more central an actor is, the more control he or she has over information flows through the network and the more able to coordinate group processes (Hossain et al., 2006). Networks with a high betweenness centralization thus have one node or a small group of nodes that have more potential to control the flows of information. Figure 3.2 shows that the network features high centralization at T1 and T2, before becoming more decentralized in the following time periods. The overall low percentages as opposed to the theoretical maximum indicate that there was little potential for a single actor or a small group to control the information flows. This was confirmed by one of the actors.

> **National Coordinator Rail**: *"It is true that everyone had received some information, but they were just bits and pieces of information. We all knew that something was going on, but there was no one in control of the process."*

It is also important to identify the most central nodes or actors in each time slice. Table 3.2 shows the three most central actors based on their degree and betweenness centralities. Although there are differences in the rankings between the time slices, some actors show

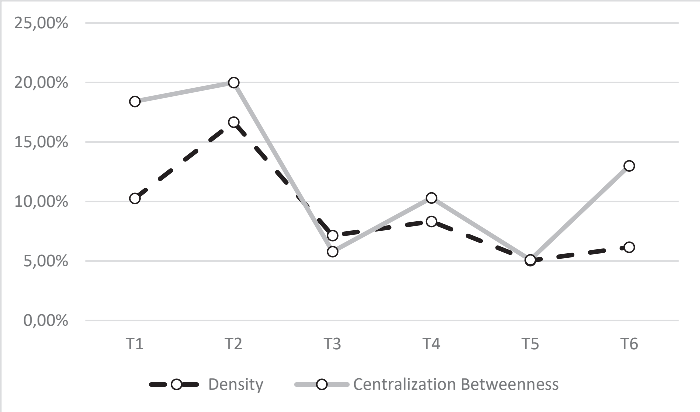


Figure 3.2 Density and betweenness centralization of the network over time.

a high level of consistency in terms of centrality. These are the National Asset Manager Coordinator (RIIB 2), National Traffic Controller (LVL 1), and the National Traffic Coordinator (RLVL) in the OCCR and the Regional Traffic Controller of area A. Their consistency can be seen as an indication of their ability to digest and distribute information in different time periods (Wolbers et al., 2013). As such their central position in the network makes them important in terms of sensedemanding and sensegiving and we should therefore follow up on the role of these actors in the sensemaking process.

Table 3.2 The most central actors per time slice in terms of degree and betweenness centrality

Time Slice	Degree	Betweenness
T1 **(15:15-15:44)**	1. RIIB 2 2. RLVL 3. WD 2 AM	1. RIIB 2 2. RLVL 3. LBC
T2 **(15:45-16:14)**	1. RIIB 2 2. 3.	1. RIIB 2 2. 3.
T3 **(16:15-16:44)**	1. Traffic Control A 2. RLVL 3. LVL 1	1. Traffic Control A 2. LVL 1 3. RIIB 2
T4 **(16:45-17:14)**	1. RIIB 2 2. Traffic Control A 3. LVL 1	1. Traffic Control A 2. LVL 1 3. RLVL
T5 **(17:15-17:44)**	1. WD RBI VL 2. RIIB 2 3. RLVL	1. WD RBI VL 2. RLVL 3. RIIB 2
T6 **(17:45-18:14)**	1. RLVL 2. LVL 1 3. RIIB 2	1. RLVL 2. Train Dispatcher A1 3. RIIB 2

Finally, we created a two-mode network on the basis of time slices of fifteen minutes to identify the critical moments of coordination in more detail. Critical periods are the ones when many actors are connected together and information can be shared to create a common understanding. Figure 3.3 displays the time slices ordered according to their normalized degree and betweenness centrality. Degree centrality shows the number of direct ties that a node has. In this case nodes are the time slices and direct ties indicate the number of actors sharing information during that time period. For betweenness centrality calculations, we follow Wolbers et al., (2013), by understanding time slices with a high betweenness centrality as critical periods in which actors could relay information to others since they were only linked to each other at that time period.

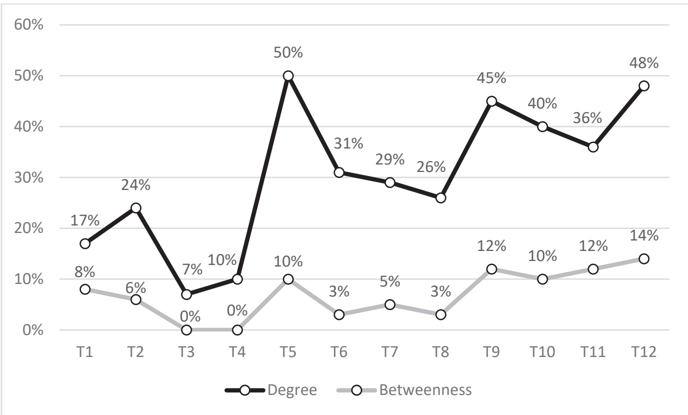


Figure 3.3 Degree and betweenness centrality in a two-mode network (15 minute time slices)

Figure 3.3 reveals that time slice 5 (16:15-16:29) features the highest degree centrality, with half of the actors involved during this time period. This means that the spike in the number of actors communicating occurred quite early on in the process. The large gap between the degree centrality of T4 and T5, represents a sudden increase in the number of actors involved during T5, as could also be seen in Figure 3.1. During time slices T6 and T8 (16:30-17:14) there is a drop in the number of actors communicating, with the time slices T9-T12 (17:15-18:14) showing once again a large number of actors present in these time periods. The betweenness scores show that time slices 5 and 9-12 were critical periods of information sharing and collective sensemaking. We used these critical periods to divide the whole process into specific episodes of collective sensemaking to study how actors make sense of a situation, the actions they subsequently undertake, and the revisions that may be made to these interpretations.

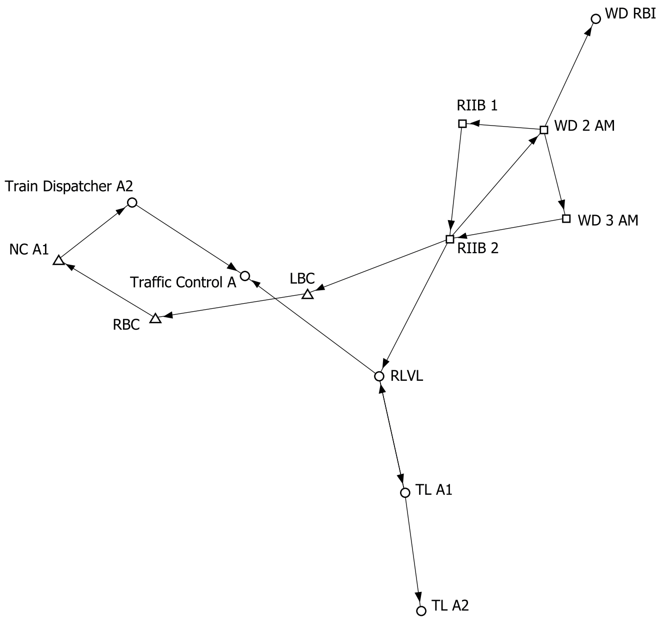


Figure 3.4 Time Slice 1 (15:15-15:44)

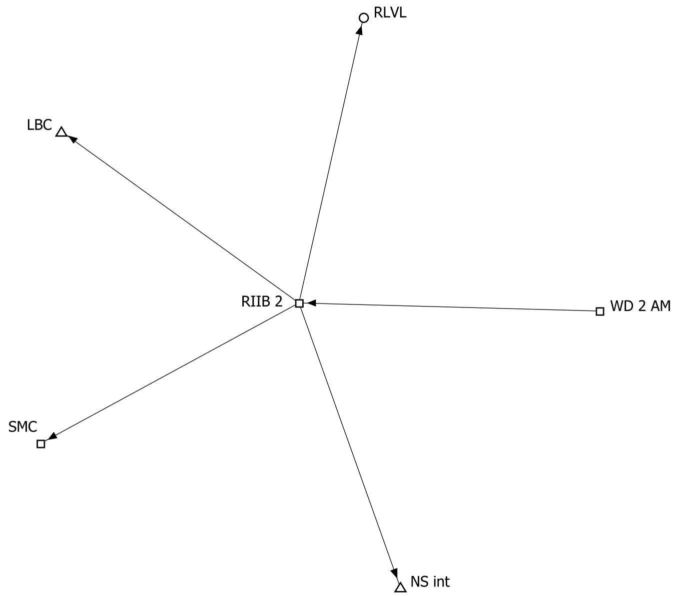


Figure 3.5 Time Slice 2 (15:45-16:14)

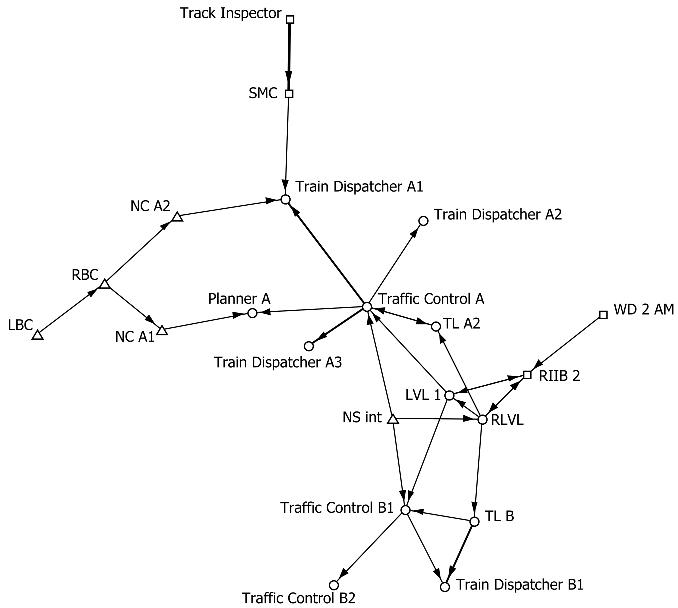


Figure 3.6 Time Slice 3 (16:15-16:44)

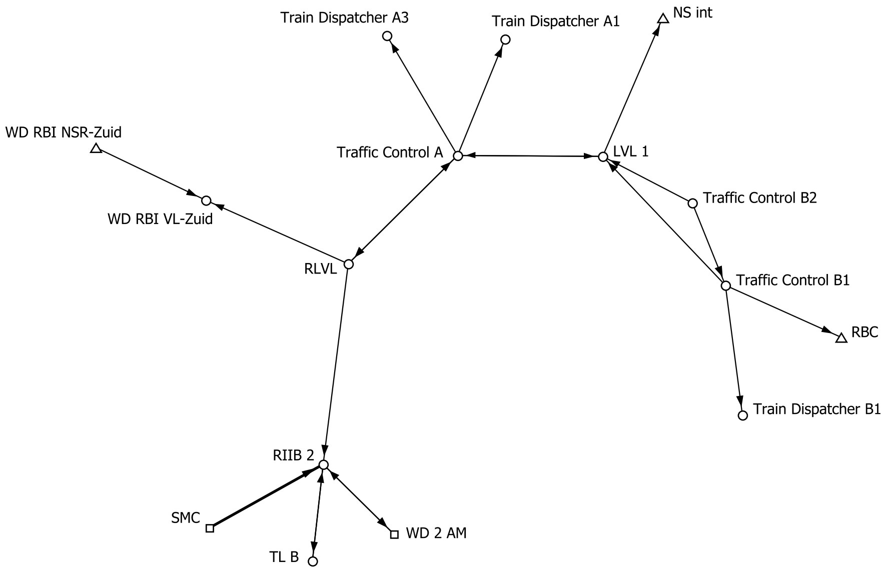


Figure 3.7 Time Slice 4 (16:45-17:14)

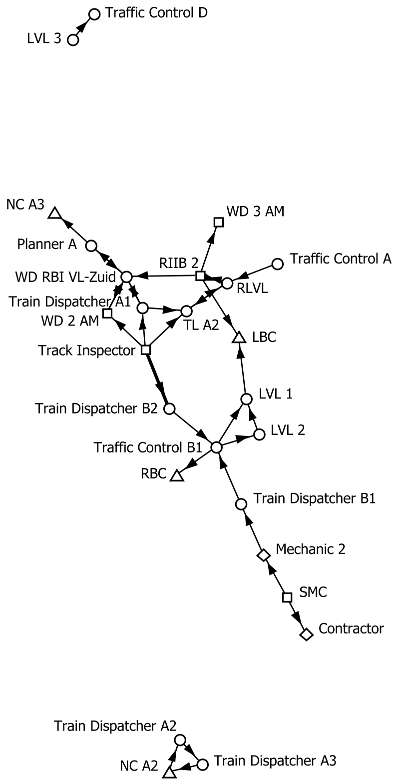


Figure 3.8 Time Slice 5 (17:15-17:44)

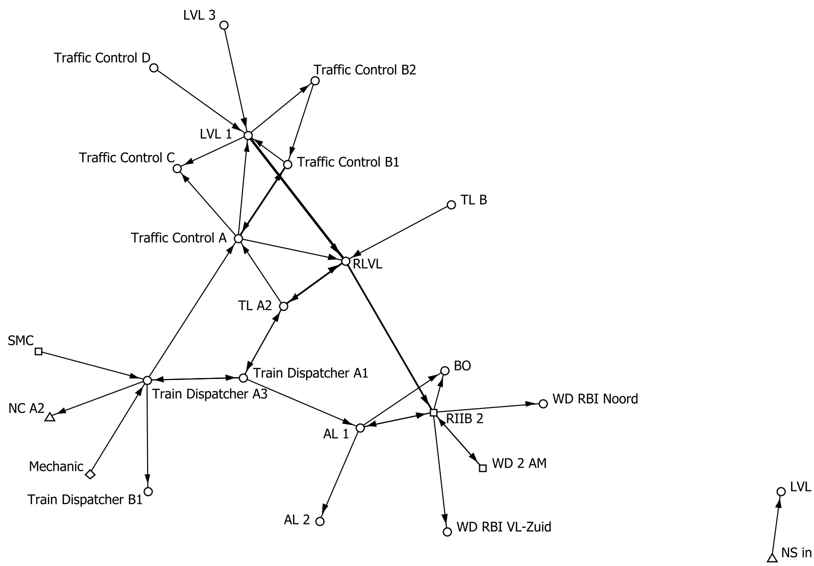


Figure 3.9 Time Slice 6 (17:45-18:14)

3.6 MAKING SENSE OF THE DECISION TO STOP THE TRAIN SERVICE

Having covered the structural and quantitative features, it is now time to turn to the content of the communication, i.e. the sensemaking processes. Table 3.3 describes the process leading to the train dispatchers' decision to stop the train service. This table is based on the one Cornelissen et al. (2014) developed for their analysis of sensemaking in the Stockwell Shooting. Using the findings from the DNA, we divided the process into three episodes. The first episode starts with the first phone call from the Track Manager to the Asset Management Coordinator (RIIB) in the OCCR and ends at time slice four (Figure 3.3, time 16:14) when the schematics with all the details were sent to the OCCR. Episode 2 starts at T5 (16:15), when there was a sudden peak in the number of actors and interactions, marking the start of the official procedure. The second episode ends at T8 (17:14), when it was discovered that no one had taken responsibility to inform the train dispatchers. The third episode consists of time slice T9-12 (17:15-18:14) during which there was considerable communication. It starts with the Track Inspector informing the train dispatchers and ends with the decision by the train dispatchers in area A to suspend the rail traffic during rush hour. For each episode we look at how the key actors (as identified in Table 3.2) try to make sense of the disrupting events or how they shape the meaning construction of others (sensegiving). The last column describes the actions that followed from the initial sense made by the key actors, from which a new cycle of sensemaking commenced.

Table 3.3 *Overview of the episodes of sensemaking among key actors following the decision to take several rail tracks and switches out of service, and outcomes.*

Time	***Event***	***Key Actor(s)***	***Sensemaking***	***Actions/ Outcome***
08:30	The Track Inspector receives the information that two rail tracks do not meet the safety standards, while reading the monthly maintenance reports on four switches which have deviated from the standard for quite some time.	Track Inspector	The Track Inspector feels that he can no longer look away and that concrete measures have to be taken, given the recent audits by the inspectorate and the worsened measurement results for the switches.	The Track Inspector decides to consult with his superior, the Track Manager.
10:30 -13:00	The Track Inspector discusses the measurement results with the Track Manager.	Track Inspector and Track Manager	After a long debate the Track Inspector and Track Manager conclude that it is too great a risk to continue using the switches and tracks. Hence, they should be taken out of service, but not immediately given the impact this would have on the train service.	The Track Inspector and Track Manager start giving the other parties in the rail system an early warning that the switches and tracks will be taken out of service at 18:00.
Episode 1: An early warning to the OCCR				
15:19	The Track Manager (WD 2 AM) gives an early warning to the Asset Management Coordinator in the OCCR (RIIB).	Track Manager and RIIB	The RIIB was told that there was a very serious situation which would have a huge impact on the train service for which he used the term red flag often: *"While you are seated, I want to share something with you (...). We have four red flags at this moment (in area A) and it's pretty serious. There have been inspections last night, which showed major deviations from standard. In terms of responsibility we have to plant a red flag now."*	The RIIB hands this information over to his colleague working the next shift (RIIB 2).
15:27	The RIIB 2 asks for more information on the situation from the Track Manager and schematics showing which switches and tracks should be taken out of service.	Track Manager and RIIB 2	The RIIB does not hesitate to abide by the track team's decision and wants to stay in control of the situation: *"It's just a fact that this red flag will be planted, but when we have more information we will be able to prepare our logistics."*	The RIIB warns his colleagues in the OCCR of Traffic Control and NS (RLVL and RLBC).

Table 3.3 *(continued)*

Time	***Event***	***Key Actor(s)***	***Sensemaking***	***Actions/ Outcome***
15:30	The RLVL calls the Team Leader of Traffic control area A.	RLVL and Team Leader	The RLVL feels that there is still not enough information to justify alarming the train dispatchers: *"We don't know exactly what is going on and why, so we first want to gather more information. Because imagine if it (red flag - authors) isn't necessary, then we would be making a lot of fuss about nothing, and I would regret that."*	The RLVL tells the Team Leader to keep his eyes and ears open, without letting the train dispatchers know anything.
15:41	Nevertheless, the information that a red flag will be planted in the rail tracks reaches the regional control centre of Area A.	Regional Traffic Controller and RLVL	Both agree that since this is a safety issue, the train dispatcher should have been called first and that the OCCR shouldn't be the first in the line of communication. They also find it strange that trains are still running over the switches and tracks despite the apparent safety risks.	Both the Regional Traffic Controller and the RLVL still believe it to be a regular situation in which a mechanic has judged the switches and rail track as no longer safe and that the train dispatcher will be called anytime soon.
15:57	The RIIB receives schematics with details on the four switches and two tracks and discusses them with the Track Manager.	RIIB and Track Manager	The Track Manager once more warns that there are safety risks and that they actually should have acted immediately, but that they have given a deferment until 6 pm: *"You know they have been running* (over the switches and tracks) *all morning, so I expect them to hold for another couple of hours. However, if the Inspectorate saw these values, we would get a big fine."*	The RIIB appreciates the postponement of the red flags in order to keep the train service in control. He shares the latest information with his colleagues in the OCCR during the standard meeting at the beginning of their shifts.
Episode 2: The official procedure is started				
16:18-16:43	The Track Inspector calls the SMC to start the official procedure.	Track Inspector and SMC	The Track Inspector enumerates which switches and tracks should no longer be used after 6 pm and that the surrounding switches should be locked to prevent trains from passing over the switches. When the SMC asks who will inform the train dispatchers, the Track Inspector states that they have informed the OCCR and thus the train dispatchers should be aware of the situation and preparations should be ongoing to adjust the train service.	Based on advice from the SMC it is decided to follow the simpler RVO procedure, instead of the more time-consuming BUTA procedure, the latter being the normal procedure in the case of deferred maintenance work. In contrast to what the RVO procedure prescribes, the SMC believes they have no role in informing the train dispatchers about the situation.

Table 3.3 *(continued)*

Time	*Event*	*Key Actor(s)*	*Sensemaking*	*Actions/ Outcome*
16:23-16:29	Once again information on the red flags reaches the traffic control centres of areas A and B from the train operating companies. Both regional traffic control centres are surprised to receive this information indirectly and to hear that the red flag has been deferred until 6 pm.	Regional Traffic Controllers of areas A & B and the National Traffic Controller (LVL).	The National Traffic Controller assures the regional traffic controllers that the normal RVO procedure will be followed: *"We expect a phone call from you later on that the train dispatchers have been informed on what will be taken out of service at 6 pm. I just received a whole bunch of information, but said sorry let them speak with the train dispatcher."*	The RLVL and LVL feel that they have no role in the process until the train dispatchers have been informed. They therefore decide not to communicate with the regional traffic controllers until the train dispatchers have been informed and it is clear which switches should be taken out of service.
16:29	By now the train dispatchers in area A are starting to look for confirmation of the 'troubling messages' they have received about several red flags with the SMC	Train Dispatcher and SMC	The SMC can't give the train dispatcher more information and instead blames the train dispatcher for acting on rumours. He assures the train dispatcher that official procedures and lines of communication will be followed.	The train dispatchers have the feeling that, given the many rumours, other actors have more information on the switches and tracks and that they are intentionally being excluded from the process: *"I got the impression that everyone knew what was going on and we, the train dispatchers, knew nothing! Who is responsible for safety? And how is it possible that we can use the switches until 6 pm?"*
16:30	The RIIB asks the Back Office of ProRail to make a logging in the communication system with the exact numbers of the switches and tracks that have to be taken out of service, which can be read by the regional traffic controllers.	Regional Traffic Controllers, Train Dispatchers, National Traffic Controller	The regional traffic control rooms are still in doubt as to whether the information in the communication system is correct and if so, in which position the switches will be locked. The latter is of great importance in terms of rail capacity. Hence, they find it difficult to formulate a contingency plan. The train dispatchers in area A even show reluctance to seek solutions, as long as they are not informed.	Given the high amount of uncertainty it is decided to prepare firm measures in order to stay in control of the train service.

Table 3.3 *(continued)*

Time	***Event***	***Key Actor(s)***	***Sensemaking***	***Actions/ Outcome***
17:08	After waiting and inquiring with the regional control rooms if they have received more details on the red flags, the RLVL urges the RIIB to ask the SMC when they will inform the train dispatchers.	RIIB and SMC	Here there is a clash between the two different frames of the situation held by the SMC and the RIIB. While the RIIB believes that the SMC will inform the train dispatchers in accordance with formal procedures, the SMC is under the impression that the OCCR has already informed the train dispatchers.	Both parties believe they are not authorized to impose restrictions on the usage of the switches and tracks. They conclude that the Track Inspector or a contractor does have the authority and therefore should do the job. The RIIB calls the Track Manager to let the Track Inspector inform the train dispatchers.
Episode 3: The train service is stopped				
17:27	The Track Inspector calls a train dispatcher in area A to inform her of the situation. The Track Inspector mentions the switches and tracks that should be taken out of service at 18:00 and indicates that the RVOs will be provided shortly. He also emphasizes that there are safety issues concerning the switches and tracks.	Train Dispatcher area A and Track Inspector	Since the train dispatchers have been using the switches and tracks for the last couple of hours they believe that there is no immediate risk and therefore do not feel obliged to cooperate. Cooperating is also seen as an invitation to the track team to let them deviate from the procedures more often. Moreover, the Track Inspector is not seen as an expert who can tell them to take the rail infrastructure out of service: "*Only experts can tell me if there is something wrong with the infrastructure (…). We need to hear it from an expert, which is a mechanic or the SMC.*"	The train dispatchers in area A decide not to cooperate and continue to operate the switches and tracks. The Track Inspector is told to get in contact with the Team Leader of area A.
17:30	The Track Inspector calls a train dispatcher in area B to inform him of the situation. Once more, the Track Inspector says the switches that should be taken out of service at 18:00 and that the RVOs will be provided shortly. He also mentions that there are safety issues with the switches and that all approach switches need to be locked.	Train Dispatcher area B and Track Inspector	For the train dispatcher it is inconceivable that the red flags have been deferred until 18:00 on the basis of its impact on the train service and workload of the operators, thereby giving less priority to the role of safety. The train dispatcher feels it is too great a risk to let another train pass over one of the switches, given the information provided by the Track Inspector.	Immediately after the phone call from the Track Inspector, the train dispatcher in area B decides to take the switches out of service. In other words: 30 minutes before the deadline.

Table 3.3 *(continued)*

Time	***Event***	***Key Actor(s)***	***Sensemaking***	***Actions/ Outcome***
17:40	A Regional Manager (WD VL RBI) calls the Team Leader of area A, but gets put through to one of the train dispatchers (A1).	Regional Manager and Train Dispatcher	The Regional Manager asks the train dispatcher what they need to take the switches and tracks out of service at 18:00. They are, however, unable to create a shared understanding of the situation. The train dispatcher expresses a lot of negative emotions, as she feels they are being left on their own: "*The whole course of events is flawed and everyone is just actively cooperating. It* (taking the switches and tracks out of service) *should happen no matter what. This is just ridiculous!*"	The train dispatcher tells the Regional Manager to get in contact with the team leader as she refuses to cooperate
17:47	A mechanic calls a train dispatcher in area A to tell him that two switches have to be taken out of service because they don´t meet safety standards. However, the information he received from the SMC is very sketchy and he is still unsure in what position the switches should be locked at 6 pm. At that moment a train approaches one of the switches mentioned by the mechanic.	Mechanic and Train Dispatcher in area A	The train dispatcher repeatedly asks whether he can use the switch since a train is approaching it, but the mechanic can't give any absolute certainty. Given the high amount of uncertainty the train dispatcher is no longer certain whether the switches in his area of control are safe to be operated.	The train dispatchers see the mechanic as an expert on whose judgement they should act. However, since the mechanic also can't provide exact details, the train dispatcher decides to let the train make an emergency stop as he believes it is no longer safe.
17:54	The train dispatcher in area A calls the SMC to check the information he received from the mechanic.	Train Dispatchers area A and SMC	The SMC assures the train dispatcher that the message on the switches and tracks comes from an expert, the Track Inspector. Nevertheless, the train dispatchers feel that there is too much uncertainty regarding which switches are safe and which ones are not, and that they are thus unable to guarantee safe rail traffic. Train dispatcher: *"Look, a situation is safe or unsafe! How is it possible that the people responsible for safety know nothing, at least not officially?"*	The dispatchers once more reject the Track Inspector as an expert, along with his information. They decide to suspend all rail traffic around the two major train stations in their area of control until they receive the correct information from a contractor, along with the official reference numbers, according to formal procedures. Consequently, there are no services between various main cities during rush hour.

Chapter 3

3.7 DISCUSSION

As the summaries in Table 3.3 show, even though it was rooted in good intentions, the track team's decision to give an early warning to the OCCR created an ambiguous situation for the other actors in the system. The early warning violated expectations in several ways. Firstly, an early warning is not a regular practice in the Dutch railway sector. Secondly, although the track team designated the situation as a 'red flag', they also allowed a six-hour delay. This sent a contradictory message. Thirdly, informing the OCCR created a top-down flow of information, which deviated from the formalized bottom-up approach for maintenance work. In such situations people have to ask themselves and others: "what is going on?" As the case has shown, the term 'red flag' played a very important role in the sensemaking process. A red flag is jargon for a situation in which the safe usage of a railway track or switch can no longer be guaranteed and so trains are forbidden to run over the track or switch. By framing their actions as placing several red flags the track team thus created the impression of an immediate safety risk. As one of the managers explained: *"A red flag can be like a red rag to a bull. A red flag means an unsafe situation"*.

Labels, like the term red flag, carry their own implications for action. They focus attention and shrink the number of possibilities as to what is occurring (Weick, 2001). In this case the term red flag triggered a routine procedure in which the train dispatchers should take the lead according to formal procedures and be informed by a mechanic or the SMC. This frame was dominant among the actors in the OCCR throughout the entire process and was reinforced through their communication and actions. For instance, there was a strong commitment to restoring action to familiar practices, i.e. to make sure that the train dispatchers were officially notified by the SMC or a mechanic in order to start the official procedure. This frame was also shared with the regional traffic control centres. Even when the regional traffic control centres confronted the national traffic controllers with the absence of an official notification and the contradictory signals they had received, the national traffic controllers repeatedly reinforced the frame of a routine procedure. In fact, they decided to reduce communication with the regional control centres (as could be seen in Figure 3.1, fourth time slice) when confusion started to increase, agitation grew among the regional operators, and communication became mainly focused on blaming instead of problem solving.

The dominance of the frame also explains why the National Asset Management Coordinator and the National Traffic Control Coordinator did not use their central position in the network (Table 3.2) to provide others with this crucial information, despite them having full details on the switches and tracks. They simply did not believe that it was their role, or that they had the authority to do so. Instead, communication and actions were aimed at restoring standard procedures, which conflicted with the intentions of the track team for an improvised course of action with the OCCR coordinating the process and informing the regional control centres. The latter framing of the situation was also shared with the SMC by the track inspector. As a result of these different interpretations of the situation, actors started to make wrong assumptions about what others knew and which actions they would take. Consequently, the task of informing the train dispatchers was not assigned to anyone. In addition, the strategy of waiting until the train dispatchers had been officially notified was severely undermined by the many rumours that were circulating, because other actors in the system were checking, updating and revising their sense of events. The time slices show that the train dispatchers and regional traffic controllers in areas A and B were approached several times by train operating companies seeking confirmation of the 'rumours' they had heard about the red flags (Figures 3.4 through 3.9).

However, the train dispatchers and regional traffic controllers could not officially confirm any information to the train operating companies, as they had still not been officially notified of the situation. The sensedemanding of the train operating companies caused a chain of reactions, which explains the sudden increase in the number of interactions between time slices 2 and 3 (Figure 3.1). More and more actors became involved and information on the red flags spread through the network uncoordinatedly. With information being dispersed among people and locations, sensemaking became fragmented, i.e. diverse accounts of the situation existed among the actors in the railway system. As a result, the train dispatchers felt isolated and lost grasp of what was happening. Train dispatchers rely on a strong dichotomy between safe or unsafe, as they are held responsible for safe operation. Hence, for them it is very difficult to understand that they are running trains over a piece of infrastructure, the safety of which cannot be guaranteed. Although they knew that there were issues with the safety of some switches and tracks, they had not received any official information or a reference number, and therefore they could not fulfil their role.

What explains the difference in response between the train dispatchers in areas A and B? The telephone conversations revealed that there were considerable negative emotions among the train dispatchers in area A, and this negativity increased during the day. These emotions were fuelled by the fact that critical information was not shared with them. This was not only seen as a threat to their social identity, but also created a state of anxiety which was widely shared among the train dispatchers in the control room. The literature on sensemaking points to the importance of emotions (Cornelissen et al., 2014; Maitlis & Sonenshein, 2010; Maitlis, Vogus, & Lawrence, 2013; Maitlis & Christianson, 2014; Weick et al., 2005). These studies show that emotions are an important factor in individual and collective sensemaking. Negative emotions, in particular, are contagious and can easily spread among group members (Bartunek, Rousseau, Rudolph, & DePalma, 2006). In this case, a collective belief that emerged among the train dispatchers of area A was that noncompliance and strictly following procedures was the best course of action. Hence, they continued to operate the switches and tracks and rejected the track inspector as an expert. Such negative emotions were less prominent in area B. An important explanatory difference is that area B had a team leader on-site, while in area A the team leader was on call. As the team leader of area B explained: *"After receiving the phone call from the RLVL I was busy tempering emotions, saying 'Guys keep on going, don't get carried away by emotion because of this uncertainty about what we can and can't do. Make sure that the trains keep running!'"*

The lack of contextual information made it difficult for the team leader of area A, who was on call, to identify the specific coordination issues and to recognize the negative emotions emerging among his train dispatchers. In area A, the regional traffic controller played an important role in the line of communication between the train dispatchers and the OCCR, as can be seen in the graphs and Table 3.2. The regional traffic controller, however, was very busy with his preparations to adjust the train service and showed resistance in his communication. Therefore, national traffic control did not want to antagonize him. Instead, new actors who were able to circumvent the formal lines of communication, such as the regional manager, stepped in to help create some common ground between the track team and the train dispatchers and to mediate in their conflict. However, the regional manager failed to develop a congruent understanding of the situation with the train dispatcher and actually contributed to the growing negative emotions. In the end the lack of a common ground between the track team and the train dispatchers resulted in the decision by the train dispatchers in both areas A and B not to comply (each in their own manner) with the track inspector's six o'clock deadline.

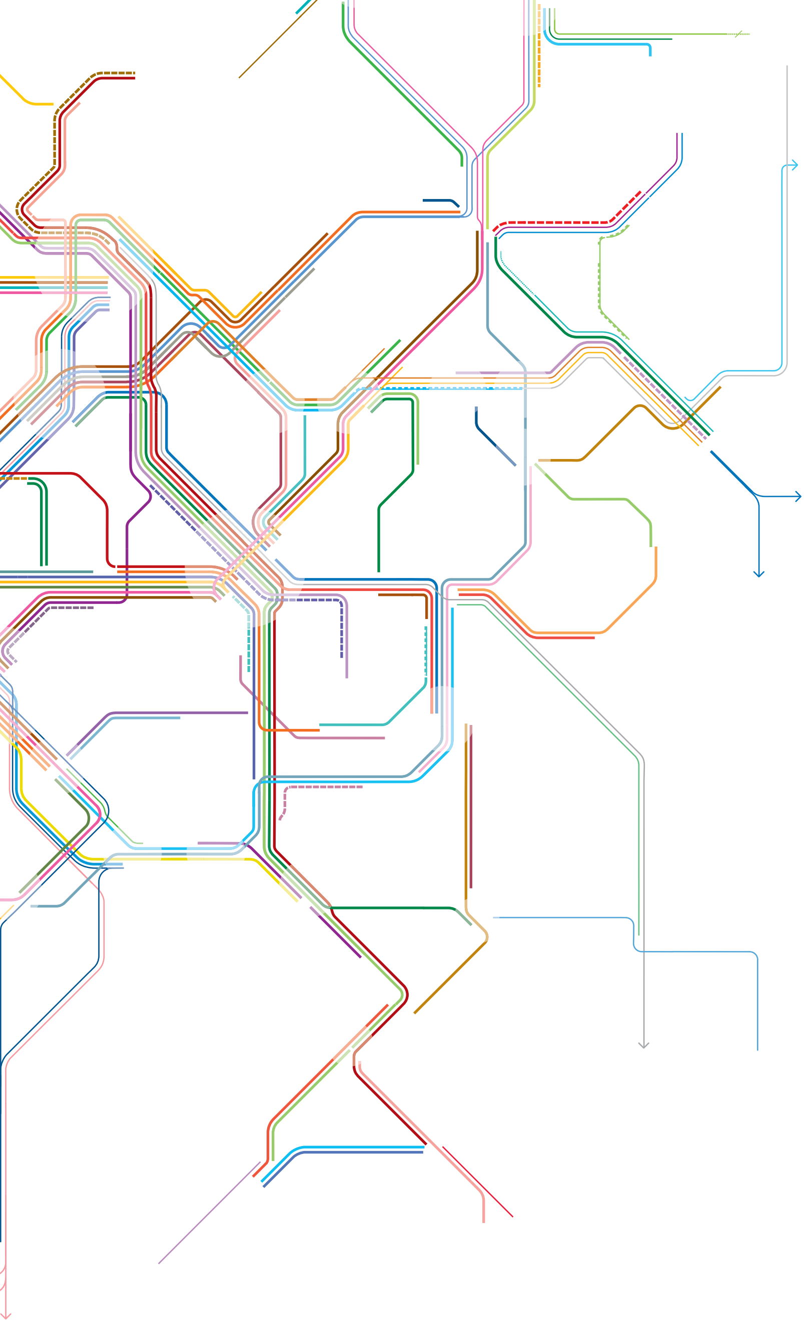
The unexpected split-second decision taken by the train dispatchers of area A to suspend the rail traffic, also cascaded into area B, where the dispatchers and regional traffic controllers were struggling to keep the traffic flowing. Large service cuts had to be made in order to cope with the reduced capacity in an orderly fashion. As a result, many passengers were stranded. Altogether, it took more than an hour for the train dispatchers in area A to receive the correct information and reference numbers so that they could gradually restart the train service. A nightly inspection of the switches by ProRail revealed that three out of the four switches could be put back into service by applying new broadened safety standards that were scheduled to enter into effect two months later.

3.8 CONCLUSIONS

We have demonstrated how and why the actors involved were unable to create a shared understanding on which to base coordinated action. The OCCR's framing of the situation as a normal procedure on the basis of the term 'red flag' and their desire to restore action to familiar practices was in conflict with the track team's intention to find an improvised way of managing the process. We have shown how these different understandings of the situation accumulated over time, leading to inconsistent actions, incorrect assumptions and a lack of effective communication. Our DNA results show how information spread among the actors in the system, rapidly and uncoordinatedly. Consequently, actors held different pieces of information and created fragmented accounts of the situation. We found that informal and indirect communication (sensedemanding) negatively influenced the process, as it increased uncertainty among the train dispatchers about the course of action to be followed and their role in the process. We observed two different responses to this uncertainty and the time pressure: one in which procedures were strictly followed and the track inspector was excluded as an authority, which eventually resulted in the decision to stop the train service (area A), and one in which safety concerns triggered improvisation (area B).

The findings in this research confirm earlier work on networks of teams, in that there are additional challenges for effective coordinated action between multiple teams with a variety of skills, functions, and knowledge (Shuffler et al., 2014; Zaccaro et al., 2012). In order for these teams to work together effectively, it is important to develop shared mental models on expected behaviour patterns concerning task procedures, team and team member behaviours and needs, and patterns of communication (Rentsch & Staniewicz, 2012). Shared mental models thus help individuals to choose actions that are coordinated with other team members. As we show in our study, failure to develop a common set of assumptions and expectations may lead to role violations, communication failures, and even conflicts between teams. Building shared mental models in a large system with many diverse teams can, however, be a challenge. It is therefore important to ensure that common understanding is established around a congruent framing of the situation through collective sensemaking (Cornelissen et al., 2014).

However, strict adherence to a framing can also have a negative outcome. Commitment to frames reduces the number of cues that are considered and so it ties actors to a certain repertoire of actions and assumptions regarding the behaviour of others (Cornelissen et al., 2014). In our case, adherence to the initial framing of the situation by the actors in the OCCR, and their attempts to restore procedures, along with the long and indirect lines of communication, created blind spots that led people to miss the signs that they were not dealing with a routine situation. Hence, it is important to be able to update frames when dealing with ambiguous events (Maitlis & Sonenshein, 2010). This particularly applies to networks of teams. As teams are geographically separated it is often difficult to quickly identify misunderstandings and prevent escalation. Hence, it is important that actors feel free to doubt and question the information they receive from their partners and to take the time to deliberate with them on the framing, instead of blaming each other for not following procedures or diminishing communication (Weick, 1993; 2005). This is not something that is easily achieved, but in the long run it can help to improve the adaptive capacity of the system.



CHAPTER 4

Challenges to Multiteam System Leadership: An analysis of leadership during the management of railway disruptions

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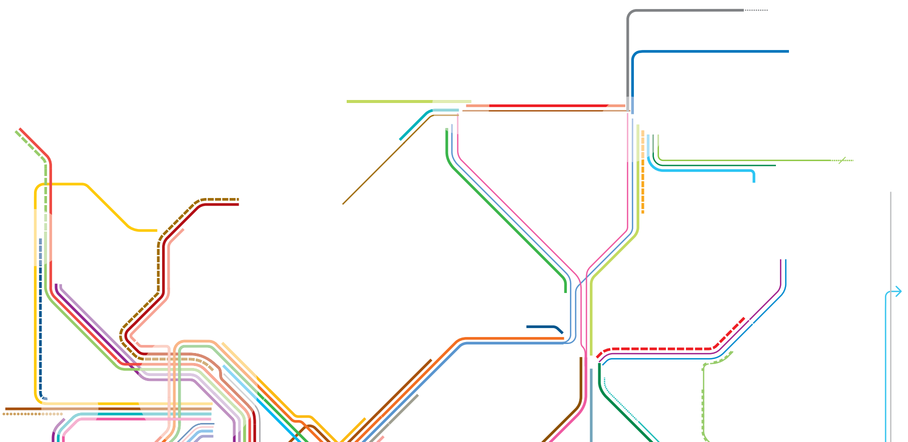


ABSTRACT

Rail traffic is controlled by operators working in multiple control centres. Although each of these control centres enjoy quite some autonomy and authority, their activities are highly interdependent. This is especially the case during the management of disruptions. In this study, we look at the role of leader teams with system-wide responsibilities and the task of synchronizing the control centres' activities. Research on leadership in this multiteam setting of networked control centres, which operate in a dynamic and time-compressed environment, is limited. Hence, this study explores the behaviours and functions of these leader teams during the management of two large-scale disruptions in the Dutch railway system. We will show how various factors influence the ability to provide leadership within this specific real-world context. This study demonstrates that combining insights from the literature on multiteam systems and resilience engineering can contribute to our knowledge of the critical challenges of control in polycentric adaptive systems.

4.1 INTRODUCTION

The Dutch railway network is one of the busiest in Europe in terms of rail traffic. Accommodating all the different train services on the relatively small rail network makes it difficult to run according to schedule. Moreover, delays can easily have knock-on-effects causing problems to spread to other parts of the network. This makes the Dutch rail network highly vulnerable to disruptions. Disruptions are an event or a series of events that lead to substantial deviations from planned operations (Nielsen, 2011). These disruptions result in growing dissatisfaction among travellers, extra expenses, and revenue losses. Consequently, responding to disturbances in a timely manner in order to restore services rapidly has become an important objective. To do so operators must assess the nature and state of the disruption and adjust operations before it becomes impossible to control (Johansson & Hollnagel, 2007). Under the influence of restructuring policies the Dutch railway system has undergone major changes over the past decades, resulting in the separation of infrastructure management and rail operations activities. This has turned disruption management into an inter-organizational challenge (De Bruijne & Van Eeten, 2007; Schulman & Roe, 2007a).

Railway disruption management involves the rescheduling of three interdependent key resources: (1) rail infra capacity, which is managed by ProRail, the infrastructure manager (2) train crew, and (3) rolling stock, which is managed by the train operating companies (TOC)[7]. Control of these key resources is distributed among multiple, geographically-separated control centres of both organizations, all of which enjoy partial autonomy and have the authority to adapt plans. The tight coupling between resources makes disruption management a complex puzzle and requires control centres to work closely together. Coordination can be achieved through pre-defined plans and procedures, but given the dynamic and uncertain environment in which operators work, real-time adaptation of plans is often necessary (Johansson & Hollnagel, 2007). In practice, situations during a disruption often changed faster than the involved parties could communicate and the decentralized control made it difficult to manage disruptions with a national impact.

This is why ProRail and NS established a joint Operational Control Centre Rail (OCCR) in 2010. The co-location of both parties was intended to encourage communication and coordination in order to reduce recovery time during disruptions. In the OCCR, ProRail and NS monitor railway traffic at a national level and can intervene in local operations when necessary. This makes it possible to synchronize adaptation by the different local control centres, while safeguarding the ability of local operators to quickly respond to small disruptions. In the literature, this kind of control has been termed polycentric control (Branlat &

7 In the Netherlands Netherlands Railways (NS) is by far the largest provider of rail passenger services.

Woods, 2010; Woods & Branlat, 2010). Polycentric control seeks to sustain a dynamic balance between the two layers of control - those closer to the basic processes with a narrower field of view and scope and those farther removed with a wider field of view and scope - as situations evolve and priorities change.

Nevertheless, this kind of large-scale coordination is not easy when working in a complex and dynamic environment (Ritter et al., 2007). It also depends on how geographically and organizationally separated teams carry out their roles and manage interdependencies across the different levels of control (Johansson & Hollnagel, 2007; Woods & Branlat, 2010). During the past year there have been several large-scale disruptions in the Dutch railway system where the situation became 'out of control' and no one really knew what was going on or what should be done. Effective leadership is thus important to orchestrate the actions of the multiple teams involved in the management of a disruption (Wilson, Salas, Priest, & Andrews, 2007). The number of studies on leadership in multiteam systems - operating in non-routine and dynamic environments - is however very limited and multiteam system research is a relatively new field of research based primarily on laboratory research (Zaccaro & DeChurch, 2012). As such, much can be learned about how leadership processes manifest themselves and influence the adaptation process in a real-world context.

In this paper we are interested in the role of leadership behaviours of the OCCR during the management of large-scale disruptions. This leads us to the following research question:

How do leader teams in the OCCR provide leadership during the management of disruptions and which challenges affect their leadership?

To answer this research question we have analyzed the management of two large disruptions. Before we introduce these cases we will first take a closer look at the development of the OCCR and its established role and responsibilities in section 4.2. In section 4.3 we will look at adaptation in a multiteam system and the role of leadership. This section provides a framework for studying leadership behaviours. The methods are described in section 4.4, followed by brief case descriptions in section 4.5. The results of the study are provided in section 4.6 and discussed in section 4.7. The conclusions are presented in section 4.8.

4.2 DISRUPTION MANAGEMENT IN THE DUTCH RAIL SYSTEM

The establishment of the OCCR has created a structure with three layers of control on a regional and national level (see Figure 4.1). ProRail currently has thirteen regional traffic control centres that are responsible for the railway traffic in specified geographical areas. ProRail controls and monitors all the train movements and its traffic controllers assign paths to all TOCs. Regional traffic controllers monitor the railway traffic in their designated areas and optimize traffic flows. In addition, train dispatchers are responsible for the safe allocation of railway tracks on the sections assigned to them. Similarly, NS has five regional operations control centres that monitor railway traffic and manage train crew and rolling stock schedules. Operators of ProRail and NS in the OCCR also monitor traffic and operations on a national level. They coordinate the activities of the different regional operators and regulate shared resources, such as rolling stock. Secondly, the creation of the OCCR means that many parties involved in the management of railway disruptions who used to be physically separated, are now co-located. They not only include ProRail's traffic control and NS' operations control, but also teams responsible for Incident Management, Asset Management and contractors.

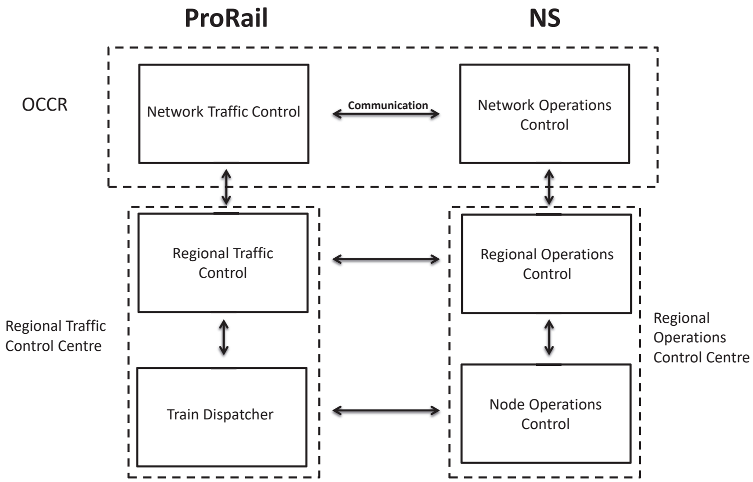


Figure 4.1 The different roles involved in the traffic management and their lines of communication.

If a disruption occurs, ProRail's train dispatchers and regional traffic controllers assess its impact on rail traffic. Only the train dispatchers have real-time information on the position of trains and therefore play a central role in the communications with people at the location of the incident (Schipper, Gerrits & Koppenjan 2015). A notification with details on the disruption is placed in the communication system (ISVL) by the Back Office, which can be accessed by most parties in the rail system. During this first phase of the disruption management process the regional control centres of ProRail and NS take the lead to prevent the disruption from propagating. Nevertheless, the operators in the OCCR have the authority to overrule all decisions made by the regional control centres. The regional traffic controller will then share an overview of the remaining rail infrastructure capacity with the national traffic control and operations control in the OCCR. The national traffic controller will check if this distribution of the remaining capacity does not negatively impact other regions. National traffic controllers have a global overview of traffic flows using time-distance diagrams. A contingency plan is then selected, together with NS' network operations controllers. These predefined plans contain alternative timetables for the most common disruptions. Before the contingency plan is implemented, a final check with the regional control centres is made to check feasibility, e.g. whether train drivers are available to operate trains. The implementation of the contingency plan initiates the second phase of the disruption management process in which recovery of the rail infrastructure commences. Once rail capacity is fully recovered, rail services are fully restored, this being the third phase[8].

4.3 LEADERSHIP IN A MULTITEAM SYSTEM

The adaptive capacity of complex systems has been found to depend on the balance between the distribution of authority and autonomy across local control centres and the capacity to avoid a fragmented response to disruptions (Woods & Branlat, 2011b). In the literature on resilience engineering the answer to this trade-off is sought in polycentric control (Branlat & Woods, 2010; Ostrom, 1999; Woods & Branlat, 2010). Polycentric control seeks to sustain a dynamic balance between local and distant centres of control, as they are in a constant interplay as situations evolve and as a result of activities and progress at each centre (Branlat & Woods 2010). Although research is building up on polycentric control, still little is known about its workings and how a dynamic balance should be maintained between both layers of control. As mentioned in the introduction, managing the interactions of the control centres (both horizontally and vertically) is not an easy task. It requires multiple teams working at different locations and with different organizational backgrounds, goals and responsibilities to effectively align their activities.

There is a growing body of literature on these so-called Multiteam Systems (MTS), i.e. networks of distinct yet interdependent (component) teams that address highly complex and dynamic environments (Shuffler et al., 2014; Zaccaro et al., 2012). MTS are officially defined as: "two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals" (Mathieu et al., 2001: 290). Contrary to most of the studies on teamwork, which focus on individuals within a single team, MTS research looks at how multiple teams function to grasp the unique opportunities, challenges and complexities of these systems (Marks, DeChurch, Mathieu, Panzer, & Alonso, 2005). For instance, although teams might be effective at within-team coordination, the system itself may still fail to adapt to a disruption, due to an inability to meet between-team coordination requirements (Luciano, DeChurch, & Mathieu, 2015). MTS research has stressed the importance of *leader teams* (e.g. representatives of the component teams), situated hierarchically above the component teams, who have system-wide responsibilities and the task of managing the interdependencies among component teams (Davison et al., 2012). Studies have shown that effective leadership has a

8 For a more detailed description of the disruption management process, see Chapter 2

positive influence on inter-team coordination and overall MTS performance (e.g. DeChurch & Marks, 2006; DeChurch et al., 2011). It is therefore important to look at the behaviour of these leaders in the adaptation process of a MTS (Zaccaro & DeChurch, 2012).

Location, timing, and the type and severity of the incident will all influence the adaptation process and the capacity of the system to adjust operations before it becomes impossible to control (Golightly et al., 2013). The way in which operators respond to a disruption (both individually and as a team) will also be context-specific, depending on individual characteristics such as experience, knowledge, and flexibility (Maynard, Kennedy, & Sommer, 2015). Nevertheless, Burke and colleagues (2006) argue that each team adaptation follows a cyclical process consisting of four phases: a) situation assessment, b) plan formulation, c) plan execution, and d) learning. In this study we will look at the first three phases. In their model Burke and colleagues stress the importance of teamwork competencies, such as mutual monitoring, communication, back-up behaviour, and leadership during the phase of plan execution. We believe that these teamwork competencies are also important in MTS settings, but argue (and will show later in the paper) that they are not only important during plan execution, but also during the phases of situation assessment and plan formulation.

First of all, adaptation requires the ability to quickly recognize cues that signal the need for adaptive actions. However, as Uitdewilligen & Waller (2012) observe, since there are many component teams in a MTS, situation assessment will be highly distributed and therefore the situation awareness of teams will also be distributed. In order to create a compatible understanding of the situation between teams it is essential to share crucial information. Exchanging appropriate information and providing each other with regular updates helps to maintain a compatible situation awareness of the dynamic environment to ensure coordinated behaviour. MTS leaders can facilitate communication and the timely and accurate exchange of information between component teams to maintain situation awareness. Moreover, during moments of stress, component team members might not be able to uphold an awareness of the system (Uitdewilligen & Waller, 2012). Leader teams can act as an information hub in order to create an overall understanding of the operational environment and potential future development trajectories of the system. The latter is important to formulate a plan or pick a contingency plan that brings the MTS's capabilities, resources and actions into line with the emergent dynamics in the operating environment. The quality of this plan depends on how well it fosters and maintains this alignment (Zaccaro & DeChurch, 2012).

Leader teams also have an important role in *monitoring the performance* of component teams in terms of their progress towards system level goals (Zaccaro & DeChurch, 2012). For example, leader teams can provide feedback in the form of verbal suggestions or corrective behaviours in the event of errors or performance discrepancies (Marks, Mathieu, & Zaccaro, 2001). Component team members may also struggle to perform their tasks due to a high workload. In this case leader teams can provide *back-up behaviour* by prompting other component teams to provide help, by shifting workload to other teams or by proactively offering help with specific tasks. Finally, given the dynamic environment in which MTSs operate, it is crucial that this is continuously monitored, both internally (status and needs of teams) and externally (environmental conditions) (Marks et al., 2001). If unexpected changes occur within an MTS's performance environment and the contingency plan no longer seems appropriate, it must be decided whether to reconsider, abandon, or adjust the original plan (ibid.). Leader teams play an important role in monitoring the system, identifying impending and actual blockages to goal accomplishment, and perhaps *adapting* the course of action when necessary (Zaccaro & DeChurch, 2012).

In Table 4.1 we have summarized the above-mentioned leadership functions and provided behavioural markers. Behavioural markers are descriptions of observable leader-

Table 4.1 Important components of effective leadership and their behavioural markers

Component	Description	Behavioural markers	References
Communication	Managing communications about team actions and goal progress across all component teams	• The leader teams gather information about the MTS's performance environment to create a 'big picture' understanding • The leader teams manage the flows of information between component teams to facilitate the timely and accurate exchange of information.	(DeChurch et al., 2011; Dietz et al., 2015; Rosen et al., 2011)
Performance monitoring	The ability to develop a shared awareness of the teams' environment and the strategies used to maintain an awareness of component teams' performance	• Leader teams monitor goal progress and goal blockages • Feedback regarding component team actions is provided to facilitate self-correction	(Alonso & Dunleavy, 2013; Salas, Sims, & Burke, 2005; Zaccaro & DeChurch, 2012)
Back-up behaviour	Knowing how and when to back up teams and team members. This includes the ability to shift workload among teams to achieve balance during periods of high workload.	• Leader teams recognize that there is a workload distribution problem within component teams. • Leader teams prompt component teams to provide back up and helping behaviour to other teams and to shift work to underutilized teams. • Leader teams proactively assist component teams with task work	(Salas et al., 2005; Wilson et al., 2007; Zaccaro & DeChurch, 2012)
Decision Making	Decision making refers to the leader team's ability to determine goals; develop plans and strategies for task accomplishment; identify contingencies, and to alter/update a course of action in response to changing conditions.	• Leader teams develop and share alternative plans for collective action in response to anticipated changes in the performance environment. • Leader teams remain vigilant to changes in the internal and external environment • Strategies and plans are adjusted to unanticipated changes in the performance environment	(Dietz et al., 2015; Marks et al., 2001; Salas et al., 2005; Wilson et al., 2007)

ship behaviours (Dietz et al. 2015) in this particular case. Some of the markers have been adopted from theory on individual teams. We have translated these markers to make them suitable for the multiteam context of our study.

Leadership behaviours are assumed to have an important influence on the relationship between the adaptation process and outcome (Maynard et al., 2015; Zaccaro & DeChurch, 2012). However, it is difficult to quantify and compare outcomes given the unique characteristics of disruptions and their contexts. We therefore relate leadership to system performance by its ability to secure the adaptive capacity of the system. Woods & Branlat (2011a) have identified three basic patterns of adaptive failure in complex systems: (a) decompensation, (b) working at cross-purposes, and (c) getting stuck in outdated behaviours. These patterns can eventually lead to a system break-down and thus need to be avoided or recognized and escaped from. Decompensation occurs when disruptions grow and cascade faster than operators can respond. In this case the capacity of operators to maintain control can suddenly collapse and the capacity of the system to respond to immediate demands might be lost. Secondly, working at cross-purposes is the result of a lack of coordination between the different control centres (both horizontally and vertically) and results in conflicting goals that undermine the system's over-arching goals. The last pattern is at play when people hold on to initial assessments of situations and lack the capacity to revise plans as conditions change. As a result, the tactics or strategies chosen do not match the actual challenges and so there is a risk of failure to adapt.

In this study we look at the adaption process in two cases, with an emphasis on the communication and coordination processes between the teams in the OCCR and the teams in the local control centres. We are especially interested in whether and how leadership behaviours are applied to prevent or correct the system from falling into one of the three maladaptive traps (see Figure 4.2).

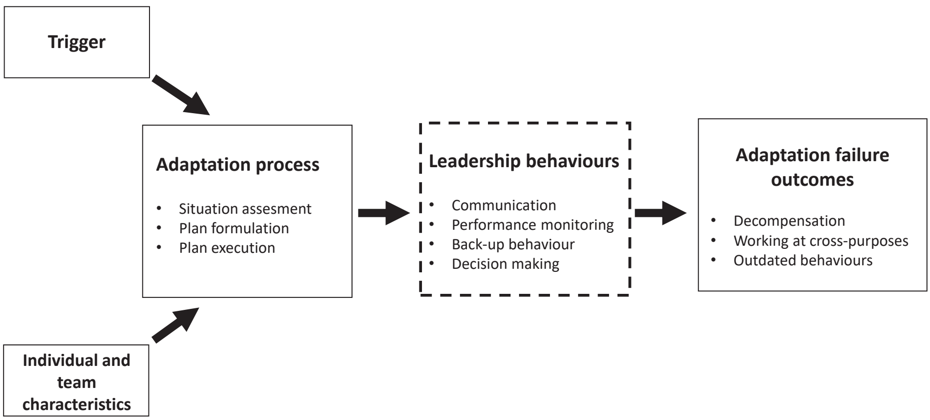


Figure 4.2 Analytical framework

Chapter 4

4.4 METHODS

4.4.1 Case selection

To examine leadership in the OCCR, two cases of large impact disruptions were studied. These disruptions were selected because of their non-routine characteristics and the rapidly changing environmental conditions, factors that increase the risk of adaptive failures and therefore necessitate effective leadership. In case 1 we examined leadership during a winter storm that challenged the ability of local operators to stay in control. In case 2 we studied the management of a broken overhead wire at the largest train station in the Netherlands. Following Woods & Cook (2006), these cases do not serve as examples of successful or unsuccessful adaptation, but we believe that they are valuable for revealing patterns in teamwork and leadership behaviours in a naturalistic environment.

Many teams are involved in the management of disruptions, each with their own tasks and responsibilities. For instance, the ability to swiftly recover from a disruption depends greatly upon how quickly maintenance teams are able to repair rail infrastructure. As the focus of this study is on the leadership of leader teams in the OCCR, we have focused our analysis on the interactions between ProRail's local and national traffic control teams and NS' local and national operations control teams.

4.4.2 Data collection

To examine the leadership of the leader teams in the OCCR, ProRail provided access to recordings of 102 telephone conversations between national and regional traffic controllers during both disruptions. Unfortunately, NS was unable to provide us with their recordings of the telephone conversations between their operators in the OCCR and the local control centres. However, a large number of documents were obtained from both ProRail and NS. We examined shift reports written by operators involved in managing the disruptions from both organizations, event reports on both disruptions, and the communication system logs. In addition to this, the winter storm case was evaluated internally by ProRail and NS. This evaluation report includes a careful examination of the communication between ProRail's national and regional traffic controllers. This extensive evaluation report was used as complementary data. For the broken overhead wire case we conducted our own evaluation, which includes 9 interviews with operators directly involved in the management of the disruption. All interviews were tape recorded and transcribed. The evaluation was presented to a group of managers from ProRail and NS for expert feedback on the findings. Finally, 10 follow-up interviews were held with managers and operators to clarify events and leadership behaviours. As some of the interviews with operators were held during their shift, it was not possible to tape record them. Instead, detailed notes were taken of those interviews. All other interviews were recorded and transcribed.

4.4.3 Data analysis

The telephone conversations (102 in total) were transcribed and then coded to capture the leadership behaviours. The software program ATLAS.ti was used to systematically code the data. Instead of the more common quantitative approach of measuring behavioural markers as a frequency or on a scale, a qualitative approach was chosen, which involved labelling the leadership functions. Pieces of the telephone conversations were labelled according to the markers (Table 4.1) provided for the leadership functions. For instance, if a national traffic controller informed a regional traffic controller that he would be re-routing international trains, this piece of conversation was coded as proactively assisting component teams. This qualitative approach made it possible to provide a rich description of leadership behaviours and challenges to leadership on the basis of a systematic analysis. The telephone conversations were also used to identify indicators for the three adaptive traps. The latter may, for instance, be a request for help, if an operator is at risk of losing the capacity to adapt. In the second step we used our additional data to complement our initial findings, identify patterns in the behaviours of the leader teams, and relate this behaviour to the three adaptive traps.

4.5 CASE DESCRIPTIONS

Before we move on to the results of our study, we will first give a brief description of both cases. A more detailed time line of the events in both cases is provided in Tables 4.2 and 4.3.

Case 1: Winter storm

The first case happened during a winter's day in 2014. Around 5:30 a.m. a massive snow storm caused numerous malfunctions to switches and guarded crossings in the southern part of the Netherlands. This region is managed by two regional traffic control centres, Eindhoven and Roosendaal. Within two hours twenty-six malfunctions had been reported. Prior to the storm, cuts to the rail service had been made to add some slack to the system. Nonetheless, due to diminishing rail capacity, regional traffic controllers and train dispatchers struggled to keep rail traffic flowing. Around 09:15, the regional traffic controller in Eindhoven temporarily stopped all rail traffic to get an overview of the situation and regain control. This came as quite a surprise to the operators in the OCCR as they were unaware of the severity of the situation. Around 11 a.m. the regional traffic control centres regained control and rail service was gradually restored. However, it took another six hours to get the rail service completely up and running due to the limited availability of train crew and rolling stock.

Table 4.2 The main events in the first case: Winter Storm

05:26 - 06:00	The train dispatchers are automatically notified of a malfunction in two guarded crossings.
06:29 – 07:27	A total of 26 guarded crossings and switches show malfunctions. This means that a lot of trains have to be rerouted over other tracks and train dispatchers have to give verbal instructions to train drivers at the crossings. This results in serious delays and crowded stations.
07:17	The national traffic controller makes a routine call to the regional traffic controller in Eindhoven. The situation is discussed, but no decisions are made on further actions.
07:33	The regional traffic controller in Eindhoven calls the national traffic control for help, but the national traffic controller asks the regional traffic controller to make a logging in the communication system of the remaining rail capacity.
07:36	Regional controllers of ProRail and NS start to cancel trains.
07:48	National and regional traffic control in Eindhoven discuss the operational conditions, but again no decisions are made on further actions.
07:59	Despite a code red, the regional traffic controller in Roosendaal starts his shift at 08:00 as if it is a regular day. Up until that moment, his area of control was being monitored by the regional traffic controller in Eindhoven. He immediately gives a situation update to the national traffic control and highlights the seriousness of the situation. No concrete decisions are made.
08:21	The regional traffic controller in Roosendaal warns the national traffic controller that he has lost sight of the overall picture. The national traffic controller promises to discuss matters with NS.
08:27	The regional traffic controller in Roosendaal again warns that he is losing control and has to stop most of the train services to regain sight of the overall picture. Help is offered by the national traffic controller, but declined. There is no further mutual consultation.
09:15	The regional traffic controller in Eindhoven tells the national traffic control that they are losing control and suggests stopping all trains in the south of the Netherlands. The national traffic controller promises to consult the other parties in the OCCR.
09:19	The regional traffic controller in Eindhoven informs the national traffic controller that he has stopped all train services in his area of control.
09:30	The OCCR decides to stop train services in the control areas of Eindhoven and Roosendaal.
17:00	Train services are restored.

Case 2: Broken overhead wire

Early on a Monday morning in 2015 a train broke an overhead wire upon entering Utrecht Central Station, the largest and most important station in the Netherlands. Power was automatically taken off the overhead system in the vicinity of the broken wire, depriving six platform tracks and two rail tracks of power. Normally it is possible to restore power to non-affected groups remotely, but due to construction work at the train station, groups had been rearranged and the power had to be restored manually. This made it difficult for the train dispatchers and regional traffic controllers to estimate the available rail capacity and so it took almost one and a half hours to implement a contingency plan. Despite this contingency plan train dispatchers and regional traffic controllers kept struggling to keep the rail traffic flowing as there was often no crew on the trains. With all platform tracks occupied, trains were queuing up to enter Utrecht Central Station. The overhead wire was repaired around noon, but it took several more hours to fully restore train services.

Table 4.3 The main events in the second case: Broken Overhead Wire

05:56	Upon entering Utrecht train station sparks are noticed upon the roof of train 80408 and the train is stopped immediately.
05:56	Power is lost on the overhead wires at platforms 9-14. Two trains are unable to move and block additional platforms.
06:13	The train dispatcher is informed that a contact wire has been found on top of the roof of train 80408 and that power has to be restored manually. Mechanics are sent to the site.
06:18	The regional traffic controller in Utrecht warns the national traffic controller that the situation is more severe than anticipated.
06:40	Regional control centre gives an initial estimation of remaining rail capacity.
07:13	NS issues a code red to remain control over the train crew.
07:18	The first contingency plan has been formulated by the OCCR and is checked with regional control centres. Regional traffic controller Utrecht demands additional cuts.
07:23	Power is mostly restored, except for platforms 9, 10, and 11.
07:40	The contingency plan is accepted by all regional control centres and implemented.
07:50	Platform tracks remain occupied since many of the trains do not have a crew to operate them. Trains are queuing up to enter Utrecht Central Station. The regional traffic controller in Utrecht decides to make additional provisional cuts.
07:52	The regional traffic controller in Rotterdam informs the national traffic controller about the provisional cuts and that NS is dissatisfied about regional traffic control in Utrecht deviating from the contingency plan.
07:59	The national traffic controller and regional traffic control in Utrecht decide to hold on to these provisional cuts until 09:00 instead of making changes to the contingency plan.
09:00	The OCCR decides to revise the contingency plan as the management of train crew remains troublesome.
10:45	Repair work on the overhead wire is started.
12:06	Repair works are finished and all rail infrastructure is back in service.
12:30	NS develops a plan to restore its rail services.
15:33	All train services have been restored.

4.6 RESULTS

In this section we will show how different leadership behaviours manifested themselves during the management of the disruptions. To structure the description of our findings we use the three basic patterns of adaptive failure to see whether or not and how the different leadership behaviours were used to prevent or correct the system from falling in one of the three traps.

4.6.1 Decompensation

The pattern of decompensation can be observed in both cases. For example, in the winter storm case, local operators of ProRail were confronted with cascading failures as the snow caused more and more malfunctions to switches and level crossings. As a result operators were quickly running behind the tempo of events. For instance, due to problems with crossing barriers, train dispatchers had to give verbal instructions to each train driver in order for a train to pass a level crossing. These verbal instructions greatly increased their workload and caused severe delays to the train services. These delays and the loss of rail capacity made it very difficult for the regional traffic controllers to keep the rail traffic running. For the local operators of NS updating the crew schedules became quite a bottleneck during both disruptions. Since last-minute changes to the crew schedule must be announced by phone, the communication workload increased rapidly and operators struggled to get in contact with the train crews. Hence, there were too few operators to manage all the anomalies and the overview of the train crew was soon lost, as one of the coordinators of NS (LBC) explains:

> **LBC:** "*If you have one or two phone calls on paper, but not in the system, you are lost. A thousand people will start to phone you and they all just want one thing: they want to know what they should do and if they will be back on time at the end of their shift.*"

As a result, trains often could not depart because there was no crew assigned to them. With the platforms still being occupied, arriving trains could not enter the stations. This caused a further escalation of the situation and an increase in workload, since train drivers and conductors on the trains queued outside the station had to be rescheduled.

Back-up behaviour by leader teams

To solve the above-mentioned deadlock and to prevent local controllers from completely losing control, the coordinator of NS in the OCCR decided to switch to the highest emergency situation (code red M3 + P3) during both disruptions. This 'code red' procedure is designed get more and better control over the rescheduling of train crew. This procedure involves several measures. First of all, management tables were placed at the largest stations. This basically meant that all crew members arriving at the station had to report to this table to be registered. Registration at these tables enables local operators to update the systems and to re-assign crew to trains. Secondly, the coordinators of NS decided to redistribute the rescheduling of the crew on long-distance trains among the other local control centres and operators in the OCCR. In addition, operators in the OCCR took over the management of the rolling stock, so additional capacity at the regional control centres became available for the rescheduling of train crew. Nevertheless, as both cases have shown, it took quite some time to fully regain control and sometimes it was even easier to just wait until the next shift of train crew and start with a clean sheet.

Likewise, although they were not acting according to a formalized procedure, we noticed that ProRail's national traffic controllers proactively assisted the regional traffic controllers by rerouting international and cargo trains; updating the communication system (ISVL) with details on the disruption and verbal agreements; arranging locomotives to tow stranded trains and cleaning up the timetables. The latter is a task that is easily shed during periods of high workload.

Performance monitoring and recognizing workload problems

However, the cases also show that operators in the OCCR struggle to determine if local operators are exhausting their capacity to adapt and back-up needs to be provided. Since national traffic controllers only have a general overview of the traffic flows, they are not able to determine the seriousness of local situations by means of the traffic control systems. Hence, it is important to have regular contact with local operators to monitor their performance. Yet, as the overhead wire case clearly showed, national traffic controllers increasingly struggled to contact regional traffic controllers in order to create a shared understanding and discuss the need for back-up. Besides, national traffic controllers often passively waited to be called for help instead of proactively offering assistance. However, in the telephone conversations we only once identified a clear request for assistance by a regional traffic controller and sometimes the help offered was rejected even through the operators were faced with a huge workload. This greatly increases the risk of intervening when the capacity to adapt has already been lost.

As Branlat & Woods (2011) observe, it is important to detect a developing problem at an early stage to be able to respond and avoid a decompensation collapse. The key information then is how hard operators are working to stay in control. In both cases it was noticed that little time and effort was invested in discussing the performance of the regional control centres and potential future risks. For example, in the winter storm case the information being shared between the regional and national traffic controller mainly concerned an enumeration of all the malfunctions. Despite the fact that the network traffic controller acknowledged the seriousness of the situation at an early stage, they were unable to translate this information to a shared understanding of the impact of all the malfunctions on the train service and the local operators' ability to stay in control. Hence the national traffic controller was unaware that the regional traffic controllers were nearing their capacity limits.

Moreover, even when there are clear signals that local operators are struggling to stay in control, operators in the OCCR don't always recognize the seriousness of the situation and immediately respond to these signals. For example, in the winter storm case the regional traffic controller specifically asked for help, but the national traffic controller responded by asking the regional traffic controller to first make a logging of the remaining rail capacity in the communication system. So, instead of discussing the operational situation by phone, the national traffic controller had to make sense of the situation with the help of a simple text message. He therefore missed important contextual information. This reliance on communication systems to monitor the performance of the local control centres entails other risks. Due to the high workload, local operators were often unable to update the system with new information on disturbances and verbal agreements. Hence, operators in the OCCR might have made sense of the operational situation on the basis of outdated or incomplete information. Furthermore, the lack of new information in the communication system might falsely give the impression that everything is under control.

4.6.2 Working at cross-purposes

Contingency plans form an important coordination mechanism in the Dutch railway system as they tell operators of ProRail and NS which trains should be cancelled and when and where trains should be short-turned. However, before a contingency plan can be implemented the disrupted area first has to be isolated to prevent congestion and a propagation of the disruption to other areas. The workload of local operators can really peak during this first phase of the disruption management process, especially if the disruption occurs at a major station, as in the second case, and trains have to be shunted and a lot of rescheduling work has to be done. Moreover, coordinating activities requires a great deal of dialogue between the control centres. For instance, the regional traffic controller has to warn neighbouring traffic controllers about the situation and order them to stop trains from moving to the affected area. ProRail's regional traffic controller also has to consult with the regional monitor of NS to decide where trains should be short-turned and what should be done with the trains stranded in the disrupted area. Hence, this first phase of the disruption management process is characterized by local improvisation and little control over the situation by the OCCR. A national traffic controller outlines the situation in the broken overhead wire case:

> **NTC: "***We don't have a contingency plan ready, but they* (local control centres) *are very active in short-turning trains. They are very busy at all locations, but how exactly and what they are precisely doing, I don't know. They are still writing everything down."*

However, during both cases it was noticed that information is often no longer shared properly during stressful situations as people tend to focus on their own task. For example, regional traffic controllers often told the national traffic control that they experienced updating and reading the messages in the communication system as an administrative burden, which had lower priority then trying to keep traffic flowing. Moreover, telephone lines quickly got overloaded and communication flows crumbled due to the large flow of direct communication between operators. This caused control centres to work at cross-purposes, as teams acted on the basis of incomplete information and faulty assumptions. In the second case, for instance, neighbouring traffic control centres were unaware of the difficulties that operators in the disrupted area were experiencing in keeping the traffic flowing. Neighbouring traffic controllers therefore kept sending trains to the disrupted area. As a result, trains were queuing up before the station, which made it more difficult to isolate the disrupted area and halt the spread of the disruption to other areas. Similarly, NS' local control rooms started to make use of each other's resources, such as train personnel, without consultation. There were also instances in which train drivers were relying on (incorrect) information from ProRail's train dispatchers, as they couldn't get in contact with their own organization.

Orchestrating action and managing the flows of communication

The OCCR has the important task of developing an overall understanding of operational conditions. To create this overall understanding, the coordinators of the different teams co-located in the OCCR regularly come together to share and discuss the information received from local operators and decide on a shared course of action. The various parties then inform the local operators of the decisions that have been made to orchestrate their activities. However, as we have observed, especially in the broken overhead wire case, the overall understanding of the situation created by the coordinators in the OCCR can quickly become outdated, as one of the national coordinators rail (LCR) explains:

> **LCR:** *"What you repeatedly see is that we are running behind the facts here in the OCCR. What often happens is that we are discussing things that are already outdated. So, while we are creating a shared understanding, the situation outside has already changed completely."*

Hence, it is important that local operators provide regular situation updates so that the operators in the OCCR can update their overall understanding of the situation. Despite this, we noticed that these big picture updates were very scarce. Instead, the operators in the OCCR had to actively collect the information themselves. This was made difficult by the overloaded telephone lines. In fact, in the broken overhead wire case, a pattern emerged in which neighbouring traffic control centres were actually providing the national traffic controllers with important new information when they contacted them for guidance.

This information disadvantage negatively influenced the OCCR's ability to monitor performance and take control when needed. First of all, since decision making by the coordinators in the OCCR was based on already outdated information, their decisions were often no longer feasible and new rounds of decision making had to be started. As a result, the role of the OCCR became reactive, instead of proactive. Moreover, the development of a collective understanding on the basis of new information takes quite some time. This conflicts with local operators' need for a quick decision in order to intervene quickly in the escalating situation. For example, in the winter storm case the regional traffic controller single-handedly decided to stop the rail traffic in his area of control while the operators in the OCCR were still discussing newly-obtained information on the situation outside. If this decision had been coordinated better, it might have had less of an impact on the management of the train crew and services could have been restored sooner. Finally, instead of being a hub for information collection and dissemination, we noticed that local control centres often bypassed the OCCR for information and consultation. Instead, they sought direct contact with the local operators managing the disruption in order to receive first-hand information. This is illustrated by the following fragment of a conversation between a regional traffic controller and national traffic controller.

> **RTC: "***I will discuss matters with Utrecht. Not to be rude, but I prefer to listen to Utrecht instead of you, because with them I have a shorter line of communication (...) If you tell me that they will be able to manage things and the regional traffic controller over there says he is not, then I will run into problems with them."*

At NS they try to solve issues with the synchronisation between and with the local control rooms by scheduling regular conference calls with their shift leaders to obtain periodic situation updates. In addition, the coordinator at NS in the OCCR can make use of four 'cards' (punctuality, control, large traffic flows and rolling stock) that are assigned to each control centre matching the operational environment. These cards indicate the priorities for each control area and provide guidelines for achieving these goals. For instance, during these major disruptions the coordinator assigned the 'control card' (preventing the propagation of disruptions) to all regional control rooms in order to shift to a clear chain of command in which there should be no discussion about decisions made by the operators in the OCCR. Nevertheless, applying these cards are not without their difficulties when it is necessary to make a trade-off between the goals of carrying passengers and achieving a balance in the rolling stock, as one of the coordinators of NS (LBC) explains:

> **LBC**: *"A chain of command starts with good agreements and communication and there you have it... Good communication is often difficult because you can't get into contact with each other. I'm also convinced that not everyone fully understands what these cards actually mean. You should actually do a check. We are currently playing the 'rolling stock' card, but do you know what that means? It means that I can cancel a passenger train to free up a train driver, because rolling stock has first priority. There should be no discussion then about the fact that the train is full with passengers and that cancelling the train will lead to a crowded platform."*

4.6.3 Getting stuck in outdated behaviour

The success of the Dutch disruption management model largely depends upon the capacity of local operators to make a correct situation assessment quickly so that a contingency plan can be implemented that matches operational conditions. In a time-compressed and dynamic environment the availability of information needed to make an accurate assessment of the situation is however often challenging, while decisions have to be made quickly to prevent the situation from escalating (Salas et al. 2001). Regional traffic controllers normally deal with this issue by relying on their experience. In other words, they anticipate that a situation will unfold according to earlier experiences and start to manage the disruption in line with the anticipated contingency plan, (cf. Schipper, Gerrits, & Koppenjan, 2015). This is not an easy task, however, when disruptions are cascading, as in the first case, or when operators are confronted with a new and complex situation, as in the second case. In those cases understanding of the situation often needs to be adjusted on the basis of new insights (Uitdewilligen & Waller 2012). In the broken overhead wire case this led to a tension between the desire to implement a contingency plan and the need to remain vigilant to changes in the environment.

Plan formulation and remaining vigilant to changes in the environment

The previous section highlighted the risks of managing a disruption without a shared plan. To reduce these risks, operators in the OCCR tried to formulate and implement a contingency plan as soon as possible. Hence, national traffic controllers urged regional traffic controllers to quickly make an assessment of the remaining infrastructure capacity. However train dispatchers and regional traffic controllers found it difficult to make an accurate assessment of the complex and evolving situations, either because there was still a lot unknown or because any assessment of the situation was soon outdated. For example, in the broken overhead wire case it took quite some time to investigate the break in the overhead wire and restore power to the overhead lines, while in the winter storm case the number of malfunctions reached a total of 26 within an hour. Moreover, in both cases we observed that regional traffic controllers struggled to divide their attention between making a situation assessment and keeping the traffic flowing to prevent a propagation of the disruption. They often preferred to focus on to the latter.

In the second case the implementation of a contingency plan was further delayed because the unique circumstances meant that predefined plans were not applicable. Hence, plans had to be adjusted by hand to the specific circumstances, which is a time-consuming task. In the meantime the situation deteriorated rapidly. Local operators of NS were struggling to assign crew members to trains, platform tracks were kept occupied, and trains were queuing up in front of the station. Consequently, the issue was no longer just a loss of infrastructure capacity due to the broken overhead wire as operators struggled to keep control over all resources. Hence, the alternative service plan being implemented no longer matched operational conditions. In fact, the OCCR's desire to swiftly move on to the plan execution phase conflicted with the capacity limits of the local operators, as one of the team leaders of the regional traffic control rooms explains:

> **Team Leader:** "*When they* (OCCR) *want to implement a contingency plan, which in my view happens more often, we are still in the first phase of managing the disruption. Dealing with the shunting of trains so we can get an overview of the situation and to see what is still possible. At that point, there is already a logging in ISVL that we will operate according to this contingency plan. When that logging was made we had seven trains waiting for a red signal! (...) I believe that there has been a check, but the desire of National Traffic Control* (to quickly implement the contingency plan) *and what we could manage in practice, didn't match.*"

Adjusting plans to unexpected changes in environment

The national traffic controller had indeed checked with the regional traffic controllers whether they thought the alternative service plan could be implemented. Although the regional traffic controllers agreed with the plan, they soon had to revise their judgement and make additional cuts to the train service. There was actually quite some doubt among the national traffic controllers as to whether the regional traffic controllers had made an accurate assessment of the available capacity and if the contingency plan could be implemented. This concern was never fully expressed to the regional traffic controllers, nor did they take the time to jointly make a good assessment of the situation in order to detect any mistakes. In fact, the operators of ProRail and NS in the OCCR decided not to significantly adjust the plans, but to hold on to the chosen contingency plan in order to create stability and to re-assess the situation later on to see if additional measures were needed.

Nevertheless, in this case the contingency plan did not lead to a stable train service as there was not enough capacity to run all the trains according to the alternative service plan. Instead of stability, incremental adjustments had to be made to the contingency plan to match it to the changing conditions. This kind of re-planning is not without risks. Not only does it lead to unreliable information for passengers, since trains are cancelled at last-minute notice, but it also causes confusion among the control centres. Revising a plan requires a great deal of renewed coordination between the different control centres and increases their communicative burden and workload. This makes the decision to revise a plan in progress difficult and highlights the importance of making an accurate assessment of the situation. In practice though, operators in the Dutch railway system (at both levels of control) often tend to simplify conditions and make a positive estimation of the possibilities to run trains, as a travel information employee (MRI) explains:

MRI: "*What you could witness here was the classical rail spasm, which you see often, to say let's try and see what happens (...) The problem is that you are totally unpredictable for the passengers. At best you are predictable in terms of underperformance (...) I wonder if we would have had the same problems if we had made bigger cuts to the train service. Then afterwards, we could have seen what was still possible and if there was room for more. Now we make initial cuts in the train service and start to clean up the mess. However, the mess does not become any smaller and we still have to make additional cuts.*"

4.7 DISCUSSION

The analysis of these two large-scale disruptions has shown that leadership is not an easy task in a MTS adapting under stress and that adaptive failures form a serious threat to the system. In Table 4.4 the barriers to leadership, as found in the previous section, have been summarized and contrasted with the markers from Table 4.1. The main findings will be discussed in the next section.

Table 4.4 Summary of the barriers to leadership observed in the cases

Component	Observed barriers to leadership
Communication	• Local operators often gave preference to immediate task performance instead of providing regular big picture updates to the OCCR or updating the communication system. • Operators in the OCCR were quickly running behind the facts due to the dynamics of the operational environment and communication difficulties. • The information provided to the national traffic controllers was often full of details, making it difficult for them to grasp the core message. • Local control centres bypassed the teams in the OCCR for consultation due to their degraded situation awareness.
Performance monitoring	• Leader teams didn't always take the time to cross-check information with the sender to create a shared understanding of the operational environment. • Leader teams didn't always express their doubts regarding the actions of local operators.
Back-up behaviour	• Leader teams didn't always recognize signals as a legitimate need for help • National traffic controllers passively waited for a request for help • National traffic controllers struggled to proactively provide assistance, due to the lack of communication with local operators. • Local operators rarely asked for help and sometimes refused the help offered
Decision Making	• Local operators struggled to divide their attention between situation assessment and immediate task performance. • Leader teams focused on quickly implementing a standard contingency plan despite changes within the internal and external environment. • Leader teams struggled to decide between holding on to an initial assessment and revising plans in progress.

First of all, we have seen that decompensation is a serious issue in the Dutch railway system during large-scale disruptions, as local operators were falling behind the tempo of events. To avoid this maladaptive trap, it is important that workload distribution problems are noticed quickly and that workload is redistributed or assistance is offered proactively. We observed two specific issues in providing back-up behaviour regarding back-up provision and requesting and accepting back-up. First of all, operators in the OCCR often struggled to adequately monitor the performance of local operators in order to detect whether they might need back-up and how this should be provided. Besides performance monitoring, it is therefore important that the local operators themselves indicate that they need assistance and that help is accepted when needed.

However, when confronted with increasing demands, local operators are not always able to recognize and express their need for assistance. As Smith-Jentsch et al. (2009) notice, back-up providers and recipients will weigh up the likely costs and benefits of coordinating back-up prior to offering it or requesting it. The interviews revealed that regional traffic controllers often refuse help because they prefer to manage things on their own. There is a fear among regional traffic controllers of relinquishing control over their process and risking losing sight of the overall picture in their own region. Moreover, some regional traffic controllers actually believe that asking for help is a sign of weakness. Studies have shown that factors like trust, team orientation and the experience of working together have a positive effect on offering and requesting back-up (Fiore et al., 2003; Smith-Jentsch et al., 2009). However, given the setting of distributed teams and continuously changing team compositions, it can be expected that these factors will be less developed and that requests for assistance will be context-specific, as one of the traffic coordinators of ProRail describes:

> **Traffic coordinator:** *"It strongly depends on who is on the other side of the phone. A good regional traffic controller knows when to hand things over, instead of wanting to do everything themselves. If I call them and tell them, I will call your colleague, or I will take over this part of your work, they shouldn't mind."*

Secondly, the telephone conversations revealed that signals of back-up needs were not always recognized by the operators in the OCCR as a legitimate need for help. This is partly due to the fact that the information shared was so detailed that the operators in the OCCR were unable to grasp the core message. This shows that just sharing information about the situation at hand is not enough, but that it needs to be translated into meaningful information for others. However, the telephone conversations also showed that operators in the OCCR regularly failed to ask for clarification of the information received in order to create a shared understanding of the situation. The interviews revealed that operators in the OCCR are often hesitant to cross-check information out of the fear of intervening in the work of the local operators.

Another key issue we identified was the information gap of the teams in the OCCR during the management of the disruptions. We expected the OCCR to have an overall understanding of the situation during the disruptions in order to orchestrate the activities of the local control centres. On the contrary, we noticed that the OCCR quickly had a degraded or outdated situation awareness due to the amount of information that had to be shared between teams, inadequate communication lines, and the pace at which the environment changed during the disruptions. This shows that effective leadership is not just the result of the actions of the leader teams, but that component teams play a critical role in facilitating the performance of leader teams by maintaining their situation awareness (Salmon et al., 2008). As such, component teams should be aware of the kind of information the leader teams need and provide regular updates, something which is easily neglected when confronted with a high-workload.

Finally, this study has revealed important tensions between coordination by plan and the need to remain vigilant to changes. Research has shown that the adaptability of teams depends on the speed with which environmental changes are recognized and appropriate responses are enacted (Burke et al., 2006). However, local control centres need to contain the disruption and make an accurate situation assessment simultaneously. As the cases illustrate, it is not always easy to do the latter. The local operators were nevertheless under pressure from the OCCR to quickly move to the implementation of a contingency plan. The broken overhead wire case showed that situation assessment and plan execution are thus not always strictly separated steps, but these activities actually overlapped and even conflicted. It resulted in an oversimplification of conditions and in the end the need to revise the contingency plan. Hence, disruption management is not always a single, linear process, but may involve several rounds of assessment, rectification and adjustment of plans (Golightly et al. 2013). This creates an important challenge for operators in the OCCR, who have to decide between holding on to an initial assessment and revising a plan in progress, the latter involves a great deal of renewed coordination between the teams involved in the disruption management process.

4.8 CONCLUSIONS

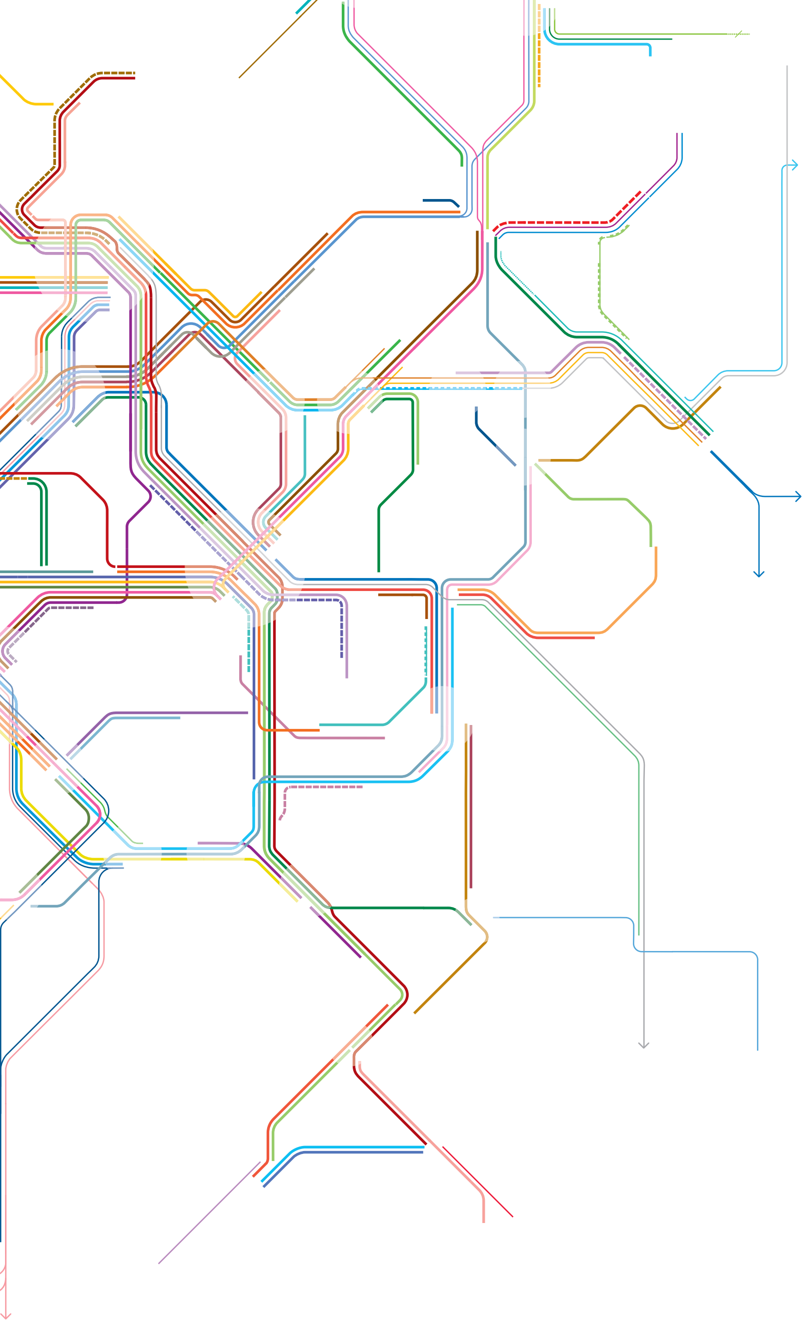
While most studies have focused on the contribution of leadership to the adaptation of single teams, leadership in a multiteam setting poses additional challenges. Both in theory (with the development of the concept of polycentric control) and practice (with the development of the OCCR) there is a strong belief that complex networks of control centres - which pursue their own sub-goals and operate in a dynamic and turbulent environment - need a higher level of control to coordinate their activities. The main aim of this study was to further investigate the role of MTS leadership in a real-world setting.

We therefore examined the role of leader teams in the management of two large-scale disruptions. This study has shown that operators in the OCCR experienced difficulties in recognizing workload problems before local operators lost capacity to control the situation; were confronted with an outdated situation awareness when coordinating activities of the local control centres, and tended to oversimplify conditions in order to swiftly implement standard contingency plans.

The challenges to MTS leadership identified in this study show that it can not be expected that polycentric control will instantly occur, simply by placing a leader team above the component teams. Leadership in a MTS requires effective teamwork between component and leader teams in which the component teams should actually facilitate the leader teams in their role. This requires specific interventions, such as joint training sessions, in order to gain a better understanding of how other teams function and to improve communication and coordination skills (Wilson, Burke, Priest, & Salas, 2005).

Naturally we are aware of the limitations of our study. The two case studies analyzed show the behaviour of a specific group of operators dealing with a specific disruption. It is therefore difficult to generalize the insights of this study, although we must point out that these findings are embedded in broader longitudinal research. As such, a larger body of knowledge on the management of disruptions has been collected over a three-year period through many hours of observations at the different control centres, interviews with operators, and by studying evaluation reports on other disruptions. Hence, the detailed descriptions of the findings from these two cases are embedded in a broader understanding of disruption management in the Dutch railway system and the behaviour of operators at both levels of control.

With this research we have shown some of the difficulties of providing leadership in a MTS. We believe, however, that leadership is important in relation to MTS effectiveness. We therefore need further empirical research on leadership in various multiteam systems to increase our understanding of the unique challenges of leadership processes in MTS and how to deal with them. In addition, in this study we have not focused on leadership behaviours prior and subsequent to the management of a disruption, but these transition phases can be of importance to the effectiveness of leadership during the management of disruptions. Moreover, the coordination between the different leader teams in the OCCR fell outside the scope of this study, but poses an interesting challenge in terms of balancing the needs of one's own team or organization and that of the system as a whole. Future research on these topics could help our understanding of leadership in a MTS.



CHAPTER 5

Differences and similarities in European railway disruption management practices

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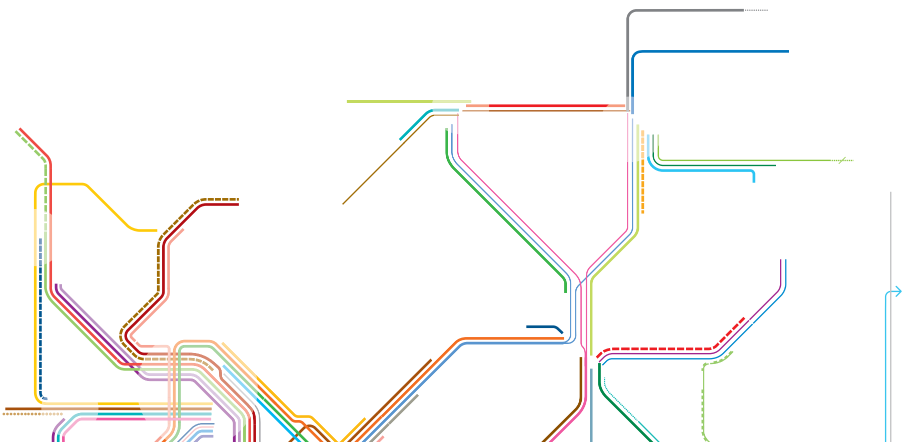


ABSTRACT

Disruptions severely undermine the reliability of railway systems. Consequently, a lot of investments are made to improve disruption management. Much has already been written about disruption management, often with the purpose of supporting operators in their decision making. However, to the best of our knowledge, this literature does not consider the structural differences of disruption management in different countries. An overview of the various ways in which disruptions are solved and conditions under which that happens could help rail infrastructure managers and train operating companies to reconsider the ways in which they operate. This paper takes stock of the similarities and differences in how disruptions are managed in Austria, Belgium, Denmark, Germany and the Netherlands. Of importance is not only how these systems work on paper, but above all what happens in practice, i.e. the habits and routines that operators have developed for solving disruptions.

5.1 INTRODUCTION

Train service disruptions pose an important challenge to railways as a reliable mode of transport (Golightly & Dadashi, 2017). European railway infrastructure managers (RIM) and train operating companies (TOC) have invested considerably in technology to help operators solve disruptions. Despite the automation of certain tasks and increasingly sophisticated information systems, railway traffic control remains a labour-intensive process performed by many thousands of operators working in control centres (Roets & Christiaens, 2015). Over the last decades these operators have experienced fundamental changes to the environment in which they operate. The introduction of market mechanisms (e.g. Council Directive 91/440/EEC), followed by regulations on a single railway market (e.g. Directive 2012/34/EU) have eroded national railway monopolies. The most important change has been the separation between RIMs and TOCs, and emergence of many private and semi-private or corporatized TOCs. It is therefore justified to speak of a networked instead of an integrated system for dealing with disruptions.

In such networked systems, reliable services require more than sound technical equipment and infrastructure. The operators of the RIM and the many TOCs still need to work closely together to provide reliable services. Interdependency becomes especially pressing during disruption management, when operators at different control centres have to solve the complex puzzle of rescheduling timetables, train crews and rolling stock in a coordinated manner. Coordination between control centres can be achieved through pre-defined plans and procedures, but ad-hoc measures are often necessary due to the dynamic and uncertain conditions under which operators work (Johansson & Hollnagel, 2007). There are many studies on railway unbundling and privatization in the academic literature (e.g. Link, 2012), but not much attention has been paid to the effects of these policies on the daily operations of controllers managing rail traffic and disruptions (See Steenhuisen & De Bruijne, 2009 for an exception to the rule). This is an important topic, since these restructuring policies and how they have been put into practice, have greatly impacted disruption management structures and practices in different countries (De Bruijne & Van Eeten, 2007).

Practical experience suggests that there are major differences and similarities in how rail systems have structured disruption management processes. A thorough literature search showed that there is currently very little research into those differences and similarities. We therefore ask: *what different types of structures and practices of railway disruption management have been developed in European railway systems?* We will take stock of both disruption management structures and practices in Austria, Belgium, Denmark, Germany, and the Netherlands. Since formalized plans set out in documents do not tell much about what happens in reality, our focus will be on *actual practices*. We will first discuss the main elements of the complexity of managing railway disruptions in Section 5.2. The research method is discussed in Section 5.3. Country characteristics are presented in Section 5.4 and then categorized in Section 5.5. The conclusions are presented in section 5.6.

5.2 MANAGING LARGE COMPLEX INFRASTRUCTURE SYSTEMS

Although restructuring policies have had a major impact on the ability of infrastructure industries to provide reliable services, not much is known on how these networks of organizations have been organized to reliably operate these systems (Berthod, Grothe-Hammer, Müller-Seitz, Raab, & Sydow, 2017; De Bruijne, 2006). We start from the premise that disruptions in rail services will occur, and that their impact has to be minimized in order to return to normal services as soon as possible. We therefore want to understand how these disruptions are managed in different systems and how operators coordinate their actions *during* the process of managing disruptions. We thus see reliability as the ability of an organization to anticipate and contain incidents in the course of its operation (Berthod et al., 2017). This places an emphasis on how systems manage their adaptive capacity to successfully manage disruptions (Branlat & Woods, 2010; Hémond & Robert, 2012; Mattsson & Jenelius, 2015). Complex systems have to deal with trade-offs that bound their adaptive performance (cf. Hoffman & Woods, 2011). In this paper, we focus on *two* such trade-offs: (a) decentralized versus centralized structure, and (b) anticipation versus resilience.

The occurrence of unexpected disruptions in complex systems places an emphasis on a decentralized structure, because detailed knowledge of the local context and direct control over resources give local actors the flexibility required to deal with these non-routine situations (Perrow, 1999). However, Perrow (ibid.) warns against the tight-coupling of complex systems and the risk of cascading failures. Disruptions can severely compromise the capacity of local operators to keep an overview of and control over the situation (Schipper, 2017). As a result decisions made locally do not always contribute to the overall performance of the system. One solution for this problem is to centralize control in order to facilitate rapid and decisive coordinated action. Centralized control, however, is not without its difficulties. Decisions require that a considerable volume of information is shared between the different levels of control; something that is not always possible when working under stress (Branlat & Woods, 2010; Schipper, 2017). Consequently, decisions may be perpetually lagging behind the actual local situation. It is therefore necessary to find the right balance between decentralized and centralized decision making.

The second trade-off concerns anticipation versus resilience (Vogus & Sutcliffe, 2007; Wildavsky, 1988). The anticipation approach involves the prediction of potential failures or disruptions in order to plan ahead (Stephenson, 2010). Part of this planning is the development of pre-defined coordination mechanisms, e.g. contingency plans, rules, and procedures, that specify roles and tasks for all operators. Pre-defined coordination mechanisms reduces coordination issues between actors, subsequently increasing responsiveness. However, it remains impossible to anticipate every situation. For instance, the type, location, and timing of an incident will influence the effectiveness of the response (Golightly & Dadashi, 2017). Consequently, there needs to be discretionary room for operators to modify plans to the specific situation through mutual adjustment and improvisation (Faraj & Xiao, 2006). Real time adaptation can be considered a resilience[9] approach that substitutes foresight for the reactive capacity of control room operators and focuses on their expertise and tacit knowledge (Roe & Schulman, 2008). However, an improvised response still needs to be swift and coordinated when dealing with a rapidly changing environment. Hence, anticipation and resilience are not mutually exclusive but constitute a trade-off when developing an effective response (Comfort, Sungu, Johnson, & Dunn, 2001).

There is not one single, optimal way of dealing with these trade-offs in general; and each railway systems will balance these trade-offs in specific ways (Woods & Branlat, 2011b). Yet, the extent of these trade-offs in various European countries is currently unknown. This, then, is the motive of the current research. We will categorize the different national structures and practices of disruption management, with a focus on the trade-offs discussed above. Disruption management happens within the specific context of a country that (dis) allows for certain solutions. We will first look at the characteristics of the different railway systems, i.e. the length of the rail network, the number of train operating companies, the average daily number of trains being operated, and the relationship between the RIM and TOCs. Next, we will present the different roles and teams involved in disruption management and the relationships between them (section 5.4). Please note that our focus is on the rescheduling of resources (timetable, train crew, rolling stock), i.e. we only consider operators working at the control centres, not those directly involved in the management of an incident or emergency, e.g. emergency services or repair crew. We will then turn to the actual disruption management process itself and categorize the countries in terms of centralization vs. decentralization, and anticipation vs. resilience (sections 5.5 and 5.6). For both trade-offs we have selected several items with which to categorize the countries. These items are derived from various strands of literature and are summarized in Table 5.1.

9 We acknowledge that this is a simplified application of the concept of resilience, aimed at addressing the fact that disruptions fall outside the design principles of systems and systems thus require additional adaptive capacity. For a more elaborate discussion on resilience, see e.g. Boin & van Eeten, 2013; McManus, 2008; Stephenson, 2010; Vogus & Sutcliffe, 2007.

Table 5.1 List of items and their descriptions used in order to categorize the various countries. Items are scored from 1 (centralized/anticipation) to 5 (decentralized/resilience).

Trade-off A: centralization (item score 1) vs. decentralization (item score 5)

Item	*Description*	*Measurement*	*References*
Distribution of control centres	This concerns the number of control centres and the distribution across the country.	Low number and limited distribution: 1; high number and distribution: 5	(Golightly et al., 2013; Stanton, Ashleigh, Roberts, & Xu, 2001; JWilson & Norris, 2006)
Allocation of decision rights during disruption	This concerns the issue where decisions on alternative service plans are made: locally or centralized	Centralized decision-making: 1; decentralized decision-making: 5	(Branlat & Woods, 2010; Stanton et al., 2012)
Autonomy of local control centres	This concerns the extent to which local control centres can make autonomous decisions on the rescheduling of rail traffic	Little autonomy: 1; considerable autonomy: 5	(Perrow, 1999; Woods & Shattuck, 2000)
Structure and lines of communication	This concerns the information flows between the control centres and the operators that process the information	Centralized information flows: 1; distributed flows: 5	(Houghton et al., 2006)
Co-location of RIM and TOCs	This concerns the issue whether RIM and TOC's are located in the same control room	Co-location: 1; full separation: 5	(Goodwin et al., 2012; Jespersen-Groth et al., 2009)

Trade-off B: Anticipation (item score 1) vs. resilience (item score 5)

Item	*Description*	*Measurement*	*References*
Role of contingency plans	This concerns the number of contingency plans and how these plans are used in practice.	Strict reliance on pre-defined plans: 1; reliance on improvisation: 5	(Chu & Oetting, 2013; Golightly & Dadashi, 2017)
Automation of control	This concerns the availability and use of automated control that can support or replace human control and monitoring	Emphasis on automation: 1; manual control: 5	(Golightly et al., 2013; Stanton et al., 2001)
Institutionalization of shared sensemaking	This concerns the extent to which shared sensemaking is organized and institutionalized	Organized sensemaking: 1; no organized sensemaking: 5	(Merkus et al., 2016; Schipper & Gerrits, 2017; Waller & Uitdewilligen, 2008)
Use of dispatching rules	This concerns the availability and use of dispatching rules	Strict employment of dispatching rules: 1; no dispatching rules: 5	(Corman, D'Ariano, Hansen, & Pacciarelli, 2011; Zhang, Lei, Wang, & Zeng, 2013)

5.3 METHODS

The focus on disruption management practices required observations and interviews, which were conducted during site visits to national control rooms and regional (or decentral) control centres from September 2015 until October 2016. Site visits commonly lasted 2 to 3 full days, most of which would be spent on observation time in the control rooms. In all cases we were granted unrestricted access to all operations and all operators. We observed daily operations to see how operators interacted, and if and how certain protocols, procedures etc. were followed. This included emergency meetings whenever disruptions took place. All observations were carried out by two or three researchers, each taking detailed note. These reports were compared to prevent misinterpretations and the omission of important details.

In addition, we interviewed operators as well as managers on location when daily operations allowed for it. The duration of these interviews varied greatly, from 15 minutes to 2 hours. Due to their confidential nature we were unable to make audio recordings. The researchers took detailed notes during each interview. The resulting reports were then compared for the reasons mentioned above. Forty-nine respondents were interviewed, as listed in Table 5.2. The Netherlands appears underrepresented in the sample, but considerable data for this country has already been collected and published (cf. Schipper et al., 2015; Schipper, 2017). We also obtained detailed presentations and written documentation on the standard operating procedures and organizational structure of each railway system. These materials supplemented our own observation and interview reports. The research findings have been returned to the contact persons in each country for a member-check to correct incomplete or incorrect data. All data obtained was used by the authors to characterize and categorize the different countries on the basis of the items in Table 5.1. Each item was given a score ranging from 1 to 5. Since there is no theoretical reason to prioritize an item, we assigned equal weight to all items.

Table 5.2 Overview of respondents per country and organization, in order of meeting

Country	Function	Country	Function
Austria		*Belgium*	
Regional traffic control Innsbruck	Regional leader	Central traffic control	Deputy operational planning
	Executive leader		Team leader operational planning
	Leader traffic and production		Manager operational planning
	Manager operations		Developer communication system
	Regional coordinator		Planner
	Emergency coordinator		General supervisor
	Train dispatcher Kufstein		Traffic officer
	Regional traffic controller Wörgl		Team leader Antwerp
Central traffic control	Leader traffic control		Regional traffic controller
	Traffic and production manager	Signal house Brussels	Instructor
Denmark		*Germany*	
Central traffic control	Director Banedanmark	Central traffic control	Shift leader
	Manager traffic control		Traffic controller West
	Punctuality manager DSB		Network coordinator
	Director disruptions DSB		Network coordinator
	Duty officer	Local control centre Frankfurt	Coordinator Frankfurt
	Monitor freight traffic		Deputy coordinator
	Duty officer DSB		Emergency coordinator
Local control centre Copenhagen	Manager Copenhagen		Train dispatcher
	Duty officer Train dispatcher		Train dispatcher Rail signaller
S-train Copenhagen	Duty officer		Rail signaller Manager Frankfurt
		DB Frankfurt region	Monitor rolling stock DB
			Traffic information DB
			Coordinator DB
Netherlands			
Local control centre Utrecht	Team leader		
	Train dispatcher		
	Regional traffic controller		
	Regional traffic controller		

5.4 COUNTRY DESCRIPTIONS

First, a brief overview of the core characteristics of each country is given, followed by a description of the roles and responsibilities of the operators, and the relationships between the operators. Roles and communications lines have been visualized in Figures 5.1 to 5.5. Disruption management practices are discussed in Section 5.5. Please note that different countries use different terms for similar positions or roles and that it was not always possible to harmonize these terms into English. Table 5.3 provides an overview of the terms used in this paper.

Table 5.3 Description of the different roles

Role	Description
Signaller	An operator who is responsible for the safe allocation of rail capacity through the control of rail switches and signals. This operator implements rescheduling decisions made by the regional traffic controller.
Train Dispatcher	An operator who is responsible for the safe allocation of rail capacity through the control of rail switches and signals. This operator is allowed to reschedule the traffic plan for its own small area of control.
Regional Traffic Controller	Is responsible for the optimization of rail traffic flows in a specific geographical area.
Network Traffic Controller	Oversees railway traffic at a national level
Network Operations Controller	Manages train operations for the main TOC at a national level
Team leader/ Duty Officer/ Shift Leader/ Team Supervisor	Oversees the work of a group of operators in a control centre and communicates with other control centres

5.4.1 Denmark

National Characteristics

The Danish railway network measures 2,667 kilometres, 2,132 of which is managed by RIM Banedanmark. Banedanmark is a government agency under the Ministry of Transport and Building. The railway network is moderately centralized with most traffic converging around Copenhagen. Only the main line to Sweden and Germany and the S-train network of Copenhagen are electrified. Outside of the Copenhagen region, the network is relatively simple with mostly non-electrified, single tracks. There are four cross-border connections to neighbouring countries, one of which is by train ferry. Passenger trains make 2,700 runs per day on average, adding up to a total of 5.84 billion passenger kilometres per year. Most of the trains are operated by DSB, which is state-owned and works on a for-profit basis. Some smaller lines in the west of the country are operated by Arriva and offer regional train services. Freight traffic is relatively small in volume, with most traffic running between Sweden and Germany.

Structure and relationships between roles and teams

The main line and regional network are monitored by train dispatchers of Banedanmark working in four regional control centres (*Regional FjernstyringsCentral,* RFC). Unlike other countries in this study, in Denmark only one position (train dispatcher) has been tasked with both monitoring the safe allocation of tracks and optimizing traffic flows in specific areas. Train dispatchers usually make use of computers to operate signals and switches, but in some cases switches are still operated using control panels. Each regional control centre has a *duty officer* who is in charge of operations and oversees the work of the train dispatchers. The duty officer also communicates with the national control centre (*Drift Center Danmark,* DCDK*)* during a disruption. The DCDK was established in 2006. Banedanmark and DSB are co-located here.

DCDK's main task is to monitor long-distance traffic and to assume a supervisory role if disruptions occur that could potentially impact the overall performance of the network. Banedanmark has 4 traffic controllers who monitor long-distance rail passenger services in the west and east of Denmark, the Coast Line, the international services to Sweden and Germany, and freight traffic. DCDK's traffic controllers use the same traffic management system as train dispatchers in the RFC. It provides them with highly detailed information on the local situation and allows them to swiftly assess the impact of a disruption. Train dispatchers have to explain every delay of more than 3 minutes, which they note in the traffic management system. Operators in the DCDK can then simply click on a train to see why it is delayed and assess whether it is necessary to intervene. In addition to this, there is a communication system that allows Banedanmark's operators to provide each other with more details on a disruption using short text messages.

On the other side of the control room, just separated by monitors and facing the Banedanmark team, a team of DSB monitor their operations. Two operators monitor the rail traffic and time-table deviations. There are also 8 operators who reschedule rolling stock and train crew when needed. Both the Banedanmark and DSB teams in the DCDK have a duty officer who is in charge of the team and oversees the operators' work. Most communication is assigned to these duty officers in order to structure the flows of information. Communication with the emergency services has also been centralized in the DCDK to avoid miscommunications.

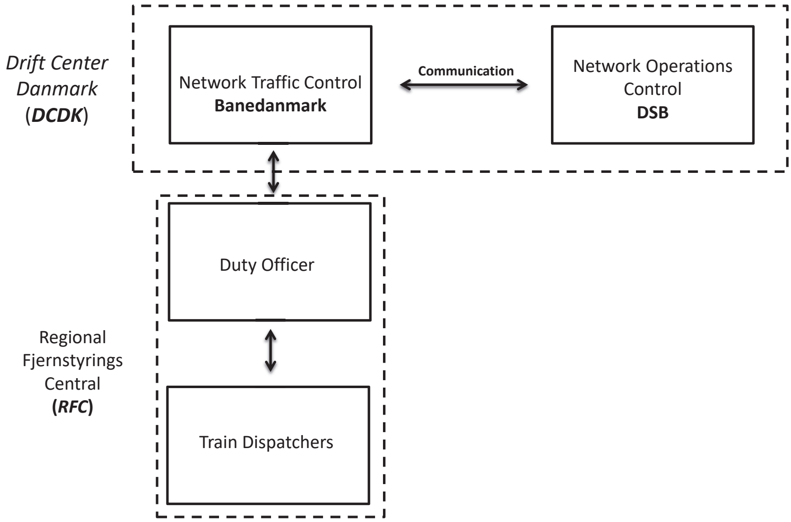


Figure 5.1 Coordination structure in Denmark

5.4.2 Austria

National Characteristics

The Austrian railway network measures almost 5,000 kilometres in length, most of which electrified, and is managed by ÖBB-Infrastruktur. A considerable chunk of the infrastructure is concentrated in and around the capital of Vienna. Long-distance (high-speed) lines connect the capital to other major cities in Austria, as well as to other European cities. Austria's central location in Europe means that there are many cross-border connections to the Czech Republic, Slovakia, Hungary, Slovenia, Italy, Germany and Switzerland. Much of the freight traffic between Germany and Italy passes through the Tirol region. ÖBB-Personenverkehr is the largest train operating company. It operates an average of 4,000 train runs per day, with a total of 10.28 billion passenger kilometres per year. Some smaller TOCs also operate cross-border connections as well as regional, and intercity services. Both ÖBB-Infrastruktur and ÖBB-personenverkehr belong to ÖBB-Holding AG, which is owned entirely by the Republic of Austria.

Structure and relationships between roles and teams

Railway traffic on the main rail lines is monitored from five regional traffic control centres (*Betriebsführungszentralen, BFZ)*. Traffic management is carried out by a regional traffic controller or *Zuglenker*. Rail traffic operations are mainly automated using the ARAMIS traffic management system, which makes it possible to track train positions and potential conflicts in real-time. In such cases, the system generates operational solutions. Moreover, routes

Chapter 5

(switches and signals) are automatically set, and passenger information is automatically adjusted. However, not all rail lines can be fully controlled from the BFZ and are managed from signal boxes located at stations. Hence, while signallers (*Fahrdienstleiter-Stellbereich)* in the BFZ are solely tasked with monitoring the safe allocation of rail capacity, signallers at the stations still operate switches and signals by order of the Zuglenker. ÖBB-Infrastruktur is also tasked with shunting operations. Consequently, signallers are quite busy with monitoring these operations. Each BFZ has an operations coordinator (*Betriebskoordinator, Beko),* who is the central operational actor. He or she communicates with the TOCs, neighbouring regional traffic control centres at home and abroad, and the national traffic control centre in Vienna. During a local disruption, the Beko will decide on a contingency plan and monitor the workload of all employees. An emergency coordinator (*Notfallkoordinator or Noko)* communicates with the emergency services and manages all emergencies in a specific system (*REM)*, which can be accessed by all parties in the rail system.

The central control room in Vienna (*Verkehrsleitzentrale Wien or VLZ)* was established in 2006. ÖBB-Infrastruktur and Personenverkehr are co-located in the VLZ. The VLZ has two operators of ÖBB-Infrastruktur who monitor the rail traffic on Austria's north-south and east-west corridors. There is also an operator responsible for the management of all information during a crisis and a network coordinator who communicates with the TOCs, both at home and abroad, and informs management. A team of operators from ÖBB-Infrastruktur and Personenverkehr jointly manage both rolling stock and train crew for the whole of ÖBB-personenverkehr. Operators from ÖBB-Personenverkehr monitor the connections between trains and update passenger information on the website.

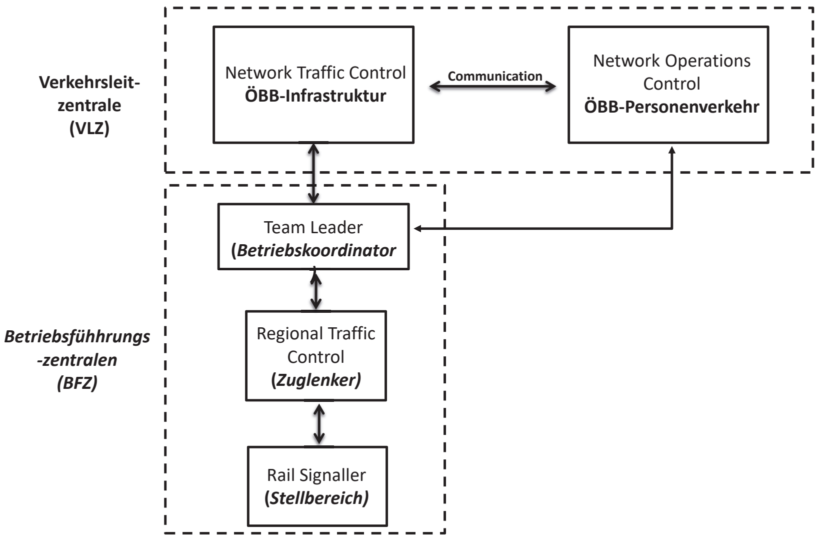


Figure 5.2 Coordination structure in Austria

5.4.3 Germany

National Characteristics

Deutsche Bahn (DB) Netz AG manages 33,295 kilometres of rail lines, the largest network in Europe. Due to Germany's central position in Europe, 6 out of 9 European freight corridors run through this country. Subsequently, rail freight transport volumes are quite high. The busiest sections are the corridors between the North Sea ports (Rotterdam/Antwerp) to the Alpine countries (Swiss, Austria, and Italy), Frankfurt – Hamburg, and the Ruhr area to Berlin and further. DB Netz monitors about 45,000 train runs, consisting of approximately 39,000 passenger trains and almost 5,500 freight trains, on a daily basis. A total of 76.93 billion passenger kilometres are travelled annually. DB Netz is one of the subsidiaries of Deutsche Bahn AG, others being DB Fernverkehr (long distance traffic), DB Regio (local and regional traffic), and DB Cargo. DB Fernverkehr is the almost-exclusive provider of long-distance passenger services. While there is far more competition on the regional and the cargo rail market in particular, DB Regio and Cargo still dominate both markets. Still, there are almost 400 TOCs operating on the German rail network, 360 of which are not part of the DB holding.

Structure and relationships between roles and teams

Railway traffic is managed from seven regional control centres (*Betriebszentrale, BZ)*. However, only a relatively small number of the more than 12,000 signallers nationwide work in the BZs and use computers for setting switches and signals. There are still over 3,400 operational signal boxes from which switches and signals are set: some even use manually operated mechanical levers. A BZ has ten train dispatchers (*Zugdisponent)* on average, who monitor the traffic flows on specific line sections and nodes. They manage conflicts between trains with the help of predefined dispatching rules. During a disruption, they take the first measures to isolate the disrupted area with the help of their traffic management system LeiDis-NK. They also take note of the reasons behind delays and disruptions in the traffic management system.

In addition, there are two or three regional traffic controllers (*Bereichsdisponent)* who oversee the work of the Zugdisponenten from a different control room. The Bereichsdisponent manages requests and complaints from TOCs, for example regarding connecting services. They also manage disruptions in consultation with the TOCs. The *Netzkoordinator* supervises all activities of the BZ. During large-scale disruptions, the coordinator communicates with the TOCs and neighbouring control centres. He or she also has the final say if there is a conflict of interest, or resources of the TOCs might be needed to solve the disruption. An emergency manager (*Notfallmanager*) manages incidents and communicates with the emergency services.

In 1997, a national control room (*Netleitzentrale or NLZ)* was established in Frankfurt am Main. Here, three to four operators (*Bereichskoordinator)* monitor long-distance and international rail traffic along the main corridors. Each Bereichskoordinator is responsible for two or more BZs. Together they monitor around 800 passenger trains and 1,200 freight trains per day. In addition, they coordinate with the traffic control in neighbouring countries. The NLZ also has a coordinator (*Netzkoordinator)*. The Netzkoordinator mainly has a supervisory role during extreme disruptions and severe weather conditions. The coordinator in the NLZ has the final say in the event of a disagreement between actors on a national level. During normal operations the Netzkoordinator is mainly occupied with monitoring the entire rail network and writing daily reports for senior management.

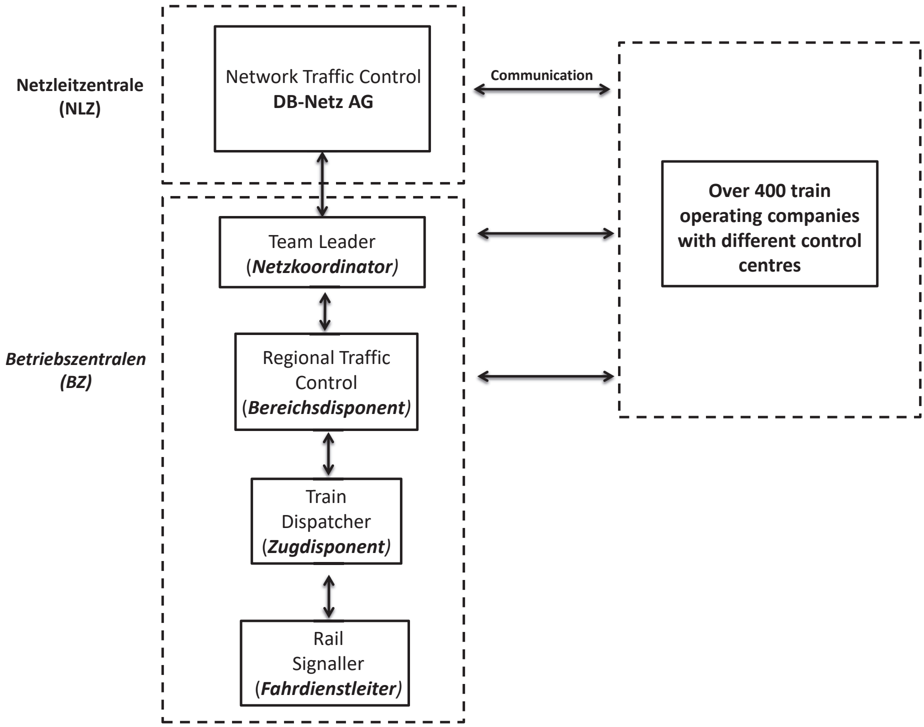


Figure 5.3 Coordination structure in Germany

5.4.4 The Netherlands

National Characteristics

The Dutch railway network measures more than 3,000 kilometres in length, often with double or quadruple tracks, and is mostly electrified. The network is dense around the four largest cities in the west of the country (Amsterdam, Rotterdam, The Hague, and Utrecht), with Utrecht being the most important node in the railway network. The main network is exclusively served by Netherlands Railways (*Nederlandse Spoorwegen or NS*). Some regional or secondary lines are operated by various smaller TOCs. The Dutch rail network is one of the busiest rail networks in Europe (per kilometre of rail track), with almost 5,500 passenger train runs per day and a total of 15.31 billion passenger kilometres annually. There is also considerable freight traffic between Germany, Belgium and the ports of Rotterdam and Amsterdam, although overall freight traffic is relatively low. The network is managed by the state-owned RIM ProRail.

Structure and relationships between roles and teams

Rail traffic is managed from 13 regional traffic control centres (*Verkeersleidingspost)*. Each centre has one or two regional traffic controllers (*Decentale verkeersleider, DVL)* who optimize the traffic flows in their control area and process orders from the TOCs. There are also several train dispatchers (*Treindienstleiders, TDL)*, whose main responsibility is the safe allocation of rail capacity on specific sections (nodes) assigned to them. All switches and signals are operated using computer-based control. In addition, train dispatchers reschedule the rail traffic in their own control areas (mostly around large stations). The latter task is delegated to the DVL. A team leader monitors the crew's workload. NS also has five regional control centres (*Regionale Bijsturingscentra)* to manage its train crew and rolling stock. These control centres more of less mirror those of ProRail. This means that there are two operators to monitor traffic flows (they communicate with the DVL), node coordinators to arrange the shunting of trains and manage train crew at the major train stations (they communicate with the train dispatcher), and a shift leader (who communicates with the team leader). There are also several operators tasked with the management of rolling stock and train crew.

The central Operational Control Centre Rail (OCCR) was established in 2010. The OCCR houses all parties involved in the rail operations under one roof to improve collaboration and communication. Consequently, a wide range of specialized teams can be found in the OCCR, including ICT, asset management, maintenance contractors, and a freight operator. All TOCs have been invited to take up workstations, but NS is the only passenger TOC active in the OCCR. Back-office functions have also been centralized. Back-office employees collect all information on disruptions and malfunctions in a specific system, alarm emergency services and contractors, and provide updates on the management of the disruptions. Each team in the OCCR is represented by a *director (regisseur)*. These directors meet at the beginning and end of every shift at meetings chaired by a coordinator (*Landelijk Coordinator Rail)*. During a major disruption the directors will often come together to provide each other with updates and to make joint decisions.

Operators of ProRail's traffic management and NS's operations management in the OCCR monitor rail traffic on a national level and coordinate the activities of the regional control centres. Two operators from ProRail monitor the rail traffic on the main corridors and communicate with the regional traffic controllers (*DVL)*. The director of the national traffic control communicates directly with the team leaders of the regional control centres. Their NS counterparts monitor the traffic and rolling stock on a national level to optimize punctuality and the distribution of rolling stock over the regions.

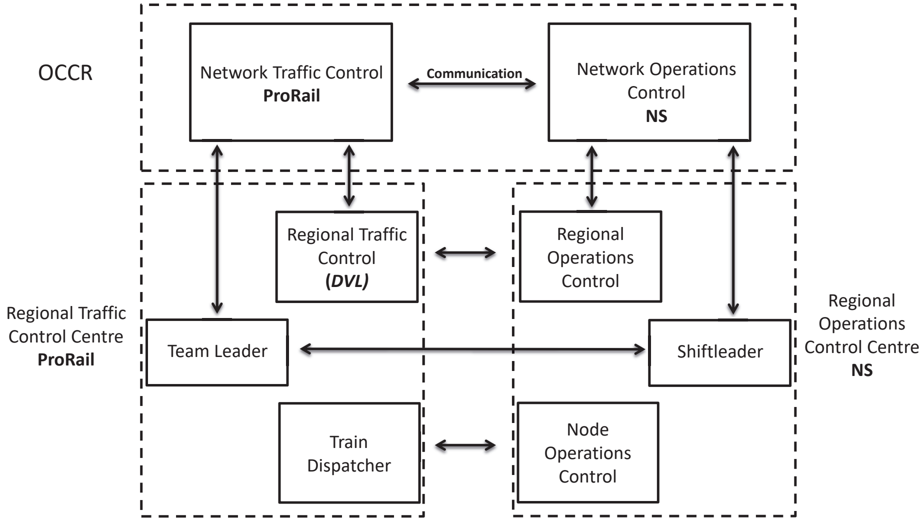


Figure 5.4 Coordination structure in the Netherlands

5.4.5 Belgium

National Characteristics

The Belgian network measures around 3,600 kilometres. Most of the network is electrified and around two-thirds feature double or more tracks. The network is particularly dense in the Flemish part of the country, marked by the cities of Brussels, Antwerp, Ghent and Leuven. Brussels forms an important, but fragile, node in the north-south and east-west corridors. The infrastructure is managed by the state-owned autonomous company Infrabel. In 2014 Infrabel was separated from the sole provider of passenger services, the state-owned autonomous company NMBS (*or SNBC in French)*. There is more competition in the freight sector, with around 11 freight operating companies. NMBS operates around 4160 train runs per day, which adds up to a total of 10.4 billion kilometres per year.

Structure and relationships between roles and teams

Belgium has around 91 signal boxes. This number has been reduced significantly over the years with the introduction of new traffic control systems, which should result in centralizing of control to initially 31 and later 10 regional control centres. Operators in the signal boxes monitor rail traffic at three different control levels. At the lowest level signallers (*operatoren)* operate the switches and signals and set the route of a train. The next rung in the hierarchy is occupied by the traffic controllers (*toezichtbedienden)* who monitor the work of the signallers and are responsible for the safe allocation of rail capacity. At the highest level, there is one operator (*regelaar),* who is in charge of the entire team and operations in the area monitored by the local control centre. The specific task of the local control centres is the safe allocation of rail capacity.

Rail traffic management is conducted by operators in the national control centre (*Railway Operations Center or ROC)*. They decide on the rescheduling of trains in the event of delays, disturbances or disruptions. The local control centres have to implement these decisions. In the ROC Infrabel and NMBS work very closely together. The country has been divided into four regions, each of which has been assigned a team, composed of operators from Infrabel and NMBS who manage the rail traffic. Belgium has a language divide between the Dutch and the French speaking regions. Consequently, the ROC has been divided in French and Dutch speaking teams, even though operators are supposed to speak both languages. The high-speed lines to France, Germany and the Netherlands are managed by a separate team. The regions themselves are also subdivided into two or three sections containing several rail lines. Regional traffic controllers of Infrabel (*Lijnregelaars)* monitor the rail traffic on one or more rail lines. To manage the rail traffic, the regional traffic controllers need to be in close contact with the local control centres. Interestingly however, the Lijnregelaars can also directly communicate with train drivers and even place an emergency call. This makes it possible for the Lijnregelaars to immediately intervene in the rail traffic. Besides the regional traffic controllers, there are two operators of NMBS, in each team, who monitor their own passenger trains.

With NMBS and Infrabel operators being part of one co-located team it is very easy for them to discuss matters face-to-face. Although there is a lot of flexibility *within* the teams in terms of roles and providing each other with back-up, interaction *between* the teams appears limited. Each team clearly functions as a separate entity, supervised by a team leader from both Infrabel and NMBS. A Traffic Officer and General Supervisor coordinate the activities of the four teams and monitor their workload. During normal operations they are responsible for collecting information on regular delays and writing management reports. Positioned in the middle of the control room are NMBS operators, who manage all the rolling stock and train crew and provide technical support to the train drivers. Overall, much communication is conducted by phone. An advanced notification system is currently being developed to reduce oral communication.

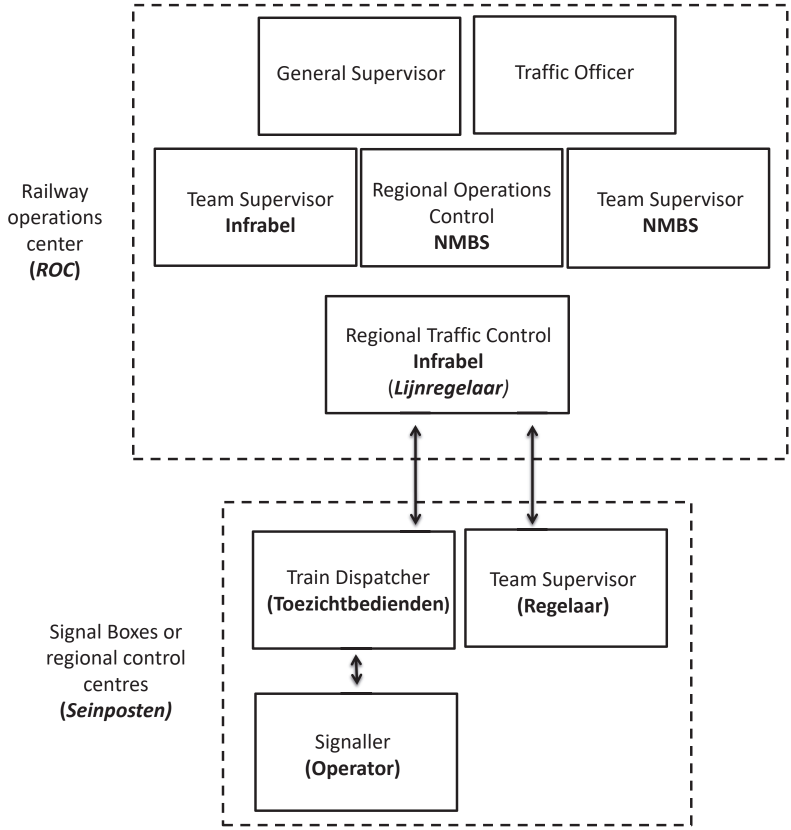


Figure 5.5 Coordination structure in Belgium

5.5 SIMILARITIES AND DIFFERENCES BETWEEN DISRUPTION MANAGEMENT PRACTICES

Having discussed team roles and responsibilities, we will now turn our attention to actual disruption management practices. The two trade-offs identified in the introduction are used to characterize and categorize the countries: centralization versus decentralization, and anticipation versus resilience. The items from Table 5.1 structure the observations.

5.5.1 Rail traffic control: centralized or decentralized?

Distribution of control centres

The overview in Section 5.4 revealed some major differences in the centralization of traffic control. Although all rail systems show an increased automatization and centralization of traffic control, the Dutch railway system is the only one to have fully replaced its signal boxes with modern regional control centres equipped with computerized control systems. In the other countries signalling is still controlled using a mix of mechanical lever frames, control panels and computers. Hence, Austria, Belgium, and Germany feature a decentralized network of signal boxes. The Dutch rail system is also an outlier with regard to the decentralized management of train crew and rolling stock by the main TOC. In Denmark, Belgium, and Austria the main TOCs have mostly integrated these processes in national control centres. In Germany there are numerous control centres from which the many different TOCs manage their operations. For instance, Deutsche Bahn has control rooms for local rail traffic (*Transportleitung Personenverkehrs*) and long-distance traffic (*Verkehrsleitung Fernverkehr*). Not all of these control rooms have been integrated in the Betriebszentrale of DB Netz.

Allocation of decision rights during disruption

In the Netherlands, Denmark, and Belgium decision-making during a disruption is done in the national control centres. Hence, no matter what impact a disruption has, the national control centre will decide on an alternative service plan. In Belgium and Denmark this alternative service plan is mostly the result of joint decision-making by the TOC and IM, whereas in Belgium, decisions are made within each of the four teams. In the Netherlands consultation between the RIM and TOC is also important, but the TOC will decide on the alternative service plan within the boundaries set by the RIM. In Germany, decision making is decentralized, with the Betriebszentralen making most decisions on rescheduling rail traffic. The Netzleitzentrale's role is to coordinate the decisions made by the different Betriebszentralen with regard to long-distance traffic. As such, their involvement in the management of a disruption depends on the situation but is usually restrained. The authority to make decisions during disruptions in Austria is divided between local traffic (*BFZ*) and long-distance traffic (*Verkehrsleitzentrale*). The BFZ manages the disruptions in their own region, in consultation with the TOCs, and only has to consult with the Verkehrsleitzentrale over long-distance traffic.

Autonomy of local control centres

There are also differences regarding the distribution of authority and the division of responsibilities between the different layers of control. In Belgium signal boxes are specifically there to guarantee safe allocation of rail capacity. Decisions on rescheduling rail traffic are exclusively made by the operators in the ROC. This strict separation of responsibilities between both layers of control seems to work quite well and the hierarchical structure appeared undisputed. In the Netherlands and Denmark, local traffic controllers are tasked with the optimization of rail traffic in their own area of control, while national operators monitor rail traffic on the main corridors. However, consultation with the national operators is mandatory if rescheduling decisions taken by the regional traffic controllers affect multiple regions. In the Netherlands we noticed that it is not always clear to operators at what point a local issue becomes a super-regional problem, resulting in ambiguity concerning when and how national operators should intervene in local operations (see chapter 4).

The Austrians also used to experience a diffuse separation of roles and responsibilities between local and national control centres, which often led to conflicts between the BFZ and the VLZ. Subsequently, the VLZ was made solely responsible for the management of long-distance and international services. The BFZ have to consult with the VLZ when rescheduling long-distance trains. The BZ in Germany have considerable autonomy within their own region. The NLZ monitors the actions of the BZ and only intervenes during major disruptions, when long-distance traffic in multiple regions is affected. In practice, we observed that intuition also plays an important role in Germany with regard to the decision to intervene in local operations and therefore there are no strict boundaries.

Structure and lines of communication

The communication structure of the different countries can be traced in Figures 5.1 to 5.5. The distinct structure of the Dutch system stands out because of its density. In the Netherlands, both the RIM and the main TOC have several local control centres that interact directly with each other. Moreover, there are also many direct connections between operators in these different control centres. This has produced a denser and more complex communication network in contrast to the other countries. Although a dense network facilitates the swift dissemination of information, it also means less control over information flows and more coordination costs (Schipper et al., 2015). In the other countries we noticed a much more centralized communication structure in which team leaders communicated with the national control centres, and vice versa. Of course, the co-location of the RIM and main TOC in Belgium, Denmark, and Austria also greatly reduces the communication burden. In Germany, communication with the numerous TOCs forms a major challenge. In all of the countries except Belgium, ICT facilitates the distribution of information to the TOCs and national control centres. For instance, the traffic controllers in the VLZ receive most information about disruptions from the traffic management system and the railway emergency management system. On the basis of this information they decide whether to intervene in the long-distance traffic or to leave the management of the disruption to the BFZ. This is less of an issue in Belgium because the ROC performs a somewhat different role than national control centres elsewhere.

Co-location of RIM and TOCs

The extent of competition and, subsequently, the unbundling of infrastructure management and rail operations varies significantly between the countries. The Netherlands, Denmark, and recently Belgium implemented a more or less complete unbundling of infrastructure management and train service operations, while this is less the case in Germany and Austria, where the RIM and the main TOC are part of the same holding. However, there is far more competition on the German rail network than in the other countries. The fragmentation of train operating services has an important influence on the relationship between the RIM and TOCs in the disruption management process. In Germany we found that although some TOCs (mostly regional branches of DB) are co-located in the BZs, most of them have opted to use their own control centres. In the other countries, where there is less competition even though legal unbundling is more predominant, we still see a very strong relationship between the RIM and the historically dominant TOC. In all these countries the RIM and TOC are co-located in the national control centre. Integration is strongest in Belgium where the teams consist of operators from both Infrabel and NMBS. Here, co-location facilitates joint decision-making through face-to-face communication. In Germany we noticed a stricter separation between the processes of DB Netz and the TOCs. Standardized text messages are sent via e-mail or text message (*Strecken.info*) in order to quickly notify all TOCs of a disruption (planned and unplanned) so that they can adjust their operations. TOCs can also make use of DB Netz's traffic management system, which gives them a real-time overview of their own trains and potential delays. However, they are unable to monitor services operated by other TOCs because DB Netz wants to avoid potential discussions about unfair treatment.

5.5.2 Disruption management: anticipation or resilience?

Role of contingency plans

The Dutch railway system relies strongly on predefined contingency plans (*Versperringsmaatregel*). Numerous alternative service plans have been developed by ProRail and NS for almost all kinds of disruptions, on all lines. A quick implementation of a contingency plan should prevent a propagation of the disruption and facilitate coordination between the different control centres. Accordingly, trains are not rerouted, with the exception of international and cargo trains. Instead, passengers are advised to use an alternative route or alternative transport (busses). This reliance on contingency plans is not without its difficulties. In practice, defining, checking, and implementing a contingency plan requires considerable communication between the different control centres. In addition, small deviations or changes in the operational environment might make these static plans infeasible, which in practice necessitates a real-time adjustment of plans. In Austria contingency plans have been developed for the most common disruptions. Although these contingency plans are detailed and numerous, they mainly serve as a template for the operators managing the disruption. Hence, on-the-spot decision making is still dominant and the final solution depends on the specific circumstances. In other words, there appears to be more operational flexibility in Austria than in the Netherlands.

In the other countries we noticed that the use of contingency plans is much less common or almost non-existent. For example, in Denmark there are around 30 predefined contingency plans, but these plans are often revised. During disruptions, operators of Banedanmark and DSB gather in an emergency room in the DCDK to decide on an alternative plan on-the-spot. This makes the disruption management process in Denmark more flexible, but also very dependent on the team of operators in charge. We also observed that most of these ad-hoc plans are not recorded for later use, so the solution is often lost after the disruption is solved. Another issue concerns the fact that both parties have to reach consensus in the heat of the moment. Similarly, in Belgium operators stressed the unique characteristics of every disruption and therefore the need for improvisation. During our observations we were struck by the fluidity of the teams and the amount of implicit coordination, i.e. their actions seemed coordinated despite relatively limited communication and the absence of a predefined plan. In Germany contingency plans have been developed with the TOCs for the main lines, but not for the entire network. These plans also mainly serve as a template. For instance, it is a common practice to reroute long-distance trains during disruptions, which is something the large and dense network allows for (many stations can be reached through various routes). These alternative routes are not part of a predefined plan, but the operators rely on their extensive knowledge of the rail network and creativity to reroute trains in consultation with the TOCs.

Automation of control

The countries in this study show a mix of automation and manual routing. For example, while the Netherlands is the only country with full computer based control and automatic route setting, regional traffic controllers have to rely on their experience to detect conflicts between trains and to find solutions. Nevertheless, while some countries still partly rely on mechanic lever frames, we noticed that all the countries are working on automation and centralizing their traffic control. For example, Denmark is the first European country planning to deploy ERTMS 2 for both train-track communication and the back office. The new signalling should make it possible to manage rail traffic from two control centres. Similarly, Austria is fully replacing older technologies for computer-based signalling and traffic control on its main lines. ÖBB's Aramis traffic management system features automatic route setting, conflict detection, and decision support during rescheduling. Similarly, Infrabel and DB Netz have bought the Swiss Rail Control System to manage its rail traffic. This system offers conflict detection and simulates possible solutions. Such systems have a huge impact on traffic management as work routinely performed by operators becomes automated, making it possible for operators to monitor larger areas and reducing the number of operators needed. Moreover, these systems also support operators to act more proactive and let them focus on solving disruptions. There are however also risks associated with automation. Modern traffic management systems often feature more possibilities than human operators can comprehend. In addition, operators may become fixated by computer screens and lose the detailed knowledge and experience of the traffic management processes that comes through manual control.

Institutionalization of shared sensemaking

A coordinated response to a disruption requires the exchange of appropriate information between the different control centres. However, simply sharing information is not enough to create this shared understanding. Operators need to combine their expertise and collectively make sense of the information. In the Netherlands, Germany, Denmark, and Austria shared sensemaking is facilitated in the form of special crisis rooms in the national control centres where the operators of the RIM and TOC gather to discuss the situation and make joint decisions. In Denmark this is done during every disruption, while the crisis rooms in the Netherlands, Germany, and Austria are only used during severe disruptions, like those caused by extreme weather conditions. In the Netherlands we also often observed that operators of ProRail and NS would arrange ad-hoc meetings at a cabinet in the control room.

In Belgium face-to-face communication between the RIM and TOC is straightforward because operators cooperate in teams. Nevertheless, we observed that operators often did not take a time-out to discuss ongoing activities and plans in a quick meeting. Most, if not all, discussions took place on the work floor. In Germany, face-to-face meetings between RIM and TOCs is extremely difficult because of the size and complexity of the network and the many TOCs working from different locations. Information exchanges have therefore become more and more standardized and shared sensemaking has to be done by phone. In all countries, shared sensemaking between national and regional control centres remains difficult due to the physical distances, as well as time lag and only incomplete information being available at various locations.

Use of dispatching rules

In Germany, rail traffic management is guided by predefined goals and rules. In the event of a disruption DB Netz's dispatching guidelines prescribe a maximum usage of the remaining capacity, the need to improve joint punctuality of all trains, and the task of quickly rescheduling in order to operate according to an alternative plan. This rescheduling is done on the basis of dispatching rules that give priority to emergency vehicles, trains with express routes, and fast-speed over slow-speed trains. TOCs can purchase an express (priority) status for their passenger and cargo trains to assure a swift and direct journey during disruptions. The dispatching rules should secure non-discriminatory access to the German rail network and provide a framework for the dispatchers. However, one of the issues with the use of dispatching rules is that delayed express or fast-speed trains will overtake slower but punctual trains. This can severely disrupt local rail traffic. A similar dispatching rule is in use in Austria. It prioritizes long-distance trains over all other trains (apart from emergency vehicles) to assure conflict-free management of rail traffic by the BFZ. It is, however, possible for the BFZ to deviate from these rules if this benefits local traffic flows, but only in consultation with the traffic controllers in the VLZ. For instance, the third dispatching rule dictates that punctual trains (-5 to +10 minutes) should remain punctual. In practice, we observed that in both instances there is quite some pressure to prioritize long-distance and express trains, even if that means delaying local traffic.

In the Netherlands, train dispatchers have a document with dispatching rules (*Trein Afhandelings Document or TAD)* for the most common situations, which have been developed jointly with NS. TADs tell the train dispatcher how long a train can wait for a connecting train and where to short-turn a train. They also provide resolution rules if there is a conflict between trains. However, not every conflict situation is covered in the TAD. Consequently, train dispatching still relies heavily on the skill and experience of the train dispatchers to decide on the right order. ProRail does not make a distinction between trains, but trains running on time are given priority over delayed trains. The same goes for Denmark, where Banedanmark decides on the priority of trains and experience plays an important role in the decision on the order of priority. Finally, in Belgium a total of fifteen dispatching rules give fast-speed trains priority over slow trains, international or intercity services priority over local traffic, and most passenger services priority over freight traffic. However, operators are allowed to deviate from these rules if doing so would help to swiftly restore services. During our observations, a bomb threat at Brussels North had blocked all traffic in the Brussels region. We observed how international trains were the first to be dispatched, followed by regional and local trains. The order of dispatching local trains, however, seemed to be based on pragmatism.

5.6 SYNTHESIS

The previous section described the practices of disruption management in the countries studied with regard to the two main trade-offs. As a final step, we will show how the countries dealt with the trade-offs. To this end, we assigned scores to each item on a scale from 1 (strongly centralized; reliance on anticipation) to 5 (strongly decentralized; reliance on resilience) on the basis of the data. The resulting scores are shown in Table 5.4.

Table 5.4 demonstrates that while countries can differ significantly on individual items, they can also show quite some similarities in how they deal with both trade-offs. This is an expression of the trade-offs: there is no one best solution. Institutions, existing routines on the basis of ‘how things are done here’, the relationship between RIM and TOCs, and the ongoing introduction of new technologies mean that the trade-offs are made in a certain direction, while not necessarily providing the ‘best’ way of doing things. This, of course, is the nature of a trade-off.

Table 5.4 Scores per country (all individual items were given equal weight; the aggregated scores are averages).

	Countries				
Item	**Austria**	**Belgium**	**Denmark**	**Germany**	**Netherlands**
Centralized or decentralized					
Distribution of control centres	3	5	1	4	2
Allocation of decision rights during disruption	3	2	1	4	1
Autonomy of local control centres	3	1	4	5	4
Structure and lines of communication	2	3	1	4	5
Co-location of RIM and TOCs	2	1	2	5	2
Average score	**2.6**	**2.4**	**1.8**	**4.4**	**2.8**
Anticipation or resilience					
Role of contingency plans	2	5	4	3	1
Automation of control	1	4	2	3	2
Institutionalization of shared sensemaking	2	3	1	3	1
Use of dispatching rules	2	2	5	1	3
Average score	**1.75**	**3.75**	**3**	**2.50**	**1.75**

Figure 5.6 visualizes how the five countries relate to each other with regard to the trade-offs. Note that this figure is purely illustrative and does not imply precise measurement. Two clusters can be discerned. 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 dealing with disruptions. As has been mentioned before, while formalization reduces the coordination burden and produces more predictable outcomes, it may also reduce a system's ability to adapt to unanticipated events. Belgium and Denmark form the second cluster as they are relatively similar. Belgium and especially Denmark combine a centralized structure with an emphasis on resilience. Indeed, operators seemed to enjoy more flexibility in the management of disruptions as compared to the Netherlands. Germany appears a bit of an outlier. It is much more decentralized than the other countries. This is very likely to be an expression of the size and complexity of the network along with the large number of TOCs as this reduces the possibilities for centralized control.

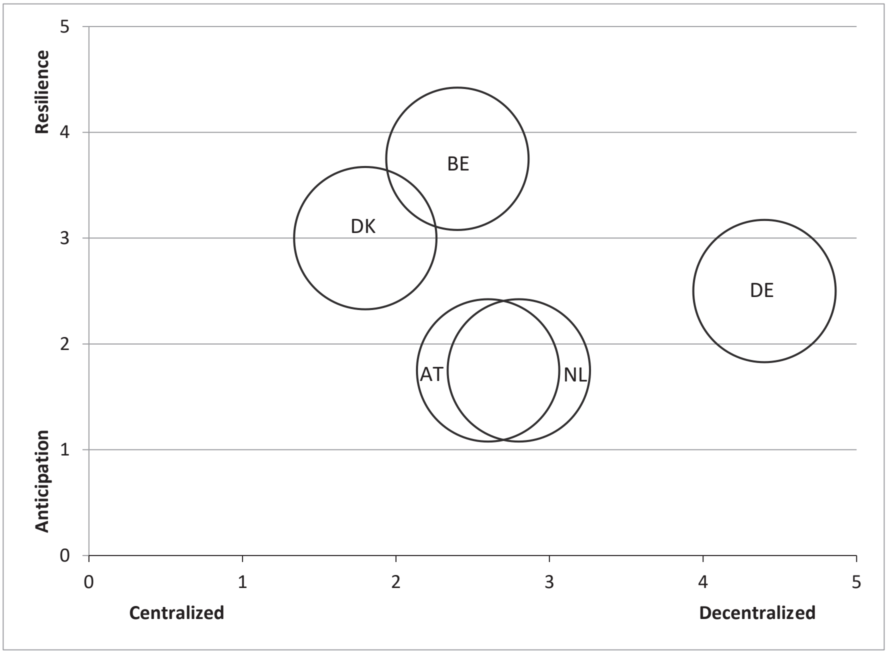
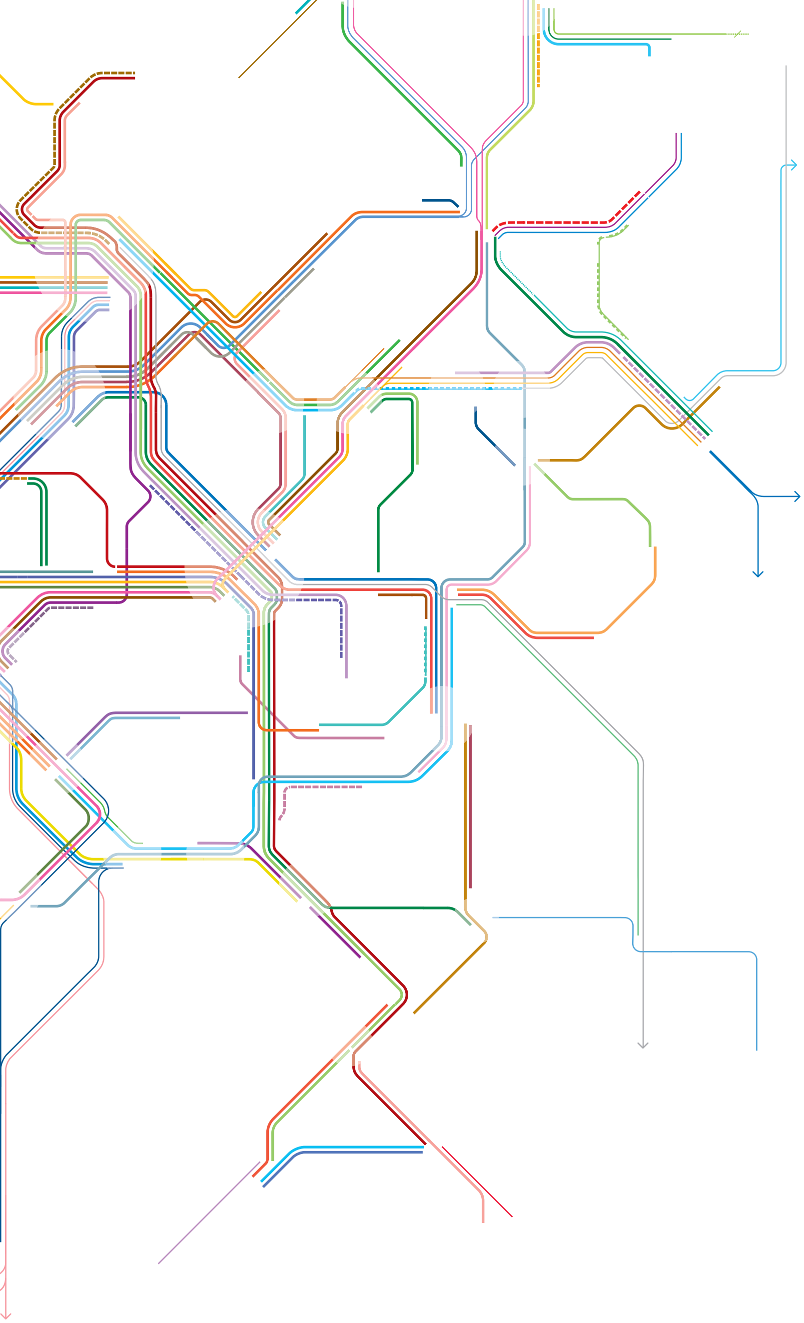


Figure 5.6 Visualization of how countries perform on both trade-offs

5.7 CONCLUSIONS

We described and categorized disruption management structures and practices in Belgium, Germany, Austria, Denmark and the Netherlands. On the basis of interviews and observations, we showed the various ways in which these countries deal with the main trade-offs between centralization & decentralization, and between anticipation & resilience. We then related the countries on the basis of these two trade-offs. We found clusters of countries, which suggests that differences on individual items can still lead to an overall similarity. Austria and the Netherlands can be characterized as moderately centralized and relying on an anticipatory approach, while Belgium and Denmark are more centralized and put more emphasis on resilience, i.e. the freedom to rely on the operator's ingenuity to solve disruptions. Germany proved to be far more decentralized than the other countries, which seems to be in line with the size and complexity of its system.

This research, with its focus on everyday practices in international perspective, is a first. Naturally, more research would be welcome. The sample could be extended and there is a clear need for a more empirical grounding of the items used. Nevertheless, we think that the current results could help rail infrastructure managers and train operating companies to reflect on their own practices and to learn from others. A goal, still far away, would be to relate the trade-offs to performance and resilience of the systems. This goal requires considerable caution. Both the complexities of the systems and their mutual differences are so immense that making a straightforward link to performance would require a leap of faith. A focus on practices is in itself complex because it takes a good command of several languages and a great deal of time before one starts to understand what operators do and how this differs from country to country. Nonetheless, this should be an important strand of research.



CHAPTER 6

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;

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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.

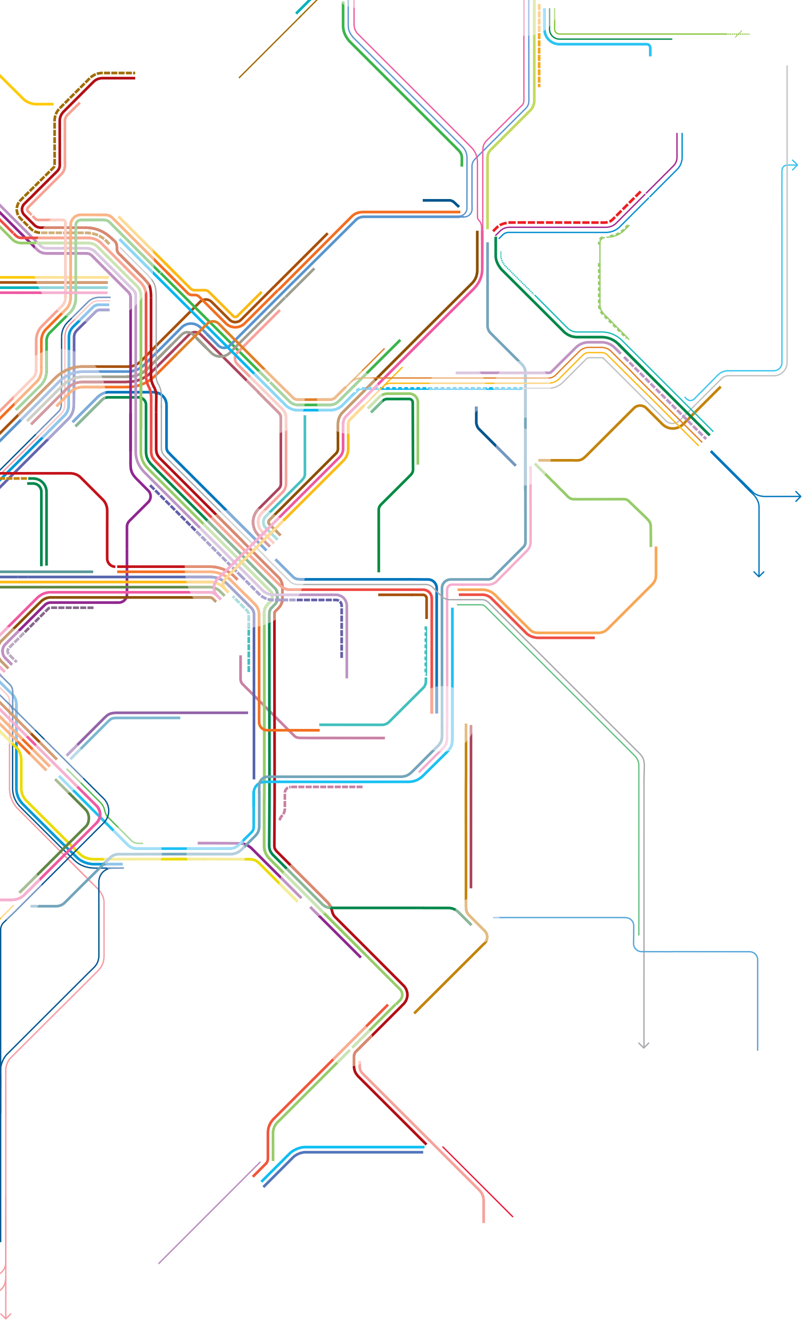
Railway systems are not the only critical infrastructure systems in which control centres are tasked with the reliable provision of services and that are very vulnerable to disruptions. Other such systems include road, electricity and telecommunication networks. Some of these infrastructures have also 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.



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Appendix

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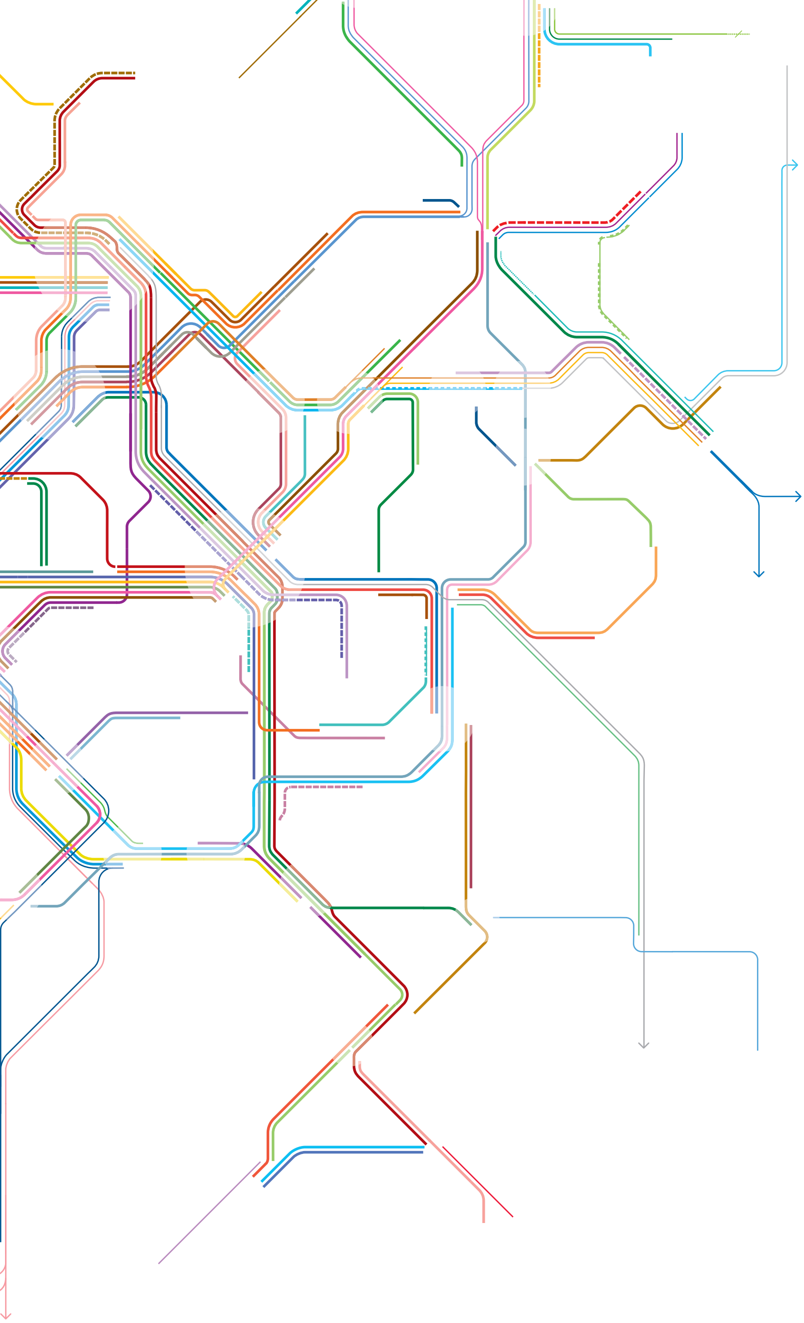
APPENDIX

List of abbreviations used for actors in network

Abbreviation	Full name or function
NTC	Network Traffic Control
NOC	Network Operations Control
RTC	Regional Traffic Control
ROC	Regional Operations Control
AL	Incident Manager
SMC	Department of ProRail which monitors the power of the catenaries
Stoco	Disruption coordinator
PLP	Platform supervisor
PCL	Process Leader
RET Mcn	Shunter
LRI	Network travel informant
RI	Regional travel informant
NSRI	Informant for train crew



Summary in English
Summary in Dutch

SUMMARY

Introduction to the research

Railway disruptions can cause substantial deviations from planned operations. Railway controllers of ProRail and NS, who work in different control centres spread across the Netherlands, are tasked with rescheduling plans to contain and minimize the impact of disruptions. While in most cases these operators are able to adequately manage disruptions, there have been instances in which there was relatively little or no rail traffic in large parts of the country. To contain these major disruptions the control centres have to work closely together and share a great deal of information. In practice, however, situations during a disruption often changed faster than the parties could communicate and the decentralized network of control made it difficult to manage disruptions with a national impact.

ProRail and NS therefore decided to develop a joint control centre: the Operational Control Centre Rail (OCCR). In the OCCR, ProRail and NS monitor railway traffic at a national level and can intervene in regional operations when necessary. Despite the establishment of the OCCR there have been several large-scale disruptions in the last couple of years during which the different control centres were unaware of what was going on and what should be done. As a result, control centres were often working at cross-purposes. The introduction of the OCCR as a boundary-spanning platform for the rail sector thus did not solve the coordination issues in the Dutch rail system. In fact, one could say that it might have even made things more complicated by introducing another layer on top of the already complex network of control centres. The overall aim of this thesis is therefore to gain a better understanding of the coordination and communication challenges *between* the different control centres during the management of large-scale, complex disruptions. The main research question is as follows:

What explains the coordination breakdowns between the control centres in the Dutch railway system during the management of large-scale, complex disruptions?”

Theoretical relevance

In recent decades there has been a growing interest among organizational scholars in the conditions that influence organizations’ ability to reliably manage large-scale, complex socio-technical systems under a variety of dynamic conditions (cf. Hollnagel et al., 2011; La Porte, 1996; Perrow, 1984; Weick & Sutcliffe, 2007). Many studies address the limitations of traditional hierarchical systems in effectively coping within complex, ambiguous and unstable task environments. The core assets of these systems standardization, formalization and hierarchy severely limit the flexibility needed to operate in these environments. Within the literature two important trade-offs can be identified in the reliable management of these systems: a) decentralization versus centralization and b) anticipation versus resilience. Highly centralized authority structures are needed to facilitate coordinated decision making, but at the same time decentralized decision-making is necessary to quickly respond to surprising events. Similarly, anticipating disruptions and developing plans and procedures help to reduce the coordination costs during the management of disruptions. At the same time, there is a competing need for mutual adjustment and improvisation to respond to non-anticipated situations.

Organizations operating in a dynamic and complex environment thus paradoxically emphasize both formal and improvised forms of coordination (Faraj & Xiao, 2006). Operators working in control centres are confronted by these trade-offs on a daily basis. They have to decide between following design principles and relying on improvisation, and between hierarchical and on-the-spot decision making. Most research has focused on these coordination and adaptation challenges in complex, dynamic and time-pressured environments from the point of view of co-located teams. In this thesis, however, we focus on a multiteam system (MTS): a network of control centres, separated by geographical and organizational boundaries. We therefore looked at the role of both trade-offs from a multiteam perspective.

Research design and methods

In this research the focus is on how the teams in the Dutch railway system work together and adapt to changes during the management of actual large-scale, complex disruptions. Studying disruption management in practice poses certain methodological challenges, especially when it comes to collecting data. Not only is it difficult to predict when a disruption will occur, but as a researcher it is also impossible to be present at more than one place at a time. In our research, recordings of telephone conversations between operators during the management of disruptions were a very valuable data source. These recordings were supplemented by observations, interviews, and document analysis. The available data was analysed quantitatively using Dynamic Network Analysis (study 1), used in a mixed-methods approach (study 2), and for a qualitative analysis (study 3). For the fourth study we collected data during five site visits to control centres in five different countries. Each site visit lasted two to three full days each. During those site visits we observed operators in the control rooms and conducted forty-nine interviews.

Study results

In chapter 2, we introduced Dynamic Network Analysis (DNA) as a valuable tool to study disruption management. Control centres must share up-to-date information in order to be able to quickly respond to disruptions and to align their activities. A good understanding of the structure of the network of actors involved in the disruption management process and the flows 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 explored the use of DNA on a simulated case of a catenary failure to capture the dynamics of the disruption management process. First of all, the DNA showed 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, DNA revealed the central role of the train dispatchers and regional traffic controllers during the first phase of the disruption management process. Thirdly, the DNA also showed 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. 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. 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.

In the *third chapter* we presented an in-depth case study of how a coordination breakdown between the 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 this coordination breakdown and the decision to stop the train service from the perspective of the system as a whole by looking at the complex interactions between teams. That's why we used a mixed-methods approach to study both the flows of information between teams, and the way this information is (collectively) interpreted. In this mixed-methods approach we combined Dynamic Network Analysis with theories of sensemaking. The results showed that the involved teams were unable to create a shared understanding of the situation. These different understandings of the situation accumulated over time, leading to inconsistent actions, incorrect assumptions, a lack of effective communication, and increasing uncertainty. This study also highlighted the risk of blind spots that are the result of a commitment to taken-for-granted frames. In the study we showed how these blind spots caused actors to miss important signals that they weren't dealing with a routine situation. As a result, they were unable to repair the coordination breakdown between the teams in time, leading to the decision to stop the train service as a safety measure.

In *chapter four* we examined the role of the teams in the OCCR in preventing the rail system from falling into the three basic patterns of adaptive failure: 1) decompensation, 2) working at cross-purposes, and 3) outdated behaviours. These patterns of adaptive failure can eventually lead to a system break-down and thus need to be avoided or recognized and escaped from. Effective leadership is assumed to have an important positive influence on inter-team coordination and the overall adaptiveness of systems. The leadership behaviours of the teams in the OCCR were therefore analyzed using the literature on MTS-leadership. While multiteam system literature stresses the importance of leader teams, 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 regional operators in order to detect a need for back-up, and how it should be provided. Secondly, regional operators often didn't ask for help, or even refused the help 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. This made it difficult to orchestrate the activities of the regional control centres. Finally, we noticed a tension between the dynamics and complexity of the disruption and the wish to quickly implement a predefined contingency plan.

In the final empirical study, discussed in *Chapter 5,* an international comparison of disruption management is made. A thorough literature search showed that there was no comparative research into disruption management. In this study we therefore explored the structures and practices of railway disruption management in five European railway systems. The comparison focused on the trade-offs described earlier, that of a) centralization versus decentralization, and b) anticipation versus resilience. To compare the countries we derived several items from the literature for each trade-off. We assigned scores to each of the items on the basis of our observations and interviews. We then took the average scores of all items to show how the countries compared on both trade-offs. This resulted in two clusters of countries. The first cluster consists of Austria and the Netherlands. They 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 was 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, and was therefore not part of either cluster. The results show there is not one best way to organize rail disruption management.

Conclusions

In the final chapter we built on the findings of the four empirical studies and answered the main research question of this thesis. We conclude that creating and maintaining a compatible understanding of the operational environment during large-scale, complex disruptions is very difficult. 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. Creating and maintaining a shared situation awareness is not only difficult because of the challenges of sharing information under pressure, but also because of the complexity and dynamics of the operational environment. Especially during complex disruptions information only slowly becomes available, and at the same time this information can be outdated once it is received. As a result, information is often scattered throughout the system, and teams receive information at different moments in time. Under time pressure operators have to decide between collecting more information or making decisions on the basis of incomplete information. The first option has proven to be difficult, because of the limitations set by the available communication channels. The second option is not without risks. Especially when dealing with nonroutine disruptions there is a chance that decision are made on the basis of inaccurate and conflicting assumptions, resulting in teams working at cross-purposes.

In this dissertation, we have pointed to the importance of collectively making sense of information in order to coordinate activities around a common framing of the situation. Our studies however showed that collective sensemaking between teams is weakly developed. Operators often do not take the time to pose additional questions, or do not feel free to cross-check the information they receive. Moreover, when a situation becomes more ambiguous, operators tend to reduce communication and hide behind their own interpretation of events and the procedures to follow. The latter however does not always have to be on purpose, as the second study has shown. The activation and commitment to a framing of the situation as a routine procedures, caused the teams to miss important cues that were lacking common ground. So, plans and procedures do not only prove to be brittle when dealing with nonroutine situations, but can actually obscure the need to improvise.

The latter also became apparent when looking at the implementation of contingency plans. Our international comparison showed that the Dutch railway system relies the strongest on predefined contingency plans. Although these plans can greatly contribute to reducing coordination costs during the management of disruptions, they prove to be brittle when dealing with nonroutine disruptions. While situation assessment and the implementation of a contingency plan require a relatively stable situation, there are situations where the operational environment can be so complex and dynamic that the understanding of the situation has to be updated continuously. As a result, new rounds of situation assessment, communication and decision making are necessary to revise the plans. In practice, we have seen that predefined contingency plans are implemented on the basis of a simplified assessment of the operational conditions. Without a sufficient plan the risk of local optimization increases and conditions can quickly degrade, as was noticed in the cases. Finally, we can conclude that the coordinating role of the leader teams in the OCCR often remains inadequate. This is not only due to their often degraded situation awareness, but is also caused by a lack of effective teamwork with the regional control centres. There is a lot of ambiguity concerning the division of roles, tasks, and responsibilities between both layers of control. This results in actors often not meeting each other's expectations, impedes information sharing, and may even cause conflicts when roles are deemed to have been violated.

The findings in this dissertation have some important practical implications. During the course of our research ProRail and NS were working on restructuring the disruption management process. This new model should lead to more and better centralized decision making, faster information sharing by means of improved information technology, and the development of better contingency plans. Although the findings in this dissertation underline the importance of these developments when it comes to routine disruptions, at the same time this shift to more anticipation and centralization could also make the system less adaptive to nonroutine disruptions. Our findings show that improved information technology does not substitute the need for improve collective sensemaking between teams, centralized decision making only possible is in close cooperation with the regional control centres and that plans and procedures could actually obscure the need for improvisation.

SUMMARY IN DUTCH

Introductie van het onderzoek

Verstoringen op het spoor kunnen de treindienst flink ontregelen. Verspreid over Nederland zorgen medewerkers van ProRail en NS vanuit verkeersleidingsposten en bijsturingscentra dan ook dat de treindienst snel wordt bijgestuurd in het geval van een verstoring. Snel bijsturen is belangrijk om de impact van een verstoring klein te houden en te voorkomen dat problemen zich verspreiden naar de rest van het spoornetwerk (de zogenoemde olievlekwerking). De meeste verstoringen op het spoor worden adequaat afgehandeld en blijven zodoende beperkt tot een klein gebied. Er zijn echter ook verscheidene grote verstoringen geweest, waarbij in grote delen van het land weinig tot geen treinverkeer mogelijk was. Tijdens deze grote verstoringen moeten de verkeersleidingsposten en bijsturingscentra intensief samenwerken en veel informatie met elkaar delen, zodat processen op elkaar afgestemd worden. In de praktijk bleek echter dat tijdens deze grote verstoringen de onderlinge communicatie trager was dan de dynamiek van de verstoring. Bovendien zorgde het decentrale netwerk van verkeersleidingsposten en bijsturingscentra er voor dat het moeilijk was om grip te krijgen op verstoringen met een landelijke impact.

ProRail en NS hebben daarom een gezamenlijke controlecentrum ontwikkeld,, genaamd het Operationeel Controle Centrum Rail (OCCR). In het OCCR monitoren medewerkers van ProRail en NS onder één dak de treindienst vanuit een landelijk perspectief en kunnen zij, indien nodig, ingrijpen bij de regionale controlecentra. Ondanks de oprichting van het OCCR zijn er in de afgelopen jaren verschillende grote verstoringen geweest waarbij de situatie zo uit de hand liep dat niemand meer een goed overzicht had van de situatie en wist wat er moest gebeuren. Dit zorgde er voor dat de controlecentra elkaar onbewust begonnen tegen te werken en daarmee de situatie zelfs verergerden. De introductie van het OCCR heeft de problemen rond de afstemming tussen de verschillende partijen die betrokken zijn bij de bijsturing van de treindienst tijdens grote verstoringen dus niet volledig op kunnen lossen. Het doel van dit onderzoek is dan ook om beter inzicht te krijgen in belangrijkste uitdagingen op het gebied van coördinatie en communicatie *tussen* de verschillende controlecentra tijdens de afhandeling van grote en complexe verstoringen. De volgende onderzoeksvraag staat daarbij centraal:

Wat verklaart de coördinatieproblemen tussen de controlecentra in het Nederlands spoorsysteem tijdens de afhandeling van grootschalige, complexe verstoringen?

Theoretische relevantie

In de afgelopen decennia is er een toenemende interesse te zien vanuit de organisatiewetenschappen in de wijze waarop grootschalige, complexe socio-technische systemen, zoals het spoor, betrouwbaar kunnen worden gemanaged onder uiteenlopende condities (cf. Hollnagel et al. 2011; La Porte, 1996; Perrow, 1984; Weick & Sutcliffe, 2007). Daarbij gaat het er om dat deze organisaties niet alleen in staat zijn om een betrouwbare dienstverlening te leveren onder stabiele omstandigheden, maar ook geplande en ongeplande incidenten kunnen opvangen zonder dat de controle verloren gaat. In de literatuur wordt er op gewezen dat traditionele hiërarchische organisatiestructuren onvoldoende flexibel zijn om in deze complexe, dynamische en ambigue omgeving betrouwbaar te opereren. In dezelfde literatuur wordt gewezen op het feit dat organisaties belangrijke afwegingen moeten maken die van invloed zijn op de coördinatie en het adaptief vermogen van complexe socio-technische systemen. In dit proefschrift hebben wij ons gericht op de *trade-off* tussen a) centralisatie en decentralisatie en b) anticipatie en veerkracht. Centralisatie is noodzakelijk voor snelle en gecoördineerde besluitvorming bij verstoringen, terwijl decentralisatie van belang is om snel in te kunnen grijpen bij onverwachte situaties. De tweede trade-off is die tussen het van te voren ontwikkelen van plannen en procedures bij de afhandeling van verstoringen (anticipatie) en de noodzaak tot improvisatie bij afwijkende situaties (veerkracht).

Organisaties die in dynamische en complexe omgevingen opereren leggen dus paradoxaal zowel de nadruk op formele als informele vormen van coördinatie (Faraj & Xiao, 2006). Werknemers in de controlecentra moeten dagelijks belangrijke afwegingen maken. Zij worden regelmatig met onverwachte omstandigheden geconfronteerd, waarbij vooraf gedefinieerde procedures en plannen niet altijd voldoen en de betrouwbaarheid van het systeem afhankelijk is van de gezamenlijke betekenisverlening en afstemming. Veel onderzoek naar deze uitdagingen op het gebied van coördinatie en adaptatie richt zich op individuele teams. In dit proefschrift hebben we echter te maken met een multiteam systeem: een netwerk van geografisch en organisatorisch gescheiden controlecentra die gezamenlijk een verstoring moeten afhandelen. Binnen deze context van een multiteam systeem wordt er in dit proefschrift gekeken hoe er met beide trade-offs wordt omgegaan.

Onderzoeksopzet en methoden

In dit onderzoek ligt de focus op hoe meerdere teams hun processen afstemmen tijdens de afhandeling van enkele concrete grootschalige en complexe verstoringen. Het bestuderen van geografisch gescheiden teams ten tijde van een daadwerkelijke verstoring zorgt echter wel voor de nodige methodologische uitdagingen, met name op het gebied van dataverzameling. Verstoringen zijn immers grotendeels niet te voorspellen en je kan als onderzoeker ook maar op één plek tegelijk zijn. In dit onderzoek vormden de opnames van telefoongesprekken tussen teams dan ook een belangrijke databron. De opnames zijn aangevuld met observaties, interviews en document analyses. De verzamelde data is daarna zowel kwantitatief geanalyseerd middels een dynamische netwerk analyse (studie 1), gebruikt in een *mixed-methods* benadering (studie 2) en kwalitatief geanalyseerd (studie 3). Voor de vierde studie hebben wij data verzameld tijdens bezoeken aan controlecentra in vijf verschillende landen die gemiddeld zo'n twee a drie volle dagen duurden. Tijdens deze bezoeken hebben wij medewerkers geobserveerd in de controlecentra en daarnaast 49 interviews afgenomen.

Onderzoeksresultaten

In *hoofdstuk 2* hebben wij Dynamische Netwerk Analyse (DNA) aangedragen als een veelbelovende instrument om verstoringsmanagement te bestuderen. De verschillende controlecentra moeten up-to-date informatie met elkaar blijven delen om snel te kunnen reageren op een verstoring en hun activiteiten op elkaar af te stemmen. Het analyseren van het netwerk van actoren betrokken bij de afhandeling van de verstoring en de informatiestromen tussen hen kan bijdragen aan een verdere optimalisatie van het verstoringsmanagementproces. Sociale Netwerk Analyse is een beproefde methode voor het visualiseren en analyseren van netwerken. Het heeft het echter als nadeel dat het alleen een statische weergave van het netwerk geeft. We hebben daarom een DNA toegepast op een gesimuleerde casus van een bovenleidingbreuk om zo de dynamiek van het verstoringsmanagementproces te visualiseren en analyseren. De DNA heeft ten eerste laten zien dat het creëren van een gedeeld beeld van de situatie en het kiezen en implementeren van een versperringsmaatregel tot een aanzienlijke stroom van informatie tussen de betrokken actoren leidt. Ten tweede kwam naar voren dat tijdens deze eerste fase van de verstoring de treindienstleiders en decentrale verkeersleiders een centrale rol hebben in het netwerk. Ten derde heeft de DNA ook laten zien dat er binnen het netwerk vaak geen directe communicatielijnen zijn tussen actoren en informatie dus via-via doorgegeven moet worden. Deze lange communicatielijnen kunnen echter leiden tot misverstanden en vertragingen in de besluitvorming. Tot slot heeft de inclusie van tijd in de netwerkanalyse zichtbaar gemaakt dat werknemers reeds aan de slag gaan met de afhandeling van een verstoring zonder dat zij volledig op de hoogte zijn van de situatie. De eerste studie heeft dan ook laten zien dat DNA een waardevolle methode is voor het visualiseren en analyseren van het verstoringsmanagementproces en dat om recht te doen aan de dynamiek van het proces de inclusie van tijd essentieel is.

In *hoofdstuk 3* hebben we een casusstudie verricht naar het plotseling staken van het treinverkeer rond twee belangrijke stations in Nederland door een gebrek aan coördinatie tussen verschillende teams in het spoorsysteem. In deze studie onderzochten we wat de reden was voor deze gebrekkige coördinatie en waarom men besloot het treinverkeer plotseling te staken. Uitgangspunt daarbij was dat de keuze om het treinverkeer stil te leggen niet verklaard kan worden door individuele keuzes, maar dat deze gezocht moet worden in de complexe interacties tussen de verschillende teams. Daarom hebben we een mixed-methods benadering gekozen, waarbij we zowel gekeken hebben naar de informatiestromen tussen teams, alsmede de manier waarop deze informatie gezamenlijk geïnterpreteerd werd. Hiervoor hebben wij gebruik gemaakt van DNA en de theorieën over betekenisverlening van ambigue situaties. In de studie werd duidelijk dat de betrokken teams niet in staat waren om tot een gezamenlijk beeld van de situatie te komen, met als gevolg verkeerde aannames, het niet delen van informatie, afwijkend handelen en een toenemende onzekerheid. In het omgaan met deze onzekerheid speelt betekenisverlening door middel van framing een belangrijke rol als een basis voor gecoördineerd handelen. De studie laat echter ook zien dat de activatie van een bepaald frame kan zorgen voor blinde vlekken. Hierdoor werden de belangrijke signalen gemist dat men niet met een routinematige situatie te maken had en bleek men niet in staat deze coördinatieproblemen tijdig te herkennen en te repareren.

De teams in het OCCR staan centraal in *hoofdstuk 4*. In deze studie hebben wij gekeken naar het leiderschap van deze teams tijdens grote verstoringen in relatie tot het vermijden van systeemfalen. Als een systeem onvoldoende in staat is om nieuwe uitdagingen te herkennen en succesvol op te vangen, dan kan de controle over het systeem verloren gaan. Er zijn drie patronen of valkuilen die tot een dergelijk falen van het systeem kunnen leiden: 1) decompensatie door uitputting, 2) elkaar tegen werken en 3) vasthouden aan achterhaald gedrag. Met behulp van de Multiteam Systeem literatuur over leiderschap hebben wij gekeken hoe de teams in het OCCR in de praktijk proberen te voorkomen dat het systeem in één van de drie valkuilen beland. Volgens deze theorie vervullen deze teams immers een belangrijke rol in de coördinatie tussen teams en het adaptief vermogen van het systeem in zijn geheel. De studie in hoofdstuk 4 heeft echter laten zien dat er grote uitdagingen kleven aan leiderschap in een multiteam systeem. Ten eerste hebben wij gevonden dat medewerkers in het OCCR moeite hebben om te bepalen wanneer medewerkers in de regionale controlecentra ondersteuning nodig hebben en op welke manier deze ondersteuning verleend moet worden. Ten tweede bleek dat regionale medewerkers vaak zelf niet om hulp vragen en als er hulp wordt aangeboden dan wordt deze tevens vaak afgeslagen. Ten derde werd duidelijk dat men in het OCCR vaak kampt met een flinke informatieachterstand en daardoor niet in staat is om het overzicht van de situatie te bewaken en de regionale controlecentra aan te sturen. Tot slot zagen wij een duidelijke spanning tussen de dynamiek en complexiteit van de verstoring en de wens van het OCCR om zo snel mogelijk volgens een standaard versperringsmaatregel te willen rijden.

In de laatste empirische studie, besproken in hoofdstuk 5, wordt een internationale vergelijking gemaakt van verstoringsmanagement. Een uitgebreid literatuuronderzoek liet zien dat een dergelijke vergelijking nog niet eerder was gedaan. In deze studie onderzochten wij daarom welke verschillende structuren en praktijken voor verstoringsmanagement er in vijf Europese spoorsystemen zijn ontwikkeld. De vergelijking richtte zich op de twee eerder besproken trade-offs: 1) centralisatie versus decentralisatie en 2) anticipatie versus veerkracht. De beide trade-off hebben wij geoperationaliseerd aan de hand van enkele items uit de literatuur. Op basis van onze observaties en interviews hebben wij vervolgens voor elk land scores toegekend aan de items. Dit maakte het mogelijk om de landen te vergelijken aan de hand van de gemiddelde scores van alle items. Dit resulteerde in twee clusters van landen. Het eerste cluster bestaat uit Oostenrijk en Nederland. Deze twee landen zijn redelijk gecentraliseerd en zijn in hun benadering van verstoringsmanagement het sterkst gericht op anticipatie. België en Denemarken vormen het tweede cluster. Zij kennen een gecentraliseerde structuur met daarbij een nadruk op veerkracht. Door de decentrale structuur bij verstoringsmanagement is Duitsland een outlier in onze vergelijking. Dit kan echter te maken hebben met de grootte en de complexiteit van het Duitse spoorsysteem. Over het geheel genomen laat de internationale vergelijking zien dat er niet één optimale manier is om verstoringsmanagement vorm te geven.

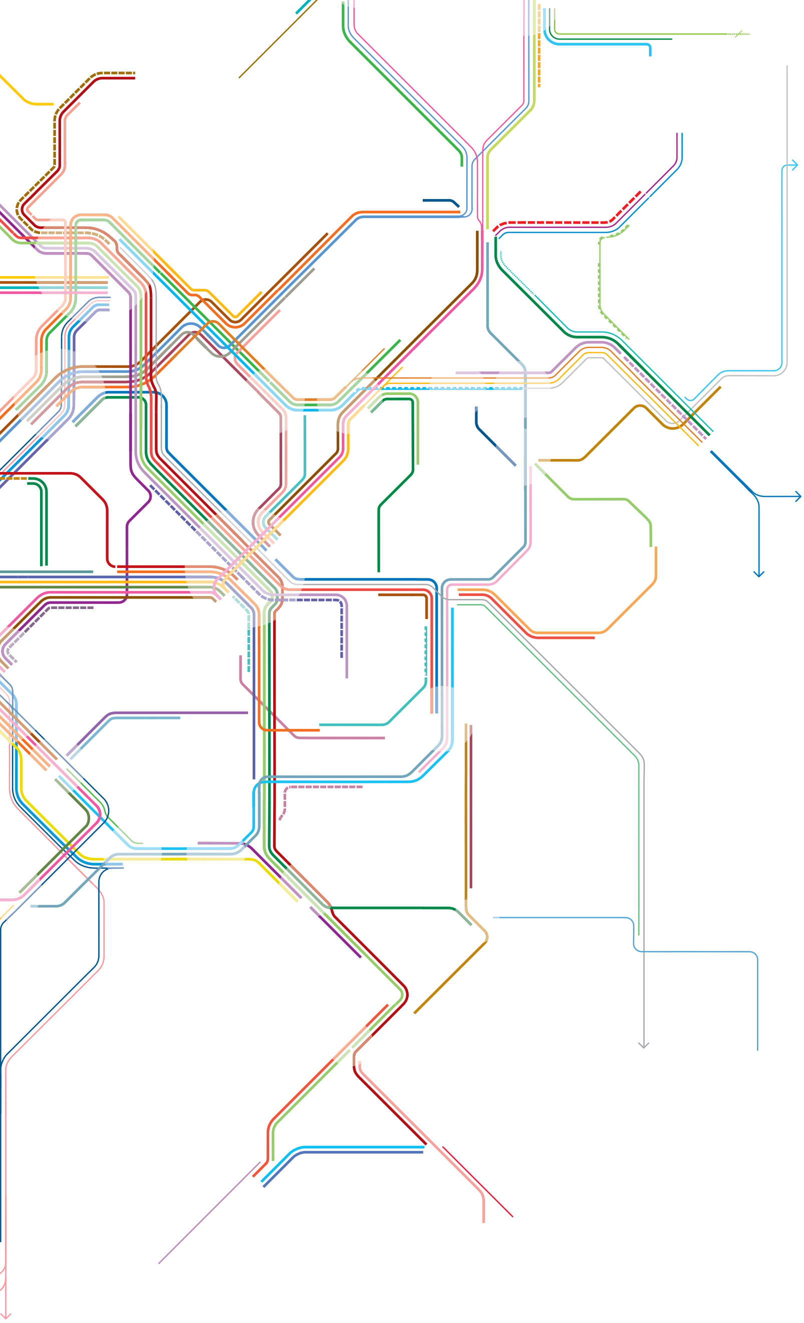
Conclusies

In het laatste hoofdstuk worden op basis van de vier studies de belangrijkste conclusies getrokken en een antwoord gegeven op de hoofdvraag. Er kan geconcludeerd worden dat het creëren en behouden van een gezamenlijk beeld van de situatie tijdens grote en complexe verstoringen zeer moeilijk is. Niet alleen is het moeilijk om onder zware werkdruk een goed beeld te creëren van de situatie en informatie te blijven delen met andere teams, maar informatie komt ook slechts langzaam beschikbaar en de situatie verandert vaak zo snel dat het gevormde beeld al snel achterhaald is. Hierdoor is beschikbare informatie vaak ongelijk verdeeld over de controlecentra. Onder tijdsdruk moeten medewerkers een afweging maken tussen het verzamelen van meer concrete informatie of het nemen van een snelle beslissing op basis van incomplete informatie. De eerste optie is lastig aangezien het collectief verzamelen van informatie al snel leidt tot een overbelasting van de communicatielijnen. De tweede optie is ook niet zonder risico, want met niet-routinematige verstoringen is de kans groot dat beslissingen worden genomen op basis van conflicterende aannames.

In dit onderzoek hebben wij gewezen op het belang van gezamenlijke betekenisverlening aan informatie, zodat een gedeeld beeld van de situatie wordt gecreëerd en activiteiten op elkaar afgestemd zijn. De studies hebben echter laten zien dat deze gezamenlijke betekenisverlening tussen teams in het Nederlandse spoorsysteem zwak ontwikkeld is. Vaak wordt niet de tijd genomen om door te vragen als men informatie ontvangt of twijfel heeft over de inhoud. Als de onzekerheid rond een situatie toeneemt verschuilt men zich bovendien al snel achter de eigen interpretatie van de situatie en de te volgen procedures. Dit laatste hoeft niet altijd bewust plaats te vinden, zoals we gezien hebben in de tweede studie. Het activeren van een bepaald frame rond een procedure kan er immers voor zorgen dat belangrijke signalen ten aanzien van het ontbreken van een gezamenlijk beeld tussen teams worden gemist. Plannen en procedures zijn zodoende niet alleen beperkt toepasbaar tijdens niet-routinematige verstoringen, maar kunnen ook de noodzaak tot improvisatie verhullen.

Dit hebben we vooral gezien rond het gebruik van versperringsmaatregelen in het Nederlandse spoorsysteem. Uit de internationale vergelijking kwam naar voren dat in Nederland het gebruik van deze maatregelen het verst is doorgevoerd. Hoewel deze plannen een belangrijke bijdrage leveren aan het coördineren van de activiteiten van de controlecentra, blijken ze moeilijk te implementeren als er sprake is van een zeer dynamische situatie. In de praktijk worden plannen dan vaak voortdurend aangepast of simpelweg doorgevoerd zonder dat ze aansluiten bij de specifieke situatie. Het ontbreken van een gedeeld plan zorgt er voor dat lokaal beslissingen worden genomen die niet altijd bijdragen aan het herstel van het systeem in zijn geheel en de situatie zelfs kunnen verslechteren. Daar komt bij dat de coördinerende rol van het OCCR vaak onvoldoende is. Dit heeft niet alleen te maken met de informatieachterstand waar de teams in het OCCR vaak mee te maken hebben, maar ook door een gebrekkige samenwerking tussen de regionale partijen en het OCCR. Zo is er veel ambiguïteit rond de onderlinge verdeling van taken en verantwoordelijkheden. Hierdoor blijft de regie vanuit het OCCR vaak uit en wordt er door de regionale partijen te laat om hulp gevraagd.

De bevindingen uit dit onderzoek hebben ook belangrijke implicaties voor de praktijk. Tijdens de uitvoering van dit onderzoek waren ProRail en NS bezig met de ontwikkeling van een nieuwe structuur voor de management van verstoringen. Dit nieuwe model is gericht op meer centrale besluitvorming, het verbeteren informatiedeling doormiddel van nieuwe communicatiesystemen en de ontwikkeling van beter toepasbare versperringsmaatregelen en procedures. De resultaten van dit onderzoek onderbouwen de gekozen richting als het gaat om routinematige verstoringen, maar wijzen ook op de risico's ten aanzien van niet-routinematige verstoringen. Zo is het belangrijk dat de focus op communicatiesystemen niet ten koste gaat van de noodzakelijke gezamenlijke betekenisverlening aan informatie, zal centrale sturing alleen mogelijk zijn als er sprake is van een goede samenwerking met de regionale partijen en mag de ontwikkeling van nieuwe procedures en plannen niet ten koste gaan van het improvisatievermogen van teams.



Dankwoord (acknowledgements)
Portfolio
About the author

DANKWOORD

Na jaren werken is mijn proefschrift klaar. Hoewel promoveren soms kan aanvoelen als een eenzaam beroep, is er een groot aantal mensen die ik wil bedanken voor hun bijdrage aan het succesvol afronden van dit proefschrift.

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Wat is een promovendus zonder zijn collega promovendi? De ondersteuning en gezelligheid van deze collega's is cruciaal bij het schrijven van een proefschrift. Nu is het zo dat als je een aantal jaar werkzaam bent geweest op dezelfde afdeling, je een zeer groot aantal aio's, tutoren en jonge onderzoekers leert kennen. Te veel om allemaal op te noemen en dat zal ik hier dan ook niet doen. Ik kan echter wel zeggen dat ik aan het begin van mijn promotietraject zeer gelukkig was met het warme welkom en de uitgebreide hulp van de meer ervaren promovendi. Daarnaast was het mooi om met een groot aantal ambitieuze en bovenal gezellige collega promovendi (ongeveer) tegelijktijdig aan het promotietraject te beginnen en gezamenlijk cursussen te volgen. Nu besteed je als promovendus vanzelfsprekend een groot deel van je tijd achter je bureau. Gelukkig stond mijn bureau in een 'blokje', die hoewel wisselend van samenstelling, door de jaren heen altijd de gezelligste van de afdeling was. Wat ik zeker ook niet zal vergeten is de gezelligheid buiten werktijd. De gezamenlijke dinertjes, borrels, verjaardagen, housewarmings, oud en nieuw vieringen, aio-uitjes en niet te vergeten de bruiloften laten zien dat we een hechte groep van collega's vormden.

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PORTFOLIO

PhD training

Netherlands Institute of Government (2013-2015):

- Core themes and the Ph.D. Research Experience
- Formulating the research problem
- Operationalisation
- Case study research
- Interpretive policy analysis
- Content analysis
- General Methodology
- Network Governance
- Getting it published
- Your postdoctoral career
- Introduction to Network analysis

Other courses:

- Casos 2013 Summer Institute (Carnegie Mellon University, Pittsburgh)
- Gephi courses (Erasmus University Rotterdam, 2014)
- Professionalism and integrity in research (EGSH, 2016)

Teaching

2011-2012 - Beleid & Instituties, Bachelor 2, Bestuurskunde, Erasmus Universiteit Rotterdam (seminars).

2014 - Introductie Bestuurskunde, Pre-Master, Bestuurskunde, Erasmus Universiteit Rotterdam (seminars).

2015-2016 - Network Governance, Bachelor 2 & 3, Bestuurskunde, Erasmus Universiteit Rotterdam (seminars).

2016 – Network Governance, Exchange students, Bestuurskunde, Erasmus Universiteit Rotterdam (seminars).

2016 – Leren Onderhandelen, Bachelor 2, Bestuurskunde, Erasmus Universiteit Rotterdam (seminars).

2017 - Designing Effective Governance Institutions, International Master, Bestuurskunde, Erasmus Universiteit Rotterdam (lecture).

Publications in peer-reviewed journals

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2018 Gerrits, L. & Schipper, D. *Wie Automatisierung das Störungsmanagement im Schienenverkehr verbessern könnte.* Internationales Verkehrswesen, 70 (1).

2013 Nijdam, M.H., Lugt, L.M. van der, Horst, M. van der, Schipper, D., Gerrits, L. & Bressers, N.E.W. (2013). *Flexibility in Port Organization and Management*. Rotterdam: Erasmus Universiteit.

Scientific and practical conferences

2013 Poster presentation, *ExploRail symposium*, Utrecht, 14-10-2013.
RailaHead symposium, TU Delft, 23-25 October 2013.

2014 30th European Group for Organisation Studies Colloquium: Rotterdam (3-5 juli 2014).
Poster presentation, *ExploRail symposium*, Utrecht, 26-09-2014.

2015 IRSPM Conference: Birmingham (March 30 – April 01 2015).
Poster presentation, *ExploRail symposium*, Utrecht, 21-04-2015.

2016 Poster presentation, *ExploRail symposium*, Utrecht. NS headquarters, 25-05-2016.

2017 Final ExploRail Research Symposium, Amersfoort, 10 October 2017.

ABOUT THE AUTHOR

Danny Schipper (1985) studied Human Geography and Spatial Planning at Utrecht University. After obtaining his master's degree in Spatial Planning, he attended the Erasmus University to obtain a second Master's degree in Public Administration within the program Governance and Management of Complex Systems.

After graduation Danny started working at the Department of Public Administration and Sociology of the Erasmus University. After a brief period as a junior lecturer, he worked as a junior researcher in the Flexibility in Port Organization and Management project. This project was part of the Port of Rotterdam and Next Generation Infrastructures research program 'Next Generation Port Infra'. In this project Danny cooperated with researchers from the Erasmus Centre for Urban, Port and Transport Economics on the investigation of factors that enable or restrict flexibility in port development and management and thus the Port of Rotterdam's ability to adapt to changes and remain competitive.

During his time as a junior researcher Danny also co-authored the research proposal 'Managing Complex System Disruptions' (MaCSyD), which was funded by ProRail and the Netherlands Organization for Scientific Research (NWO) within the ExploRail research program on Whole System Performance. In 2013, Danny started as a PhD candidate within the MaCSyD-project, as part of a larger consortium of researchers from Erasmus University, Delft University of Technology and VU University Amsterdam. For his research he spent numerous hours at the control centres of ProRail and NS.

During his PhD Danny published several articles in international peer-reviewed academic and practitioner journals. He presented his findings at national and international conferences and has organized several workshops for NS and ProRail to share his findings and recommendations. Moreover, Danny was chair of the Governance and Management of Complex Systems research group from 2014 to 2015 and taught several courses in the Public Administration bachelor, pre-master and master programs.

In 2017, Danny started as a postdoctoral researcher, which gave him the opportunity to extend his comparative study into disruption management practices of European railway systems.