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

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[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

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[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

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[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

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[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.