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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 doesn't 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.

1. Motive and research question

Train service disruptions pose an important challenge to railways as a reliable mode of transport (Golightly and 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 and 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 TOC's 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 predefined plans and procedures, but ad-hoc measures are often necessary due to the dynamic and uncertain conditions under which operators work (Johansson and Hollnagel, 2007). There are many studies on railway unbundling and privatization in the academic literature (e.g. Link, 2012 this journal), but not much attention has been paid to the effects of these policies on the daily operations of

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controllers managing rail traffic and disruptions (See Steenhuisen and 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 and 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 don't 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 2. The research method is discussed in Section 3. Country characteristics are presented in Section 4 and then categorized in Section 5. The conclusions are presented in section 6.

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 et al., 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 (cf. Branlat and Woods, 2010; Hémond and Robert, 2012; Mattsson and Jenelius, 2015). Complex systems have to deal with trade-offs that bound their adaptive performance (cf. Hoffman and 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 (1999) 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 don't 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 and 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 and 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 and Dadashi, 2017). Consequently, there needs to be discretionary room for operators to modify plans to the specific situation through mutual adjustment and improvisation (Faraj and Xiao, 2006). Real time adaptation can be considered a resilience[1] approach that substitutes foresight for the reactive capacity of control room operators and focuses on their expertise and tacit knowledge (Roe and 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 et al., 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 and Branlat, 2011). 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 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 and 6). For both trade-

[1] 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 and van Eeten, 2013; McManus, 2008; Stephenson, 2010; Vogus and Sutcliffe, 2007.

Table 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).

Item	Description	Measurement	References
Trade-off A: centralization (item score 1) vs. decentralization (item score 5)			
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 et al., 2001; Wilson and 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 and 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 and 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; Schipper et al., 2015)
Co-location of RIM and TOC's	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 and Oetting, 2013; Golightly and 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	(Waller and Uitdewilligen, 2008; Merkus et al., 2016; Schipper and Gerrits, 2017)
Use of dispatching rules	This concerns the availability and use of dispatching rules	Strict employment of dispatching rules: 1; no dispatching rules: 5	(Corman et al., 2011; Zhang et al., 2013)

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 1.

3. Method

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 min to 2 h. 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 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 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.

4. Country description

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 Figs. 1–5. Disruption management practices are discussed in Section 5. Please note that different countries use different terms for

Table 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		
S-train Copenhagen	Duty officer		Rail signaller
			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		

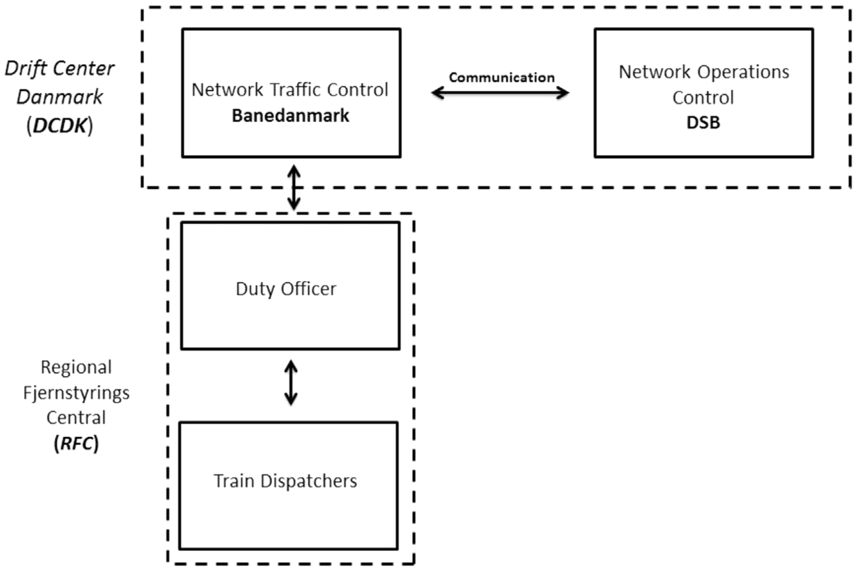

Fig. 1. Coordination structure in Denmark.

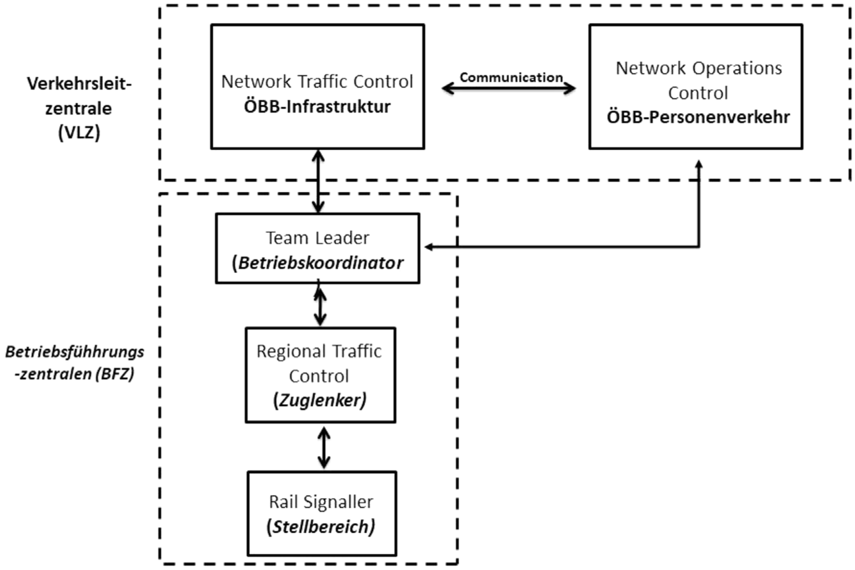

Fig. 2. Coordination structure in Austria.

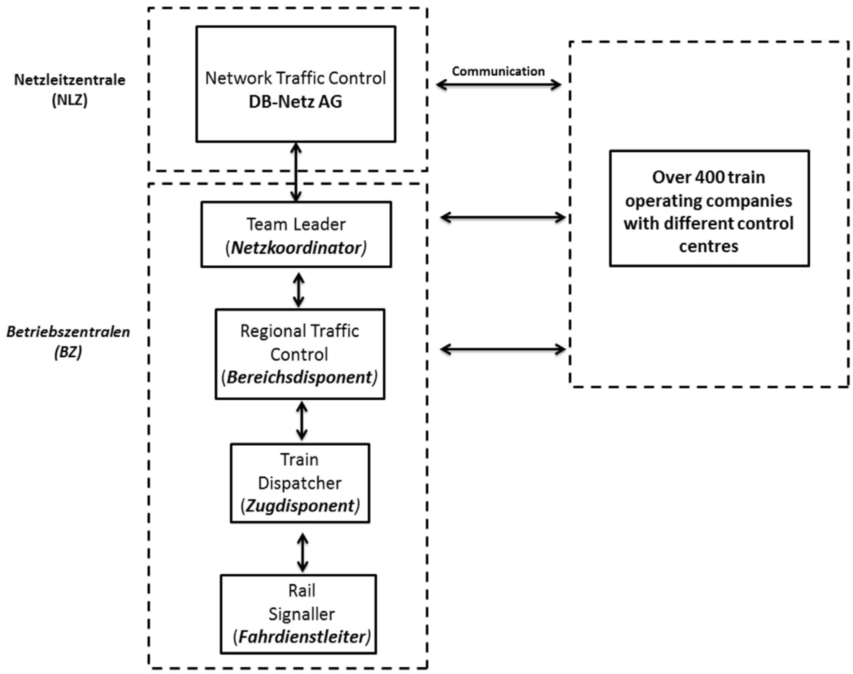

Fig. 3. Coordination structure in Germany.

similar positions or roles and that it was not always possible to harmonize these terms into English. Table 3 provides an overview of the terms used in this paper.

4.1. Denmark

4.1.1. National characteristics

The Danish railway network measures 2667 km, 2132 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 2700 runs per day on average, adding up

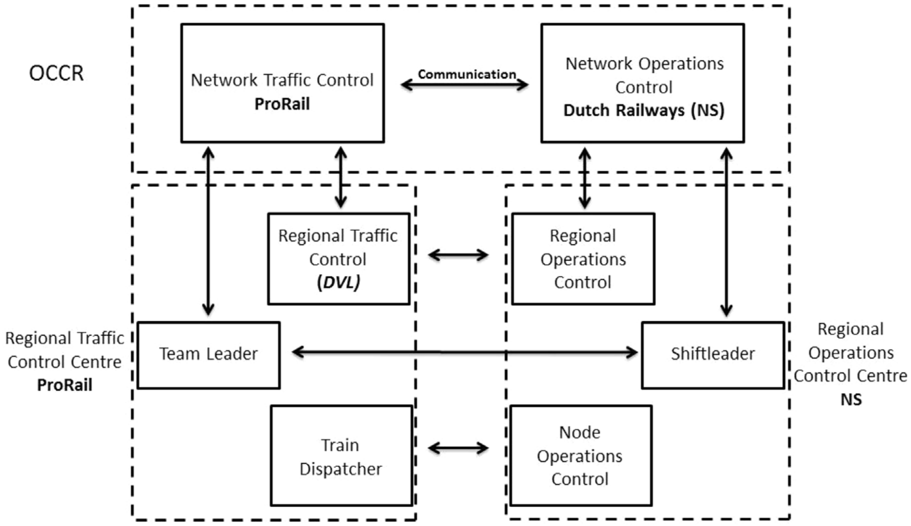

Fig. 4. Coordination structure in the Netherlands.

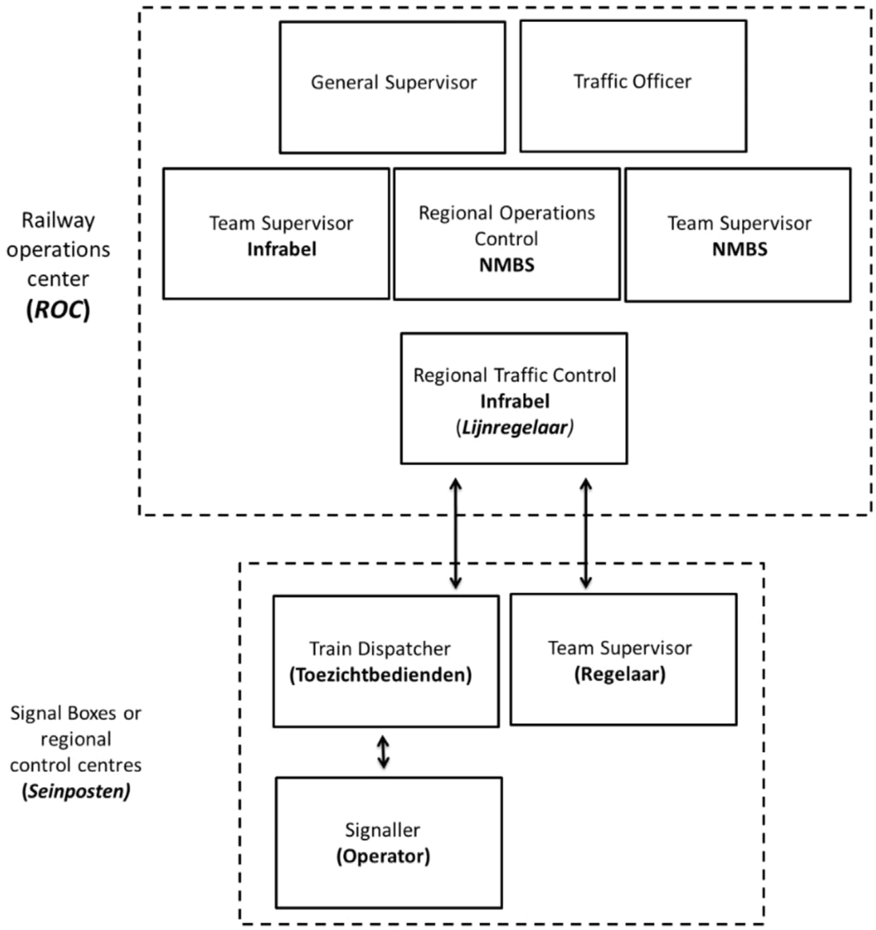

Fig. 5. Coordination structure in Belgium.

Table 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

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.

4.1.2. 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 Centre 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 min, 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.

4.2. Austria

4.2.1. National characteristics

The Austrian railway network measures almost 5000 km 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 4000 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.

4.2.2. 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 (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.

4.3. Germany

4.3.1. National characteristics

Deutsche Bahn (DB) Netz AG manages 33,295 km 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 5500 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.

4.3.2. 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 3400 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 1200 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.

4.4. The Netherlands

4.4.1. National characteristics

The Dutch railway network measures more than 3000 km 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 Dutch 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 5500 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. The network is managed by the state-owned RIM ProRail.

4.4.2. 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.

4.5. Belgium

4.5.1. National characteristics

The Belgian network measures around 3600 km. 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.

4.5.2. 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 Centre 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.

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 1 structure the observations.

5.1. Rail traffic control: centralized or decentralized?

5.1.1. Distribution of control centres

The overview in Section 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.

5.1.2. Decision making during a 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.

5.1.3. 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 isn't 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 (cf. Schipper, 2017).

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.

5.1.4. 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 TOC's. 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.

5.1.5. Communication structure

The communication structure of the different countries can be traced in Figs. 1–5. 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.

5.2. Disruption management: anticipation or resilience?

5.2.1. The use 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.

5.2.2. Automation of operations

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.

5.2.3. 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 Dutch Railways 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 didn't 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.

5.2.4. 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 $+10$ min) 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 doesn't 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.

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 4.

Table 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.

Fig. 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

Table 4
Scores per country (all individual items were given equal weight; the aggregated scores are averages).

Item	Countries				
	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**

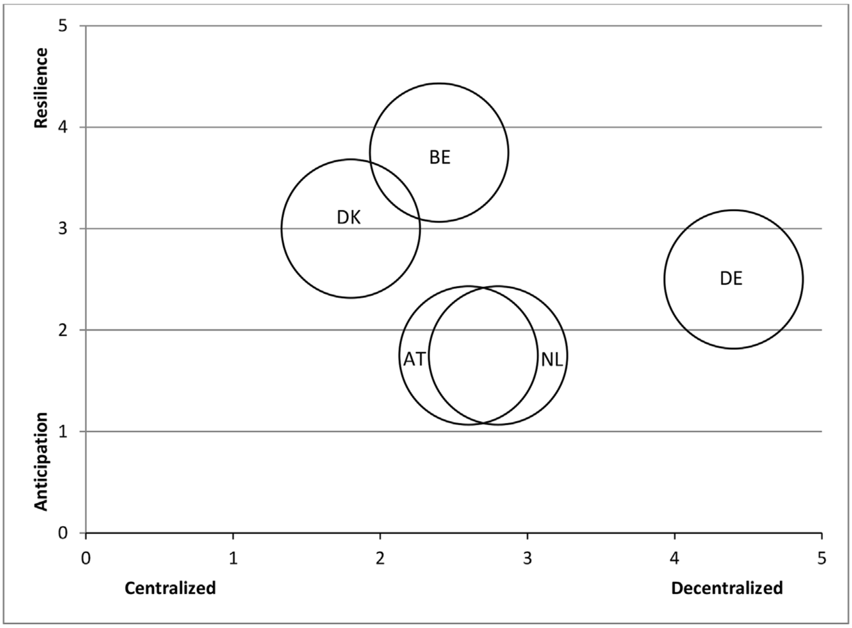

Fig. 6. Visualization of how countries perform on both trade-offs.

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.

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.

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