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Real-time information for disruption management in intermodal freight transport

PER WIDE

Department of Technology Management and Economics

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Department of Technology Management and Economics
Chalmers University of Technology
412 96 Gothenburg, Sweden
Telephone + 46 (0)31-772 1000

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Division of Service Management and Logistics
Department of Technology Management and Economics
Chalmers University of Technology

Abstract

This thesis focuses on the recovery phase after operational disruptions in intermodal freight transport, which is a vital aspect of mitigating impacts such as late deliveries and thus achieving high operational efficiency. Intermodal freight transport is influenced by the ongoing development of information and communication technologies. Real-time information from these technologies has been shown useful for managing disruptions at the operational level. Previous research on intermodal freight transport has focused on the effects of actions enabled by real-time information, which has generated a lack of understanding the importance of real-time information concerning the process that result in these actions, such as using real-time information to manage operational disruptions. In this thesis, the process of managing disruptions in the recovery phase by using real-time information to detect a disruption, predict its impacts and take suitable action is termed *disruption management*. The purpose of this thesis is to contribute to the understanding of the importance of real-time information for disruption management in intermodal freight transport.

This thesis draws from a compilation of five studies conducted to examine various aspects of real-time information used during the recovery phase in different intermodal freight transport settings. The studies involved applying various methods used in qualitative case studies, such as interviews, observations, and a focus group, as well as a quantitative study involving discrete event simulation. The main results are as follows. First, the results identified how real-time information supports the phases of disruption management (i.e., detection, prediction and action) depending on different factors of real-time information. Second, connections between operational coordination regarding information and buffers are discussed in terms of how they influence the real-time information used for disruption management. Last, an investigation of the efficiency effects was made with different scenarios for real-time information regarding prediction of impact. Through these results, the thesis provides insights into the importance of real-time information for disruption management and theoretical contributions to intermodal freight transport by conceptualising the role of real-time information for disruption management at the operational level and its effects. The detailed descriptions of real-time information for recovery provides practical contributions for transport managers to understand and evaluate their processes at the recovery phase.

Keywords: recovery actions, real-time information, disruption management, intermodal freight transport, transport system, operational planning

List of appended papers

Paper 1

Wide, P. & Roso, V. Information on resource utilisation for operational planning in port hinterland transport. *Transactions on Maritime Science*, 10(2), pp. 477-487.

An earlier version of the paper was presented and published in the proceedings of the 30th Annual NOFOMA Conference, 14-15 June 2018, Kolding, Denmark.

Contributions: The paper was a single-author conference paper by Wide. The paper was after the conference reworked together with Roso.

Paper 2

Wide, P. (2020). Improving decisions support for operational disruption management in freight transport. *Research in Transportation Business & Management*, Vol. 37, No. 100540.

An earlier version of the paper was presented and published in the proceedings of the 23rd Annual Logistics Research Network (LRN) Conference, 5-7 September 2018, Plymouth, UK.

Contributions: Single-authored paper, written solely by Wide.

Paper 3

Wide, P. (2020). Real-time information for operational disruption management in hinterland road transport. *World Review of Intermodal Transportation Research*, Vol 9, No. 4, pp. 358-375.

An earlier version of the paper was presented and published in the proceedings of the 31st Annual NOFOMA Conference, 13-14 June 2019, Oslo, Norway, where it received the Best Doctoral Paper NOFOMA 2019 award.

Contributions: Single-authored paper, written solely by Wide.

Paper 4

Wide, P., Andersson, D., Roso, V. (2021) Operational Coordination in Intermodal Hinterland Transport as Support for Managing Operational Disruptions – an information processing perspective. *Operations and Supply Chain Management: An International Journal*, Vol. 14, No. 4, pp. 507-519.

An earlier version of the paper was presented and published in the proceedings of the 25th Annual Logistics Research Network (LRN) Web Conference, 9-11 September 2020, Cardiff, UK (online).

Contributions: The paper was initiated by Wide, who led the research design, data collection and data analysis with support from Andersson and Roso. The writing of the paper was a joint effort.

Paper 5

Wide, P., Kalahasthi, L.K., Roso, V. Efficiency effects of information for operational disruption management in port hinterland freight transport - Simulation of a Swedish dry port case.

Status: Invited for submission in December 2021 to the Logistics Research Network (LRN) 2021 Special Issue in the international journal of Logistics: Research and Application. An earlier version of the paper was presented and published in the proceedings of the 26th Annual Logistics Research Network (LRN) Web Conference, 8-9 September 2021, Cardiff, UK (online).

Contributions: The paper was initiated by Wide, who additionally performed the data collection and developed of the simulation model. The analysis and writing of the paper were led by Wide with support from Kalahasthi, and Roso supported with the writing of the paper.

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Per Wide

Gothenburg, November 2021

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1 Introduction

This chapter provides the background and motivation of the research in this thesis, before outlining the purpose and connected research questions. Lastly, the scope of the research and an outline of the thesis are provided.

1.1 Background

Disruptions are frequently impacting freight transport operations. Recent disruptions provide examples of high impacts on the freight transport operations. Two prime examples have been the bankruptcy of Hanjin Shipping in 2017 and the container ship that ran aground and blocked the Suez Canal in 2021. Such types of disruptions, which have high impacts and low probability of occurring (Tang, 2006), are often highlighted in media and have been the main focus in previous research on disruptions in intermodal freight transport (Li et al., 2018; Chen and Miller-Hooks, 2012), studied in this thesis. Nevertheless, the issue of disruptions is frequently present in the day-to-day freight transport operations (Meyer et al., 2014), as the transport operations are impacted by operational disruptions with frequent occurrence and lower impacts (Tang, 2006; SteadieSeifi et al., 2014). These operational disruptions, hereafter referred to as disruptions, have impacts on a smaller scale than those of the accident at the Suez Canal, which blocked a key route for transport operations for an entire week. Additional costs borne by the transport chain due to impacts from these disruptions are primarily connected to delays (Sanchez-Rodrigues, 2010). These extra costs impact the planned efficiency of intermodal freight transport operations (Hrušovský et al., 2021) and may add more costs, for instance, for express deliveries to achieve planned delivery times (Goel, 2010). Intermodal freight transport chains are affected by various disruptions outside intermodal terminals, including late arrival of ships (Elbert and Walter, 2014) or of trucks (Li et al., 2018), or disruptions within intermodal terminals, for example, a port, creating congestion that adds turn-around times and waiting times (Caris et al., 2011). Both the origin of disruption and its costs of impacts have in the intermodal transport literature had the port as a common denominator (Li et al., 2018), but in recent years other perspectives have been included, such as land-based intermodal transport chains (Hrušovský et al., 2021) and port hinterland transport (Li et al., 2018; Elbert and Walter, 2014).

Freight transport systems supply transport services for the demand of transport that occurs in the interplay between producers of goods and consumers (Crainic and Kim, 2007). High efficiency in freight transport is an important factor in lowering environmental carbon emissions, as, for example, the freight transport is the main contributor to greenhouse gas emissions and congestion in the European Union (European Commission, 2016). One suggested solution to reduce emissions and to lower the environmental impact of freight transport is intermodal freight transport, which is the transport of standardised units involving at least two different modes of transport (Bontekoning et al., 2004). Transporting freight via intermodal solutions, which can be achieved by using modes of transport such as rail and sea instead of road, can improve operational efficiency and, in turn, lower costs and environmental impact (Lowe, 2005). Nevertheless, road transport remains the most widely used mode of transport in Europe (Eurostat, 2020), one that intermodal freight transport still struggles to compete with (Vural et al., 2020). Improving the management of disruptions in intermodal freight transport can lower the additional costs associated with the negative impacts of disruptions (Hrušovský et al., 2021) and, in that way, increase the intermodal freight transport competitiveness.

The development of information and communication technologies (ICTs) has provided opportunities to achieve high operational efficiency in intermodal transport chains (Giannopoulos, 2004; Harris et al., 2015) to compete better with road transport (Bärthel and Woxenius, 2004). Information sharing that provides visibility between actors involved in intermodal freight transport systems has been a key subject in previous research (SteadieSeifi et al., 2014; Harris et al., 2015; Wiegmans et al., 2018). Possible improvements initiated by information can enhance the efficiency of a process plan, for example, by optimising the setup of processes to decrease administration time (Sternberg, 2011), by improving intermodal access processes to decrease turn-around times (Jacobsson, 2020) and by optimising planning for multiple processes (SteadieSeifi et al., 2014; Crainic et al., 2009). Although such improvements are important ways to increase the efficiency of intermodal freight transport, they are not the sole factors of achieving high efficiency from information (SteadieSeifi et al., 2014). Another factor where information can influence the overall efficiency of transport operations is how well the freight transport system in operational planning decisions can manage disruptions (SteadieSeifi et al., 2014), that change the planned transport (Meyer et al., 2014; Yu and Qi, 2014). Planning of freight transport can optimise planned freight operations but cannot guarantee execution, due to disruptions. Disruptions in transport operations due to, for instance, limited infrastructural capacity or accidents can cause delays and make plans infeasible (Hrušovský et al., 2021), generating a need for response to achieve recovery (Blackhurst et al., 2005). Recovery is made after the disruption has occurred and includes actions to mitigate impacts (Chen and Miller-Hooks, 2012; Reis, 2019). In this thesis, the dynamic update of plans after disruptions has occurred is referred to as *disruption management* (Yu and Qi, 2014). When disruptions occur, disruption management is vital to avoid or limit the impacts during the recovery phase (Blackhurst et al., 2005; Meyer et al., 2014). Transport systems that struggle to manage disruptions cannot achieve their planned efficiency due to late deliveries and/or decreased resource utilisation (Wilson, 2007; Elbert and Walter, 2014; Li et al., 2018).

Although a key element of disruption management is the use of information (Hrušovský et al., 2021; Li et al., 2018; Messina et al., 2020), challenges arise while using information to manage disruptions in transport operations (Meyer et al., 2014; Hrušovský et al., 2021). The specific characteristics of intermodal transport can create issues when operational disruptions occur, and information is used for the management of those disruptions. First, intermodal freight transport entails increased handling of transport unit (e.g., container or trailer), such as during transhipments between modes. Due to this extra handling, intermodal freight transport has increased interdependencies compared to unimodal freight transport, with more actors involved and more interconnected processes to be performed (Monios and Bergqvist, 2015; Dürr and Giannopoulos, 2003). Such increased interdependencies influence the management of operational disruptions and need to be considered for rippling impacts between multiple actors (Ivanov et al., 2014). Second, disruption often originates from outside the action scope of one actor (Behdani, 2013), which provides the need for interorganisational information and coordination that have been reported as an issue in intermodal transport chains (van der Horst and De Langen, 2008). Third and last, when disruptions occur, decisions at the operational level are limited to a short time window (often minutes or hours) (Brehmer, 1992), which requires information about disruptions to be available close to real-time (Elbert and Walter, 2014; Wiegmans et al., 2018). In this thesis, *real-time information* is referred to as information about the transport flow status that is frequently updated as transport operations are executed (Goel, 2010; Wiegmans et al., 2018).

To address some of the issues for disruption management raised above, researchers have emphasised the need for actors to make decisions for transport operators via real-time information when disruptions occur (Meyer et al., 2014; SteadieSeifi et al., 2014; Li et al., 2018). However, studies on real-time information for disruption management have been scarce and tended to provide fragmented approaches for specific disruptions (Li et al., 2018; Elbert and Walter, 2014), or highlighted various types of information (van der Spoel et al., 2017; Wiegmans et al., 2018). Moreover, research on real-time information for disruption management in intermodal freight transport (Hrušovský et al., 2021; Albertzeth et al., 2020; Li et al., 2018) has focused on which recovery actions to take and why, particularly in terms of effects on operations, but has made few connections to what real-time information is available to achieve recovery actions. By assuming the availability of real-time information for decision-makers, those approaches have not fully captured the importance of real-time information in disruption management at the operational level. There has been a rule of thumb that real-time information is important when managing disruptions in the recovery phase without further elaborations or the focus has been on the technology to use. For instance, Meyer et al. (2014) proposed a novel prototype of a system to manage operational disruptions in freight transport at the freight forwarder and highlighted issues of using real-time information for the process of disruption management. For intermodal transport, Hrušovský et al. (2021) proposed a similar decision support system (DSS) but focused on the technology used to provide such DSS and lacked details on real-time information connected to transport operations performed to establish the process of disruption management. Even if real-time information is acknowledged to be an important component for the recovery phase, to gain the benefits of minimised impacts on efficiency by managing disruptions via real-time information, the process of disruption management needs to be considered to capture more than the actions made. The process not only includes the outcome, that is, recovery actions, but additionally, for example, the detection of disruptions (Blackhurst et al., 2005).

1.2 Purpose and research questions

The purpose of this thesis is to contribute to the understanding of the importance of real-time information for disruption management in intermodal freight transport. The purpose aims to minimise impacts from disruptions on efficiency in intermodal transport operations. To cover the purpose, three research questions were derived as explained below.

The time aspect of managing disruptions has been highlighted as important in minimising the impacts of disruptions on efficiency (Sheffi, 2015), but there are few intermodal freight transport studies relating real-time information to the timepoint of managing disruptions. Early disruption management, that is, managing disruptions directly as they occur, can lower impacts or at least include the availability of more suitable actions for their management (Sheffi, 2015; Dunke et al., 2018). Obtaining real-time information has been highlighted as a mean to achieve early disruption management (Sheffi, 2015; Meyer et al., 2014). Even though ICT and information sharing have been key subjects in research on freight transport, the freight transport industry continues to suffer from limited adaptation of information technology (IT) systems for information sharing (Vural et al., 2020). Moreover, Carlan et al. (2019) identified manual working practices used by operators in transport planning that are needed to manage information between ICT tools. For disruption management, those practices create problems for accessing real-time information, and, in turn, delayed recovery and the increased impact of disruptions (Sheffi, 2015). Additionally, literature on information sharing in freight transport has focused either on technology that provides the information, including ICT and IT systems, and possibly enhances visibility (Dürr and Giannopoulos, 2003; Giannopoulos, 2004) or on the benefits of using the various information systems (Harris et al., 2015). Nevertheless, the limited use of ICTs in intermodal freight transport indicates that despite a heavy focus on information-sharing technology, the connection between improving information sharing and visibility to make real-time information available has remained unclear. For the purpose to focus on the importance of real-time information in disruption management, attention on how ICT can increase visibility has not been enough. In response, this thesis was first interested in understanding how real-time information supports disruption management before ICT can provide such information. Therefore, the first research question is:

RQ 1: *How does real-time information support disruption management in intermodal freight transport?*

Because factors of real-time information were found to constrain the process of disruption management, the thesis next set out to explore real-time information between different actors. In intermodal freight transport, the coordination between actors involved has been raised as an important concept for real-time information between actors. The involvement of multiple actors, resources and activities in the intermodal freight transport chain creates interdependencies that need coordination (Monios and Bergqvist, 2015). Additionally, coordination influences the real-time information shared between actors (Gumuskaya et al., 2020b) and thus available at the operational level. Nevertheless, the operational coordination has not been connected to the disruption management. To gain insights to the purpose of this thesis, the importance of real-time information for disruption management, it is of interest to understand how the operational coordination influences the real-time information for disruption management. This leads to the second research question:

RQ 2: *How does operational coordination influence the availability of real-time information for disruption management in intermodal freight transport?*

Last, the third research question was guided by the aim to complement the conceptualisations made concerning real-time information and disruption management in studies conducted to answer research questions 1 and 2 with indications for the effects on efficiency. Previous research has shown improvements in costs and modal split for container transport, when different scenarios for information are applied when delays in transport operations connected to the seaside of a port (Gumuskaya et al., 2020a; Elbert and Walter, 2014). Instead of focusing on improving efficiency from various information about disruptions for planning purposes, this thesis is interested in effects on efficiency in terms of realising planned efficiency even when disruptions occur, or at least mitigating impacts from disruptions on efficiency.

RQ 3: *What are the efficiency effects of real-time information on disruption management in intermodal freight transport?*

1.3 Research scope

Intermodal transport is defined as "the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes" (Economic Commission for Europe, 2001, p. 17). The movement of freight is made in networks consisting of transport chains with links and nodes (Lumsden et al., 2019). Flodén (2007) included three primary parts of an intermodal freight transport chain, consisting of a distribution/collection system, a main haul, and terminals. The distribution/collection system, also known as drayage (Bontekoning et al., 2004) or hinterland transport, when connected to a port (van Klink and van den Berg, 1998), includes transport operations between a terminal and receivers. Such transport is characterised by a relatively short distance but nevertheless highly influences total costs for the intermodal freight transport chain (Bontekoning et al., 2004). The hinterland transport part of the intermodal transport chain has been the main contributor for empirical data in this thesis. The main link (haul) is terminal-to-terminal transport, which, for example, can be made via sea or rail. The nodes are intermodal terminals specially designated for shifts between modes or consolidating freight (Rodrigue, 2020). In the latter case, once the load unit is broken, the intermodal chain breaks as well, and unimodal transport is initiated. In this thesis, the primary transport flows are intermodal, although some of the freight flows studied include consolidation and therefore represent part of a unimodal transport chain in connection to the studied intermodal transport chain.

The scope of the research conducted for the thesis appears in Figure 1, which takes the perspective on the intermodal transport chain adopted from Flodén (2007) and its inclusion as a subsystem in a logistics and supply chain system (Woxenius, 2012).

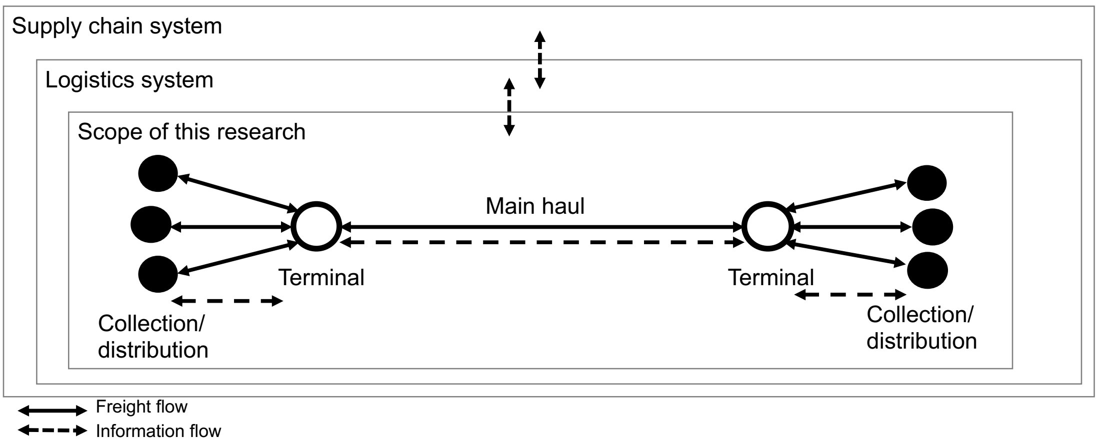

Figure 1. Overview of the scope of the research, adopted from Flodén (2007) and Woxenius (2012).

The terminal nodes in Figure 1 are nodes where changes between modes are made, such as a port, or a rail terminal. The figure illustrates both the flow of freight and information, in solid and dashed lines, respectively. The information flow can be present between the actors within the intermodal freight transport and between different system levels (Lumsden et al., 2019). The black nodes for collection/distribution represent senders and receivers of freight, and the collection/distribution part shown in the figure can be one mode of transport, primarily performed via road (Flodén, 2007), although other nodes may be present between. For example, the transport from the port (e.g. terminal in Figure 1) can be performed via rail and then shift to road at a node (black node in the figure) (Roso et al., 2009). Additionally, the collection/distribution nodes can be warehouses, production sites or terminals for senders and/or receivers. If those nodes are terminals, then they are included in the scope of the research, as depicted in Figure 1, however, if they are represented by, for example, a production site, then they are considered to be part of the logistics system and thus outside the scope of the research. As a result, the research follows the view of Woxenius (2012) that the transport chain is a part of a larger logistics system that includes more activities than the transport chain. The logistics system, in turn, is a part of a larger supply chain. The supply chain consists of the whole value-adding chain from supply to the point of consumption (Lambert and Cooper, 2000). The author of this thesis recognises that other views on logistics and supply chains exist (see Larson and Halldorsson (2004)). By adopting a transport chain scope, this thesis considers impacts outside the transport chain as potentially possible. Supply chain impacts, such as the loss of sales, loss of reputation or stops in production (Wilson, 2007; Giunipero and Aly Eltantawy, 2004), due to disruptions in the transport chain are viewed only as potentially possible in the case that the impacts are not mitigated within the transport chain.

This thesis is based on studies conducted in Sweden and the studies have been focused on the Swedish part of international transport chains. As a result, regional transport chains have been covered and not international or local chains (Rodrigue, 2020). Last, the thesis is limited to the modes of rail and road for intermodal freight transport.

1.4 Outline of the thesis

The rest of the thesis is outlined as follows. Chapter 2 provides an overview of literature relevant to the topic and outlines the theoretical framework, after which Chapter 3 describes the methodology used and various aspects of the research design and research quality. Next, Chapter 4 summarises the five appended papers, whereas Chapter 5 discusses the main findings and contributions to the outlined purpose and connected research questions. Last, Chapter 6 provides the conclusions of the research, and outlines directions for future research.

2 Frame of reference

This chapter first presents an overview of used key concepts in Section 2.1, followed by an overview of approaches to manage disruptions in Section 2.2. The overview of approaches primarily refers to literature on supply chain risk management as a mean to put the research conducted for this thesis in relation to these concepts in Section 2.3. Next, an overview of intermodal freight transport studies related to manage disruptions is provided in Section 2.4, before connections are made between coordination and disruption management to address interorganisational aspects of the recovery phase in Section 2.5. To complement the assumptions in intermodal freight transport related to real-time information for managing disruption, the phases of disruption management are further elaborated in Section 2.6.

2.1 Key concepts

This section provides an overview of the key concepts used in this thesis. The key concept of transport disruptions is first presented and connected to the concepts of recovery and efficiency. After that, an overview of the concepts of disruption management and real-time information is provided.

2.1.1 Transport disruptions

Disruptions connected to product flows operations can be classified as either disasters or operational disruptions (Tang, 2006). The focus in this thesis on operational disruption management in the recovery phase is thus a focus on operational disruptions, that is, disruptions that frequently often but have limited impact on operations even if they threaten normal business operations. Transport disruptions cause the freight flow to a stop (Wilson, 2007). Hrušovský et al. (2021) divided sources of operational disruptions in intermodal transport into demand changes and capacity restrictions. Although they also classify changed travel times as operational disruptions, this thesis instead views changed travel times as an impact of disruptions. Changed travel times could, for example, originate from bad weather conditions or from high traffic flows causing congestions (van der Spoel et al., 2017; Li et al., 2018). In this thesis, a disruption is viewed as a change in a plan (Yu and Qi, 2014) that requires re-planning via additional decision-making (Hrušovský et al., 2021). In a similar direction, Otto (2003), in discussing supply chain event management, has referred to deviations as being differences between a planned status and an actual status, represented by specific characteristics of the object. Those definitions of disruption are similar to the one used for supply chain disruptions, which view a disruption “as the combination of (1) an unintended, anomalous triggering event that materialises somewhere in the supply chain or its environment, and (2) a consequential situation which significantly threatens normal business operations of the firms in the supply chain” (Wagner and Bode, 2008, p. 309). Disruptions in transport operations have been studied from the perspective of supply chains (Ivanov et al., 2017; Behdani, 2013), in which a transport disruption is one possible disruption among many (e.g. supply disruption and demand disruption), and from the perspective of freight transport chains (Li et al., 2018; Hrušovský et al., 2021). Furthermore, the term *disruption* is often expressed in relation to the terms *risk* and *uncertainty*. Sanchez-Rodrigues (2010) has referred to risk as a function of outcomes and probability that can be estimated and uncertainty, such that “when decision-makers cannot estimate the outcome of an event or the probability of its occurrence” (Sanchez-Rodrigues, 2010, p. 46). Wagner and Bode (2008) have highlighted that a risk can be positive, and one could gamble with risks, but in supply chains, risk has been used as a negative term. The authors viewed the term *risk* as negative and associated it with the damage or loss resulting from a disruption. These terms are viewed in this thesis in relation to a decision being made, such as uncertainty in a planning decision (SteadieSeifi et al., 2014) and do not allow for capturing real-time information in the same extent that disruption.

2.1.2 Recovery and efficiency

The focus of this thesis is the recovery phase, as the time after a disruption has occurred that impacts the planned efficiency and has the aim to achieve the state of recovery where the efficiency impact is resolved. A state of recovery occurs after the deviation of a plan is detected and actions to manage the disruption have been implemented. Even though the recovery phase has been highlighted in previous literature on intermodal freight transport (Li et al., 2018; Albertzeth et al., 2020) (or the phase after a disruption has been covered without referring to it as recovery phase (Hrušovský et al., 2021)), a common term used does not seem to be present, even if the literature on intermodal freight transport revolves around the actions taken during the recovery phase. In this thesis, such recovery actions are viewed as being taken during the recovery phase to achieve a state of recovery. Chen and Miller-Hooks (2012) have discussed recovery activities as those "that might be taken in the intermediate aftermath of a disruption" (Chen and Miller-Hooks, 2012, p. 110), and have connected those activities to actions taken. Furthermore, the author raised that recovery is a second state after the deviation occurs, which is in line with the view in this thesis that the recovery phase includes more than an action. This view on the recovery phase is influenced by Blackhurst et al. (2005), that the recovery is achieved by performing activities beyond mere actions. This broader view includes a process of disruption management during the recovery phase such as the detection of the disruption and the prediction of its impacts before any action is taken (Messina et al., 2020; Meyer et al., 2014).

After disruptions occur that may negatively influence a planned delivery, efficiency revolves around resource utilisation measures of time and capacity, at least as discussed in literature on intermodal freight transport. For instance, the planned efficiency for the arriving trucks to a terminal, including their turn-around time (Zhou et al., 2018), will be altered due to a disruption. When operations are disrupted, a common result is congestion around a terminal, such as trucks that arrive at a port later than planned due to disruptions (Li et al., 2018). Such delays directly influence the resource utilisation in the transport chain (Elbert and Walter, 2014). For example, poor resource utilisation can arise when costly emergency deliveries are required to meet promised delivery times (Goel, 2010). In turn, those delays generate indirect impacts on environmental measures, including emissions (Li et al., 2018).

2.1.3 Disruption management

Achieving recovery via different recovery actions requires *disruption management*, viewed as the process that ends up in a re-plan decision (recovery action) when a plan, for example, an intermodal transport plan, during execution is exposed to a disruption (Yu and Qi, 2014). That process entails dynamically revising the plan in consideration of the new constraints and negative impacts of disruptions, due to which the plan has become suboptimal or even infeasible, is referred to as *disruption management* (Yu and Qi, 2014). To be able to re-plan an intermodal transport plan during its execution requires real-time information (Hrušovský et al., 2021; Li et al., 2018). Conceptually the disruption management has been proposed as being automated via information systems (Séguin et al., 1997; Feldman et al., 2013). Nevertheless, practice-oriented studies have identified human involvement in disruption management (Meyer et al., 2014; Carlan et al., 2019). In particular, Meyer et al. (2014) have identified major problems in the process of monitoring transport operations and detecting the need for re-planning to end up with a re-plan action. Disruption management has in freight transport has primarily been discussed in terms of vehicle routing problems for individual transport orders but not from the perspective of intermodal freight transport, which needs to include the larger network (e.g. actors and modes) instead of taking individual orders in to consideration (Hrušovský et al., 2021).

2.1.4 Real-time information

As stated in Chapter 1, in this thesis real-time information is viewed as information about the operational status of the intermodal transport chain that is updated during the execution of transport operations (Goel, 2010; Wiegmans et al., 2018). The concept of real-time is important for recovery, because changes in operations require real-time information for early recovery (Meyer et al., 2014; Sheffi, 2015). Nevertheless, the concept has been used to illustrate instant information updates without any clear definition in intermodal freight transport (Hrušovský et al., 2021; Li et al., 2018). What is viewed as being in real-time depends on purpose and context. Real-time information has been used in different logistics contexts for various purposes but without clearly distinguishing what is viewed as occurring in real-time (Sternberg et al., 2012; Li et al., 2018). Giusti et al. (2019) have discussed real-time in relation to transport planning, for synchromodal logistics, as what is performed during execution of operations and therefore needs status updates during execution. That view is in line with the view in this thesis that real-time information provides status updates for operations. To elaborate on real-time information, this thesis adopts the four factors of communication identified by Mohr and Nevin (1990) of content, frequency, medium and direction, which have previously been used to explain different perspectives on information in logistics (Myrelid and Jonsson, 2019) and intermodal freight transport (Jacobsson et al., 2017).

First, *content*, what the information includes, needs to be connected to the transport operations and disruption management. That follows the view in literature on intermodal freight transport that the content of information needs to provide insights into transport operations and/or disruptions (Wiegmans et al., 2018). For example, certain content will provide insights into disruption management for different operations, including the arrival times of trucks or ships at a port (Li et al., 2018), in terms of container release times that influence the impacts of delayed trucks or ships on port operations (Elbert and Walter, 2014; Zuidwijk and Veenstra, 2014). Second, regarding *frequency*, information for disruption management needs to be updated. Because the frequency of updates can differ depending on contextual factors and actors. For example, if a ship between two continents is delayed, then the information could be regarded as being in real-time even if the updates are once a day, but for a shorter collection or distribution component of an intermodal freight transport chain, the updates need to be more frequent (e.g., every hour). Third, the *medium* refers to how the information is communicated. The view on information in intermodal freight transport comes from a focus heavily oriented towards information and communication technologies (ICTs) and transport management systems (TMS) that generate information (Coronado Mondragon et al., 2012; Goel, 2010; Harris et al., 2015). Benefits as increased freight flow control in real-time can been achieved by using IT systems and ICTs (Bock, 2010; Buijs and Wortmann, 2014; Stefansson and Lumsden, 2009). Jacobsson et al. (2017) have even highlighted the importance of those tools by including digital in their discussion of information exchange as being “a horizontal, inter-organisational, bi-directional, digital, and structured interaction between actors in intermodal freight transportation” (Jacobsson et al., 2017, p. 107), implying the need for technical support for information. That contrasts the view from Barratt (2004) who, from a supply chain perspective, included that information can be shared via both non-technical and technical aids. Meyer et al. (2014) have described how those systems provide real-time information about operational transport operations for disruption management, while additionally mentioning manual information inputs, such as phone calls. Similar findings regarding manual parts in intermodal freight transport have been identified concerning phone calls and papers (Reis, 2019). Fourth and last, *direction* refers to both the horizontal and vertical in a chain and within an organisation and whether the information is communicated in one way or exchanged such that a response is needed (Jacobsson et al., 2018).

An additional elaboration of the concepts of data, information and knowledge has been used in intermodal freight transport (Wiegmans et al., 2018), stems from the field of knowledge management (outside the scope of the presented research) (Wallace, 2007). Data consist of the raw data provided, which become information when presented for a given purpose, such as for planning transport operations (Wiegmans et al., 2018). By combining information, transport planners can have a basis for their decisions, which revolves around a built up knowledge (Wiegmans et al., 2018). The research presented in the thesis has not examined planners’ knowledge. Rather the purpose of supporting the planners in performing disruption management has been in focus in the studies and therefore information has been chosen as the starting point for the studies.

2.2 Approaches to manage disruptions

The management of unplanned events in freight flows has been subject to research attention for decades, mainly from the perspective of logistics and the supply chain. The focus has mainly been on supply chains, evolving from supply chain risk management (Fan and Stevenson, 2018) to more recent adaptations of supply chain resilience (Wieland and Durach, 2021). The research stream on supply chain resilience has gotten additional attention via the COVID-19 pandemic broke out in 2020, with many journals have released special issues on the topic (Davis-Sramek and Richey Jr, 2021; IEEE, 2021). Because a key part of supply chain resilience is the management of transport disruptions (Ivanov et al., 2017), transport-focused research indicates value for literature on supply chains.

In an effort to manage disruptions to avoid unwanted additional costs, various strategies have been proposed (Christopher and Holweg, 2017). Those strategies follow approaches based on risk management and involve the steps of identification, assessment, treatment and monitoring of risks (Fan and Stevenson, 2018), or the implementation of resilience strategies (van der Vegt et al., 2015). The objective is an optimal combination of those strategies to avoid, postpone, reduce or transfer the risk of disruptions (Wagner and Bode, 2009). From a time perspective, researchers have divided those strategies into ones that generate actions taken before disruptions and ones that generate actions made after disruptions (Tomlin, 2006; Albertzeth et al., 2020). Wieland and Wallenburg (2012) added to this perspective with two additional ways of managing disruptions in terms of resilience, namely robustness and agility. Robustness, similar to risk management, refers to focusing on proactive and anticipative strategies before disruptions occurs, for example, by using predefined recovery actions (Ivanov et al., 2017) or making inventory and/or supply chain design decisions (Wieland and Wallenburg, 2012). Agility includes how quickly a system reacts and responds to a disruption to solve the situation. For that purpose, the use of information has been emphasised, for instance by ensuring visibility of operations (Christopher and Lee, 2004) by improved communication between actors (Wieland and Wallenburg, 2012). Robustness and agility involves generating multiple alternatives, such as having multiple suppliers (Tang, 2006) or back-up transportation (Zhen et al., 2016), or making business continuity plans (Norrman and Jansson, 2004), or setting up new channels of communication (Wieland and Wallenburg, 2013) in order to prepare a system to act accordingly when disruptions occur.

Another classification of those strategies was raised by Wagner and Bode (2009) by viewing what the strategies aim to manage, either the cause or the impact. Cause-oriented strategies focus on reducing the probability of a disruption, such as by making new design decisions discussed above (Wieland and Wallenburg, 2012). By considering the causes of disruptions, those strategies are performed before disruptions occur. The other class of proposed strategies focuses on limiting or mitigating the consequences of disruptions, that is, the impacts. Similarly, to robustness and agility, those strategies are from a time perspective represented both before and after disruptions occur. A distinction can be made that a strategy before a disruption occurs, preparing to mitigate potential disruptions and a strategy after disruptions occur consider responses to achieve recovery following actual disruptions (Behdani, 2013; Blackhurst et al., 2005).

2.3 Focus on managing disruptions in the thesis

To differentiate the approaches adopted before or after disruptions occur, mitigation actions are viewed as being taken before disruptions occur, whereas recovery actions are viewed as being taken afterwards (Tomlin, 2006; Albertzeth et al., 2020). Even though recovery actions aim for mitigation, in this thesis they are viewed as actions taken only if a disruption occurs to respond to a disruption and achieve recovery, whereas mitigation actions are taken no matter if a disruption occurs or not (Tomlin, 2006; Blackhurst et al., 2005). Figure 2 illustrates this focus in the thesis on recovery in relation to a disruption and the view of resilience as an overarching umbrella term. Nevertheless, research on resilience has mainly taken an approach of designing transport and/or logistics chains before execution (i.e. mitigation) and not paid attention to recovery following disruptions (Behdani, 2013). Even though, aspects of operational recovery have been discussed in terms of transport resilience, the viewpoints have concentrated on contingency plans that should be implemented when disruptions occur or the increased need for information sharing (Woodburn, 2019). Those viewpoints are not the perspective of the process of disruption management as followed in this thesis, including detection and prediction before a contingency plan can be utilised. Moreover, resilience has primarily been used in connection to disruptions with high impacts (Wan et al., 2018), which may explain why resilience is lacking the aspects of operational disruptions, as treated in this thesis. The operational view on disruption management to update plans during the execution of operations differs from the view present in around resilience of designing a supply or transport chain correctly before the operations are performed. Additionally, as seen in Figure 2, the learning process after disruptions can be present both for cause oriented and impact oriented approaches, to adjust the design of the chains (Blackhurst et al., 2005).

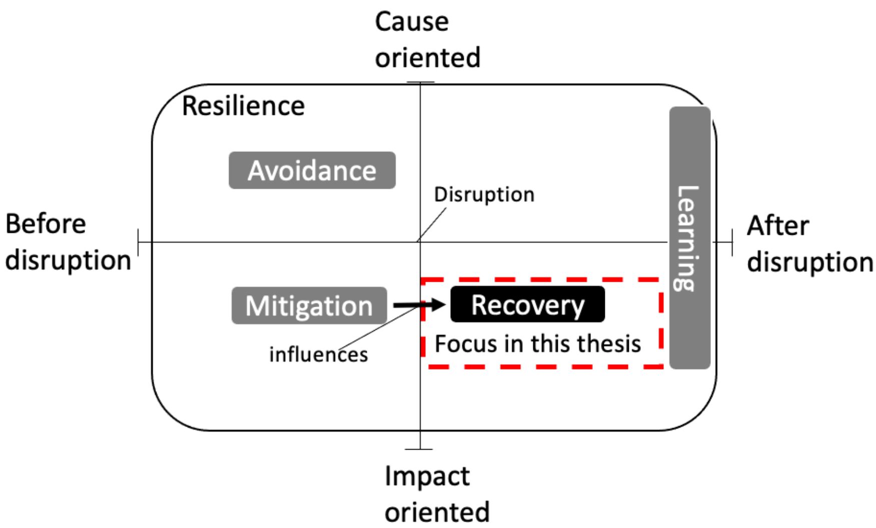

Figure 2. The focus of this thesis on recovery and other approaches in relation to the time axis of before or after a disruption and the axis of being cause or impact oriented.

Actions in the recovery phase require exchange between actors (Bode et al., 2011). Nevertheless, mitigation actions, such as buffers (Bode et al., 2011), influences the information needed between actors in the recovery phase (Timmer and Kaufmann, 2019; Wieland and Wallenburg, 2012). From a supply chain perspective, exchange between actors in the recovery phase has been discussed as the opposite of buffering, that is, as mitigation action (Timmer and Kaufmann, 2019). Mitigation actions provide different possibilities to act when disruptions occur, as illustrated by the arrows in Figure 2. For example, if no alternative mode of transport has been outlined, then the shift to another mode after disruptions occur becomes challenging. At the same time, if inventories are in place, then the need for re-planning may be redundant. Buffers could include back-up transportation (Zhen et al., 2016), buffers of inventory or lead-time (Angkiriwang et al., 2014). Given the nature of transport operations, to be a part of transport service (Lumsden et al., 2019), for example, the service of delivering a container to a warehouse, the service needs to be produced and consumed at the same time. That implies that buffers utilised in transport operations are mainly represented by capacity and time buffers (Lumsden et al., 2019). The inventory buffer strategy, as most strategies discussed in the literature (Chopra and Meindl, 2003), takes a supply chain perspective and includes decisions that the owner of the freight can make, which is often not the same actor responsible for the intermodal freight transport chain. Examples of those mitigation strategies are having multiple suppliers, alternative modes of transportation, alternative suppliers, possibilities for transhipment between warehouses, using vendor-managed inventory, carrying additional inventory, or postponement (Wilson, 2007).

The mitigation actions taken before disruptions occur stem from a risk-management tradition in which approaches are developed to identify risks that enable decision-makers to anticipate deviations from plans before operations are performed (van der Vegt et al., 2015). The mitigation actions are important for the recovery from disruptions, but often do not consider time aspects of the disruptions (Dunke et al., 2018; Heckmann et al., 2015). Without a given risk source, most of these approaches tend to fail to provide decision-makers with sufficient support (van der Vegt et al., 2015). Delivering predefined recovery actions that lack active anticipation via real-time information of disruptions and impact provides the limitations of these strategies for managing disruptions after they have occurred (Feldman et al., 2013). For recovery actions to minimise impacts, a high level of visibility has been proposed (Meyer et al., 2014; Gumuskaya et al., 2020a), such as via a decision support system (DSS) (Séguin et al., 1997), while the benefits of lower levels of product buffers or time buffers can be obtained as well (Christopher and Lee, 2004; Zuidwijk and Veenstra, 2014). Real-time information about the operations can support decision-makers in the recovery phase in taking suitable actions (Séguin et al., 1997). The recovery phase is additionally in focus in this thesis because it has been studied less than the mitigation strategies (Nel et al., 2018; Behdani, 2013). Christopher and Holweg (2017) have provided a possible explanation for this, that previous approaches have revolved around planning ahead, not how to respond to events as they happen. Furthermore, despite the maturity of the field of supply chain risk management, little knowledge is present for monitoring risk, which is directly linked to recovery (Fan and Stevenson, 2018).

2.4 Recovery actions in intermodal freight transport

When a disruption occurs, actions aiming to achieve recovery need to be quickly implemented to minimise impact with the support of visibility for an impact assessment of the disruption and the effects of recovery actions (Ivanov et al., 2017; Sheffi, 2015). Evaluations of recovery actions have been studied in different freight transport settings. For container transport, Gumuskaya et al. (2020a) investigated impacts of the delays of containers arriving at a port with an updated planning process. The authors found that comparing scenarios with complete and incomplete information about transport orders during such delays, the complete information scenario provided better results for costs and modal split for inland transport than the incomplete information scenario. Albertzeth et al. (2020) investigated how mitigation and recovery strategies influence recovery. They deployed the mitigation strategies of buffers, stock at a distribution centre, and the recovery action of alternative routes for transport disruptions in road freight transport between a production site and a distribution centre. Additionally, a scenario of using no strategy (of stock or alternative route) was included, as well as a mixed scenario between the two strategies. The results showed that the worst strategy (i.e. no strategy) for the service level is the best strategy for costs, and that strategies with higher costs improved the service level. Nevertheless, the scenario adopting no strategy was dominant for both costs and service level. Therefore, the authors concluded that the choice of strategy depends on how a company aims at managing costs and service levels. An interesting result was that the buffer strategy was found the most costly without offering the best service level. Burgholzer et al. (2013) studied the impacts of disruptions on intermodal transport with the options of road-rail network or water network for alternative routes. The results showed that a model aiming to reduce transport time chooses the road-rail network more frequently than the water network during disruptions. Similarly, Hrušovský et al. (2021) evaluated the strategy of waiting, making a transhipment at a node or re-routing freight for road and rail intermodal freight chains. These three strategies were implemented for a DSS to evaluate the use of these strategies in comparison to a planning model without a re-plan strategy. The results indicated that the performance of the DSS was reasonable, such as of computational times, compared with not using a DSS. Meyer et al. (2014) explored operational control in a case study on road transport via a consolidation terminal. The results showed issues with using the real-time information to detect disruptions, which lead to development and testing of a DSS. Li et al. (2018) highlighted disruption management regarding the arrival of trucks at a port and considered disruptions for trucks outside the port (referred by the authors to as land-side disruptions). Depending on the punctuality of the trucks arriving at the port, different strategies were evaluated. The strategies included serving arriving trucks on a first come first served (FCFS) basis, serving trucks picking up containers closest in the yard first (i.e., maximising port equipment utilisation), and the last strategy, which was a mix between priority and closest containers. For early or late truck arrivals, the turn-around time increased, and FCFS performed worst of the four strategies, whereas the strategy of minimising port equipment utilisation performed the best. Elbert and Walter (2014) provided an example of using real-time information, namely the estimated time of arrival (ETA) for ships arriving at a port, to manage operational disruptions. In a simulation model, the study highlighted increased train utilisation with an ETA versus without an ETA. Additionally, a scenario involving a buffer of containers was used if the planned containers were not ready for the train on-time. This strategy represents a buffer in the system instead of sharing real-time information about the ETA before the container arrives at the port.

In the studied literature above, two distinct categories of actions to achieve recovery are present. These are recovery actions via the use of real-time information as a common denominator (Li et al., 2018; Meyer et al., 2014; Hrušovský et al., 2021) and (mitigation and) recovery actions using buffers. The buffers provide no need for real-time information whereas the recovery actions of re-routing or transhipments requires that information. Predefined buffers of time and/or products then function as shock-absorbers (Bode et al., 2011) for disruptions and therefore support the operational planning in avoiding impacts from a disruption or at least mitigating its impacts. In connection to recovery via real-time information, disruption management has been highlighted as important to supporting the operational planning to minimise impacts on the intermodal transport chain (Hrušovský et al., 2021). Nevertheless, the recovery actions discussed above have been described as actions that should be taken to facilitate the management of disruptions. With the study from Meyer et al. (2014) on road freight transport as an exception, no study has been devoted to the process of ending up in these actions, such as detection of a disruption (Blackhurst et al., 2005), as suggested to be achieved via cooperation and exchange between actors (Bode et al., 2011; Timmer and Kaufmann, 2019). Li et al. (2018) and Elbert and Walter (2014) touch upon the issue of real-time information and provided insights into specific types of information. Nevertheless, Burgholzer et al. (2013) even states their assumption that "each transport unit always has complete information." Thus, each transport unit knows immediately when a disruption occurs about its disruption parameters" (Burgholzer et al., 2013, p. 1581). Even if recovery actions are in place, for example, to alter the route if disruptions occur, to be able to manage disruptions it is vital to first detect disruptions before an action can be taken (Meyer et al., 2014; Sheffi, 2015).

With the aim of bridging gaps in the understanding about using real-time information for disruption management and making connections to the disruption management process, the next sections discuss how coordination influences the real-time information that can be used for disruption management and the phases of disruption management in relation to the information.

2.5 Connecting coordination and disruption management

The exchange between actors in the recovery phase, as discussed above, includes interorganisational aspects that influence the real-time information. An important approach to understand the relationships in intermodal transport has been the concept of coordination (Monios and Bergqvist, 2015; Xie et al., 2017; Zhou et al., 2018). For container transport to and from ports, Lang and Veenstra (2010) concluded that coordination is a key factor to achieve benefits associated with updated operation plans when containers are delayed to port. Moreover, viewing intermodal freight transport as a network or chain gives rise to an increased number of interdependent transport operations that need coordination compared with a direct link in a network (Woxenius, 2007). The coordination approaches are in line with the interdependencies present in intermodal transport operations. To achieve recovery, such as via actions based on real-time information, operational coordination considered in this thesis is viewed as influencing the real-time information shared between actors. The focus on coordination is particularly present in the intermodal transport part of port hinterland transport (van der Horst and De Langen, 2008). The main focus has been on contractual issues in coordination (van der Horst et al., 2019) and incentives for alignments and alliances in coordination (van der Horst and van der Lugt, 2011). Gumuskaya et al. (2020b) identified a lack of operational coordination in the hinterland transport literature and highlighted its importance in supporting the dynamic nature of operational decisions. The authors developed a three-layer hierarchical framework of contracting processes, planning processes, and physical processes.

2.6 The phases of disruption management

Following the terms of research on technological solutions used to manage disruptions, the main phases of disruption management are the detection of disruptions, the prediction of their impact and action of suitable alternatives (Séguin et al., 1997; Feldman et al., 2013). These terminologies for the phases in disruption management correspond to similar phases of recovery, viewed from a supply chain management perspective. For instance, Blackhurst et al. (2005) discussed disruption discovery, disruption recovery and supply chain redesign, which include the same phases of detection, understanding how companies can recover (i.e. acting) and the broader perspective on how the supply chains learn from disruptions, thereby leading to the redesign of the supply chain. Similarly, Macdonald and Corsi (2013) followed these phases for recovery from disruptions with high impact in supply chains. Behdani (2013) discussed the disruption management cycle that is performed after a disruption has occurred. The cycle includes the phases of disruption detection, disruption reaction, disruption recovery, and disruption learning. However, a clear distinction of disruption management at the operational level is not made in that model, for the step of predicting the impact of a disruption is missing. Including the prediction phase is important because a disruption can impact in various ways (Reis, 2019), such that predictions are needed to determine possible impacts. The actions emerging from disruption management have been discussed above, and the phases of detection and prediction are described below in association with different characteristics of information.

2.6.1 Detection

The detection phase of disruption management describes what has happened by gathering and understanding real-time information connected to the transport system (Mishra et al., 2017; Batalden et al., 2017). The time at which a disruption is detected is important because it initiates disruption management (Macdonald and Corsi, 2013). The time between finding out that a disruption has occurred and identifying its first impact on the business (e.g. transport chain) has been called detection lead time (Sheffi, 2015). The later that the disruption is detected, the fewer the options available are to avoid or mitigate impact, or else the detection may be made after the impact, thereby resulting in reactions to the impact. Additionally, the secondary consequences of a disruption may be more amplified than the first impact (Świerczek, 2014).

Detecting a disruption, such as when the actual status differs from the planned status with a defined threshold (Otto, 2003), requires identifying the status of operations. What is detected in terms of the planned status and the actual status varies depending on what the status represents. The attributes for detection, for example time, quantity or quality (Otto, 2003), indicate what disruption is being detected in the transport chain. Detecting a difference between the planned status and the actual status for a predefined purpose may detect a disruption in current operations (Blackhurst et al., 2005) or a disruption able to impact planned operations (Feldman et al., 2013). As pointed out by Dunke et al. (2018), a disruption can stem from many diverse sources of disruptive events, which creates a need for real-time information about many parts of the transport system (Meyer et al., 2014; van der Spoel et al., 2017). Regarding different impacts that can be detected, Reis (2019) categorised the impacts from a disruption into primary impacts, secondary impacts and tertiary impacts. A primary impact is exemplified in delays in a transport leg, a secondary impact includes, for example, not having an IT system to identify the delay and a tertiary impact is when contract rules limit the options to book new transport. Nevertheless, the author made no connection between detection and these impacts.

Detection can vary depending on how the monitoring of visible operations is performed to obtain real-time information related to disruptions (Fernández et al., 2016). Fernández et al. (2016) argued that detection is made via reactive monitoring based on real-time information about an occurred disruptive event, that is, monitoring information about performance indicators for an operation (Adhitya et al., 2007). Alternatively, the predictive monitoring of information from operations and the surrounding system environment are used to predict the disruptive event. The real-time information concerning operations, or the surrounding variables, can be presented to the responsible planner at different time points. The time of visibility is further important, as Goel (2010) distinguished between no updates, once a day, at checkpoints at the end of operations or at checkpoints during operations. In their study, more frequent updates yielded earlier detection and better on-time delivery when the disruptions occurred. How the visibility and monitoring are executed is in turn connected to the tracking and tracing systems being used. The source of real-time information in transportation systems can be linked to freight, vehicle or infrastructure (Stefansson and Lumsden, 2009). Meyer et al. (2014) investigated a case in which three state-of-the-art systems were in place to capture and analyse real-time information about operations. These three systems were an enterprise resource planning (ERP), a GPS-based transport tracking system and an advanced planning system (APS). The information from the ERP and GPS systems was automatically connected to the APS. Even though the case had up-to-date systems, the authors found that the support systems failed to have updated real-time information or manual detection by planners, which caused problems with timely detection. Issues with the manual detection were connected to the number of sources of real-time information, such as information for transport operations about weather, road conditions and driver schedules (van der Spoel et al., 2017). These issues resulted in the delayed detection of disruptions (Meyer et al., 2014).

Where a disruption is detected in the logistics and transport system is another important aspect of when detection is made (Behdani, 2013; Nel et al., 2018). Disruptions in supply chains are categorised as internal within an organisation or external when outside the organisational boundaries but either within or outside the supply chain network of the company (Christopher and Peck, 2004). Wilson (2007) investigated the influence of transport disruptions on a supply chain consisting of five echelons and concluded that transport disruptions between the first tier and a warehouse had the greatest impact on the supply chain. A system for freight transport can be adapted to the three levels of infrastructure, transport flow and material flow, according to Wandel et al. (1992).

2.6.2 Prediction

After detection, the business impact of what could happen needs to be analysed in the prediction phase (Mishra et al., 2017; Séguin et al., 1997). ICTs have enabled more visibility for operations and the surrounding environment and supported future time periods for predictions to have certain accuracy for a look-ahead period in the near future (Dunke et al., 2018). Even though a large focus on developing methods for predictions has been present in intermodal freight transport, Veenstra and Harmelink (2021) found limited use of these methods in practice for ship arrivals, leading to low prediction quality. Prediction depends on the detection of disruption. If the detection is made before the impact by anticipating an impact from a disruption, then the prediction is of a future state that is undesirable (Feldman et al., 2013). Predictions can further be made about how long a disruption will impact the chain (Dunke et al., 2018). Predictions can be made by a system based on real-time information or historical data or can be manually performed based on human experience (Batalden et al., 2017; Knemeyer et al., 2009). For the prediction to be reliable, it needs to consider the surrounding environmental variables in the transport chain (van der Spoel et al., 2017). Meyer et al. (2014) described how the complex relations between shipments in a transport system complicate understanding impacts further down in a transport chain, while van der Spoel et al. (2017) indicated that more information than mere traffic updates on a route is needed for reliable predictions of arrival times at a terminal, for instance, truck drivers' intentions and schedules.

2.7 Synthesis of the studied literature

The studied literature discusses different perspectives on minimising impact from disruptions, with focus on avoidance, mitigation or recovery. As research area on disruptions in intermodal freight transport has matured, several researchers have recognised the importance of real-time information during recovery from disruptions. However, previous intermodal freight transport literature predominantly examines a limited scope of various actions that influence the impact with limited insights into the connection between real-time information and the process of disruption management prior to these actions. The theoretical framework presented in Figure 3 includes a logical base for connecting the description of operations involved in and the concepts around managing impacts from disruption at an operational level with a focus on disruption management.

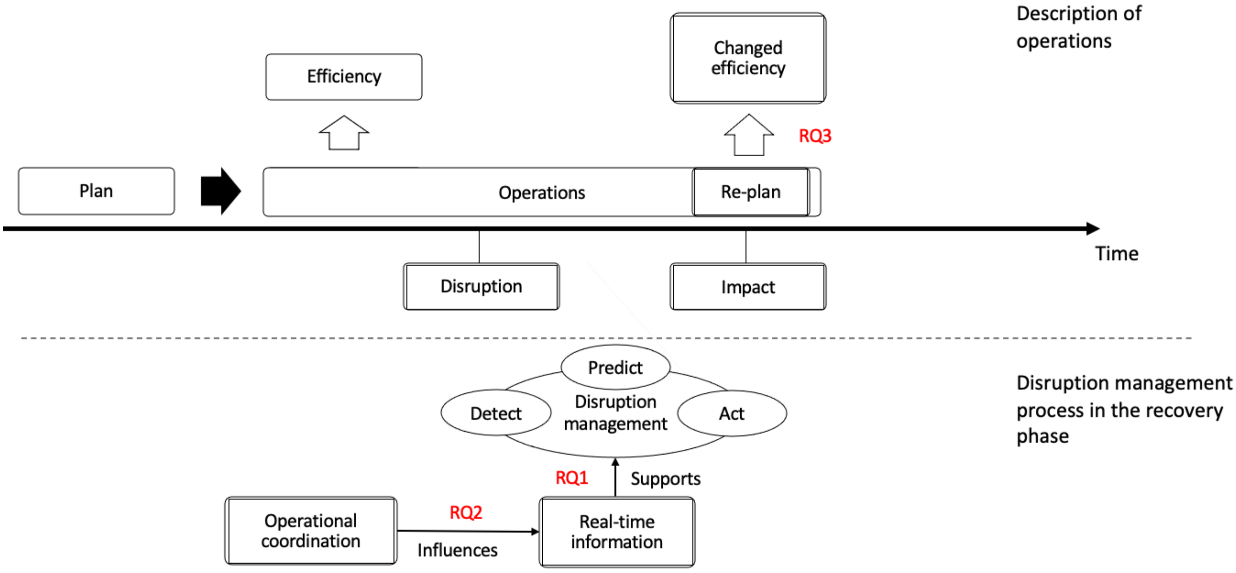

Figure 3. Conceptual framework of disruption management, including the research questions in this thesis.

The framework in Figure 3 displays a timeline where first an operational plan is created (e.g. a transport plan), which leads to operations that, in turn, generates the efficiency. The operations continue after a disruption occurs, as illustrated in the figure. As operations continue after disruptions occur, they require a re-plan, with a changed efficiency. Disruption management aims to mitigate impacts during the recovery phase by providing support with real-time information for the phases leading up to an action. As shown in the figure, the process of disruption management consists of three phases: detect, predict and act. Operational coordination is viewed as influencing the real-time information for this purpose. Additionally, the figure illustrates the positioning of the research questions in relation to the concepts.

2.7.1 Real-time information for disruption management

To illustrate a synthesis around real-time information for disruption management in intermodal freight transport, the discussed real-time information in the recovery phase is put in relation to the factors from Mohr and Nevin (1990). Figure 4 provides the view on real-time information taken in this thesis.

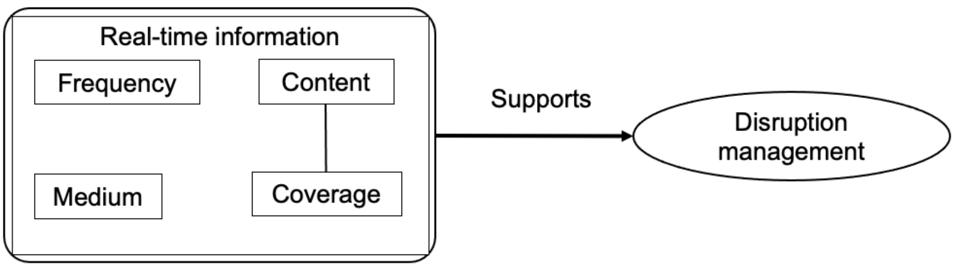

Figure 4. The view in the thesis on real-time information based on the factors that support disruption management, adopted from Mohr and Nevin (1990).

The factor of frequency has been discussed in terms of different updates of the information influencing the impacts (Goel, 2010) and whether the information is complete or not (Li et al., 2018; Gumuskaya et al., 2020a). In connection, the content of the information has not been elaborated further. Instead, the content, such as the arrival of trucks or ships at a port, for instance, has been viewed as being fixed for the specifically problem investigated (Li et al., 2018; Elbert and Walter, 2014). Indications of the importance of various content in information have been given, including from an explorative study on the prediction of truck arrivals at a terminal (van der Spoel et al., 2017). An additional factor of coverage, not included by Mohr and Nevin (1990), related to the content factor of real-time information with implications for the disruption management, raised from a logistics and supply chain perspective, is whether disruptions occur in operations from the own organisations' part of a chain or in operations in other parts of the chain (Nel et al., 2018; Wilson, 2007). Connecting this distinction to requirements for the content of real-time information (i.e. link between content and coverage, in Figure 4), it is reasonable to assume that real-time information from different parts of a chain influences disruption management. The factor of medium, as freight transport research in general, has been discussed as revolving around a DSS (Hrušovský et al., 2021), with different supports from information systems as well as manual parts to make information available (Meyer et al., 2014). No clear indication for the factor of direction related to real-time information for disruption management was found in the literature. In sum, mainly fragmented approaches on various aspects on information and disruption management have been found. These fragmented approaches provide little insights into connections between real-time information and a disruption management process of detection, prediction and action.

3 Research Methodology

This chapter describes the main methodological choices made in the research conducted for the thesis and how these choices impacted the results. The chapter starts with a section of the research process. This is followed by research design, that connects the research questions to the various studies and elaborates on the performed sampling, data collection and data analysis. Finally, the research quality is discussed at the end of the chapter.

3.1 Research process

The research started as a part of the European Union (EU) project "AEOLIX", which is an acronym for architecture for European logistics information exchange. The project started in September 2016 and ended in August 2019, while this research started in February 2017 when the author started a PhD student employment position. The main objective of the project was to increase knowledge about sharing information among actors in logistics (AEOLIX, 2017). The beginning of the research conducted for the thesis was guided by the focus in this EU project on developing of a cloud-based solution for information sharing between all logistics actors in the project, which provided a base for the research in this thesis towards studying possible future usage of such a solution, namely for disruption management. Therefore, as illustrated in Figure 5, Study 1 of the presented research did not have a distinct focus on disruption management as the following studies did. Another starting point for the research in this thesis, illustrated in Figure 5 that aligned with the focus of the EU project was the improving of efficiency via the processes of planning and operations. After understanding how the plan leads to operations and how plans are adopted depending on the feedback received regarding efficiency, it became clear that the problem was managing operations subject to disruptions. That change of direction in the research focus is illustrated in Figure 5.

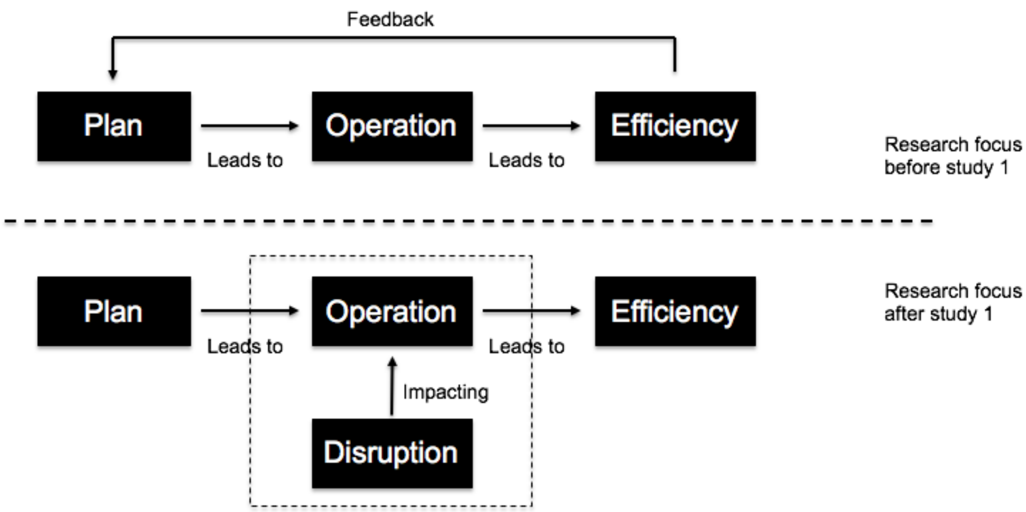

Figure 5. Research focus before and after Study 1.

For the remaining time of the PhD process (i.e., since September 2019), the research was funded by the Value2Sea project, an interregional EU project for the Öresund-Kattegat-Skagerrak region, and by the Swedish Logistics and Transport Foundation (LTS). The aim of the Value2Sea project is to identify potential improvements for the transport chains in the region by using new technology, implementing logistics and transport concepts for the benefit of the environment and easing congestion in economically viable ways (Value2Sea, 2021). The research project provided the performed studies in this thesis with a scope of intermodal freight transport in connection to a port, hinterland freight transport. Additionally, the project provided possibilities for new collaboration with transport researchers, which broaden the understanding and gave additional insights into freight transport for the conducted studies.

3.2 Research design

Managing disruptions with real-time information can be viewed as responding to practical problems found in the initial studies conducted in this research. Influenced by the research questions, my background and my understanding of the studied literature, the research studies were designed. The research on real-time information for disruption management is argued in Chapters 1 and 2 to not have been extensively covered in the context of intermodal freight transport. The presented research connects to previous research view on practically oriented research. Furthermore, the research, similar to many studies in the studied and used literature, departed from input on supply chain and logistics research, for example, the literature on supply chain risk management or supply chain resilience. The supply chain and logistics literature have strong roots in a positivistic, deductive and closed system thinking (Aastrup and Halldórsson, 2008; Adamides et al., 2012). These roots have influenced the methods used in the studied literature, and the conceptual frameworks derived from them in the appended papers. Additionally, my engineering background has influenced the research conducted, such as wanting to “engineer” a system, which Checkland (2012) described as hard system thinking, similarly to a closed system thinking. In this approach, the underlying assumption exists that a manager can plan a transport or logistics system to function as desired, assuming that the humans involved, for example, in operations, will follow these planned logics, or at least that a manager will sufficiently impose these logics (Aastrup and Halldórsson, 2008). Nevertheless, input from other viewpoints, highlighted as being important for new views in logistics (Stentoft Arlbjørn and Halldorsson, 2002), has been considered during the research process and in selecting methods in the various studies. For instance, because all companies approach risks and manage disruptions differently, as well as take different approaches to sharing information, there is a lack of standard solutions to study. No standard solution for guidance makes it interesting for in-depth studies, for example of how planners receive and use real-time information for disruption management. Nevertheless, the planners were viewed as following planned logics on how to perform the planning and monitoring of operations. Rather, the main approach for the conducted studies followed the objective to understand the planning processes and associated disruptions by describing and explaining these processes and the connected real-time information. This approach provides an exploration of real-time information for disruption management in the studies conducted as port of the research, which in combination with the ideas of disruption management provided knowledge about how the system could use real-time information for a given outcome (reduce impact of disruptions). Additionally, Study 4 was based on a conceptual framework originating from organisational theory and an open system approach, which gave input to a broader view than a hard system perspective.

3.2.1 Research studies

Studies 1-4 were conducted as case studies involving qualitative methods for data collection and analysis and Study 5 was a case study following a quantitative approach. Two key elements were considered in the studies for studying disruption management in intermodal freight transport. The first was operational disruptions, which can occur not only in the operations of an organisation but also outside an organisation. This requires considering the environment of the actor, including its interorganisational considerations, when studying disruption management. The second element was operational actions, which in relation to disruption management are time-dependent, meaning that they need to be taken within a certain, often brief, time frame. Therefore, it is of interest to consider how these re-plan actions are performed not only from a conceptual viewpoint (e.g., incorporated into a mathematical model) but also depending on the real-time information provided and the process of disruption management. To capture these parts of disruption management, qualitative case studies were deemed to be most suitable for studying disruption management within its real-world contexts (cf. Yin (2014)), to capture multiple aspects and to gain in-depth understanding (Flick, 2014; Ellram, 1996) of real-time information for disruption management. Research questions 1 and 2 are both "how" questions, which are suitable to answer by qualitative case study approaches (Ellram, 1996). After these studies were conducted, a quantitative study was designed, to give insights into the efficiency effects of real-time information for disruption management. That study was guided by the third research question which is a "what" question addressing efficiency effects, for which simulation provided a suitable approach (Ellram, 1996). Discrete event simulation has been shown to be suitable for simulating operational decision-making in logistics research, such as decisions about distribution and transport planning (Tako and Robinson, 2012). The simulation enables performing what-if analyses of a real-world system without having to interrupt the ongoing operations (Banks, 2004). This is furthermore linked to findings in the first studies, as the limited support of real-time information for disruption management in the studied chains did not make it possible studying the effects without interrupting ongoing operations. All studies can be viewed as single case studies, which were deemed suitable to be suitable for providing in-depth data regarding real-time information for disruption management (cf. Flyvbjerg (2006)).

3.2.2 Structure and process of the research design

The purpose of the research was central in all the studies and guided the research questions, as described in Chapter 1. Developing the research questions involved a continuous process of reformulation during the research, which Maxwell (2013) highlighted as being positive for the research design. The links between the research questions, the studies and their connected outcomes as papers are illustrated in Figure 6, which shows that Studies 1-3 were previously reported in a licentiate thesis (Wide, 2019). Notably, the papers connected to these studies were further developed after the licentiate thesis.

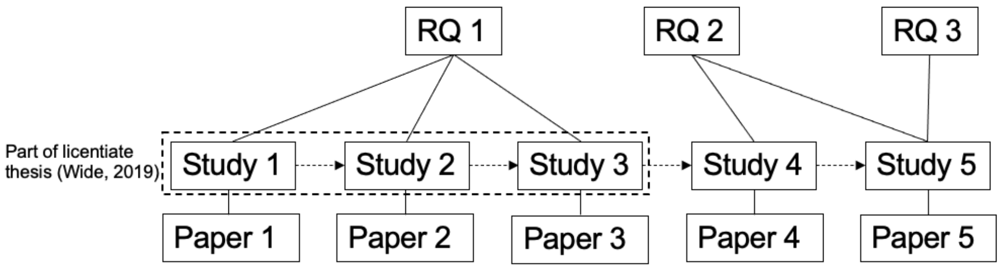

Figure 6. Overview of links between research questions and the studies as well as between studies and papers.

Studies 1-3 provide insights into research question 1, as the studies, to varying extents, aim at describing and explaining the links between real-time information and disruption management. Study 1 did not have an explicit focus on disruption management but provides exploration of real-time information for operational transport planning. The results from this study redirected the research towards disruption management because using real-time information to detect changes to a plan was identified as problematic in the transport planning. Therefore, Study 2 set out to explore the phases of disruption management, contributing with insights into how real-time information supports various detection and prediction in different stages of disruptions. Building upon these insights, Study 3 investigated the real-time information about where in the transport system such information could support the management of disruptions and their impacts. Because Studies 1-3 were guided by a focus on the actor responsible for re-plan actions, a single actor approach was used to capture how real-time information supports disruption management (research question 1).

Guided by research question 2, the objective of the Study 4 was to cover multiple actors to capture the interdependencies between their operations that generate the need for coordination, while keeping real-time information for disruption management in focus. The link between coordination and the previously found empirical results regarding real-time information for disruption management guided this study. As such, Study 4 elaborated upon operational coordination as a way to steer real-time information available for disruption management. Last, research question 3 guided Study 5 to connect the concept of disruption management from the previous studies to the efficiency effects of intermodal transport operations.

The research within each study was iterative, as each study was based on a different framework developed during the study and included an iterative process between collecting and analysing the data. For example, a first version of the framework for each study was developed before the collection of data, which was based on important concepts identified in the literature. For each study, the framework was modified after new perspectives emerged from the empirical data collection. The iterative approach, both between the studies in the research and within each study, is comparable to an abductive approach (cf. Ketokivi and Choi (2014) and Dubois and Gadde (2002)). Furthermore, this is illustrated by how the literature was used during the research process. Each study involved a review of relevant literature for the study's scope and purpose, and the literature was continuously reviewed between all studies for the overall purpose of the thesis.

Table 1 provides an overview of the performed studies, their approaches for data collection and data analysis. Additionally, Table 1 connects back to the research questions that they originated from (as presented in Figure 6) via last column of contribution to answering research questions (RQs).

Table 1. Overview of studies and links to the research questions.

Study	Study characteristics	Data collection	Data analysis	Contribution to answering RQs
Study 1	Qualitative case study	Semi-structured interviews, observations and a document review	Thematic coding around resource utilisation	RQ 1: Initial description of real-time information in operational planning processes
Study 2	Qualitative case study	Semi-structured interviews and observations	Thematic coding around the phases of disruption management	RQ 1: Description of the phases of disruption management and connections to real-time information
Study 3	Qualitative case study	Semi-structured interviews and a focus group	Thematic coding about disruption management and transport system levels	RQ 1: Description of real-time information in different parts of the transport system influences the disruption management process
Study 4	Qualitative case study	Semi-structured interviews	Thematic coding about coordination from information processing perspective and disruption management	RQ 2: Description of how approaches to coordination influence real-time information for disruption management.
Study 5	Simulation study	Data generated from operational IT system and expert estimations	Cost representation for results from simulation software for efficiency measures	RQ 2: Description about buffers support for actions based on real-time information RQ 3: Indications around the effects of different real-time information and actions on the efficiency of transport operations.

3.2.3 The suitability of case selection strategies

The thesis is based on case studies on disruption management in three intermodal freight transport chains, in which the five studies were performed. The sampling strategy for the three chains was based on chains involved in the research projects, which were chains sampled on an early stage in the research projects before the author of the thesis became involved. The selection can be viewed as purposive sampling (Maxwell, 2013), as these chains were deemed suitable as study objects. The possibility of gaining in-depth knowledge from the chains, with a commitment through one of the research projects was weighted to be valuable. Additionally, other criteria were present for the chains. That the actors in the transport chains chose to participate in the specific project indicated an interest in improving the technical development of their processes. Furthermore, the actors in Studies 1-3 were chosen because they represented the actor with responsibility for the tasks, made by the transport coordinator (Woxenius, 2012), for planning the transport operations. By being responsible for those transport operations, the actor was expected to have the knowledge about the case of disruption management for the transport chain (see Papers 1-3 for details). This knowledge was viewed important input for assessing real-time information in relation to disruption management in a transport system. The actor was expected to be able to detect disruptions and have an overview of transport chains that would enable them to handle disruptions to minimise the impacts on delivery to customers. The chain used for Studies 4 and 5 provided an opportunity to examine the case of disruption management in an intermodal transport chain between a port and receivers, with a dry port setup and to include different actors involved in this intermodal freight transport (see Paper 4-5 for details). That opportunity allowed broadening the initial knowledge about real-time information on relation to disruptions from Studies 1-3 by including viewpoints from multiple actors and the possibility to study coordination between actors within the transport chain.

The starting point for selecting the first interviewees for Studies 1-3 was the operational planning and monitoring of transport operations at the actors, to capture the management of disruptions in real-time at the operational level. Thereafter, snowballing sampling was used by letting the interviewees recommend other relevant contacts (Bryman and Bell, 2011), to capture relevant interviewees at the actor. The interviewees for Study 4 were sampled via purposive selection of experts of the studied transport chain and via snowballing by the further recommendation of the experts interviewed (cf. Maxwell (2013)). Snowballing could have been impacted by how broad the network of people in the studied transport chain was from the interviewee. To mitigate a biased selection of only some actors, the author and other involved researchers first aimed at understanding the freight flows in the transport chain in detail to make ensure that important actors had been covered to capture existing interdependences and the coordination in the transport chain.

3.2.4 Coverage of intermodal freight transport systems

As a result of the chosen representation of disruption management in the transport chains, the five conducted studies cover different scope of an intermodal freight transport chain, as illustrated in Figure 7. The figure does not illustrate the actors involved in the different studies.

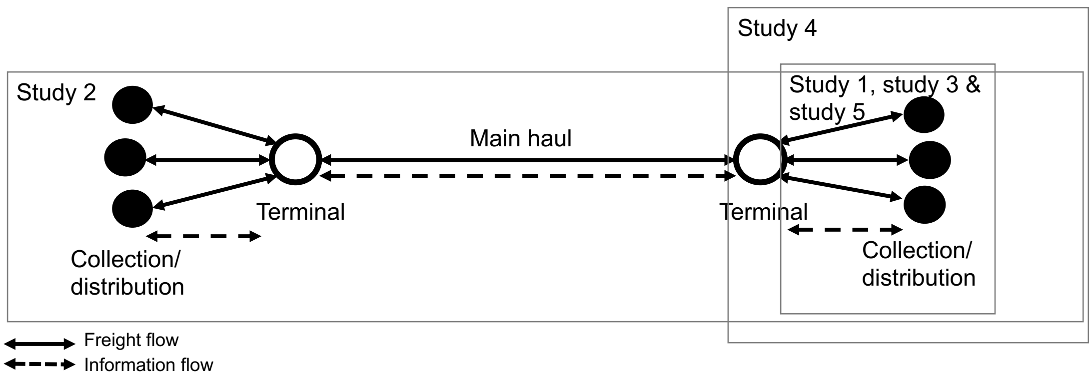

Figure 7. Overview of the scope of studies in relation to a general intermodal freight transport chain.

Studies 1 and 3 were based on the road freight transport of trailers to/from a port and customers. The second study was conducted on a rail and road-based freight transport system of trailers. The third chain, on which studies four and five are based, is a rail and road transport system from a port to customers. The scope of these two studies differs, as study 4 included the port, whereas Study 5 did not. All studies covered the Swedish parts of the transport system, even if the chains are also all parts of international intermodal freight transport chains. The studies aim to cover most parts of the intermodal freight transport, but as seen in Figure 7 consideration of the main haul has only been covered in study 2. The other studies gained insights into the main haul but did not explicitly cover the transfer of the load units of that haul. The rail transport part in study 2 was considered to be the main haul, as most of the freight transported from the terminal in southern Sweden was from consignors in the region. The small share of freight that had origins outside Sweden could be argued as having another main haul, one involving sea transport, with the rail transport being a collection/distribution part via rail.

3.2.5 Data collection

The five studies followed different approaches for data collection, as summarised in Table 2. The question guides for the interviews used in each study are appended in Appendix A and a detailed list of respondents is appended in Appendix B.

Table 2. Overview of data collection in the studies.

Study	**Source of data**	**Data collection**	**Approach**
Study 1	Semi-structured interviews	Six interviews with four planners (1 out of each in the three available planning groups) and two managers	• Use of question guide • Extensive notes • Verification of answer summaries via email
	Observations	Terminal operations and the planning and monitoring process on three occasions (1-3 hours)	• Guided visits of terminal operations • Sitting next to planners during the planning process • Extensive notes • Verification of observations via email
	Document review	Documents for performance indicators	• Review of documents for performance evaluation or quality purpose
Study 2	Semi-structured interviews	Eight interviews with planners (covering all available (three) planners) and logistics business developers	• Use of question guide • Extensive notes • Follow-up interviews • Verification of answer summaries via email
	Observations	Terminal operations and the planning and execution process on three occasions (3 hours and on 2 working days)	• Guided visits for terminal operations • Sitting next to planners during the planning process • Extensive notes • Verification via follow up section where planner explained to observer
Study 3	Semi-structured interviews	Interviews with planners and their group manager in Study 1 that served as the basis for the study, complemented with a follow-up interview with the group manager	• Use of question guide • Extensive notes • Verification of answer summaries via email

	Focus group	3-hour discussion with two software developers and two business consultants	• Open discussion • Topic around solution for predicting arrival times for trucks to a terminal • Extensive notes
Study 4	Semi-structured interviews	Nine interviews with managers and operators at actors involved in the studied transport chain from the port to receiver.	• Use of question guide • Recording and transcription of interviews • Follow-up interview and follow-up questions via email • Use of multiple interviewers
Study 5	IT system data	Data on containers arriving at dry port via rail and on priority notification for containers covering one year	• Empirical data limit to trains with priority containers • Removal of outliers
	Expert estimations	Estimations given from CEO at the dry port operator and haulier and the freight transport manager at the main receiver	• Estimations where no empirical data was available • Estimations represented in terms of triangular distribution

The methods applied in the various studies aimed to contribute to answering the research questions. For research question 1, the data collection was guided to explore how real-time information supports disruption management. For that purpose, semi-structured interviews were considered to be suitable due to their flexibility in data collection (Bryman and Bell, 2011). This allowed interviewees to describe what they viewed as important to the topics and for the interviews to take directions other than those originally planned. In this way, the semi-structured interviews were an important way of gaining rich and in-depth data about real-time information for disruption management and thus of building up the knowledge around these concepts. The interviews mainly targeted the planning process combined with expansion of the focus on real-time information in relation to disruptions. Therefore, disruption itself was not the focus but the real-time information that the planners received when any type of disruption occurred. In this way, operational disruptions were covered while limiting the biases from the planners towards influencing certain disruptions with higher perceived impact than others. The interviews in the studies extensively covered the planners involved (see Papers 2 and 3 for details), such as all planners from all planning groups in Study 1 and all planners in Study 2. In addition to the planners, interviews with managers and logistics developers provided broader perspectives on the planning process, such as putting the planning and monitoring performed in relation to customers' needs.

To complement the interviews, Studies 1-3 involved using observations which aimed at confirming the data from the interviews and gaining further detailed data on how disruptions were managed. Observations are a good source of in-depth data of day-to-day situations that are able to complement interviews (Flick, 2014). Two types of observations were made. First, an observation of the planned transport operations in a terminal was conducted to understand parts of what was being planned and how some operations at the terminals were executed. Second, direct observations were made of the planning being performed by the transport planners. Additional data were collected to provide a full picture. For example, Study 1 included a document review, while Study 3 featured a focus group. The document review allowed to get data about information that was documented at the studied actor that supported the planners in different ways. The focus group allowed for elaboration by participants as a group (Bryman and Bell, 2011), which complements the interviews that were made with individual participants only. In the focus group, representatives of two system developers from a software developer of logistical solutions and two logistics consultants from a consultancy firm discussed real-time information for predicting the arrival times of trucks at a terminal in the studied transport chain, which could serve as a support system for detecting disruptions and predicting impacts. Both the software company and the consultancy firm were involved in one of the research projects and had connections with the transport chain. This allowed for the participants to speak specifically about the studied chain instead of transport chains in general. Nevertheless, both firms wanted to find solutions to establish an estimated time of arrival for the terminal to provide project deliverables, which could have meant that the project goals influenced the discussion. To mitigate this possibility, the author participated in the focus group discussion but only to steer it by asking questions to cover certain topics more extensively, without colouring the discussion due to my knowledge of the interview data. One of these topics concerned which real-time information they considered to be reasonable or not to include in a system for predicting arrival times.

Addressing research question 2, which concerned how operational coordination influences available real-time information for disruption management, Study 4 involved capturing interdependencies between actors and their operations and resources. Therefore, covering the views of different actors on this subject via semi-structured interviews with multiple actors was deemed to be suitable. The interviews aimed at addressing coordination and disruption management and were therefore based on questions about activities performed, connections to resources as well as other actors and information about the operations. Through the interviews, it was possible to acquire data from different actors, at different levels in the transport chain, both managerial and operational, to cover different viewpoints on the performed operations and connected coordination and information. The interviews with the managers provided a good overview of the transport chain studied, which was complemented by the interviewees at the operational level with greater details about certain operations. Due to the COVID-19 pandemic, all interviews in Study 4 were performed online, except for an initial interview with the transport manager at the main receiver of containers in the transport flow. The online setting may have influenced the connections made between the researcher(s) and the interviewees, which may have been improved by conducting in-person interviews. Nevertheless, online interviews provided easier access to the interviewees, who seemed to consider online meetings to be more convenient than having researchers visiting them at work.

A common approach taken in all these methods of data collection was maintaining an open view regarding real-time information. Information in connection to the disruption management was in focus in data collection, although no emphasis was placed on the boundaries of information, such as on what information was received or how. This approach originated from the focus on the disruption management process, which needs support from any type of real-time information. The approach influenced the data collection, such as influenced the question guides used, although the data collection mainly targeted disruption management via updates in the transport planning process. For this target, the data collection considered mainly updated information during the operations. The lack of real-time information additionally provided identification of the use of experienced-based information. The medium used for the information, its content and its direction were aspects considered but without being limited to one aspect (e.g. only information via information systems). Additionally, this approach towards information provided the possibilities to cover more detailed description of the main focus of disruption management, which may have been limited if aspects of information were included in the data collection, such as in the question guides.

Targeting research question 3, concerning the efficiency effects of real-time information on disruption management, involved using the method of a discrete simulation model in Study 5. The empirical data for the simulation model comprised both data from the IT system in use, such as the number of containers on the train registered by the rail terminal operator. These data are influenced by how consistent the operators are in reporting into the IT system. The data set used originated from two different systems, because the terminal had updated its system during the time period covered by the data, which could potentially indicate issues with reporting in the new system. The data were taken from the old system for the first time period, when the operators were familiar with what to do, and from the new system after a couple of months of learning, when the CEO of the IT system provider deemed that the operators had learned to work fluently with the new system. As an additional point, the accuracy of the data used in the model was given a reasonability check (Banks, 2004) by a freight manager at a receiver and the CEO of the terminal and haulier. For the input parameters for which no data were available, expert estimations were used for triangular distributions, as suggested by Banks (2004).

3.2.6 Data analysis

The analysis performed for research questions 1 and 2 followed a similar structure of the analysis of the content of empirical data (Flick, 2014), as it is the content of data that was of main interest in this research. In all studies with the qualitative case study approach (Studies 1-4), data were analysed by following the same base structure of thematic coding, which includes classifying the data in themes (Braun and Clarke, 2006). The themes in this research were derived to match the research questions on the studied area (Braun and Clarke, 2006) and were influenced by the abductive approach in the studies. The themes followed both the categorisation of similarities and differences and connections between themes (Maxwell, 2013). In the review of the relevant literature, the frameworks were developed (see appended papers) to guide the analysis of the empirical data. These frameworks inherited the assumptions from the used literature. Additionally, due to the abductive research approach, these frameworks guided data collection, such as question guides, while, on the other hand, they were influenced by the empirically collected data. One issue arising from this approach was separating the original ideas from the used literature with adaptations due to input from empirical data, so as not to mix results into the framework that guided the analysis of the data. To mitigate this mix, the studies included frameworks in discussion sections, as a framework combining the framework for analysis with the results. In one way, themes for the analysis were defined, for example, phases of detection, prediction and action (Study 2) and levels in the transport system (Study 3) and the empirical data filled these themes and added relevant points to the topics.

Analysis for research question 3 was made for output from simulation with the support of the analysis program (AutoStat), from which confidence intervals for the efficiency measures were derived. The measures were derived from input from actors in the transport chain and studied literature.

3.3 Research quality

Following critiques of subjective approaches in case studies (e.g. Flyvbjerg (2006)), different strategies for ensuring research quality have been used to mitigate risks related to subjectivity in case studies. To address the research quality of the research conducted in this thesis, this chapter includes the research quality for the qualitative case studies and the quantitative simulation study, respectively.

3.3.1 Research quality of the qualitative case studies

Halldórsson and Aastrup (2003) provided insights into ways of facilitating research quality when using qualitative methods in logistics research in terms of trustworthiness, including credibility, transferability, dependability and confirmability.

Credibility focuses on matching the reality of respondents with how the researchers perceives the given data (Halldórsson and Aastrup, 2003). Sharing research findings with respondents is one way to potentially ensure that the researcher understands the interviewee correctly (Bryman and Bell, 2011). In the research for this thesis, notes from the semi-structured interviews and observations were shared with the respondents to provide confirmation that the author had understood the answers correctly. Furthermore, use of various methods of data collection is a way to increase the credibility (Bryman and Bell, 2011). The qualitative case studies used semi-structured interviews as the main method of data collection, but other methods were used to strengthen the credibility, such as observations at on-site visits of both transport operations and planning processes, a document review and a focus group. Additionally, the interviews were conducted with persons in different positions at the actors to gain different perspectives, such as on the planning and monitoring process. The simulation study included system data, complemented with expert estimations for parameters where no data was available.

Transferability refers to how findings can explain the studied concepts in other contexts (Halldórsson and Aastrup, 2003), because findings in one context can justify useful interpretation in other contexts (Goffin et al., 2012). Instead of aiming for generalisability, the research in this thesis is referring to transferability for contextual generalisation (Halldórsson and Aastrup, 2003). Bryman and Bell (2011) suggest using thick descriptions to achieve transferability, by giving rich details about the studied objects. The empirical data in this thesis described the transport planning and coordination of operations as the starting points to develop a rich context for the actors in connection with the disruption management performed. Furthermore, this research included follow-up interviews to acquire more in-depth data and the results were related to the findings in the literature as a comparison check for transferability. The goal of these checks was to cover how the findings may relate to the same phenomenon studied in other contexts.

Dependability involves the consistent replication of results, where the similar instruments of the phenomenon generate comparable measurements (Halldórsson and Aastrup, 2003). The aim is to achieve findings and conclusions similar to what other researchers would obtain if they examined the same case study. To achieve dependability Halldórsson and Aastrup (2003) discussed the importance of the trackability of the research process and suggested documenting the process, including process decisions made, data sources used, questions asked and theories used. The process of the research conducted for this thesis was documented, and question guides were used for the semi-structured interviews. Similarly, the analysis of the collected data was done using defined frameworks adopted from the literature. Moreover, the methodological choices were discussed with research peers internally and externally at conferences, providing support that these choices are plausible to have been taken by other researchers if performing similar studies.

Confirmability considers how the data are interpreted by researchers in an effort to maintain objectivity (Bryman and Bell, 2011; Halldórsson and Aastrup, 2003). It is important that findings are based on data and can be tracked to a source, which allows verifying that the analysis of the data is free of bias from the researcher(s) in the most objective way possible. This traceability for interpretations of data can be achieved by documenting questions and theories underlying every finding and interpretation (Halldórsson and Aastrup, 2003). Studies 1-4 all included question guides and frameworks that supported this documentation. Other tactics include using evidence from multiple sources and creating a chain of evidence or having key interviewees review a draft of the report (Yin, 2014). To cover confirmability, the extensive notes were taken during the data collection in the research conducted for this thesis, such as during interviews, observations and the focus group. Studies 1-3 did not entail any transcriptions of recordings from the interviews, which could generate the possibility of missed points. To mitigate that risk, summary notes were submitted to the interviewees. Furthermore, the analyses were performed following the frameworks developed from the literature to analyse the content of the data in a structured way. The analyses for the single-authored papers were done by the author alone, but also for these analyses the process and findings were shared with other researchers within and outside the research group, such as at conferences, and with participants in the study. For the studies where multiple authors were involved, the main responsibility of analysis was at the first author, but the other authors were involved in the analysis as well. Additionally, the results in all studies were presented and discussed at internal and external conferences, which aimed at capturing biases from the author(s).

3.3.2 Research quality of simulation study

During the simulation study (i.e. Study 5), the framework for ensuring research quality in logistics studies developed by Manuj et al. (2009) was followed. The framework consists of eight steps, ranging from formulating the problem to documenting results. In Table 3, the steps are connected to the main adaptations made in the study.

Table 3. Steps performed to ensure the research quality of the simulation study (i.e. Study 5).

Steps	Adaptation made for Study 5
1. Formulate problem	The problem was formulated with input from Study 4, as the same transport chain is studied in both studies about efficiency effects of real-time information for disruption management. The case of delivering prioritised containers when a train arrives to a dry port delayed was found to be suitable for illustrating this problem.
2. Specify variables	Variables of interest were defined (see paper 5 for further details), which during the development of the conceptual model and simulation model were adjusted.
3. Develop and validate conceptual model	Assumptions and model components were defined with reference to Study 4 and checks with system experts, as CEO of the software developer for the used IT system, the CEO of the dry port operator and haulier and the transport manager at the receiver.
4. Collect data	Real-world data were taken from the IT system used at the dry port and from expert input (see paper 5 for further details).
5. Develop and verify computer-based model	AutoMod was used as simulation program. Manual walk-throughs of the simulation model behaviour via support of dummy variables were used for verification.
6. Validate model	Checks for the reasonableness of outputs from model and face validity from system experts.
7. Perform simulations	Representation of one workday was chosen, which was performed for 100 runs. For rationale behind these decisions, see paper 5.
8. Analyse and document results	AutoStat program was used to generate confidence intervals for the chosen output variables with varying delays, which was used in analysis for a cost purpose and results were documented in the report (paper 5).

4 Summary of appended papers

The following sections summarise the appended papers and highlight their contributions. The complete papers are found in the appended papers section at the end of the thesis.

4.1 Paper 1 – Information on resource utilisation for operational planning in port hinterland transport

A port's hinterland freight transport needs high resource utilisation to manage high maritime transport demands. Transport operations are executed in a dynamic environment, which changes the operations and generates the need for re-planning at the operational level. Re-planning alters the initial objective of resource utilisation. Information is one way to support the decision-makers by indicating the resource utilisation for the re-plan to understand how the re-plan changes the resource utilisation. In freight transport, resource utilisation is linked between resources, such that one resource depends on another to achieve its targeted resource utilisation. Resource utilisation further depends on the chosen system perspective. This complexity of resource utilisation complicates measuring and assessing resource utilisation in a complete transport system. Furthermore, the aim in the previous literature has mainly been to obtain high resource utilisation at the planning stage, without considering dynamic changes for operational decisions in the transport system. However, operational decisions may benefit from getting information about resource utilisation to make improved re-planning decisions. Therefore, the purpose of Paper 1 is to explore use of information related to resource utilisation for operational planning in port hinterland freight transport to facilitate the improvement of the same. To support this purpose, a framework combining different aspects of resource utilisation was developed. The framework was used to analyse data about the information used for resource utilisation in a single case study. The results from the case study identified three categories for use of available information for resource utilisation. These categories were real-time operational planning decisions consisting of information about resource utilisation available for real-time decisions, experience-based planning decisions which used information about resource utilisation based on experience, and information for input to make strategic decisions. The results imply that limited information about resource utilisation is being provided for re-plan decisions and only for one part of the utilisation, for example, payload instead of actual space used in a trailer.

The paper contributes by identifying the need for information that captures the complexity of resource utilisation also for re-planning decisions. Re-planning decisions in the case studied were mainly executed without direct connection to information about the resource utilisation. That lack of information generates issues for the planners with understanding how re-plans could impact the resource utilisation. This indicates the issue of performing operational freight transport decisions, taking resource utilisation into consideration, when changes in the system generate a need for re-planning decisions.

4.2 Paper 2 – Improving decisions support for operational disruption management in freight transport

Early actions after a transport disruption occurrence are of importance to avoid escalation into the supply chain. However, because research on transport disruptions has focused on the strategic level, knowledge about recovery after a disruption occurs at the operational level remains limited.

Therefore, the purpose of Paper 2 is to provide insights into operational disruption management in freight transport to achieve improved decision support for the recovery phase.

The paper originates from conceptualising the phases of operational disruption management, that is, detection, prediction and action, built on the previous literature. A single case study is used to investigate these phases for transport operations. The data from the case indicate different stages of a disruption, in which five types of detection can be performed. The detection can be made before any impact occur on transport operations in terms of detecting disruption, such as a car accident, or of an impact from a disruption, such as a road queue. Detection types after transport operations are impacted are divided between the detection of a primary transport chain impact, or if detection is made further down the transport chain, that is, detection of secondary transport chain impact, snowball impacts on upcoming transport operations, or even supply chain impacts. Additionally, it was found that issues for the detection types arose when complete definitions of what status should be checked to detect a disruption were lacking for the planners. Last, the influences of detection types on disruption management were identified made by linking them to the phases of prediction and action, which determine whether the final recovery action is proactive or reactive.

The paper contributes to the literature on disruption management in freight transport with additional understanding of performing recovery actions. The types of detection found in the recovery phase give insights into how to perform early recovery actions. These insights further established a basis for future development of DSSs for recovery actions in freight transport. Improved support for detection facilitates settings for prediction of the impact of transport operations leading to possibilities for recovery actions before transport chains are impacted.

4.3 Paper 3 – Real-time information for operational disruption management in hinterland road transport

The literature on disruption management in the port hinterland transport has mainly focused on recovery actions from a port perspective but with few approaches that include real-time information. Therefore, the purpose of Paper 3 is to explore real-time information for operational disruption management in road hinterland transport, in order to improve the road hinterland operational transport efficiency. A conceptual framework was developed that included the two aspects, namely, the phases of disruption management and the levels of a transport system. The framework was used to analyse the data collected in a single case study to provide insight into actions connected to disruption management. The results show how information from different levels of the transport system, or lack thereof, influences the actions performed in disruption management and that limited information at one level generates unnecessarily escalated impacts before detection from information at the next level. Additionally, information providing input for disruption management revolved around transport checkpoints (i.e. at transport nodes), such as information about when a truck arrived at a terminal, instead of continuous updates on information for status at links. This structure for the information used provided issues with early disruption management. The vaguely defined planned status at links were found as a possible explanation for use of information at checkpoints. The planned status at checkpoints was often more clearly defined, such as when a truck should arrive at the port to be able to make ship departure on time.

The paper contributes to the understanding of real-time information for managing operational disruptions in hinterland transport by connecting the details of such transport operations to information at different levels of the transport system. Furthermore, the results contribute to freight transport connected to ports by responding to the indicated need for research into disruptions outside ports.

4.4 Paper 4 – Operational coordination in intermodal hinterland transport as support for managing operational disruptions – an information processing perspective

Intermodal freight transport involves multiple actors that need to coordinate activities and resources. Previous port hinterland transport literature has mainly studied this from a strategic perspective, such as contracts and alliances. This has raised the need to examine the actual coordination performed during operations. The purpose of Paper 4 is to investigate the role of information, through an information processing perspective, for operational coordination in supporting operational disruption management in intermodal hinterland transport. Building on organisational information processing theory (OIPT), the operational coordination of a port hinterland transport chain was examined to provide insights into information for disruption management. Data were collected in semi-structured interviews from seven different actors involved in a port hinterland transport chain. The results indicate a focus in the studied chain towards reducing the need for information, namely by using buffers, instead of increasing information processing capacity. A focus on reducing the need for information processing provides less information available for disruption management. Additionally, the buffers hide issues of disruption management and generates little need to increase information processing, without considering the costs of both buffers and information processing. Last, most of the IT systems used in the chain for the transport operations focus on static monitoring of activities that provide information about static events and therefore lack the capacity to process information that can support early operational disruption management.

The paper contributes to port hinterland literature with insights into operational coordination by examination through the information processing perspective. These insights provide an understanding of the interplay between reducing the need of information processing or increasing the capacity for the information processing, which adds to the discussion about operational coordination. Additionally, the paper contributes by connecting these two approaches to the information for disruption management, generating insights into how information for disruption management is generated via operational coordination.

4.5 Paper 5 – Efficiency effects of information for operational disruption management in port hinterland freight transport - Simulation of a Swedish dry port case

Dry ports have been proposed as a solution for relieving port operations and providing possibilities for intermodal freight transport in the port hinterland. Even though information has been highlighted as important for the efficiency of port hinterland transport, for example, by supporting disruption management, the studies examining the efficiency effects of information for disruption management in port hinterland transport with a dry port are scarce. Therefore, the purpose of Paper 5 is to investigate the operational efficiency effects of information for operational disruption management in hinterland transport with a dry port setup, to facilitate efficient intermodal hinterland transport. This was done through the development of a simulation model of a real-world hinterland transport chain case with a dry port connecting the modes of rail and road. The simulation model was tested for when a train delay occurs to the dry port (i.e. by 30 minutes to 4 hours) and different information is given following different disruption management approaches. The results show that full information provides the possibility for disruption management to improve the resource utilisation of trucks and manage to fast deliver of prioritised containers during the delay of a train.

The paper contributes with insights into efficiency effects from various information given when a train delay occurs. The hinterland transport chain with a dry port contributes to broadening the scope in previous hinterland transport literature on disruptions that have focused on ports. The scope used provides insights on efficiency measures important in the hinterland transport rather than the port.

5 Discussion

To highlight the significance of the findings in the appended papers, the discussion in this chapter first addresses the findings in connection to the research questions and thereafter in connection to the purpose of the thesis. Four main contributions emerge of the thesis: (1) a detailed description of the connections between real-time information and the process of disruption management, (2) adding aspects of operational coordination to real-time information for disruption management in intermodal freight transport, (3) elaborating on the efficiency effects of real-time information for disruption management and (4) exploring the importance of real-time information for disruption management in intermodal freight transport.

5.1 RQ 1 - How does real-time information support disruption management in intermodal freight transport?

Real-time information supports disruption management to a varying extent related to delays found between the occurrence of a disruption and the initiation of disruption management. Such delays have previously been discussed in terms of detection lead time (Sheffi, 2015). The research in this thesis provided insights into how real-time information for disruption management influences this delay time. The representation of real-time information in connection to the phases of the disruption management process indicates how these delays for the disruption management process increase. Revisiting the part of the conceptual framework in Chapter 2 regarding this point, real-time information supports the initiation of disruption management in intermodal freight transport, in terms of whether it occurs before or after a transport chain is impacted, as illustrated in Figure 8.

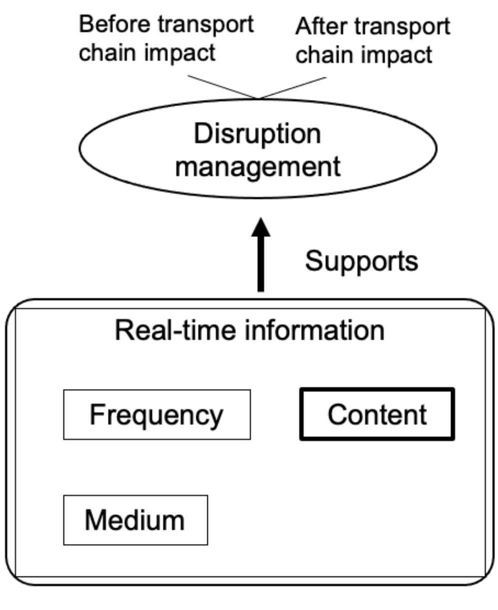

Figure 8. How real-time information supports the initiation of disruption management in intermodal freight transport.

Disruption management after impacts on the transport chain have occurred leads to ad-hoc fire-fighting of these impacts, instead of following the concepts of disruption management with detection and prediction of disruptions before they impact the transport chain and actions made with minor adjustments to the transport plan. For real-time information to support early disruption management, information is needed before impacts on the transport chain occur. Such support varies depending on whether the real-time information supports the detection of a disruption or its impacts. To highlight the support, the four factors from are discussed, followed by more details around content and other factors found to support disruption management.

The support from real-time information for disruption management was found to mainly be connected to the content of the information, that is, what the real-time information represents (see Paper 2), which therefore is highlighted in Figure 8. The information content can provide different types of detection, at different points of time in relation to disruptions and their transport impacts. The frequency factor of real-time information (not emphasised in Figure 8) is secondary to content, for real-time information that provides content for the detection of impacts instead of disruptions can be updated every second without giving the same support to disruption management as real-time information about a disruption that is less frequently updated. Nevertheless, frequency influences how information with content about disruptions supports disruption management. Regarding the factor of medium, support was found to vary depending on manual parts in the disruption management process. In contrast to the focus on the medium for real-time information in literature on IT systems and ICT as tools to improve efficiency in intermodal freight transport (Harris et al., 2015; van der Spoel et al., 2017) as well as DSS for improving disruption management (Hrušovský et al., 2021), the detailed description of real-time information for disruption management in this research shows limitations even when IT systems are in place. For example, the real-time information from GPS does not guarantee early detection due to manual checks of the information, which is similar to findings in other freight transport contexts than intermodal (Meyer et al., 2014). Issues of manual parts of providing real-time information for detection were found to delay the detection in Studies 1-3. Because manual monitoring is not constantly executed, time delays arise between when real-time information is available and when detection is made. As a result, a continuous flow of real-time information about operations with suitable content is not enough to realise early detection unless manual processes are integrated or replaced. Last, the direction factor of information was not observed to influence the support for disruption management.

5.1.1 How the content of real-time information supports disruption management

The research for the thesis showed that content is the main factor supporting the time for when disruption management is initiated, given its connections to what is detected. Instead of following a certain content in the information connected to a certain disruption (Li et al., 2018) or elaborating on various information contents (van der Spoel et al., 2017), the research elaborated on a general view on information for the purpose of disruption management to conceptualise how the content of information can support disruption management. The support for disruption management from the content factor of real-time information was mainly connected to the first step of disruption management, that is, detection of a disruption, as illustrated in Figure 9.

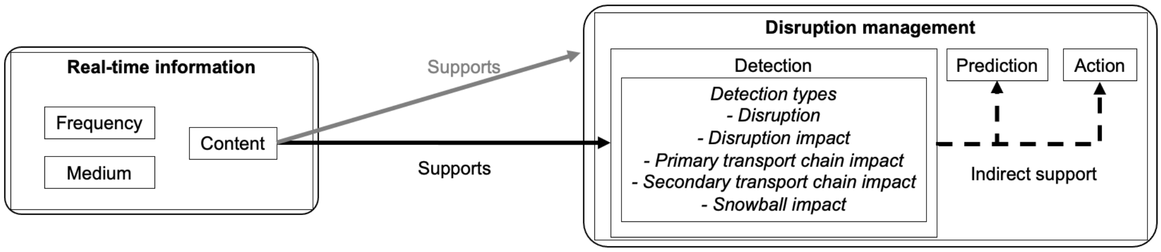

Figure 9. Representation of additional points of the support from real-time information for disruption management.

The notion of a disruption is commonly used in literature on intermodal freight transport to indicate when a transport operation is impacted (Burgholzer et al., 2013; Albertzeth et al., 2020; Li et al., 2018) follows the logic of business impact (Wagner and Bode, 2008). Following this reasoning for the example of a traffic accident, it is not viewed as a disruption until the truck is delayed in the queue created by the accident. This has created limited discussion about what occurs before a transport disruption that may impact the transport operations, which is important for disruption management (Hrušovský et al., 2021). By broadening the focus from only recovery actions and separating a disruption and its impacts, following the disruption management idea of dynamic revision of plan due to negative impacts from disruptions (Yu and Qi, 2014), different detection types were identified. As Figure 9 shows, the content of real-time information is connected to support different detection types, including detection of disruptions, disruption impacts, primary impacts on the transport chain, secondary impacts on the transport chain and snowball impacts (see Paper 2 for further details). The support from information for detection was found to have different indirect implications for the phases of prediction and action, indicated by the dashed arrows in Figure 9. Because the detection types found connect information to the detection of a disruption and its impacts, they contribute with insights into how various approaches managing operational disruptions are performed due to information given. Furthermore, these insights add to the view on a disruption in disruption management that generate a need for a re-plan (Yu and Qi, 2014), by considering real-time information, not only for the impacts that have occurred but extending to cover events that may eventually impact the plan. This way of approaching disruptions and impacts is more in the direction of ideas involving supply chain event management (Otto, 2003). The view of potential impacts during the recovery phase, even matches with the anticipative view for mitigation actions (Wieland and Wallenburg, 2012), but then anticipation of potential transport chain disruptions impacting supply chains than potential disruptions impacting transport operations.

In regard to the shown importance of early detection of disruption to minimise impacts (Sheffi, 2015), the identification of these disruption types becomes important. If a disruption can be detected before an impact, then it is possible to minimise or even avoid that impact. Once the impact has occurred, the possibility to act is fewer. Actions taken after the transport chain has been impacted require greater effort to adjust the transport operations, by creating a completely new plan or fire-fighting occurred impacts. Actions taken before a transport chain is impacted illustrate how such recovery actions can change plans in a structured way compared with actions taken after an impact by ad-hoc solutions through fire-fighting. Additionally, the findings indicate a value to discuss various content of information for a disruption, such as information about disruptions and information for predicting information, both of which are connected to information before a transport chain is impacted. After the transport chain has been impacted, the information about impacts can represent secondary or snowball impacts. These detection types make a specific distinction of information for disruption management for the given context, instead of the common notion of information used in previous research on disruptions in intermodal freight transport (Li et al., 2018; Hrušovský et al., 2021).

The factor of content was found to be linked to additional factors than the four represented by Mohr and Nevin (1990). These additional factors revolved around the structure and coverage of information and are discussed below. Figure 10 includes these factors to provide an overall illustration of how real-time information support for disruption management.

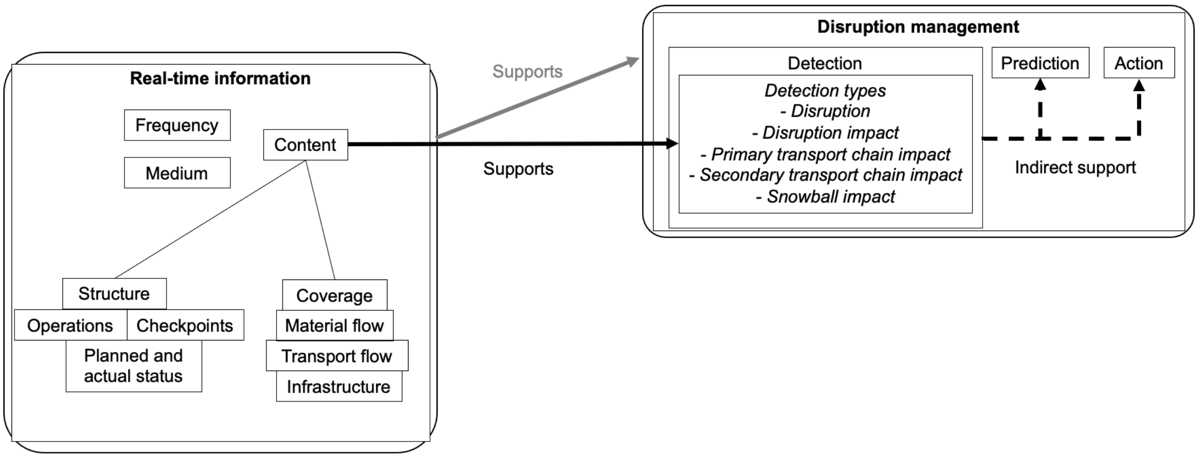

Figure 10. An overall illustration of how real-time information supports disruption management.

5.1.2 How the structure of real-time information influences its content

Real-time information about the performance of transport operations, which is commonly used to identify disruptions (Fernández et al., 2016), was found to be used for detection (Paper 1). The structure of real-time information, which revolves around either continuously updated real-time information during transport operations (i.e. links) or at checkpoints (i.e. nodes). Because the performance measures were related to checkpoints in an aim to evaluate the system's performance at checkpoints, these measures were of limited value for detecting disruptions. The information structure and content were shown to be linked, since real-time information related to a checkpoint provided input for detection types after the transport chain has been impacted. If detection before transport chain impact is wanted, then real-time information from operations (i.e. links) is needed. For example, if a truck driver calls in the disruption of being stuck in a queue, then the prediction of the impact on operations at the terminal can be made, and these operations can be altered before the impact occurs. The information at links can lead allow mitigating the impact on these operations. While, if detection is made at a node, such as the detection of a late truck at a terminal, then it revolves around the occurred impact on transport, and fewer actions will be available for the upcoming operations, such as the terminal operations.

In relation to the structure of real-time information (i.e. available at checkpoints or during operations) and the factor of content, an additional insight concerns issues of detection during operations. An important aspect (raised in Papers 2 and 3) is the need for real-time information about planned status as well as actual status. This need follows the definition of detecting a disruption (or impact from disruption in another part of the transport system) by a difference between actual and planned status (Yu and Qi, 2014; Otto, 2003). Although attention in the literature on freight transport has been given to real-time information about actual status, such as track-and-trace applications (Stefansson and Lumsden, 2009), the research conducted for this thesis revealed a need to obtain not only actual status but have planned status for comparison to achieve detection.

5.1.3 How the coverage of real-time information influences its content

Another factor of how real-time information supports disruption management was found in the coverage of real-time information. The coverage factor is from where in the transport system real-time information is available. Previous research has taken different perspectives on coverage for disruptions, such as examining how transport disruptions impact a supply chain differently depending on where in the chain they occur (Wilson, 2007) or where a disruption occurs relating to an organisation, that is, inside an organisation's own boundaries or outside those boundaries (Nel et al., 2018). Given its focus on real-time information, this thesis views coverage to represent where in a transport system that information is provided. This conceptualisation of coverage was made by adopting the three levels from Wandel et al. (1992) for a transport system of infrastructure, transport flow and material flow (see Paper 3 for further details). The different levels provide real-time information for different detection types. For instance, real-time information from the infrastructure level, such as traffic information, has content that supports the detection of disruption and disruption impact. Real-time information from the transport flow and material flow levels has content that provides detection of primary and secondary impacts in the transport chain as well as snowball impacts. Real-time information was found available to a larger extent at the levels of material flow and transport flow, than at the infrastructure level. For real-time information to represent content connected to disruption in the infrastructure level, it needs to cover a scope outside the transport operations, because disruptions outside the operations that may impact the operations have to be captured. This information can include, for example, the traffic situation or terminal capacity, which mainly is real-time information from outside the organisational scope and in need of interorganisational information sharing. Low levels of information sharing reported in intermodal freight transport (Vural et al., 2020) therefore limit real-time information to have content that supports early disruption management.

5.2 RQ 2 - How does coordination influence the availability of real-time information for disruption management in intermodal freight transport?

Previous research on intermodal freight transport has focused on ICT and IT systems as tools to enhance operational efficiency (Harris et al., 2015), among other approaches, via disruption management (Hrušovský et al., 2021), to provide increased competitiveness of intermodal freight transport (Vural et al., 2020). In contrast to the focus on these tools to provide real-time information, the research conducted for this thesis (Study 4) highlights operational coordination as a way to provide real-time information for disruption management between actors, as coordination has been indicated to influence the real-time information available (Lang and Veenstra, 2010). Moreover, the existing interdependencies between multiple actors, resources and activities in an intermodal freight transport chain emphasise the importance of coordination (Monios and Bergqvist, 2015). By broadening the perspective on real-time information for disruption management from one actor to multiple actors in an intermodal freight transport chain, interorganisational aspects were added by the research in this thesis. Additional insights into the availability of real-time information for disruption management could be found by capturing the coordination made between actors to manage their interdependencies. Previous research on intermodal freight transport has provided little attention to the operational coordination (van der Horst et al., 2019; van der Horst and van der Lugt, 2011) and is therefore complemented with detailed descriptions of operational coordination from the research in this thesis. In addition to the previous operational coordination framework in intermodal freight transport (Gumuskaya et al., 2020b), the information processing approaches for coordination contribute to the advancement of knowledge about operational coordination, as do the connections made between operational coordination and disruption management via real-time information.

The studied intermodal freight transport chain coordinated its interdependencies via plans and rules based on static conditions of the transport. As a result, any disruption that occurred required other mechanisms of coordination, such as information and/or buffers. These two coordination mechanisms represent two different sides of the information processing perspective, either to increase the information processing capacity (information) or decrease the need for information processing (buffers). Additionally, the two parts of coordination (information and buffers) are connected to disruption management, as illustrated in Figure 11. The approach to coordination influences the levels of information and buffers in the silos in Figure 11, and therefore the disruption management performed.

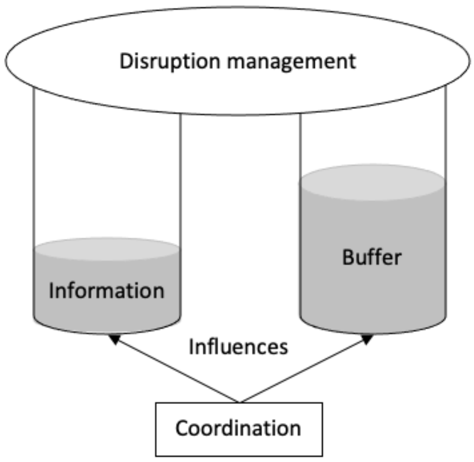

Figure 11. Illustration of findings that the coordination influences the real-time information or buffer for disruption management.

The buffers present in different parts of the studied intermodal freight transport chain, reduced the need for real-time information when a disruption occurred, which influenced the real-time information available for disruption management. When information was used for the purpose of coordination, such as when IT systems or relationships between actors were used to exchange information, this provided a setup for real-time information for the disruption management. A found aspect concerning use of IT systems for coordination was that they did not provide real-time information to all actors. Similarly, established relations were found to function in sharing information between certain actors, providing issues to cover all needed actors. Additionally, knowledge about which actor that needs what real-time information about a disruption, for example, the decision-maker for a certain part of the chain, was limited, which created gaps in the use of the coordination via information. For disruption management, these problems generated issues to quickly get hold of real-time information for the decision-makers, as the coordination did not provide the needed setup for information.

5.3 RQ 3 - What are the efficiency effects of real-time information on disruption management in intermodal freight transport?

The effects of different actions, such as transhipments, re-routing, or the use of buffers when a disruption occurs, have been examined in research on intermodal freight transport (Hrušovský et al., 2021; Albertzeth et al., 2020; Burgholzer et al., 2013). The research conducted for this thesis (see Paper 5) has added to these approaches by examining the efficiency effects of different information scenarios for disruption management. Scenarios for various information about predictions of a train delay was given of full information, no information or incorrect information. Full information represents a possibility to use trucks to maximise resource utilisation due to existing buffers of containers at the terminal that provided possibilities for delivery of these containers before the train arrived.

The results indicate that different information scenarios enable disruption management with different effects on the efficiency. Similarly, positive efficiency effects have previously been indicated for different information scenarios in the context of ports, such as for known or unknown arrival times of containers at a port (Gumuskaya et al., 2020a). As an extension to the port focused research, this thesis provides insights into the scope regarding a train delay to an intermodal freight terminal, namely dry port. The studied scenarios provide insights into when lack of information can provide benefits. The focus on optimisation arising in the disruption management has positive effects on efficiency measures but at a cost for other measures, as shown regarding the measure of time for delivering prioritised containers. Such imbalance in efficiency indicates a need for discussions in intermodal freight transport about sharing the positive effects from information on disruption management. Additionally, a lack of understanding of different actors' preferences, such as how urgent prioritised containers are, influences the disruption management. For example, if the actor responsible for the disruption management has little or no understanding of the preferences of the shipper, then the actions taken during a disruption may serve to achieve an objective that is secondary for the shipper and at the same time lowers the efficiency of the transport operators. The shippers' preferences are outside the scope of the research in this thesis. Nevertheless, if the shipper had knowledge about the effects of delivery conditions on the efficiency of the transport operations when a disruption occurs, relaxation of these constraints may be possible.

The scope of the simulation model (Study 5) covers the prediction and action phases of disruption management, as illustrated in Figure 12, but not disruption management between different levels or multiple transport operations, as discussed in research questions 1 and 2. For example, the detection was made outside the scope, providing that the disruption management had no options to change routes, as the rail route was already in use. The scope exemplifies when detection of a disruption (in this case train delay) is made by another actor and different information for prediction is given, which in turn will impact various efficiency effects differently.

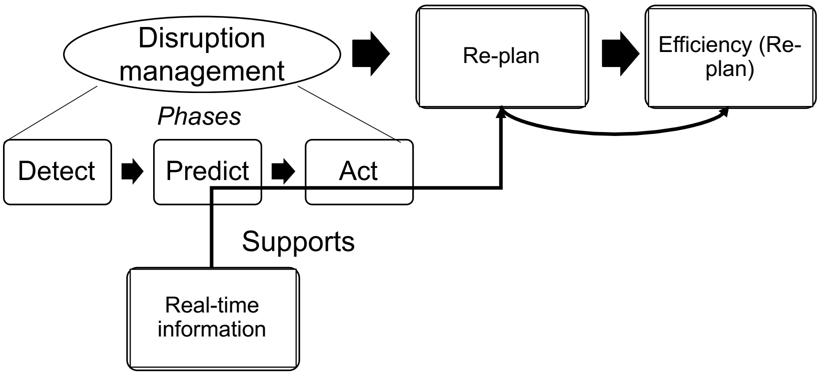

Figure 12. Overview of the analysis of real-time information for efficiency effects (thin black arrows).

The simulation scope covers the boundaries of an intermodal terminal operator and a road transport operator, represented by the same actor, in the collection and distribution part of an intermodal freight transport chain. If these actors had been represented by two actors instead of one, it is reasonable to assume that the found disruption management options identified would have been more limited, because the two actors would have had to share the real-time information and responsibility for disruption management for the studied operations. Therefore, for intermodal freight transport chains to achieve the full potential of disruption management, a broader coverage of the system is needed. The more limited the coverage, the fewer the action options available for disruption management. Broader coverage in the scope of the simulation could include operations at the warehouses of the shippers or operations at port.

5.4 Discussion on thesis contribution to purpose

This thesis aimed to contribute to the understanding of the importance of real-time information for disruption management in intermodal freight transport. The importance of real-time information was found to differ depending on the role real-time information had for disruption management. The real-time information was found to be of more importance for disruption management if it had an active role and of less importance if it had a passive role. The active role for real-time information provides disruption management that anticipates disruption impacts, whereas the passive role of real-time information provides disruption management that responds to transport impacts that have occurred due to a disruption. The two approaches of disruption management, both of which are consequences of the real-time information, set different conditions for managing operational disruptions. On the one hand, the active role represents detection, prediction and action in disruption management based on real-time information, which provides possibilities for early detection, the prediction of impacts and action while impacts can be minimised by finding valid options for actions. This approach sets certain prerequisites on the real-time information, such as discussed around research question 1, and on interorganisational aspects, such as discussed around research question 2. Additionally, real-time information for disruption management can provide anticipative actions before impacts, which can generate less sensitive intermodal freight transport, raising the competitiveness of intermodal freight transport. On the other hand, the passive role represents the phases of disruption management based on a lack of real-time information or based on real-time information connected to impacts. This approach provides detected transport impacts that need to be resolved. Because the detection revolves around impacts that have occurred, the disruption management resolves transport impacts instead of anticipating them. As a consequence, a fire-fighting mode is present in which pre-defined actions may no longer be valid and costly solutions must be found to solve the situation, such as waiting for the next day or offer express deliveries.

The detailed description of real-time information for disruption management in this thesis not only provides intel to the role of real-time information but a zoomed-in perspective on the recovery phase. In Chapter 2, the thesis argues that the literature on intermodal freight transport lacks a connection between real-time information and action and is influenced by other literature focusing on product flows, such as about supply chain management and logistics, that has focused on mitigation strategies (Behdani, 2013). This influence has led to a focus on mitigation strategies in designing the supply chains that mitigate certain transport impacts, such as multiple suppliers and multiple transport options (Wilson, 2007). The role of real-time information found broaden the conceptualisation of the management of disruptions before or after a transport disruption occurs. The perspective on the supply chain and logistics mainly stems from supply chain risk management, that management made before a disruption occurs is anticipating and that management made after a disruption has occurred is reactive. These perspectives were in this thesis both found after a disruption has occurred. The conceptualisation that the management of disruptions during the recovery phase can be both anticipative and reactive indicates the importance of an active role of real-time information. This could inspire research that generates descriptions of interorganisational solutions for the recovery phase, such as disruption management via real-time information (Meyer et al., 2014), rather than solutions for one actors, often the shipper perspective, to support the recovery phase, such as via a buffer strategy or multiple suppliers strategy (Wilson, 2007).

Nevertheless, the active and passive roles of real-time information for disruption management are not limited to the recovery phase but additionally linked with mitigation actions. None of the five performed studies conducted for this thesis focused on mitigation, but the indications from mitigation strategies during the recovery phase were present. The importance of these mitigation strategies is not questioned by this research. Rather this research acknowledges that both mitigation and recovery are needed, and the mitigation strategies set the frame for recovery. For example, mitigation strategies such as buffers or designs with multiple alternative modes influence the recovery of the options available to manage a disruption or its impacts. This thesis suggests that a focus solely on mitigation or on product flow level will limit the development of real-time information abilities to support recovery in the transport operations. The focus of on wanting to manage disruptions before the operations are performed (e.g. by buffers) provides a limited focus on recovery and the role of real-time information in this phase. In those cases, in which impacts alter the transport plan even though buffers are in place, the lack of disruption management focus via real-time information leads to recovery via fire-fighting. This research provides understanding of way to avoid fire-fighting by first understanding the role of real-time information in the recovery phase to be able to systematically perform disruption management. Moreover, the research has generated valuable examples of when buffers have positively influenced the disruption management during the recovery phase by increasing options for actions in the case of disruptions, as captured in Study 5. In this way, the benefits of real-time information can be linked to the existence of buffers. The discussion of the interplay between buffers and information for disruption management during recovery adds a new perspective to the literature on intermodal freight transport that has viewed buffers or information limited to recovery actions (Hrušovský et al., 2021; Albertzeth et al., 2020). These findings of the research highlight that it is important for any actor that plans any part of an intermodal transport chain to make active choices about the role of real-time information for disruption management. Recovery achieved via buffers or real-time information should not only be put in contrast to one another but considered jointly if needed.

The scope of intermodal freight transport covered in this thesis primarily relates to land-based collection/distribution parts. The main haul included (i.e. in Study 2) is a rail connection, and for the collection/distribution, the modes of road and rail transport were in focus. The focus on a port as an intermodal terminal for disruptions has been predominant in previous research on intermodal freight transport (Li et al., 2018), giving that the scope in this research adds to this previous perspective on ports. The ideas for disruption management via real-time information in this research will be similar whether the intermodal terminal is a port or an inland intermodal terminal, as seen in other studies connecting sea and rail modes (Elbert and Walter, 2014), or truck and sea modes (Li et al., 2018). Nevertheless, including the port as an intermodal terminal offers other types of actors and operations that need coordination (Zhou et al., 2018), other than in the studied intermodal freight transport chains.

Real-time information, as previous research on disruption management in intermodal freight transport regarding frequency updates and medium has discussed (Hrušovský et al., 2021; Li et al., 2018), can provide benefits for the initiation of disruption management. Additionally, this thesis broadens the view on real-time for disruption management by providing insights into content. The emphasis on representing information in real-time may not be important to support disruption management but rather the representation of operational status during the operations are executed is the important part. Other aspects of information provide different time points for when the disruption management performed in relation to a disruption and its impacts. Real-time information for disruption management may benefit from another term in literature, for example, updated disruption information.

The research in this thesis provides insights with a focus on the phase of detection. This focus is connected to the sequential connections between the phases of disruption management (i.e. detection, prediction and action), in which detection is the vital first step that real-time information supports. Once this information is provided, the information for prediction and action can be established. This detection focus is influenced by the studied transport chains. In other chains with more developed connections between the detection phase and information, the focus may have shifted to insights into the prediction phase. Nevertheless, the limited adaptation of information reported in the transport industry (Meyer et al., 2014; Vural et al., 2020) makes it likely that other chains had provided conditions similar as the chains studied for this thesis.

5.4.1 Revisiting the theoretical framework

The results from the performed studies added to the framework from Chapter 2, as seen in the updated framework in Figure 13. The thesis has discussed the recovery phase via the connections made from real-time information for disruption management. As illustrated by the thick black arrows in the figure, depending on the real-time information the disruption management can be steered towards the disruption or the impact, or even after the impact. The different real-time information for disruption management in the thesis provides various instances of steering towards achieving re-plans closer to the disruption instead of after the impact(s). The thesis has further broadened the view of operational coordination on real-time information for disruption management, as well as the change in efficiency due to varying information regarding the prediction phase.

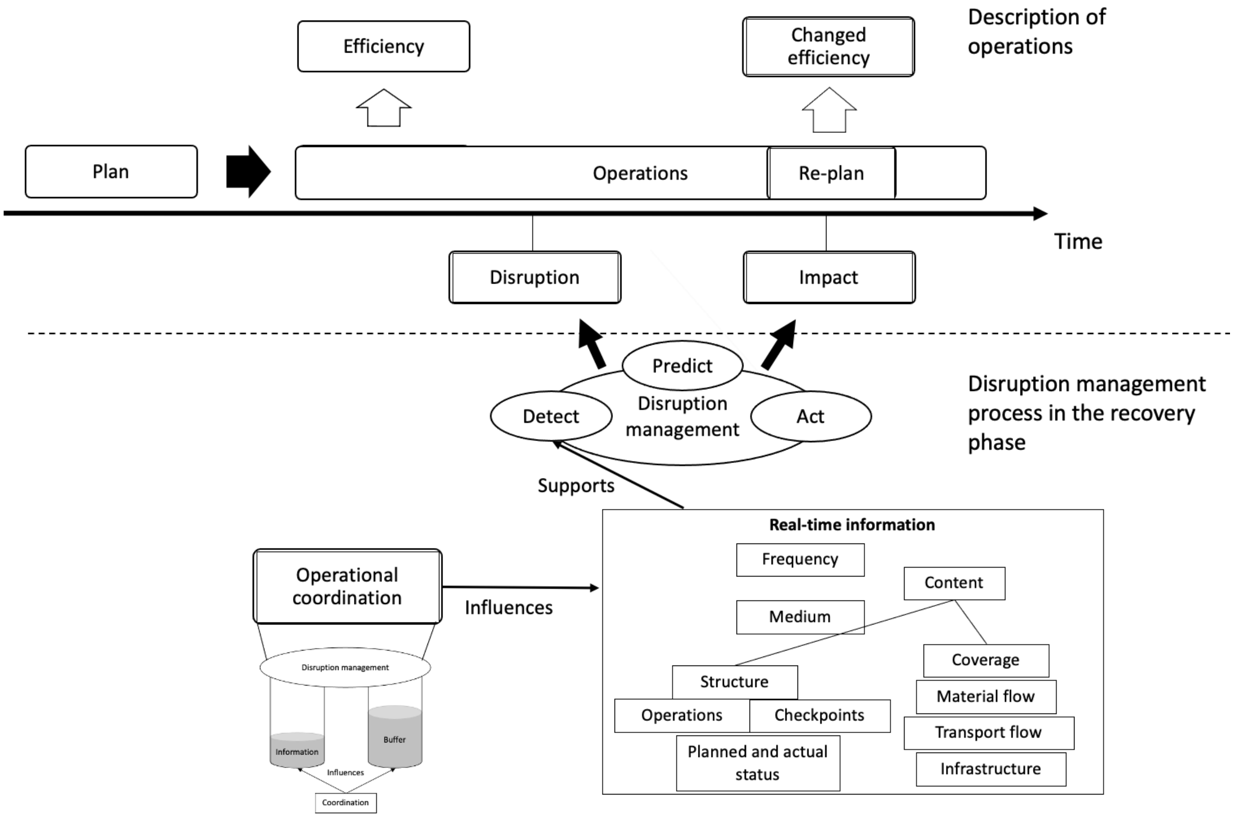

Figure 13. Revisited conceptual framework for disruption management in intermodal freight transport.

5.4.2 Discussion beyond the scope of the thesis

Disruption management within the intermodal freight transport chain influences the logistics and the supply chain (Wilson, 2007). This thesis did not investigate effects outside the intermodal freight transport chain, but indications can be made. Expanding the reasoning above regarding buffers and information, improved real-time information for disruption management can have consequences for the shippers of the freight. For example, in Study 4, the shipper had high levels of product buffers at the destination. If early disruption management via real-time information was achieved in that intermodal freight transport chain, these buffers could be viewed as excessive. If actions can be made before impact, for example, before impact on the rail haul, which is viewed as inflexible in the case of disruption, then intermodal freight transport can achieve advantages similar to those of road transport (fast delivery) by shifting to road for those occasions. Although such shifts will negatively influence the environmental impact on those occasions if they lead to more shippers choosing intermodal freight transport, then the environmental impact will be decreased. Improved disruption management in the intermodal freight transport may lead to a changed mindset towards mitigation strategies (e.g. buffers) for the transport at a supply chain level. For example, if a transport should be made between a supplier and a production plant and the products are needed in 10 days from now, then an intermodal freight transport option may be used. However, if the products are needed 5 days from now and the intermodal freight transport takes 4 days, then the shipper could consider a buffer of only a day too small for the choice of intermodal freight transport and opt for road transport instead. Although some geographical aspects could limit options (Bontekoning et al., 2004) (e.g. the need for sea transport), the choice may be possible for intermodal freight transport after the port in the collection/distribution part of the intermodal chain (as in the Studies 4 and 5). Moreover, the real-time information for disruption management in the intermodal freight transport can serve as input for predicting impacts on logistics operations (e.g. snowball impacts from transport impacts), which can support disruption management for logistics operations, not only for transport operations, as described in this thesis.

It is not evident that the results from intermodal freight transport in this thesis are generalisable to other types of freight transport. Results in the literature on road freight transport indicate similar issues around real-time information for disruption management (Meyer et al., 2014), providing some indications towards the results applicability in other freight transport settings. The benefit of disruption management is likely for transport operations in last-mile deliveries in e-commerce, in which customers want deliveries to be trackable and reliable ETAs. To achieve such services of reliable ETA for transport operations requires real-time information, as indicated by other studies (van der Spoel et al., 2017; Elbert and Walter, 2014), promoting the approach of real-time information for disruption management.

The process view on disruption management in this thesis provides an extended view on how to manage disruptions during the execution of operations. This view can provide insights to the literature on resilience regarding the operational part of recovery, such as risk monitoring, which has lacked attention than other parts of risk management in literature on supply chains (Fan and Stevenson, 2018). The resilience approaches mainly propose contingency plans to be carried out when disruptions occur (Woodburn, 2019). This thesis adds insights into the detection of disruptions before these contingency plans can be implemented. Via the operational perspective taken for the research in this thesis, it is possible for the resilience research in supply chains and logistics, to not only focus on disruptions with high impact and a low frequency of occurrence but to further include operational aspects found in this research in connection to pre-defined strategies. By viewing actions as flexible and not limited to a pre-defined plan, this research highlights the possibility for context specific disruption management by considering the information for the operations actually performed, not possible events before the operations are executed.

5.5 Theoretical contributions

For intermodal freight transport, the findings provide insights that can guide the disruption management process. Previous research on intermodal freight transport has examined impacts from disruptions depending on different actions (Albertzeth et al., 2020; Hrušovský et al., 2021), and with the research presented in this thesis, insights are added to the process of detecting disruptions and predicting impacts to achieve these actions. These insights were possible by adopting the phases of disruption management from the literature with a main focus outside the intermodal freight transport scope, such as road freight transport (Meyer et al., 2014) and supply chain management (Sheffi, 2015; Séguin et al., 1997; Otto, 2003). The detailed descriptions about real-time information and the phases of detection and prediction highlight the importance for understanding real-time information for disruption management.

The results in this thesis aid the field of intermodal freight transport with insights into managing operational disruptions. In the literature on intermodal freight transport, the management of operational disruptions has been conceptualised around the idea that real-time information should provide support (Elbert and Walter, 2014; Li et al., 2018) and investigations of efficiency outputs without explicit links as to how the real-time information is made available (Burgholzer et al., 2013; Albertzeth et al., 2020). In this thesis, the exploration of various factors for real-time information contributes to increasing the understanding of how real-time information supports disruption management (or not). The connections made between the factors and a disruption, and it impacts, add understanding to how real-time information supports disruption management and additionally explains how delays in disruption management occurs. Furthermore, the results explain how the phases of disruption management are linked to real-time information, which contributes to increasing the understanding of how to do the process of disruption management with support from real-time information.

In the initial studies, and as highlighted in previous literature on freight transport (Meyer et al., 2014), the lack of support from real-time information for disruption management generated delays in the disruption management. While the literature on intermodal freight transport has focused on real-time information that could be shared between actors (Wiegmans et al., 2018) or technologies to share this information (Harris et al., 2015), coordination as a source for information exchange between actors had not been extensively studied. The literature on coordination in intermodal freight transport highlights important aspects of contracts and alliances (Monios and Bergqvist, 2015; van der Horst et al., 2019), but few studies have addressed the coordination taking place in the day-to-day business connected to the transport operations (Gumuskaya et al., 2020b). The results in this thesis connecting information in coordination to disruption management contribute is twofold. First, the results contribute to the lack of studies on operational coordination in intermodal freight transport by explaining how the coordination of interdependencies is performed at the operational level between multiple actors from the perspective of information processing. Second, by connecting the information processing perspective of coordination to disruption management, the results contribute to increased understanding of how coordination influences the real-time information available for disruption management. These insights can be connected to ICT and IT systems to provide tools that support real-time information for disruption management, not only for intermodal freight transport operations but for freight transport in general (Harris et al., 2015).

This thesis connects the real-time information to the efficiency effects of recovery actions, which adds to previous investigations into recovery actions under the assumption that real-time information was available (Burgholzer et al., 2013; Albertzeth et al., 2020). The research in this thesis highlights a disruption scenario in which different real-time information about prediction of an impact is given. Additionally, the investigated efficiency effects contribute with insights into intermodal freight transport by elaboration around that the effects fall on different actors and are influenced by constraints from another actor. This outlines the need for the actors in intermodal freight transport to discuss what actor that gain with benefits and losses in efficiency effects from different objectives in the disruption management, due to set constraints on the transport operations.

By conceptualising real-time information for disruption management, the research in this thesis engages in the discussion of approaches to manage disruptions. Research on product flows at the supply chain and logistics levels, where the transport disruptions studied in this thesis are one possible disruption (among production or supplier disruptions (Ivanov et al., 2017)), has predominantly focused on mitigation strategies instead of the recovery phase (Behdani, 2013; Nel et al., 2018). The research in this thesis contributes to this view by considering the interplay between information and buffers in the recovery phase. Buffers and information are mainly placed on opposite sides of a continuum (Bode et al., 2011), as this research similarly found empirical evidence of (Study 4). At the same time, buffers can provide possible action options for the recovery via disruption management (Study 5). By understanding these interplays, the thesis contributes to research not only on intermodal freight transport but additionally on supply chains and logistics. If the intermodal freight transport improves the management of operational disruptions via the increased understanding of the real-time information approach for recovery proposed in this thesis, supply chain and logistics research could increase its understanding on how to manage transport disruptions in the transport operations, instead of designing supply and logistics chains with buffers as a mitigation strategy for transport disruptions (Angkiriwang et al., 2014; Wilson, 2007).

5.6 Practical contributions

The practical contributions from the results of the thesis include a description of disruption management for transport operations. Transport managers can use the proposed framework below to evaluate and understand their own recovery approach.

Framework for real-time information for disruption management in intermodal freight transport:

i) Identify available real-time information for disruptions and impacts for three phases:
   a. Detection
   b. Prediction
   c. Action
ii) Evaluate real-time information regarding:
   a. The content of real-time information in relation to disruption and impacts
   b. The coverage of real-time information in relation to the levels of the transport system
   c. The structure of real-time information in relation to operations or checkpoints
iii) Increase the needed information processing (e.g. by using coordination structures already in place)

By identifying available real-time information concerning disruptions and impacts relating to the phases of detection, prediction and action, the managers can get an understanding of how their recovery is performed. In that process, a question is whether the real-time information supports actions before or after the impacts on transport operations occur. Thereafter, the real-time information can be evaluated in relation to the three factors of information proposed in this research. Thereby, the managers can evaluate the real-time information to gain knowledge of how their disruption management is performed. If this evaluation indicates issues about real-time information, such as content, then the managers can investigate how they can increase the information processing. The research highlights that already existing coordination structures could support this, not only implementing new ICT.

6 Conclusions

This chapter presents the conclusions of the research conducted for this thesis and provides an outline for future research.

6.1 Concluding remarks

This research addressed the importance of real-time information for disruption management in intermodal freight transport. With high operational efficiency obtained via disruption management, intermodal freight transport can increase its competitiveness against road freight transport. The research adopted a focus on real-time information for disruption management after operational disruptions have occurred. Depending on the role of real-time information, the disruption management either leads to actions being taken before or after impacts on transport operations occurs. The thesis concludes that for intermodal freight transport to achieve management of disruptions with mitigated impacts after a disruption has occurred, an active role of real-time information is of importance. The active role of real-time information requires the content of real-time information to support early detection, such as detection of disruption or disruption impact, not of transport chain impacts. To achieve this, the real-time information mainly needs to be able to capture indications of disruptions that will impact transport operations and not be limited to provide detection of transport impacts. The research proposes how real-time information supports disruption management in generating recovery actions before intermodal freight transport operations are impacted by disruptions. Moreover, the research concludes that real-time information for the recovery phase is limited by a sole focus on mitigation strategies. This research indicates how operational coordination influences the real-time information by the balance between these two phases (mitigation and recovery) through coordination via buffers or information. The research illustrates how buffers reduce the practical need for information flows and therefore limit the real-time information available for disruption management. Nevertheless, not all instances of buffers should be viewed as competitors to real-time information. Therefore, the research concludes that intermodal freight transport needs to strategically balance the use of buffers and the real-time information available to facilitate early recovery and not end up in recovery of fire-fighting impacts. Last, not all actors' efficiency measures will be affected with the same magnitude when achieving early recovery. Therefore, it is important to understand the effects of early disruption management, it is important to consider a broader part of the intermodal freight transport chain beyond one actor's boundaries.

6.2 Future research

The presented research focuses on real-time information for the management of operational disruptions and discusses aspects in relation to buffers. The costs of real-time information, such as implementations of ICT, or of buffers were not quantified in this research. The occasions when real-time information mitigates impact need to be compared against the costs of the efficiency of the plan (i.e. including buffers) or the cost to generate the needed real-time information. Unlike buffers, which raise costs in operations no matter if disruptions occur or not, the disruption management based on real-time information is only performed when disruptions occur.

In a future where sections of the transport system can be automated, such as autonomous trucks or ports, achieving an active role of real-time information for disruption management can generate a competitive advantage, in that the real-time information needed to manage disruptions in these automated parts is already taken into consideration. Real-time information for disruption management, based on this research, investigated for autonomous transport systems could be subject to future research. Such research may involve new actors but mainly other settings for the real-time information available or provide insights into the completeness of real-time information for recovery in these new settings.

Moreover, this thesis provides description of the disruption management process in relation to real-time information. It is possible that this process can be automated and steered by machine learning approaches or made manual and steered by individuals involved. To further elaborate on the process, future research can focus on these two aspects. Research on the automated process could add methods, such as machine learning, able to complement the presented phases of disruption management with data management perspectives that have not been covered in this thesis. Research on the manual process could add individual aspects, such as planner's knowledge or perceptions of risks, to the process. In this way, the planner's knowledge can be viewed as a dynamic capability that foster the process, and/or the planner's perceptions of risks can be viewed as being significant to the process. These approaches can provide insights into planners' knowledge and distinguish between information and knowledge for disruption management.

Last, with the aim of expanding the generalisability of the idea of an active role of real-time information for disruption management, other types of intermodal freight transport systems could be considered, such as including ports for main haul or waterways for collection/distribution parts, and the scope could be extended to other parts of the world. Moreover, future studies could broaden the scope to include the effects of disruption management in transport operations on logistics chains or supply chains to further demonstrate the value of active role of real-time information for disruption management. Additionally, the research presented in this thesis provides initial thoughts about the problematisation of real-time information. Future research on real-time information could aim to generate definitions of real-time in various intermodal freight transport setups and if certain disruptions need earlier (real-time) information than other disruptions. The presented research has made connections between real-time information and detection, and connections with efficiency were made for various prediction information. Therefore, complete connections between real-time information and all phases of disruption management could be subject to future research, such as studies in which various real-time information for both detection and prediction are investigated for their effects on efficiency.

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Appendices

Appendix A

Question guides:

Study 1

Question guide for planners (questions to general manager adopted to capture planning process)	
Themes	Examples of general questions
Transport decisions - Getting an overview of transport chain decisions taken	For what activities are you taking decisions for? Follow-up / areas to cover: Which flows? Which actors are involved?
Decision input - Information used for decisions	What information is needed for taking a decision? Follow-up / areas to cover: Information source? Frequency? How is information received?
Decision process - Understand how planners execute decisions	Can you describe your work? Follow-up / areas to cover: In what sequence do you take decisions?
Effects of decisions taken - Understand how decisions are perceived to effect resource utilisation	What resources are influenced by your decisions? Follow-up / areas to cover: How is their utilisation effected by your decisions? – Time, capacity, environment
Feedback for decisions - Understand how feedback from resource utilisation is used - Understanding how planners are evaluated	What feedback information regarding resource utilisation are you using? Follow-up / areas to cover: How are you using these? How do you know if your decisions are good or not?

Study 2

Question guide for planners	
Themes	Examples of general questions
First round of questions Planning process of transport operation	What in the freight flows around the main DC do you plan? What decisions are made during this plan? What information are you in need of for these decisions? How do you know if your decisions for a plan are good?
Second round of questions Triggering events and performance deterioration (Dunke et al., 2018), milestones in operations and deviations (Otto, 2003) and recovery phase in transport operations (Sheffi and Rice Jr., 2005)	What changes do occur to the plans that you made? What has during the last months been problems needing re-plan decisions? What do you when these changes occur to the original plan? How do you receive information about actual status of operations? How do you compare this information with your plan? What information do you get when changes in a plan occur? How do you get this information? When during the transport operations do you get this information? Do you consider this information reliable? What do you do with this information, to end up in a decision to re-plan?

	How do you link a change in one transport operation to other parts of the plan? Is there other information, that you do not get, that you think could provide better input around the changes?
Question guide for logistics business developers	
Recovery phase (Sheffi and Rice Jr., 2005) from broader context than transport operations, snowball effects (Świerczek, 2014) and ripple effect (Ivanov et al., 2014)	Where in the company are the plans made by the planners used as input? What parts of the freight flows are influenced by the made plans? How well do the planners share their knowledge about the freight flows to other parts that could be in need of this information? What information do you think the transport planners is lacking to better consider changes during operations? How are the changes in the made plans generating problems within the company?

Study 3

Question guide for planners	
Themes	Examples of general questions
Management of operational disruptions	What deviations do occur to the plans that you made? What information do you get when deviations in a plan occur? – from whom? *Infrastructure – link/node ETA* *Transport flow – transport chain ETA* *Material flow – end customer ETA* What do you do when these deviations occur to the original plan? *Detect:* How do you receive information about actual status of operations? – At what detail level (Pallett/trailer/order/operation, etc) How do you compare this information with your plan? *Predict/Act:* How do you link a change in one transport operation to other parts of the plan? Is there other information, that you do not get, that you think could provide better input around the changes? What do you do with this information, to end up in a decision to re-plan?

Study 4

Question guide for actors involved in the intermodal chain operations	
Themes	Examples of general questions
Role in hinterland freight transport chain	What is your role in the intermodal chain?
Coordination: *Performed planning - activities, resources and other actors involved*	What activities do you plan? What other actors are involved? What resources are involved?

Information connected to these actors, activities and resources,	From what actors do you get information for the planning? What information systems do you use? – What actors have access to this information? What information provides you with updates when the operations are performed?
Operational disruptions and information connected to this	What disruptions do you have on a day-to-day basis? What happens then? What information do you obtain, by whom? What information do you not obtain?
Question guide for IT provider	
Role in hinterland freight transport chain	What is your role in the intermodal chain?
Information system solution	How does the system work? What information does the system include? What actors share what information? – About what?

Appendix B

List of respondents for performed semi-structured interviews in the studies.

Study	Interview number	Actor	Responder position
Study 1	1-2 (additional interview)	Logistics service provider	Transport planner
	3	Logistics service provider	Transport planner
	4	Logistics service provider	Transport planner
	5	Logistics service provider	Manager transport planning
	6	Logistics service provider	General manager
Study 2	1-2 (follow-up interview)	Shipper and transport coordinator	Transport planner
	3-4 (follow-up interview)	Shipper and transport coordinator	Transport planner
	5-6 (follow-up interview)	Shipper and transport coordinator	Transport planner
	7	Shipper and transport coordinator	Logistics business developer
	8	Shipper and transport coordinator	Logistics business developer
Study 3	1-5	Logistics service provider	Transport planners and manager transport planning from study 1
	6	Logistics service provider	Follow-up interview with manager transport planning
Study 4	1-2 (follow-up interview)	Shipper and dry port owner	Transport manager
	3	IT provider for dry port	CEO
	4	Nine interviews with managers and operators at various actors involved in the studied transport chain. Freight forwarder	Sales manager
	5	Port Authority	Sales manager
	6	Freight forwarder	Operative planner
	7	Municipality for dry port	Project leader
	8	Port operator	Sales manager (rail)
	9	Port operator	Operative planner