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Recovery actions in freight transport through real-time disruption management

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Abstract

This thesis focuses on the management of disruption in freight transport. The management of disruption is of importance to achieve planned efficiency in the transport system by mitigating or avoiding the impacts of disruptions, such as late arrivals of deliveries. The transport system is influenced by the ongoing development of information and communication technologies, which makes real-time information related to the transport operations available. This information has been shown to be useful for disruption management and has created possibilities for a shift towards more autonomous transport systems. This thesis investigates the real-time disruption management, as the recovery phase of disruption at the operational level, using relevant information after a disruption has occurred. The studied literature has mainly considered this phase to be reactive and focused on recovery strategies as proactive actions before disruptions occur. This thesis considers proactive recovery actions as made after a disruption but before it impacts the transport chain. These kinds of recovery actions provide less impact from disruptions on the freight transport system than reactive recovery actions made after the impact has occurred do. The purpose of this research is to investigate real-time disruption management in freight transport, in order to generate possibilities for proactive recovery actions.

Two cases of real-time disruption management have been investigated in this thesis, in three different studies. Each study examined different aspects regarding detection of disruptions, of what is detected, how it is detected and where in the transport system it is detected, influence on the initiation of real-time disruption management. The results from the performed studies point towards the importance of that detecting different objects of a disruption, which is further influenced by how and where in the system the detection is made. Furthermore, these insights into the detection phase are connected to the other phases for real-time disruption management, prediction and action, in order to state the possibilities of generating proactive recovery actions.

In contrast to the developed literature of strategic recovery strategies, this thesis establishes a detailed description of the viewpoint of real-time management of disruptions. As the identified objects for detection in this research are shown to be represented by different information, it is valuable for the development of disruption management to match future autonomous parts of the transport system and develop decision support systems accordingly. Furthermore, the research contributes with two dimensions in which recovery actions can be viewed as proactive. This is generated either with real-time disruption management performed after impact but before impact on the transport system or after the impact on transport system but before impact on upcoming operations. The practical contribution includes concepts revolving around real-time disruption management, which can be used for an outline for needed information in order to generate possibilities for proactive recovery actions.

Keywords: Disruption management, proactive recovery actions, freight transport, transport system, real-time information, operational planning

List of appended papers

Paper I:

Wide, P. (2018), 'The usage of resource utilization indicators as feedback for operational freight transport decisions – from a logistics service provider perspective'

The paper was peer-reviewed, presented and published in the proceedings of the 30th Annual NOFOMA Conference, 14-15 June 2018, Kolding, Denmark.

Paper II:

Wide, P. (2018), 'Real-time disruption management for proactive recovery actions in transport planning'

The paper has been submitted to an international logistics journal. 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, United Kingdom.

Paper III:

Wide, P. (2019), 'Proactive recovery actions in real-time transport chain disruption management – a logistics service provider perspective'

Submitted to proceeding of the 31th Annual NOFOMA Conference, 13-14 June 2019, Oslo, Norway.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

The freight transport system has inefficiency issues with low utilisation of resources, which, for example, generates high levels of empty running trucks (McKinnon and Ge, 2006) or trucks with high waiting times (Jacobsson et al., 2017). Inefficiency in the transport system is one obstacle in reaching the set emission targets of the European Union (European Commission, 2017). One common way to support efficient transport is through transport plans combining transport resources with demand of freight orders (Crainic and Laporte, 1997). The main objective in the planning is to find the best routes and allocation of resources according to the demand, under constraints of delivery requirements (SteadieSeifi et al., 2014). For example, consolidation of freight lowers the logistics costs but increases the number of decisions made in the transport chains (Neves-Moreira et al., 2016) and the whole supply chain (Jiang et al., 2014). The plans to achieve higher efficiency in combination with trends of globalisation and outsourcing in freight transport are making execution of transport operations in supply chains more complicated to monitor and control (Ivanov et al., 2014). The problems of monitoring and controlling complicated transport operations are making transport systems more sensitive when changes in a plan occurs, defined as disruptions (Yu and Qi, 2014). Sensitive transport systems that struggle to manage disruptions suffer from late deliveries. Late deliveries can cause loss of sales, loss in reputation or production stops for the supply chain (Wilson, 2007, Giunipero and Aly Eltantawy, 2004). This shows the importance of managing disruptions in transport systems in order to obtain higher efficiency of transport operations and the supply chain (Ivanov et al., 2017).

Managing disruptions may include decisions based on risk management, which are based on a high or low probability of occurrence and an low or high impact of a disruption (Knemeyer et al., 2009). The decisions taken based on risk management indicate the possibility to derive probability and impact of risks before a disruption occurs and set strategies for the transport chains to avoid disruptions or better mitigate impacts when disruptions occur. These strategies are decided upon before the disruptions occur (Tomlin, 2006) and include shock-absorbers, e.g. time buffers (Bode et al., 2011) or back-up transportations (Zhen et al., 2016). Accordingly, these strategies are associated with a cost whether or not a disruption occurs or not in comparison to strategies that take action only when a disruption has already occurred (Tomlin, 2006). A disruption may be managed after an occurrence at a strategic, tactical, or operational level. Actions at the strategic and tactical levels are similar to risk management approaches by including strategies for recovery and learning from disruptions (Blackhurst et al., 2005). The operational level uses these predefined recovery strategies to respond to disruption. Real-time disruption management is when the impacts of a disruption is managed by providing operational decision makers with information in real-time after the disruption has occurred (Meyer et al., 2014, Yu and Qi, 2014). When a disruption occurs decisions on the operational level have a limited time window for action (Brehmer, 1992), setting prerequisites for information about disruptions to be close to real-time information in order to perform the needed operational recovery actions. Furthermore, the technological advancements of transportation management (TM) applications have generated new possibilities for getting real-time information through information and communication technologies (ICT) to improve supply and transport chains (Perego et al., 2011). This indicates that there is a potential for real-time disruption management at the operational level. The TM applications support decisions for both optimised transport planning and execution (Mason et al., 2003). For disruption management, these technologies generate support in providing decision makers with visibility of more reliable and timely information (Meyer et al., 2014, Ivanov et al., 2017). Further, the disruption management in the transport system needs to adopt to the development and shift towards autonomous parts in the transport system (Batalden et al., 2017), e.g. autonomous trucks or ports. Information previously shared between humans may not be available in the future and therefore the need for support in disruption management for technical systems will be higher. The settings for recovery actions by active use of real-time information at the operational level have been studied less than the recovery measures defined before disruptions in supply chains (Bendul and Skorna, 2016, Behdani, 2013). The focus on disruptions in supply chains have included inventory and demand disruptions (Snyder et al., 2016) but less attention has been given to disruptions in transport (Hishamuddin et al., 2013, Ho et al., 2015).

Recovery after a disruption at the operational level has generally been associated with reactive recovery actions, following that reactive actions include response and adaption to a change and proactive actions anticipate a change (Wieland and Wallenburg, 2013). This reasoning gives that managing a disruption before it occurs, e.g. through evaluation of risks generating back-up transportation, is a proactive recovery action and managing a disruption after it occurs generates reactive recovery action, e.g. actions to recover from disruption. The support of information provides a new way to view proactive recovery when a disruption has occurred, through actively searching for early detection of disruption and making prediction of impact so that the recovery action can be made proactively (Feldman et al., 2013). Reactive recovery is then represented if the action is made after the impact of disruption in transport system has occurred. Both the reactive and the proactive recovery actions after a disruption has occurred use predefined recovery measures. In contrast to reactive recovery actions, proactive recovery actions benefit from real-time avoidance or mitigation for the impact of a disruption before being exposed to the full potential of the disruption. This proactive approach builds on the time delay between disruption and impact of supply or transport chains (Sheffi and Rice Jr., 2005). The earlier the detection of disruption and prediction of impact are completed, the available recovery actions are associated with smaller adjustments to the transport system (Norrman and Jansson, 2004, Otto, 2003). Costly express deliveries may not be necessary as other options are still available to fulfil the performance goal of on-time delivery (Goel, 2010). In order to achieve the possibilities to act proactively after disruption in transport systems has occurred, the real-time disruption management phases of detect disruption, predict impact and act accordingly need to be performed during the time window between disruption occurrence and transport chain impact (Séguin et al., 1997, Feldman et al., 2013).

Issues with the phases of real-time disruption management have been reported in the studied literature, which limits the possibility of recovery actions for disruptions to be made before the impact on the transport chains. For example, detection after the disruption impact on a transport chain, due to manual parts of real-time disruption management and issues of analysing all connections between shipments (Meyer et al., 2014), generates a reactive action related to disruptions. Furthermore, the phase of prediction does not sufficiently include all needed types of information from the surrounding environment, for example of truck arrival times (van der Spoel et al., 2017). A prerequisite for real-time disruption management at the operational level is visibility of operations (Christopher and Lee, 2004). Feedback from operations is needed to obtain visibility and lack of information about operations leads to difficulties detecting the disruption, predicting the impacts, and thereafter acting proactively on different alternatives (Meyer et al., 2014). In the studied supply chain management, logistics and freight transport literature, numerous of technological developments, i.e. TM applications and information sharing technologies like the Internet of Things (IoT), have been suggested to improve the visibility in the transport system

(Mason et al., 2003, Witkowski, 2017). The technologies have been viewed as one aspect to support the detection and initiate disruption management by creating visibility of operations. The Internet of Things suggests a complete connectivity in real-time for a supply or transport chain, which theoretically could generate information about anything that could ever be of interest for managing disruptions (Witkowski, 2017). This development could provide beneficial settings for proactive recovery actions in the management of disruptions after they have occurred but before transport chain impact. Further, solutions for decision support systems (DSS) have been proposed to use this large amount of information to support the actions related to the disruptions (Séguin et al., 1997, Meyer et al., 2014). Depending on the level of human involvement in the system, the autonomous level can go towards completely autonomous systems (Batalden et al., 2017), which, theoretically, could act by itself. The solutions are creating new demands and possibilities for information influencing real-time disruption management, which do not match the current use of information for recovery after disruptions. The studied literature for these solutions for disruption management has focused on the technical development of the systems, e.g. DSS (Séguin et al., 1997) and supply chain event management (SCEM) systems (Fernández et al., 2016), resulting in lacking understanding of real-time disruption management to utilise the time between disruption and impact (Li et al., 2018, Meyer et al., 2014). This in combination with the previously shown focus on predefined recovery strategies limit the taken recovery actions.

1.2 Purpose and research questions

The previous sections demonstrate the need for real-time disruption management to adopt to the changing information developments in transport systems. At the same time, there are issues of proposed solutions, e.g. real-time system solutions or predefined recovery actions to facilitated proactive recovery actions in real-time disruption management. Therefore, the purpose of this research is to investigate real-time disruption management in freight transport, in order to facilitate proactive recovery actions. The purpose supports the long-term aim of increased efficiency in freight transport. The purpose is broken down into two research questions, presented in the following sections.

The monitoring of operations and their environments is needed to initiate real-time disruption management through the detection of a disruption. The monitoring is proposed to be supported by information from ICT solutions to create visibility of the transport system (Stefansson and Lumsden, 2008). The monitoring is represented to be reactive, when detecting an occurred disruptive event, or predictive, when detecting the disruption event before it has occurred (Fernández et al., 2016). Reactive monitoring assesses performance indicators to detect a disruptive event, and predictive monitoring captures information relevant for the process to prevent an event (ibid). However, the level of real-time information sharing for transport chain operations is reported by previous literature to be low (Sternberg, 2011, Jacobsson et al., 2017), making it interesting to ask how the detection from monitoring is made for disruptions at an operational level. Moreover, the point in time when the detection is made has been identified as important, as previous literature view early detection after disruption as important for the initiation of disruption management (Sheffi, 2015, Norrman and Jansson, 2004). These points lead to the first research questions:

RQ1: How is detection of disruptions in freight transport influencing when real-time disruption management is initiated?

The second research question was developed after the first study of using performance indicators as feedback for resource utilisation. Detection through performance indicators mainly generated detection of disruptions after impacts from disruptions on the transport chain had occurred, resulting in reactive recovery actions. In order to facilitate a shift from reactive recovery action in real-time disruption management to proactive, the focus on this research changed towards early detection and prediction for proactive recovery actions. If detection and prediction are made before transport chain impact, there is a possibility for proactive recovery actions. These actions have mainly been discussed from the time perspective of actions before a disruption by anticipation of the disruption but not before impacts on the transport chain. The time delay between disruption and impact (Sheffi and Rice Jr., 2005) has been identified. However, the understanding of how to utilise this time window is lacking. For example, how the detection of disruption and prediction of impact should be performed in order to provide possibilities for proactive actions before the transport chain impact is not fully understood (Meyer et al., 2014, van der Spoel et al., 2017). This raises interest in understanding how real-time disruption management influences the possibility for the transport chain to be proactive.

RQ2: How is real-time disruption management able to generate possibilities for proactive recovery actions in freight transport?

1.3 Research scope

The research focuses on the parts of real-time disruption management in freight transport as illustrated in Figure 1. The figure shows the context in which the research scope is fitted. The transport system matches freight orders and transport resources in order to achieve the highest possible efficiency but are impacted by a disruption during the execution of these plans. The disruption generates impacts on the transport system, which in turn generates the need for real-time disruption management. The real-time disruption management influences how much the transport system is impacted by the disruption and therefore improved understanding in real-time disruption management is assumed to positively influence impact from disruption and support higher efficiency. The potential magnitude of influence on efficiency is outside the scope of this research. This research focuses on how a disruption is managed in a transport system and not the disruption per se, i.e. what type of disruption that has occurred. The actor perspective taken for managing disruptions in a transport chain is the logistics service provider (LSP), due to their role as transport coordinator (discussed further in Chapter 3.3).

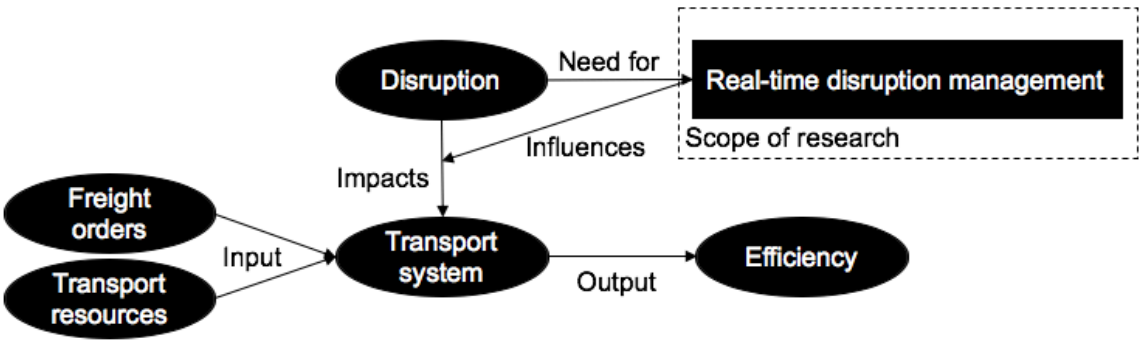

Figure 1. Illustration of the scope for the research and the connected context.

Freight transportation is addressed through disruption management, where concepts from literature in the field of supply chain management are used. The rich body of disruption literature revolving around supply chains, e.g. supply chain risk management and supply chain disruptions, generates a general foundation for concepts and tools for disruptions applied in this research. This literature takes a perspective that does not put the transport function of supply chains in focus, and therefore this research adds transport literature to cover settings and perspectives specific for freight transport.

1.4 Outline of thesis

This chapter has motivated and introduced the research focus, with connected purpose and research questions, of this thesis. In Chapter 2 the frame of reference for the research focus is presented. Thereafter, the research design is described by including how the research questions guided the studies and how the studies were performed. The chapter further explains the research process and choices connected to case selection and finally covers research question. Chapter 4 gives a summary for the appended papers. In Chapter 5 the results from the research is presented, connected to the research questions. Chapter 6 includes the discussion, before Chapter 7 provides the conclusions and contributions of the thesis as well as proposed future research.

2 Frame of reference

This chapter examines the found literature relevant to answering the research questions. Supply chain management literature is used in Chapter 2.1 to position the research on disruption management in this thesis against important aspects of disruptions from the literature, as resilience and supply chain risk management. Furthermore, this literature provides general concepts and tools for disruption management. These concepts and tools are applied to the transport chain context to build up the conceptual model around real-time disruption management in Chapter 2.2.

2.1 Strategies for managing disruptions in supply chains

Many different approaches for managing disruptions have been proposed in the literature related to supply chain management, logistics and freight transport. Wieland and Wallenburg (2012) represent two different ways of managing disruptions in terms of resilience, namely robustness and agility. Both ways are in the need of detecting that a disruption has occurred, however the approaches after detection differ. Robustness refers to focusing on proactive strategies before a disruption occurs, e.g. using predefined recovery strategies (Ivanov et al., 2017) of inventory and design decisions (Wieland and Wallenburg, 2012). Agility includes how quick a system reacts and respond to a disruption emphasising the use of information, e.g. visibility of operations (Christopher and Lee, 2004) through communication between actors (Wieland and Wallenburg, 2012). Robustness and agility are both discussed at a strategic level and generate multiple options, including 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 communication channels (Wieland and Wallenburg, 2013) in order to prepare the system to act accordingly when disruption occurs.

These strategies assume reoccurring disruptions at the operational planning level, where occurrences can be predicted with a certain probability and therefore managed with the proposed recovery strategies predefined and ready for implementation. Furthermore, the learning process for a disruption that reoccurs discussed by Blackhurst et al. (2005) indicates need for strategic or tactical decisions to redesign the system in order to avoid or mitigate a negative business impact from this disruption. Indeed, both strategic and tactical planning measures are important parts of the operational planning to respond to both reoccurring and non-reoccurring disruptions, but they often lack consideration of the different time aspects of the disruptions (Dunke et al., 2018, Heckmann et al., 2015). Even though it is acknowledged that the recovery strategies need to be quickly implemented after disruptions and supported by visibility for impact assessment and the effects of recovery (Ivanov et al., 2017), more details on how to achieve the time aspect of earlier detection is not covered. Predefined buffers of time or products function as shock-absorbers (Bode et al., 2011) for most disruptions, especially non-reoccurring disruptions, and therefore support the operational planning in avoiding impact from a disruption or at least increase the gap between disruption and impact. Via the predefined recovery strategies, the discussed approaches lack active anticipation of disruptions and impact, leading to limitations of these strategies for managing the disruption after it has occurred but before its impact (Feldman et al., 2013). A system applying the strategy of using real-time data to management disruption, e.g. DSS (Séguin et al., 1997, Meyer et al., 2014), needs a higher level of visibility but may gain the benefit of lower levels of buffers (Christopher and Lee, 2004).

Supply chain risk management is another important component of the literature covering disruptions. It differs from the disruption management investigated in this research. Disruption management revolves around a plan, e.g. a transport plan, that during execution is exposed to a disruption (Yu and Qi, 2014). The disruption leads to an impact on the original plan, resulting in the plan not remaining optimal or even feasible. A dynamically revision of the plan, taking into consideration the new constraints and negative impacts from disruptions, is referred to as disruption management (Yu and Qi, 2014). Disruption management treats disruption as a change in a plan, regardless of the root cause (Yu and Qi, 2014). In the same direction, Otto (2003) discusses Supply Chain Event Management (SCEM) and refers to deviations as being a difference between a planned status and an actual status, represented by a specific characteristic of the object. A disruption only has an impact if the deviation exceeds a defined threshold. Along the same lines, Dunke et al. (2018) proposed supply chain performance deterioration, which is critical when the difference between planned and actual performance deterioration exceeds an accepted value. A potential trigger becomes a disruptive trigger when it influences the supply chain performance.

These perspectives on managing disruptions in disruption management differ from supply chain risk management (SCRM), which refers to a broader perspective as a cause, involving a supplier or other part of a supply chain, that prevents the system from functioning normally (Snyder et al., 2016). SCRM generally focuses on risks and includes identification of a risk, assessment of a risk, treatment of a risk and monitoring of a risk (Fan and Stevenson, 2018). Focusing on the disruption as the change of planned and actual status in disruption management, in contrast to SCRM, has little focus on the origin and source of the disruption. In SCRM, a big focus has been on classification of risks as operative or disruption risks (Tang, 2006, Wagner and Bode, 2008). Furthermore, Dunke et al. (2018) discussed that their proposed perspective of disruptions is overcoming shortcomings of simplified evaluation in terms of the disruptive trigger having an influence on a single performance measure. Instead, the authors argued for a perspective including the facts that one disruptive trigger can influence several performance measures and that several disruptive events can influence the same performance measure. Attempts to combines these the two viewpoints have been made. For example, Behdani (2013) included both viewpoints in an agent-based model, arguing for supply chain risk management to be handling risks and preventing impacts before any impact in the supply chain. After the impact on the supply chain the disruption management contains the response and the recovery related to the impact.

2.2 Real-time disruption management

The main phases for real-time disruption management are detection of disruption, prediction of business impact and performing action (Séguin et al., 1997, Feldman et al., 2013), following the terms of technical solutions. Other terminologies for phases in disruption management have been used, including similar content. Blackhurst et al. (2005) discussed disruption discovery, disruption recovery and supply chain redesign, which include the same phases of detection, understanding how a firm can recover (acting) and the broader perspective of how the supply chain learn from the disruption and redesign the supply chain. However, a clear distinction of real-time disruption management is not made in that model, as the step of predicting the impact from disruption is missing. Including the prediction phase is important as it is needed in order to consider the detection lead time, which is the time between finding out that a disruption is taking place and the first impact on the business (Sheffi, 2015), e.g. first impact on a transport chain.

2.2.1 Detection

The detection phase of real-time disruption management is descriptive as what has happened should be answered by gathering and understanding information connected to the transport system (Mishra et al., 2017, Batalden et al., 2017). A disruption is when the actual status differs from the planned status with a defined threshold (Otto, 2003), which generates the need for a status of operations in order to detect a disruption. The timing of when a disruption is detected is important as it initiates the real-time disruption management. The later the detection is made, the fewer are the options available to avoid or mitigate impact, or the detection is made after impact giving reactions to impact rather than proactive recovery actions. The detection of disruption in this thesis consists of three detection factors of, what is detected (Otto, 2003), how it is detected (Goel, 2010) and where the detection is performed in the transport system (Nel et al., 2018). These factors represent different viewpoints in the thesis influencing when the detection is made, and real-time disruption management is initiated. These factors are described more in detail in the following sections.

What is detected, in terms of planned and actual statuses, varies depending on the visible objects. The attributes for detection indicate what disruption is being detected in the transport chain, e.g. time, quantity or quality (Otto, 2003). 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 detect a disruption impacting planned operations (Feldman et al., 2013). What to detect mainly means focusing on a disruption in general. However, as pointed out by Dunke et al. (2018) a disruption can stem from many different sources of disruptive events. Secondary consequences of a disruption may be more amplified than the first impact (Świerczek, 2014). Detection of disruption occurs if information about operations is available, via visibility, and monitored. Visibility generates an overview of a complete pipeline or chain (Christopher and Peck, 2004). In order to obtain visibility, information has to be shared between the involved actors (Christopher and Lee, 2004). This collaboration is vertical if within a company, as for example between different departments or horizontal if information is shared across companies in a chain (Barratt, 2004). What information that can be shared between the actors are depends on what in the operations that are visible. What is in focus for visualisation influences how early detection of disruptions initiates the disruption management process, which generates possibilities for a problem solution in a timely manner before associated with higher costs (Sheffi, 2015, Norrman and Jansson, 2004).

How the detection is made can vary, depending on how the monitoring of visible operations is performed in order to obtain information related to disruptions (Fernández et al., 2016). Fernández et al. (2016) have argued that detection is made via reactive monitoring, based on information about an occurred disruptive event, i.e. monitoring information about performance indicators for an operation (Adhitya et al., 2007). Alternatively, predictive monitoring by information from operations and the surrounding system environment are used to predict the disruptive event. The information concerning operations or surrounding variables can be presented to the responsible planner at different time points. The timing of visibility is further of importance, as Goel (2010) distinguished between no updates, once a day, at checkpoints at the end of operations or checkpoints during operations. More frequent updates gave earlier detection and better on-time delivery when the disruptions occurred. How the visibility and monitoring is executed is in turn connected to the track and trace systems being used. The source of information in transportation systems can be linked to freight, vehicle or infrastructure (Stefansson and Lumsden, 2008). Meyer et al. (2014) looked into a case where three state-of-the-art systems are in place to capture and analyse 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 were automatically connected to the APS. Even though the case had current systems, the authors found that the support systems failed to have updated information or manual detection by planners as causes of the problems with timely detection. Issues with the manual detection were connected to the number of sources for information, e.g. information for transport operations of weather, road conditions and driver schedules (van der Spoel et al., 2017). These issues resulted in delayed detection of unexpected disruptions (Meyer et al., 2014).

Where in the system a disruption is detected is further of importance for when the detection is made (Behdani, 2013, Nel et al., 2018). Risks for disruptions are categorised in supply chains as internal in a company or external, either outside the company boundaries but within the supply chain network of the company or external to the supply chain network (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 tier 1 and a warehouse have the greatest impact on the supply chain. A system for freight transport can be adopted to the three levels of infrastructure, transport flow and material flow from Wandel et al. (1992). The level of infrastructure, which is the lowest of the levels, supplies capacity to match the demand from the middle level of transport flow. In other words, the infrastructure level is the infrastructure where the transport flow is being operationalised, namely roads, terminals, ports, etc. The transport flow, the second level, generates flows of unit loads to fulfil the demand of material flow, representing the transport market. The third level is the material flow includes flows of product or articles in contrast to the transport flow which focuses on consignment (Woxenius, 2012). A link in the material flow could, for example, represent the flow between production and a warehouse. Due to cost optimisation, this link can be represented at the transport flow level by other links, e.g. between production and consolidation terminals before arrival at a warehouse (Woxenius, 2012). The transport between the production and consolidation terminal can further be represented in the infrastructure level by different route choices, etc.

2.2.2 Prediction

After a detection is made, the business impact of what could happen needs to be analysed in this predictive phase (Mishra et al., 2017, Séguin et al., 1997). The diagnostic part of this phase, as why did this happen (Mishra et al., 2017), is not included in this research as the root cause and learning process after a disruption is not included in the research scope. Information and communication technologies have enabled more visibility for operations and the surrounding environment and supported future time periods for a prediction to be of certain look-ahead in the near future (Dunke et al., 2018). The prediction is dependent on the detection of disruption. If the detection is made before the impact, by anticipating a disruption, the prediction is made of a future state that is undesirable (Feldman et al., 2013). Predictions can further be made on how long a disruption will impact the chain (Dunke et al., 2018). The predictions can be made by a system based on real-time information or historical data or can be manually performed via human experience (Batalden et al., 2017, Knemeyer et al., 2009). In order for the prediction to be reliable, it needs to consider surrounding environmental variables in the transport chain (van der Spoel et al., 2017). Meyer et al. (2014) described the complex relations between shipments in a transport system making it difficult to understand impacts further down a transport chain. van der Spoel et al. (2017) indicated that additional information than traffic information on a route is needed for reliable predictions of arrival times at a terminal, as truck drivers' intentions and schedule.

2.2.3 Action

After detection of disruption and prediction of impact, the phase of action needs to evaluate different available options to manage the disruption before an action is taken (Feldman et al., 2013, Séguin et al., 1997). Thereafter, the phase concludes in a prescriptive way of what to do (Mishra et al., 2017). The later the detection of a disruption is made, the fewer alternatives for the actions are available (Goel, 2010). Otto (2003) introduced four modes for actions in supply chain event management of repair, re-schedule, re-plan and learn. The first three modes are different magnitudes of changes to the original plan, where repair is the smallest change, e.g. contacting a truck driver to correct the route, because the driver is heading towards the wrong destination. Actions for impacts on a transport system which can be minimised further down the chain by re-scheduling assignments for a shipment (Crainic et al., 2009) and changes to plan of a re-plan for the whole shipments, by changing the planned route (Crainic et al., 2009) or the mode of transportation (Goel, 2010). Furthermore, re-plan actions can include changing prioritisation for a shipment for incoming and outgoing flow at a transport node, e.g. a distribution centre (Van Belle et al., 2012). For this re-plan action, the distribution centre needs information about arrival times for all other incoming and outgoing shipments (Li et al., 2018). The possible actions depend on the duration of time for the two previous phases of detection and prediction. Even if the recovery actions at this stage should be taken upon early detection and prediction these actions are influenced by recovery strategies of overcapacity in a system, defined at previous strategic and tactical planning level. Zhen et al. (2016) investigated the pre-disruption strategies of business interruption insurance and back-up transportation, defined as, if one distribution centre is disrupted products are transported from another distribution centre. Actions at operational level for changes of mode and back-up transportation need predefined strategies, e.g. contracts with multiple transport operations, similar to production firms may applying dual sourcing on components (Tang, 2006). The previous mentioned learning process from disruptions include these recovery strategies to be in place for the next time such a disruption occurs, but it further includes redesign of a chain in order to avoid disruption in the future (Blackhurst et al., 2005). The authors further elaborated on that the costs of getting information associated with actions based on visibility need to be considered in comparison to costs for premium freight or buffers with recovery strategies.

If the recovery action is classified as proactive or reactive in the studied literature is related to when the action is performed. A proactive action is made before the disruption, while a reactive action follows the disruption. Feldman et al. (2013) describe a proactive approach as finding that the system is going into an undesirable state at a time point before this happens. Similarly, in supply chain risk management, Berg et al. (2008) defined proactive processes of identifying a risk, evaluating the risk, managing the risk, monitoring the risk and making contingency plans and reactive processes to handle the incident or accident and execute contingency plans. Wieland and Wallenburg (2013) defined proactive in supply chains connected to an anticipation of a change and reactive as response and adaption to a change. The timing of when the action is performed is the main driver in the difference between the two options. The general notion for the time perspective of pre-disruption and post-disruption, as proactive respectively reactive, fails to denote the previously discussed time between disruption and impact. An action between the time after detection and before impact for a certain actor indicates a proactive action even though it is made after disruption occurs.

2.3 Overall research concepts

Figure 2 illustrates the main concepts for this research, and it is a zoom-in of the research scope from Figure 1 in Chapter 1.4 and extension of the main concept of real-time disruption management. The real-time disruption management has been identified to include the three phases of detect, predict and act. The recovery actions taken due to a disruption are classified into reactive or proactive. A proactive action is made by anticipating a certain impact and a reactive action is made by reacting or responding to an occurred impact. The real-time disruption management is initiated by a detection of a disruption. The detection includes the factors of when the disruption is detected, where in the transport system the detection is made, what is detected and how the detection is performed. The real-time disruption management is influenced by when it is initiated, where early detection is of importance. In this research the focus is on when the disruption is detected, and the real-time disruption management is initiated and therefore the other factors act as influencing factors for this factor.

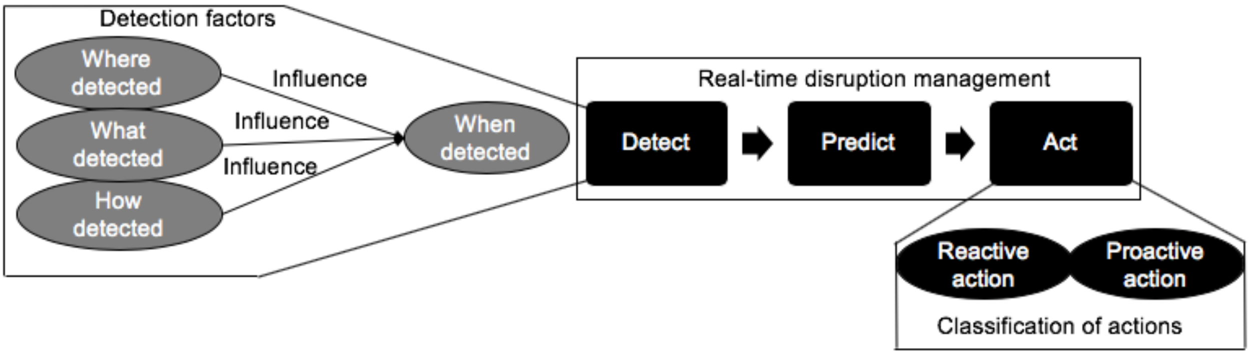

Figure 2. Conceptual model for the research with representation of the different concepts.

3 Research design

The research design includes the research questions, the planned methods and studies, while at the same time ensuring research quality (Bryman and Bell, 2011). Maxwell (2013) presents the central position of research questions in the research design, with connections to the research goals, conceptual framework, methods and validity. In this thesis the studies were guided by research questions of *how is detection of disruptions in freight transport influencing when real-time disruption management is initiated* and how is real-time disruption management able to generate possibilities for proactive recovery actions in freight transport. This is shown in Figure 3, which illustrates the connections between the research questions, performed studies and papers. The first research question was divided into three detection factors (what, how, when), which guided parts of all the studies. The first study gave insights into what and how detection is made to initiate real-time disruption management. The second study gave further input for what and how is detected and added the connection to the second research question of the phases of prediction and action of real-time disruption management. The third study covered the detection factor of where in the system a detection is made and added insights into facilitating proactive recovery actions. The research design in this research is influenced by an engineering view of how to get something to work by designing a solution. The conceptual framework focuses on parts included in a technical solution, i.e. decision support systems, rather than on other approaches, e.g. issues connected to transport planners not trusting the given information. The engineering approach is reflected in the entire research, as it is represented in each study by understanding how disruption management is done in order to move towards a solution. As a result, the focus is on moving towards the direction of a solution that works, rather than explaining why real-time disruption management is done in a certain way.

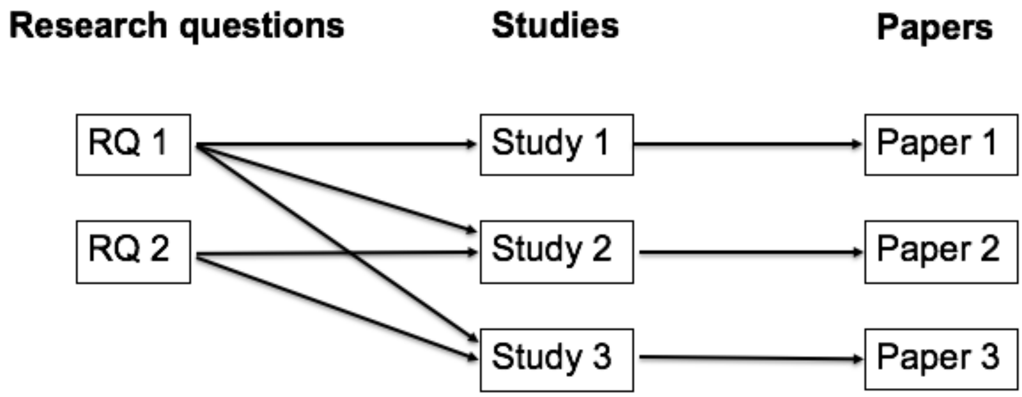

Figure 3. Connections between the research questions, performed studies and the produced papers.

Both research questions in this thesis are posed as “how-questions”, which, according to Yin (2014), can be more suitable to answer with case studies. This together with the aim of investigating real-time disruption management within its real-world context (Yin, 2014), guided this the research to case studies. This research is based on empirical data from two case studies, where the data come from qualitative methods (Bryman and Bell, 2011). As discussed by Flick (2014), the subject of a case might not be clear, as it can, for example be a person, organisation or institutions. Yin (2014) has a similar take on this but adds cases that are less concrete, such as communities, relationships, decisions and projects. In this research the selected study object revolves around the decisions made at the operational level in connection to disruptions in freight transport. The performed case studies focus on real-time disruption management to be represent the management of disruptions in real-time planning and the coordination of execution in a transport system.

Yin (2014) described the qualitative case study linked to a description of the deductive approach of establishing a theoretical framework and data collection plan before fieldwork. In contrast, case studies can be used in an inductive approach for the research and create theory generation (Eisenhardt, 1989). Ketokivi and Choi (2014) introduced a third approach of theory elaboration as the purpose of a case study. These case studies use a mixed approach of the inductive and deductive approaches. The overall research process between the studies for this research and the process within each study were iterative between literature and empirical data, including similarities to presented approach the from Ketokivi and Choi (2014). The iterative approach was chosen for this research since the outcome of Study 1 was not given and, therefore, at this stage of the research the focuses in the second and third studies were open. For the overall research process, the three studies in this research represent different parts of real-time disruption management. The second and third studies are clearly linked to real-time disruption management, while the first study mainly focuses more on usage of feedback from performance indicators in transport planning. The next section provides more details on how the research process has been iterative.

3.1 Research process

The presented research is part of the European Union (EU) project "AEOLIX", which stands for Architecture for European Logistics Information exchange (AEOLIX, 2017). The main objective of the project is increased knowledge of sharing information among actors in logistics (ibid). The beginning of this research process was guided by the focus in the financing EU project, with low level of information shared between actors in logistics. The direction towards the development of cloud-based solution for information sharing between all logistics actors in the EU project, provided a base for the focus of this research towards future possible usage of this solution, namely usage for disruption management. Therefore, the first study did not have a distinct focus on disruption management, in comparison to the second and third papers. The project started in September 2016 and this research started in February 2017 when the author started a PhD student employment. Figure 4 outlines the time line for the studies of this research.

Figure 4. Timeline for the research process, represented by the studies and the papers.

Another starting point for this research, additional to the focus of the EU project, was the planning process, since understanding how planning processes are performed guided the early stage of this research approach. After understanding how the plan leads to operations, where the plan could be adopted after feedback regarding efficiency, it became clear that the problem was managing operations subject to disruptions. This change of direction in research focus is represented in Figure 5.

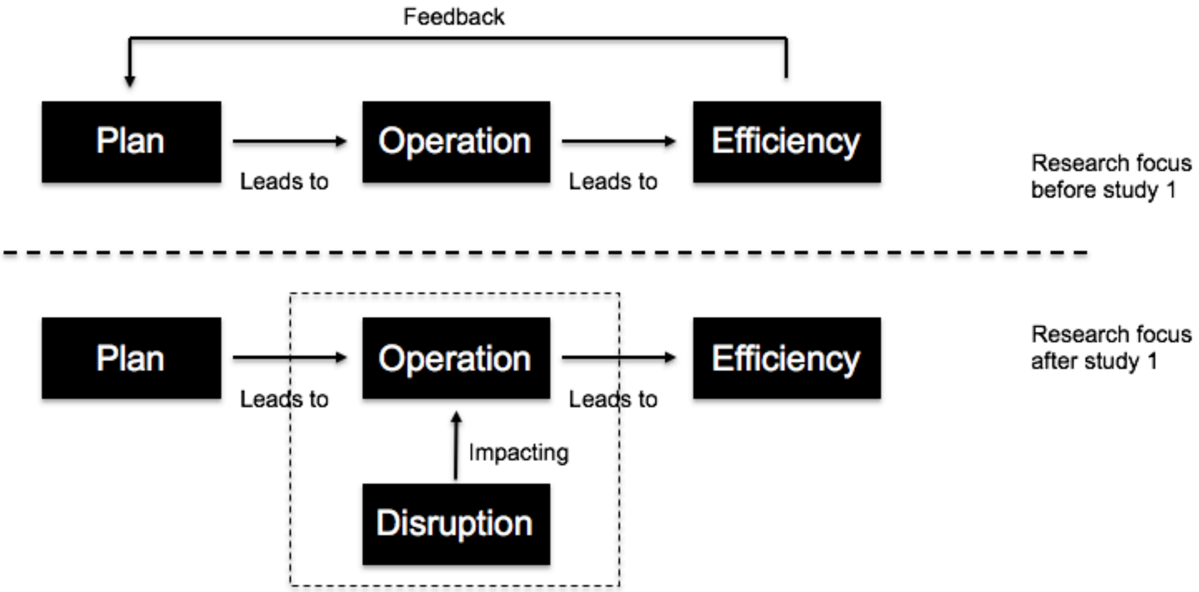

Figure 5. Illustration of research focus before and after Study 1.

Nevertheless, the first study gives input for the disruption management used in the second and third studies. As described by Fernández et al. (2016), the monitoring of operations includes either detecting disrupted events or predicting events and allowing for prevention before disruptive event occur. Detecting disruption events uses information from the operations and assessment, and performance indicators ara one option for this approach that is covered in the first study. The first study focused on the usage of performance indicators as feedback to transport freight planning and identified the comparison of actual and planned statuses with a time delay after the change occurred. These comparisons are used with the main aim of detecting disruptions as market changes, etc. and were not adopted for real-time disruption management at the operational level. Therefore, the second study added the perspective of real-time information, or at least near real-time information, which generates possibilities to detect deviation between planned and actual status at the operational level in a timely manner. In this way detection can be made before disruptive events occur, as the information captured not only includes operations but also the environmental variables off the surrounding system. The first study contributed to the thesis by including performance indicators representing what to detect as well as how actual and planned statuses are compared to detect disruption and influence when the detection of disruption is made. The second study extended contribution to thesis on what is detected in terms of information for operations and surrounding environments and how, in terms of real-time information, in relation to when the detection is made. The study further connected the detection to the phases of prediction and actions in order to generate proactive actions after disruption but before impact. The third study added where in the system the disruption is detected and when the real-time disruption management is initiated and connects this to the proactive recovery actions.

Furthermore, the studied literature between the different studies was iterative. A continuous and iterative review of literature has been performed during this research. This refers to that the review included different search words and finding literature through references or in the citations of articles identified as interesting for the scope of the study. For example, during the first study the literature about efficiency in transportation, e.g. KPIs of resource utilisation, was investigated in combination with transport planning literature. For the second and third studies disruption management was mainly studied. The third study builds on the second study but extends the scope for disruption management scope by focusing on where in the system the real-time disruption management is performed.

The research approach for each study was iterative, as each study was based on different frameworks developed during the study and included an iterative process between collected data and analysis. For example, each study was based on a framework before data collection was executed, which was based on important concepts identified in the literature. For each study the frameworks were developed after new perspectives were gathered from collecting the empirical data. This iterative process is further described for each study in Chapter 3.3. The iterative approach, both for the complete research and within each study, is comparable to the abductive approach as discussed by (Ketokivi and Choi, 2014). The approach resulted in contributing to the studied literature by elaborating on the management of disruption in transport systems, in terms of clarifying the dynamics of real-time disruption management.

3.2 Case selection for empirical data

The sampling strategy for the two case companies for this research was based on companies involved in the research project, which could be seen as convenient sampling (Flick, 2014). The possibility of getting deep knowledge from the case companies, with commitment through the research project, was weighted to be valuable. Nevertheless, other criteria coordinate between the research and the companies. That the companies choose to participate in the specific project indicated an interest in improving technical development in their processes. Further, the companies were governing the function of their transport chains, which indicated a leading role in managing disruptions. The starting point for all data collection was in connection to the operational planning and coordination of execution in the companies, in order to capture the management of disruptions in real-time at the operational level.

The transport system in this research is from a perspective of a logistics service provider. This was chosen since the role of this actor is linked to the transport coordinator, as pointed out by Woxenius (2012). By coordinating the transport, this actor should have knowledge about the transport chains in order to make decisions for the outline of the transport chains in the transport system. This knowledge indicates important input for assessing disruption management in a transport system. The logistics service provider should be able to locate disruptions and have an overview of transport chains to handle these disruptions in order to minimise impact for customer delivery. The represented planning and coordination of execution by the logistics service providers in this research have had the main responsibility for acting on disruptions in terms of changing the transport chain.

After selection the companies to be involved the types of respondents were determined. Transport planners were considered to have the most knowledge about what happened at the operational level and how they managed this. Therefore, transport planners were viewed as the starting point for data collection to cover the real-time disruption management. The transport planners involved in the planning and coordination of executed operation processes were covered in each case. In one case company all three available planning areas for the studied transport chains were covered and the selected interviewees were based on the personnel with the most experience. For the other case company all three available transport planners for the studied transport planning were interviewed. After the interviews with the planners the author chose to include interviews with transport and general managers and logistics developers, in order to cover a broader perspective to mitigate parts are missed due to focusing only on transport planners.

3.3 Data collection and analysis

So far in this chapter the focus has been on how the research question guided the studies, in this section how the studies that contribute to the research questions will be covered. The processes of collecting data and analysing of data, in order to contribute to the research questions, are explained separately for each of the presented studies. Table 1 represents an overview of the three studies, the empirical data collection and contributions to research questions. The performed interviews in all studies were semi-structured interviews in order to be flexible in the data collection (Bryman and Bell, 2011), to allow interviewees to include important points for them and for the author to be able to go in other directions in the interview than originally planned. In this way, the author did not steer the answers from the respondent and the respondent had the opportunity to diverge into topics that they found important to the asked questions. The observations made in the studies, were all aiming at confirming what the planners said in the interviews and getting more detailed data on how the management of disruptions was performed.

Table 1. Overview of empirical data and contribution to thesis for each performed study.

Study	Data collection	Contributions to RQs
Study 1: Usage of performance indicators as feedback for resource utilisation in operational transport planning	Six interviews with planners and managers and observation of the planning process on three occasions. Case company documentation for performance indicators.	Understanding the usage of performance indicators in operational transport planning gives an overview of how feedback is used in operational management in transport chains. This indicates what is detected and how it is detected, influencing when the detection of a disruption occurs.
Study 2: Proactive recovery actions from real-time disruptions management	Eight interviews with planners and logistics business developers and observation of the planning process on three occasions.	Understanding about when initiation of real-time disruption management is influenced by the detection factors of what and how, and the phases and information needed to generate proactive recovery actions before impact on transport chain from disruption occurs.
Study 3: Where in transport system real-time disruption management is indicated and performed	The interviews with planners and their group manager in Study 1 served as the base for this study. This was complemented with one follow-up interview with the group manager. Further, a three hours long focus group was held with two software developers and two business consultants.	Understanding where in the transport system real-time disruption management influences when detection is made and how real-time disruption management at the different system levels in transport chains generates possibilities for proactive actions.

3.3.1 Data collection Study 1

At one logistics service provider six semi-structured interviews were performed with three freight planners, one with each of the three studied planning groups, a planning group manager and a general manager. The studied planning revolved around the setup of regional transport chains made on the road, for a detailed description see Paper 1. One of the three planners had knowledge and work experience from two of the three studied planning groups and was therefore interviewed twice. The interviews focused on the role of resource utilisation in the planning and what feedback regarding this was received, and how that feedback was used. The author wanted to ask questions which allowed for the answers to provide a broad understanding of how the planning was performed. Therefore, the interviews used a question guide with topics developed from the studied literature. The topics included transport decisions, as what decisions are made, information input and use for decisions and what feedback was used to learn from the consequences of decisions made in terms of resource utilisation, see Paper 1 for more details. The interviews with the transport planners and manager were not recorded as the interviewees were not comfortable being recorded. Extensive notes were taken during all interviews and sent back to interviewees for validation purpose. All interviews, expect with the general manager, were performed at the interviewee's work places, which were desks in an open space area. This setup led to some potential participants not being interviewed since they heard the performed interview and therefore found that they could give no more input, than what had been given by the senior planner.

Three on-site observations of the freight planning department and terminal were conducted to complement the data collected through interviews. The first observation included both observations on planned transport operations in the terminal to understand what was being planned and how some operations at the terminals were executed. The second and third observations were direct observations of the performed planning from the transport planners. These observations lasted around three hours respectively one hour. During these observations the author sat next to a planner that explained their planning and coordination of executed operations process, going through all planning groups for the studied transport chains. Furthermore, documents for reported indicators to management or quality work, such as for the International Organisation for Standardization (ISO), were examined by the author. This documentation showed how the case company worked with reporting performance indicators and shared this with their transport planners.

3.3.2 Data analysis Study 1

The literature was used to build a conceptual framework, see Paper 1 for further details, serving as a base for the empirical data collection. Literature was studied with focus on performance indicators and transport efficiency, primarily in terms of resource utilisation and operational planning of transport chains. The study consisted of primary data from semi-structured interviews and secondary data from observations and document review. The collected data were analysed on its content following the concepts in the framework. The concepts used for the structured analysis included what type of resource utilisation the feedback covered, time, capacity and environment. After this analyses the focus was developed to include how the feedback was used. Therefore, the what information for feedback was combined with how the usage of feedback from indicators related to direct or different types of indirect usages. This was done by going through the all notes from the interviews and observations and comparing to the concepts in the framework. Depending on when they received what performance indicators and how they used the performance indicators these could be classified into the part covering usage in the framework. The types of coverage for performance indicator on resource utilisation was done through comparison of the indicators to explanations of the different types of resource utilisation drawn from the reviewed literature. The documentation gave further support for the author in the analysis to confirm the different types of performance indicators.

3.3.3 Data collection Study 2

One planning group of transport chains via road and train, from suppliers to a central disruption centre and between this disruption centre to two other disruption centres, were the focus for the data collection. The case company acts as both transport coordinator, shipper and terminal operator for the studied transport system and the transport planners mainly gave input from the transport coordinator perspective for how to plan and coordinate the studied transport chains. Therefore, the interviews with the logistics business developers covered how other parts of the case company influenced the real-time disruption management performed by the planners. Further descriptions of the case company are found in Paper 2. The empirical data were collected from eight semi-structured interviews, performed with all the three transport planners working at the planning group and two logistics business developers. The logistics business developers were not only connected to the transport chains covered in the study but also had responsibilities in other parts of the case company, e.g. terminal activities. The second round of follow-up interviews were performed with the planners. The first round of interviews with the planners focused on an overview of executed operational transport planning and the second round focused on information about disruptions. This division was made in order to first cover the processes in planning and coordination of execution and then gain more insights on how disruption management in these processes are treated. The first part included what decisions were made by the planners and how they made the decision, e.g. information systems in place, etc. The business developers were interviewed before the second round of interviews with the planners. The focus of these interviews was to capture both the planning and coordination of execution in relation to disruptions from a broader perspective in the case company. After these interviews the author had a broad overview of the planning and coordination of execution processes and therefore the second round of interviews focused on how disruptions were managed in these processes. The focus of the questions followed the structure of how the phases of real-time disruption management from the studied literature were represented. The phases included detection, prediction and action. The detection involved how disruptions were detected, what was detected in a disruption, in terms of disruption or impact and when a detection was made in relation to before or after the transport chain impact. The prediction included how and of what predictions were made, what the action focused on and if actions taken were made before or after transport chain impacts. The interviews around disruptions were found to be influenced by what the interviewees remembered about disruptions, depending on what the issues had been in the latest days or weeks, not representing a fair overview of frequency of disruptions. However, the understanding of the planning and coordination of execution combined with the aim of the interviews to find out how the real-time disruption management was performed, rather than the occurrence of a specific disruption, mitigated these biases to some extent. Further, the performed observations served as a good approach to see the disruption management for some real cases, as during the observations some disruptions occurred, and the management could be captured by the author and compared with statements in the interviews. This setup led to more in-depth data about their management of disruption in comparison to only performing interviews.

The observations were performed during three on-site visits at the central disruption centre, including both observation of transport operations and the planning and coordination of execution.

The transport operations included the terminal operations of loading and unloading and provided understanding for the overview of how these operations constraint the planning. The direct observations of the planning and coordination of execution were made by the author sitting next to planners watching what was done. The first observation was mainly about getting an overview of the process, including planning and coordination of operations. The second observation was after the first round of interviews, giving more information about the process. During these interviews the author sat next to a planner who explained the process. This was conducted for around 3 hours. The final observation was made after the second round of interviews, in which the focus then became capturing the disruption management. The planners explained what happened and what their next steps were, e.g. when the planners got phone calls that were not heard by the author. This observation was made during two working days. The three planners sat next to each other so the author could move between the planners, depending on the current task for the planners. If a planner received information about a disruption the author could switch seats and get information about what was going on. If the planner was busy during the coordination of the execution, e.g. managing a disruption, the planner and author went through the management of the disruption after the disruption was resolved. Extensive notes were taken during all interviews and observations.

3.3.4 Data analysis Study 2

Literature was reviewed for the study with a focus on disruption, risk and event management in transport, and supply chains, and used to develop a framework. The framework (see Paper 2) was used to analyse the collected data. The framework consisted of the time phase after disruption and before transport chain impacts. During these points the detection, prediction and action had to be performed in order for actions to be considered as proactive for the transport coordinator. Otherwise, the actions were considered reactive. The empirical data on what was being planned were used in the analysis to build an understanding of how potential disruptions were treated already in this stage, with for example time buffers. These insights were considered for the analysis when disruptions occurred, as the buffers influenced the management of the occurred disruptions. The empirical data for the real-time disruption management were analysed making connections to the phases of detection, prediction and action. The author reviewed the notes from interviews and observations to find how these phases were treated in relation to before or after transport chain impact. By studying the data on management of disruptions it was found that different things were detected, as different ways of getting data were used, e.g. system support or manual reporting. Building on this, the author identified different objects that were detected in connection to a disruption, representing what was detected, e.g. disruption or impact. These objects were shown to be of importance when the detection was performed, in terms of before or after the transport system was impacted. Furthermore, to build a complete picture of how the phases of real-time disruption management are connected, depending on detection of the objects of what to detect, the objects were coupled in the analysis to what this meant for the phases of prediction and action.

3.3.5 Data collection Study 3

The third study is based on the same case company and transport chains as the first study. Therefore, the five semi-structured interviews with transport planners and the transport manager from Study 1 served as the base for the planning and coordination of execution processes in this study. This empirical data was complemented with a follow-up interview with the planning group manager and a focus group. The interview used a guide to capture how the real-time disruption management was performed focusing on the three phases of real-time disruption management of detection, prediction and action found in the reviewed literature. For these phases the focus was on what kind of information was provided and used to detect disruptions and how these generate settings for the predictions and actions related to the disruptions. The follow-up interview was performed via telephone and extensive notes were taken and sent back for validation to the transport manager. The focus group included the participants of two system developers from a company that develops software for logistical solutions and two logistics consultants from a consultancy firm. Both the software company and the consultancy firm were involved in the research project with connections to the case company. Both firms wanted to find solutions for a suitable build-up of estimated time of arrival for the case company to provide project deliverables. During the focus group the participants discussed predictions of arrival times for trucks to a terminal in the case company, which could serve as the support system for detecting a disruption and predicting impacts. The author participated in the focus group discussion but only steered the focus group in the sense of asking questions to cover some topics more extensively, e.g. which information was considered reasonable or not reasonable to include in a system for predicting arrival times.

3.3.6 Data analysis Study 3

A framework was developed to represent where in the transport system a detection could be made. Brief description is found in Chapter 2 and more in detailed version in appended Paper 2. The empirical data were analysed by the author considering the notes of interviews and observations in regard to the three levels in a transport system from Wandel et al. (1992), being material flow, transport flow and infrastructure. The detection for initiation of real-time disruption management in relation to the impact from the disruption in the data were grouped into one of the three different levels. Thereafter, the different detections were analysed by adding when the detection was made, before or after the impact at that level. In this way, the framework gave an understanding of when the disruption was detected in relation to the impacts at different levels. After this the detection phase and impacts were connected between the levels by adding the phases of prediction and action. For example, a detection at the infrastructure level was connected to the prediction of impact connected action at a higher level. The infrastructure level was viewed as where the operations were executed, and the transport flow was viewed as the planned checkpoints in the transport chain. The material flow was viewed as the critical checkpoints in the transport chain that needed to be achieved according to plan or the customer delivery would be impacted. The available information from the different levels for detection were analysed in relation to when the detection was made and how this influenced the possibilities for predictions. In the final step of the analysis the phases of detection and prediction at the different levels were extended by the phase of actions. In this way, the analysis could point towards possibilities of generating proactive recovery actions.

3.4 Research quality

Flyvbjerg (2006) discussed the critique of subjective approach of case studies. To mitigate these risks of subjectivity in case studies, different strategies for insuring research quality have been developed. This is especially important in the field of logistics research, as it has been shown to have poor quality of case studies (Pedrosa et al., 2012). Halldórsson and Aastrup (2003) discussed research quality in qualitative methods in terms of trustworthiness, including credibility, transferability, dependability and confirmability. These quality criteria are in the following sections discussed for this research.

Credibility focuses on matching the reality of respondents with the researchers (Halldórsson and Aastrup, 2003). Sharing research findings with respondents is one way of dealing with the researcher understanding the interviewee correctly (Bryman and Bell, 2011). The researcher shared notes from the semi-structured interviews and observations with the respondents to provide confirmation that the author had understood the answers correctly. Furthermore, triangulation (Bryman and Bell, 2011) with data from different sources pointing towards the same findings were used. The interviews were made with persons at different positions in the case companies as well as other methods were used, i.e. observations, documentation review and focus groups, to strengthen the credibility.

Transferability refers to how findings can explain the phenomenon studied in other contexts (Halldórsson and Aastrup, 2003), as findings in one context can justify useful interpretation in other contexts (Goffin et al., 2012). Bryman and Bell (2011) suggest thick description as a tactic for achieving transferability, giving rich details of the studied object. The empirical data in this thesis mainly took the transport planning and coordination of execution as starting point to provide rich contextual of the case company in connection to the disruption management performed Furthermore, this research includes follow-up interviews in order to get more in-depth data. The results are related to previous literature for a comparison check for transferability. The goal of these checks is to cover how the findings can relate to the phenomenon studied in other contexts. Instead of generalizability included in internal validity, the research is referring to analytical generalization (Yin, 2014). The case companies in this research mainly had the function of real-time disruption management within the organisation. If one case company had this function performed by another actor in the transport chain, the focus would probably have been more on the relationship between these two actors. However, the focus was on the function of real-time disruption management and not by what actors the function is performed.

Dependability involves the consistent replication of results, where the similar instruments of the phenomenon results in comparable measurement (Halldórsson and Aastrup, 2003). The aim is to achieve that another researcher could do the same case study and get the same findings and conclusions. Halldórsson and Aastrup (2003) discussed the importance of the trackability of the research process. The authors suggest documentation of the process, including process decisions, data sources and the documentation of questions and theories to achieve confirmability. The process of this research was documented, and question guides were used for the performed semi-structured interviews. The analysis of the collected data was done using defined frameworks from the literature.

Confirmability deals with how the data is interpreted by the researcher in order to keep 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, verifying that analysis of the data is drawn free of bias, in the most objective way as possible, from researcher. This traceability for interpretations of data can be achieved by documenting questions and theories underlying every finding and interpretation (Halldórsson and Aastrup, 2003). Other tactics include the use of evidence from more than one source and creating a chain of evidence or having key interviewees review a draft of the report (Yin, 2014). To cover confirmability, the aim for data collection in this research was to take extensive notes during interviews, observations and the focus group. No transcriptions of recordings from the interviews does generate the possibility of missed points by the author. The submission of the notes to the interviewees was used as a mitigation strategy for this. Further, the analysis was done related to frameworks developed from the studied literature in order to analyse the content of the data in a structured way.

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 – The usage of resource utilization indicators as feedback for operational freight transport decisions – from a logistics service provider perspective

4.1.1 Summary

Freight transport struggles to obtain high resource utilisation, being one cause of issue to that supports the set emission objectives from the European Union for the transport sector. In order to achieve higher resource utilisation, the dynamic changes influences on the transport operations need to be mitigated. Transport operations are executed in a dynamic environment, which changes to the operations and generates the need for re-planning at the operational planning level. Re-planning alters the initial objective for the resource utilisation. Feedback is one way to support the decision maker by indicating the resource utilisation for the re-plan in order to understand how the re-plan changes the resource utilisation. The decisions made commonly aim to achieve different performance goals, measured by performance indicators (PI). PIs regarding resource utilisation in freight transport are linked between resources, in terms of one resource being dependent on another to achieve its targeted resource utilisation. Resource utilisation is further dependant on the chosen system perspective. This complexity of resource utilisation makes it difficult to measure and assess resource utilisation for a complete transport system. Furthermore, the aim in previous literature is mainly to obtain high resource utilisation at the planning stage, without considering the dynamic changes for operational decisions in the transport system. Operational decisions may benefit from getting feedback from performance indicators to make better re-planning decisions. Therefore, the purpose of this paper is to explore the usage of performance indicators as feedback by considering the operational freight transport decisions made by a logistics service provider. To support the purpose, a framework combining different aspects of resource utilisation and usage of feedback is developed. The framework is used to analyse data from a single case study. The results from the case study identify issues of using performance indicators as feedback. The used performance indicators lack a broad system perspective of resource utilisation, leading to their feedback for re-planning limited to certain parts of the overall resource utilisation.

The paper shows the need for performance indicators that cover a broad system perspective, which is needed to capture the complexity of resource utilisation. Re-planning decisions in the case are mainly executed without direct connection to a performance indicator of resource utilisation. The lack of feedback generates issues for the planners to understand how the re-plans impact the resource utilisation. This indicates the issue of performing operational freight transport decisions, taking into consideration performance indicators, when changes in the system generate a need for re-planning decisions.

4.2 Paper 2 – Real-time disruption management for proactive recovery actions in transport planning

4.2.1 Summary

Disruptions in freight transport may impact the complete supply chain. Quick and efficient actions after a transport disruption occurrence is of importance to avoid escalation to the supply chain.

The purpose of this paper is to increase understanding of real-time disruption management in transport chains by examining the phase after a disruption has occurred.

The paper starts with a concept that illustrates the possibilities for proactive actions after disruption has occurred. A single case study is used to investigate the phases of detection, prediction and action after disruption and before transport chain impact, defined as the impact on any transport operation. The data from the case indicate different stages of a disruption where five types of detection can be performed. The detection can be made before any impact of transport operations in terms of detecting disruption, e.g. a car accident, or an impact from a disruption, e.g. a road queue. Detection after transport operations are impacted are divided between what is being detected, such as primary transport chain impact, or if detection is made further down the transport chain, e.g. secondary transport chain impact or even snowball impacts on upcoming transport operations, or even supply chain impacts. Detection objects are linked to influence the phases of prediction and action, which will determine the final recovery action to be proactive or reactive.

The paper contributes to the literature of disruption management in freight transportation with additional understanding of performing proactive recovery actions after disruption has occurred. The identified detection objects of what to detect regarding a disruption generate insights that establish a base for future development of decision support systems for proactive recovery actions in freight transportation. Better support for detection facilitates settings for prediction of impact for transport operations leading to possibilities for recovery actions before transport chains are impacted.

4.3 Paper 3 – Proactive recovery actions in real-time transport chain disruption management – a logistics service provider perspective

4.3.1 Summary

The aspects of when and where in a transport system a disruption is detected and managed influence real-time disruption management. Disruption management in the studied literature has mainly focused on recovery strategies defined on beforehand rather than on recovery actions based on real-time information. These are recovery actions taken in real-time supported by information about executed operations and their surrounding environments. The purpose of this paper is to investigate how recovery actions are influenced by where in the transport system real-time disruption management is initiated.

A conceptual framework is developed that includes the two factors of where and when in the system a detection is made. The framework is used to analyse the data collected from a single case study in order to provide insight for actions connected to the disruption management. The combined representation of when and where in the system gives input to technical systems supporting real-time disruption management through insights in information from which the system level generates different possibilities for proactive recovery actions. The study further shows how the information needed for proactive actions before transport chain impact in real-time disruption management are connected to the infrastructure level. The information from the other levels support the actions for secondary or snowball impacts further down the transport chain, or even the supply chain.

5 Results

This chapter presents the results of the research questions defined in Chapter 1.3 to cover the objective for this research of investigating real-time disruption management in freight transport. Figure 6 illustrates the connection between the conceptual model, see Chapter 2 for more details, and its connection to the research questions and studies. This figure represents the accumulative approach for the results in this research, as Study 1 covered one part of the overall research and Studies 2 and 3 are widen the understanding of the real-time disruption management by building on insights from each other and including more aspects. Therefore, the first research question is covered by the results from all three studies, and the second research question is covered by the results from Studies 2 and 3. Combining the results from all the three performed studies results in that a broader understanding of the detection of disruptions (RQ1) can be achieved compared to each single paper alone, whereas combining the results from Studies 2 and 3 creates an understanding of how real-time disruption management generates proactive recovery actions (RQ2).

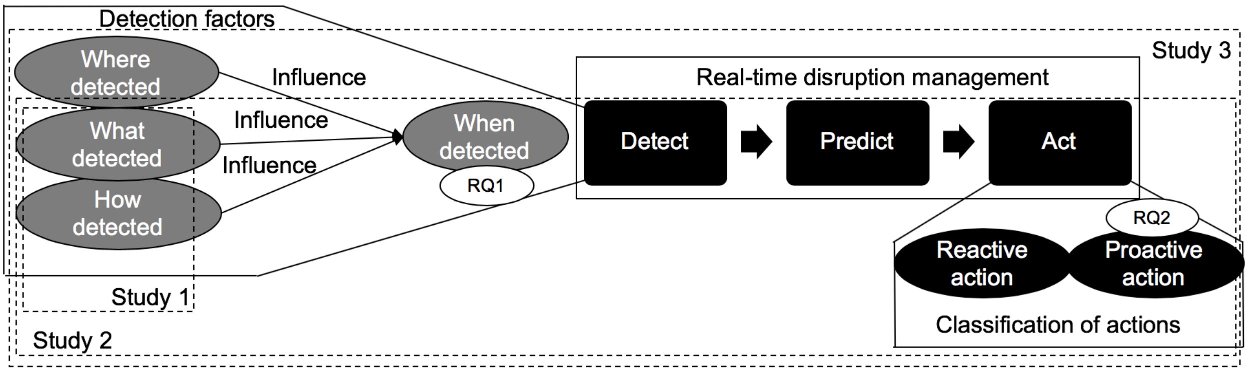

Figure 6.The conceptual model of the framework in connection to the research questions and the studies.

5.1 RQ1: How is detection of disruptions in freight transport influencing when real-time disruption management is initiated?

When the detection of a disruption, such as the difference between planned and actual status exceeding a predefined threshold, is generated, it is influenced by the studied detection factors in different ways, i.e. what is detected, how it is detected and where in the system it is detected. When a disruption is detected, it consequently influences when real-time disruption management may be initiated. If a disruption is not detected, the management of the disruption is not initiated, which leads to delayed real-time disruption management.

5.1.1 What is detected

Through the analysis of what is being detected, the disruptions are found to generate different impacts that can be detected in a transport chain. What the performance indicator or the information about the disruption includes becomes of importance when wanting to detect a difference between the planned status and the actual status. The information used for disruptions through performance indicators for resource utilisation was found in Study 1 to mainly cover parts of the complete performance. For example, a performance indicator of a load factor in a trailer included only the pay load and not the weight or volume of the actual freight. As the performance indicators aim to evaluate the system performance and are not direct indicators for the differences between planned and actual statuses in real-time disruption management, these indicators are limited for detecting disruptions. In Study 2, information about the status of the executed operations was found to come from different parts of the execution, which consider different impacts of the disruption. Figure 7 includes identified objects that can be mapped for detection.

The detected objects are detection of disruption, detection of disruption impact, detection of primary transport chain impact, detection of secondary transport chain impact and detection of snowball impact. To illustrate the differences among the objects, the disruption example of a traffic accident is used. The detection of the accident indicates a detection of the object disruption. If the accident generates an impact in terms of traffic queue, this traffic queue is the object of disruption impact. The primary transport chain impact in this example is when the first transport operation is impacted, which is when a truck arrives to the traffic queue. The secondary transport chain impact is represented by a truck arriving late to a consolidation terminal or port. The snowball impact is related to detection when upcoming operations further down in the transport chain cannot be performed, e.g. when a terminal operator has prepared the freight and the trailer is not ready.

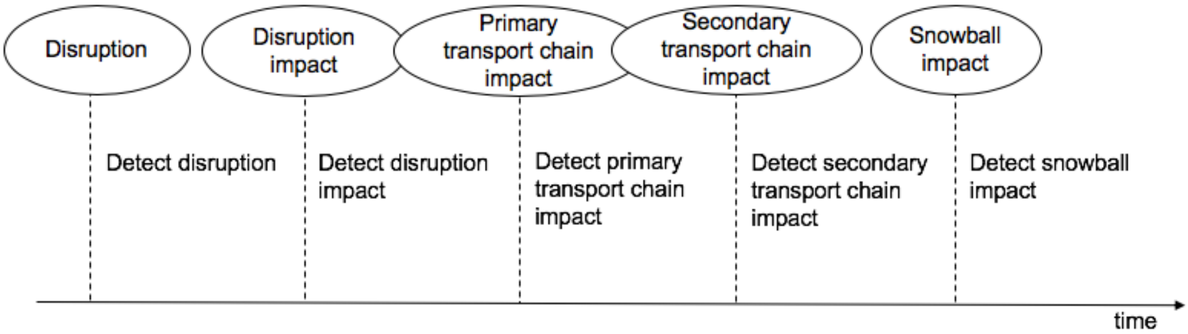

Figure 7. Different detection objects during the progress of a disruption.

When the real-time disruption management is initiated depends on which of these detection objects are detected. For example, detection of a traffic queue initiates the management of disruption before the transport chain has been impacted, whereas detection of a truck being in the traffic queue initiates it after the transport chain impact.

5.1.2 How is disruption detected

The main parts of how a detection occurs are through a detection of change in operations or the operations and their surrounding environments. These detection approaches are affected if the disruption was detected at checkpoint or through continuous information during operations, or if the detection was made manually or automatically by a supporting system. A detection of disruptions by performance indicators are equal to a detection through checkpoints in the transport chain, as both are mainly detected occurred impacts on transport chains. This is because detection via checkpoints does not mainly not considering the actual status for the operations during the execution. Furthermore, results with issues of manual parts of detection were found in all studies to delay the detection, even when continuous information of operations was available. Continuously provided information about operations, for example, by GPS data, does not automatically generate detection before impact. For example, manual monitoring is not constantly executed, leading to a time delay between when information is available and the detection. In other words, a continuous flow of information about operations is not enough to generate early detection. How a detection is made, automatically or manually, influences when the disruption is detected. The case studies indicated that information to the transport planners that originated mainly from transport operators, such as truck drivers or terminal personnel, occurred after the transport chain impact. Even though truck drivers reported during operations, the reporting was made after the transport chain impact had occurred, resulting in a detection after the transport chain impact. In connection to this, an additional point was found in Study 2 to illustrate that a detection can only be made if the planned status and the actual status of operations were defined and known for real-time disruption management. Even if the actual status during an operation was given, the lack of an explicitly stated planned status generated issues of detecting a disruption. For example, the transport planners knew when the planned time for arrival at a checkpoint should be, but they were not aware of the planned status during operations. This leads to that the current geographical location of a truck being available (actual status) during the operations, but the planners did not know if this matched the planned status for the operations to achieve the future planned arrival. This leads to later detection, resulting in a postponed initiation of the disruption management.

5.1.3 Where is disruption detected

In Study 3, where a detection is made in a transport system was found to influence when disruption management was initiated. By representing the transport system in the three levels inspired by Wandel et al. (1992), i.e. material flow, transport flow and infrastructure, a new viewpoint for detection was proposed. The infrastructure level represents the executed operations and their surrounding environment, the transport flow level represents the checkpoints for a transport chain, and the material flow represents the critical checkpoints in the transport chain to achieve customer delivery (e.g. arrival to port). The division of the transport system into three levels generated a structure where it was possible to illustrate detection at different levels in a transport system and the interplay with the time aspect of when the detection was made. Similarly, to findings of what is detected, the more in detail in the transport system the information from execution is, the earlier a detection of disruption can be made. Furthermore, a detection of impact at one level generates input before an impact at another level. For example, if the detection is made of a disruption at the infrastructure level, i.e. disruption or disruption impact in Figure 7, disruption management can be initiated to minimise the impact before the transport chain impact occurs. A detection of transport chain impact on infrastructure, e.g. truck in a queue, generates possibilities to initiate real-time disruption management that can include predictions of impacts on future planned transport operations by considering the transport flow level and proactive recovery actions for these operations. In connection to how disruptions are detected, a detection at checkpoints is found to take place for checkpoints at the levels of transport flow or material flow. These are viewed as important for the transport system to achieve on-time customer deliveries. However, the focus on these checkpoints without considering the infrastructure level generates delayed detections made at the higher levels in the transport system.

5.1.4 Summarising of the detection factors for initiation of real-time disruption management

To sum up, the three factors for the detection of disruptions studied in this research are shown to influence when the real-time disruption management is initiated in different ways. The influence of when detection is made, in terms of before or after the transport chain impact, differs for the detection factors as summarised in Table 2. Study 3 showed that if real-time disruption management should be initiated before any (primary) transport chain impact, continuous information of the executed operations and surrounding environmental variables connected to the infrastructure level are needed. Automatic detection is not explicitly needed, as the detection can be made by manually comparing the planned status and the actual status. However, the automatic comparison between the statuses with system support can directly alert a difference in threshold size. This is not subject to the possibilities of time delays, as manual detection of information about planned and actual statuses was found in Studies 2 and 3 to be available but not compared.

Table 2. Summarising the results for the detection factors in relation to when real-time disruption management is initiated.

Initiation of disruption management	Where detected	What detected	How detected
Before transport chain impact	Infrastructure	Disruption Disruption impact	Continuously Manual or automatic Indicators of operations and surrounding environmental variables
After transport chain impact	Infrastructure Transport flow level Material flow level	Primary transport chain impact Secondary transport chain impact Snowball impact	Checkpoints or continuously Manual or automatic Indicators of operations

5.2 RQ2: How is real-time disruption management able to generate possibilities for proactive recovery actions in freight transport?

The phases (detection, prediction and action) for real-time disruption management were investigated in relation to each other to understand how the possibilities for proactive recovery actions are generated. For the recovery actions of disruptions to be proactive, all phases of disruption management (detection, prediction and action) are required to be performed before the impact from disruption on the transport system. Two main dimensions were found in Studies 2 and 3 for these proactive recovery actions, as actions after disruptions have occurred utilise real-time information to mitigate before the transport system impact. Possibilities for proactive recovery actions are generated by either anticipating a primary transport chain impact from a disruption or detecting a transport chain impact on an operation and predicting the impact on upcoming operations at other parts of the transport chain. In the first dimension, the recovery actions are proactive before a transport chain is influenced. In the second dimension, the recovery actions are reactive for the current operation executed but proactive by considering potential impacts on upcoming operations in the transport system.

Figure 8 represents how the phases of detection and prediction for real-time disruption management influence the recovery actions to be reactive or proactive for current or upcoming operations. For these actions to be proactive for the current operation, e.g. the transport operation of moving a number of shipments between the suppliers and the consolidation centre, the detection has to be made before the primary transport chain impact (upper left box in Figure 8). This can be done via detection of the objects of disruption or disruption impact. Any of these detection objects provide possibilities for predictions of the primary transport chain impact (upper right box in Figure 8). The prediction facilitates the possibilities of a proactive recovery action before the impact has occurred. Taking the disruption of a traffic accident as an example, the detection of the disruption, i.e. the accident or the disruption impact of a traffic queue, is used to predict how the accident or queue affects the primary and/or secondary impacts of the transport chain. In this way, the route for the truck heading towards the accident can be changed proactively before the primary transport chain impact. Detection of the primary transport chain impact, secondary transport chain impact or snowball impact, e.g. a truck driver arriving to the queue or a late arriving truck to checkpoint or from terminal personnel waiting for the truck to arrive, indicates real-time disruption management initiated after impact and, therefore is connected to reactive recovery actions for the current operation (lower right box in Figure 8). Even though the recovery actions for the current operation are reactive, the transport chain impacts for upcoming operations can be predicted and generate proactive actions for these operations (upper right box in Figure 8). The reactive actions before the transport chain impact (lower left box in Figure 8) are not possible, as this research takes an LSP perspective in which reactive recovery actions are only made when the transport chains are impacted by a disruption.

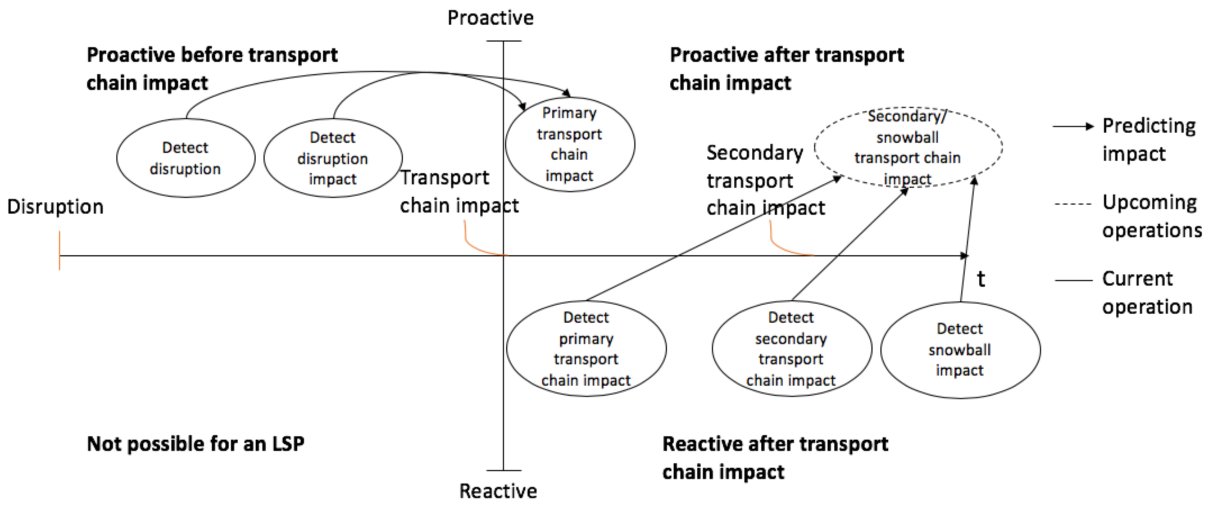

Figure 8. Representation of detection and prediction of disruption objects in relation to proactive or reactive classes of action.

The case companies in this research lacked system support for real-time disruption management, e.g. decision support systems performing detections or predictions from available information but had system support to visualise information connected to the operations, e.g. GPS data. This influenced how they detected disruptions. The case companies focused on the on-time completion of the checkpoints in the transport chain, to achieve planned customer delivery without focusing on the information from the operations. As a result, each single operation received less attention than the checkpoints they were going to fulfil. For the recovery actions, this resulted in no detections or predictions being available before the transport chain impacts, and the actions mainly focused on solving the impact for current operations reactively or solving impacts for upcoming operations. For example, when a truck driver calls in a disruption of being stuck in a queue (detection at right lower right box in Figure 8), the prediction of the impact of operations at a terminal can be made (upper right box in Figure 8), and these operations can be adopted before the impact, e.g. executing assignments for other shipments and not waiting for the delayed shipment. This can lead to avoidance, or at least mitigation, of the impact on these operations.

Where in the transport system that the real-time disruption management is initiated, discussed in Chapter 5.1.3, influences where it is performed. Table 3 summarises the connection between the different identified objects of detection, predictions and actions and the different levels in a transport system. The actions in Table 3 are adopted from Otto (2003), and where in a transport system are inspired by the levels from Wandel et al. (1992). Each column in Table 3 illustrates what can be detected, what can be predicted and what types of actions that can be made in each level. The infrastructure level represents the details about the operations, and the transport flow contains the checkpoints in the transport chain. The checkpoints that are viewed as critical for customer delivery are represented in the material flow. The columns in Table 3 demonstrate that, for recovery actions to proactively executed before any type of transport chain impact (see Figure 8), the performed real-time disruption management (not only detection, see Table 3) needs to be connected to the infrastructure. Results from Study 3 show that the real-time disruption management connected to the infrastructure level needs information from the surrounding operations environment for predictions for the transport flow or material flow level, not only for detection as discussed. For example, for the prediction of time for a delivery to a customer to be reliable, information about different possible delays, such as a delay from a traffic queue or a delay from a supplier not having freight ready for pick-up, must be included. The division of the transport system in different levels further illustrates that information used for real-time disruption management via checkpoints generate a good overview of transport flow but does not include the detection of a transport chain impact on the executed operation. As detection is made after the operation is completed, no prediction for this operation can be made, and, thus, the real-time disruption management generates a reactive action for the executed operation.

The actions are found to differ in terms of size of change in the transport system. As seen in the columns of Table 3, the proactive actions connected to detections and predictions before the transport chain impact are made with smaller adjustments to the transport system. The reactive actions after the transport chain impact has occurred include more efforts to adjust the transport system, by re-planning a complete plan or fire-fighting occurred impacts. The different actions for managing disruptions through fire-fighting or repairs, re-scheduling or re-planning were made to further illustrate that proactive recovery actions changed plans in a structured way compared to the reactive actions that lead to ad-hoc solutions through fire-fighting. To understand how a disruption influences upcoming operations in a transport system, the predictions in the second row of Table 3 need information to cover these operations, e.g. planned future routes or unloading times and locations. The reactive actions were mainly made based on a lack of information about upcoming operations. This is connected to the observations of reactive actions from the planners relying on predefined measures from strategic and tactical planning to change plans when fire-fighting occurred disruption impacts, instead of actively obtaining information about operations to manage disruptions before the impacts occurs.

Table 3. Connections between transport system perspectives and the phases of real-time disruption management.

Where in system / Phases	Infrastructure	Transport flow	Material flow
Detect	Disruption, e.g. accident Disruption impact, e.g. traffic queue Primary transport chain impact, e.g. truck in queue	Secondary transport chain impact, e.g. late arrival to terminal Snowball impact, e.g. terminal operators waiting for truck	Secondary transport chain impact, e.g. late arrival to terminal Snowball impact, e.g. terminal operators waiting for truck
Predict	Predict disruption impact	Predict snowball impacts	Predict snowball impacts

	Predict transport chain impact (both primary and secondary)	Predict other snowball impacts	Predict other snowball impacts
Act	Avoid disruption impact Repair or re-schedule to avoid transport chain impacts Repair or re-schedule to manage primary impacts and avoid secondary transport chain impacts	Re-plan to manage impacts and avoid snowball impacts Manage impacts - fire-fighting	Re-plan to manage occurred impacts and avoid snowball impacts Manage impacts - fire-fighting

6 Discussion

This chapter firstly discusses this research in connection to other approaches for disruption management. Thereafter, the results of this research are discussed regarding how the detection initiates real-time disruption management. Finally, the results are discussed in relation to each other regarding the possibilities to generate proactive actions in real-time disruption management.

This research took a starting point in real-time disruption management as a different way of minimising the impact of disruption on the transport system compared to the studied literature. Real-time disruption management consists of performing the recovery at the operational level based on real-time information after a disruption has occurred rather than predefined recovery strategies from strategic or tactical planning levels. The results can generate new aspects for the strategic recovery strategies to consider for an improved disruption management for the overall transport and supply chain system. The research in this thesis broadens the view of recovery of disruptions through the presented aspects of real-time disruption management. With these aspects, active detection and anticipation of impacts can be achieved instead of focusing on the development of predefined recovery strategies.

6.1 Detection of disruption influencing initiation of real-time disruption management

This research shows the detection of disruptions in the case studies in a similar way as Otto (2003), which presented a deviation as “a difference between a planned status and an actual status” (Otto, 2003, p. 2). This deviation is a disruption when a certain threshold has been exceeded. The results from the three studies add viewpoints about the detection of disruptions by demonstrating what happens, assuming that planned and actual statuses and predefined thresholds are not given. The detection objects in Figure 7 are explicit about what to detect, which add to the studied disruption management literature of not generally detecting a disruption or a risk. For all the presented objects in Figure 7, detection can be measured through the dimensions of time, quality and quantity presented by Otto (2003). However, what these statuses are, and where in the system they are represented have been shown by the detection factors in this research to be of importance. For example, a traffic accident generates a disruption with a deviation in a certain threshold from the planned and actual speed in traffic flow. For the transport system, it is not obvious to cover the statuses in traffic flow, since the transport system first has a disruption when the trucks are affected in terms of a delay. The broadening of what can be detected for planned and actual statuses, such as the detection objects in Figure 7, is important for the development of support systems, e.g. decision support systems, as a starting point of what the system should detect and include.

In line with Meyer et al. (2014), the manual analysis of information has been observed to generate delays for the detection. This research complements this insight, as the results consider the dimensions of detection factors for disruption in the real-time disruption management. Since the case study in Meyer et al. (2014) was made at a company with a state-of-art track and trace system, their results focused on issues with analysing a large amount of information (as information was available) and connecting it to the complete transport system. In contrast, the results from this thesis point towards that the main issue of obtaining information for analyses to even be able to detect disruptions and initiate real-time disruption management, even though the cases had ERP and GPS systems in place. This connects to the point of what is detected, since the information needs to represent relevant objects for detection. Furthermore, the visibility for monitoring with the purpose of detecting disruptions needs to consider these objects. If the visibility is too focused on information from performance indicators, such as the indications from Fernández et al. (2016), the detection is made by the objects after the transport chain has been impacted. For example, checking whether the trucks are arriving as planned (as the performance indicator in this case) does not generate detection until after the trucks arrive later than planned. This detection leads to initiation of real-time disruption management after the transport chain impact and, therefore, no proactive recovery actions for the executed operation. If the arrival of trucks can be predicted instead, taking different disruption impacts (before the transport chain impact) into consideration, the real-time disruption management can generate possibilities for proactive recovery actions for the executed operation.

One important thing for all the objects in Figure 7 is that they were developed from a real-time disruption management focus, which did not include the type of disruption that had occurred and generated no definition of what may represent the object disruption. Depending on the amount of information available about a disruption, the object disruption can be different. Looking at the example of the traffic accident, the disruption can be viewed as the traffic accident, and sensors about traffic flow will detect the disruption. However, the traffic accident can also represent the object disruption impact if the accident occurs as a result of broken brakes. If the status information for all cars and trucks had been available, the prediction of an accident caused by a car with broken brakes could have been made before the traffic accident occurred. This information can also be for the truck itself, through detecting that a truck will break down (primary transport chain impact) by having information about the truck status available, e.g. engine pressure or tire pressure, to detect the objects of disruption or disruption impact. Nevertheless, these objects are developed from a transport function perspective for the initiation of real-time disruption management to be made as early as possible. Depending on what information is available from operations and the surrounding environments, a judgement of reasonability for information must be made on what will represent a disruption and disruption impact. Connecting these objects to the perspectives of strategic disruption management can create better judgements for different disruption types and place these objects in a bigger picture in the transport system.

Results about how to detect disruptions are in line with Fernández et al. (2016) in terms of information from operations and the surrounding environments being used for detection. The manual or automatic treatment of information for disruptions regarding how detections are made is in line with Meyer et al. (2014), as that lack of support of technical system for automatic detection generates manual detections mainly after the impacts. Furthermore, the results about how to detect disruptions are in line with Goel (2010), which discussed how the information was presented to the decision maker influences when the detection is made, e.g. at checkpoints in the transport chain or more continuously during operations. The research in this thesis adds to this finding, in that the visibility of statuses at checkpoints needs to consider information during the executed operation in order to influence detection of disruptions before the transport chain impact. This issue of how to detect is linked to what is detected, as continuous updates about checkpoint statuses, e.g. arrived or not arrived, only detect transport chain impacts and include no information about objects connected to the status during the operation. For example, the information concerning arrived or not arrived does not include what happened during the operations, e.g. traffic queue, delay at pick-up. To detect a disruption before the transport chain impact, the checkpoint status needs to include information during the operations, as well as predict the impacts at the checkpoints. A status check for checkpoints that includes information about operations and their surrounding environments, e.g. estimated arrival time (van der Spoel et al., 2017), will provide better settings for earlier detection and positively influence the initiation of real-time disruption management.

The investigation of the factor regarding where the detection is made in the transport system adds further understanding to when the real-time disruption management can be initiated and performed. Instead of focusing on where in the system a disruption occurs, related to actors and organisations as discussed by Christopher and Peck (2004) and Nel et al. (2018), this research focused on where a disruption occurs in the transport system in order to minimise the impact on the transport system. This way of representing the where in the system generated insights on how the detection at different levels influences when the detection occurred, and the management of disruption can be initiated. The detection of objects from disruptions before the transport chain impact was connected to the executed transport operations represented by the infrastructure level. The detection in this level gave possibilities of an earlier initiation of real-time disruption management compared to the detection of objects after the transport chain impact, which was associated with the levels of transport and material flow of the transport system.

6.2 Possible proactive recovery actions from real-time disruption management

The general view of proactive as anticipating and acting on a disruption before it occurs, and reactive as reacting and responding to a disruption has been established in the literature (Fernández et al., 2016, Wieland and Wallenburg, 2013). Building on the thinking that a proactive approach predicts an undesirable future state for an operation generates possibilities for proactive actions to be carried out after disruptions have occurred but before impacts. For example, a disruption from an accident on the planned route for a transport operation has the possibility to generate proactive actions before the truck arrives at the point of the accident. This reasoning has been put forward in previous literature, such as Sheffi and Rice Jr. (2005) or Feldman et al. (2013), and the research in this thesis adds the details for the transport system to utilise this opportunity. The results in this research highlight this concept of proactive recovery and complements with the two found dimensions of proactive actions: before any transport chain impact or after the primary transport chain impact but before secondary or snowball impacts. These dimensions are connected to the initiation of real-time disruption management via the detection phase to the phases of prediction and action.

This research further illustrates the need for detailed information about operations and their surroundings to generate possibilities for proactive actions from real-time disruption management, which is in line with suggestions from van der Spoel et al. (2017). These authors identified the need to consider more sources of data for reliable estimation of arrival time, such as the truck drivers' schedule and intentions based on their experiences. This leads to the estimation of arrival time not only considering the traffic situation. Their proposed approach revolves around obtaining the operations status and predicting the upcoming actual status, which can be compared to the planned checkpoint status of arrival to a terminal. Complementing that approach, the results in this thesis find the need for a defined planned status during operations. In this way, it would be possible to detect disruptions more easily than if a prediction for the completion of the operation needed to have been made to understand whether a disruption has occurred. This is especially true if no system is supporting the planners for detection. Depending on the implemented information systems supporting the real-time disruption management, the same disruption object can be detected in different ways. Taking the traffic accident as an example, the detection can be made from information of a real-time traffic situation or information from broadcast messages about the traffic accident. These ways of receiving information before the impact can replace a delayed detection of a truck driver calling more easily than other types of disruptions, e.g. disruptions originating from natural disasters. These ways to detect disruptions early provide the basis for the impact prediction to be performed, which leads to possibilities for proactive recovery actions.

The prediction of transport chain impacts is further made difficult due to the possibility that more than one disruption event can influence the impact, as discussed by Dunke et al. (2018). The more disruption events that should be covered, the more extensive information about operations and surrounding environments is needed. Real-time disruption management with the sole aim of achieving proactive actions before any transport chain impacts, such as the estimated time of arrival solution discussed by van der Spoel et al. (2017), may risk taking a limited view of one part of the system. This leads to not realising the potential impacts on other parts of the system, which Meyer et al. (2014) discussed as the complex relations between shipments. Therefore, it is important to create system solutions for real-time disruption management that cover more than one part of a transport chain, or even connected to parts in the supply chain following the transport chain. This approach needs a complete overview of the transport chain, which was shown to be difficult even for the logistics service providers. Furthermore, what is reactive in one part of the system can be valuable input for proactive actions in another part or actor in the transport system or even supply chain. The discussed approaches of including more information from the transport system, in the previous paragraph, are in line with the request from Dunke et al. (2018) to consider that one disruption may influence many different performance indicators. The authors indicated the need to consider many disruption events that may generate an impact. Even if the research in this thesis mainly focused on the impact from one disruption event, the results for real-time disruption management provide insights on how objects for different disruptions can be combined by information sources to cover many different potential disruptions at the same time. A logistics service provider that shares the information about the disruption with other actors in the transport and supply chain, can in this way, generate possibilities for proactive management of disruptions for other parts of the system. In connection to this, the performed studies indicated that relatively small impacts from disruptions on transport chains were managed with reactive actions through predefined strategies for the impacted operations. Extra costs for time buffers in plans are accepted by the logistics service provider as long as the freight arrives on time, which limits the development of real-time disruption management. Nevertheless, as seen in Study 2, if the upcoming operations that are predicted to be impacted are performed by other actors in the transport system, the need to share the information about the transport chain impact becomes important for the complete transport system to manage the disruption. As the transport system is one part of the supply chain, transport operations that are impacted to a high degree may further influence the supply chain. In these cases, the sharing of this information about disruptions in the transport system may be of importance for actors in control of operations in the supply chain.

7 Conclusions and contributions

This chapter includes the conclusion and contribution of this research and provides an outline for future research.

7.1 Conclusions

The aim of this research was to investigate real-time disruption management in order to facilitate proactive recovery actions. Real-time disruption management was represented by the phases of detection, prediction and action. The phase of detection of disruptions, which initiates the real-time disruption management, was used as the starting point for the studies in this research and, thereafter, the connection to the phases of prediction and recovery actions was made. To utilise the time between disruption and impact for proactive recovery, the real-time disruption management needs clear aims for the treated detection factors in this research. The detection of disruptions needs to differentiate amongst different objects of a disruption. The detection of any of these objects is influenced by how and where in the system they are being compared to an actual status and a planned status. Actual and planned statuses were incomplete during operations in the transport chain due to low visibility and detailed plans for operations. Therefore, the prediction of actual statuses, which can be compared to a known planned status, e.g. checkpoint, can be useful. However, for real-time disruption management, these predictions need to be reliable, which in turn, is challenged by the need for a high level of visibility of information about operations and the surrounding system environments.

The detection of disruptions and the performed prediction of impacts influence the possibilities for actions in connection to the disruptions being proactive or reactive. The proactive recovery actions as a result from real-time disruption management can be made in two dimensions. It can be made before any impact on the transport chains, by early detection of the disruption, followed by prediction of impact on the transport chain. In this way, the impacts from a disruption can be avoided before impacting the transport system or at least mitigated before impacting the transport system. The second way of generating possibilities for proactive recovery actions is achieved when detections are made after transport operations have been impacted and proactive actions for upcoming operations in the transport chain can be made. This generates reactive actions for the ongoing transport operation and, therefore, does not mitigate the influence on efficiency for the executed operations. As a result, depending on the magnitude of the impact from disruption, the proactive actions before any transport chain impact contribute to lower impacts on the complete transport system in comparison to the proactive recovery actions after the primary transport impact has occurred.

7.2 Contributions

The results in this thesis contributes to existing disruption management concepts with detailed descriptions and analyses on the phases of real-time disruption management. These details of real-time disruption management contribute to the research fields of disruption management, discussed in Chapters 1 and 2.1, with a detailed understanding for an operational approach to managing disruptions, in contrast to the strategic and tactical approach for recovery in risk management (Knemeyer et al., 2009) and resilience (Wieland and Wallenburg, 2012). The real-time disruption management approach in this thesis covers the time aspects of recovery with influence of what, how and where in the system something is detected. The results further illustrate different proactive recovery actions that contribute to a changed focus of viewpoints for proactive and reactive recovery actions in connection to disruptions.

The research on real-time disruption management in this thesis can also support a future transport system to perform disruption management with more autonomous features. Future systems that are expected to have less or no human involvement, e.g. no truck drivers, could benefit from this research in terms of improving solutions for disruption management. Through this research, the detection phase is shown to be central, as it initiates the real-time disruption management. Detection of a disruption is shown to be made by different objects of a disruption and depending on how information is made available. Therefore, understanding how and what that should be detected is of importance for the development of disruption management in future transport systems. For example, the simple task of checking all the tires on trucks are today performed by the drivers, either before the transport operation or while noticing a flat tire during a transport operation. However, without a driver, there is a need for solutions, e.g. sensors, to detect this disruption. Depending on the objectives for these sensors, different objects would be detected, and the planners would be informed at different time points about the flat tire. The sensors could detect a change of tire pressure, the truck not driving as steadily as usual or that the detection may have only been connected to the GPS of the truck noticing the flat tire through a late arrival to checkpoint, e.g. by geofencing, after the transport chain impact, as speed would have been reduced during the operation. As this research has shown, depending on the solution for the detection system, the recovery actions taken that are related to disruption will be influenced to be proactive or reactive. Furthermore, solutions of support systems estimating when a truck arrives at terminal, could include sensors, such as the status of the truck, which either is ok and not, which would influence the arrival time to deviate from expected values and, therefore, impacting arrival time. Without considering such information, a future support systems will fail to predict a reliable arrival time, as pointed out by van der Spoel et al. (2017), and the manual reporting from the driver, represented in this research, will not be present. This research contributes to the fields of freight transport management, logistics management and supply chain management through increasing knowledge in real-time disruption management by highlighting different detection objects and their connections to predictions and actions, which will assist the future development of support systems.

This research investigation of real-time disruption management further provides an understanding on how to shift from costly predefined measures for recovery to actions based on real-time information. The predefined measures of buffers can assumedly be lowered as transport chains become better at utilising information for real-time disruption management. This implies a need for change in the complete planning structure, not only in the coordinating execution part of disruption management. However, this is only a beginning of motivating change in this direction. Moreover, the improved understanding of real-time disruption management in transport chains is of importance for the complete supply chain. A supply chain that receives early information about disruptions in transport chains can, in turn, adjust and adapt proactively before major supply chain impacts occur. Furthermore, transport chains that minimise impacts from disruptions become more reliable for a supply chain, which instead can steer focus to other types of disruptions in the supply chains.

7.3 Future research

Future research can include broader actor perspectives for real-time disruption management. This research shows that the actors executing the transport operations, such as truck drivers or terminal personnel, have a role in providing information and as the receiver of information when disruptions are detected. Research with broader actor perspectives can be complemented with wider perspectives for the roles of these actors in the real-time disruption management. Future research can further include the perspectives of the shippers to derive an understanding on how they use information from disruption management in transport chains for their own operations in the supply chain. In this sense, the proactive actions in connection to disruptions for upcoming operations in a supply chain can be covered. Furthermore, future research can address some of the limitations of this research. For example, this research is focused on logistics service providers, with no input from any of the other actors involved in the transport system. Future research can include studies with more logistics service providers, e.g. in one industry, to address the drawbacks of generalisability of the results in this research due to the application of case studies.

Going more in-depth into the proposed research direction, the findings in this research can act as a base for future research in the technological development of decision support systems for transport chains. Empirical data of implementation of decision support systems with origin from this research can provide results if the proactive actions are generated. Studies testing solutions that include different sources of information for prediction are needed to provide insights into the information that generate reliable predictions in disruption management, e.g. for arrival times. Both the detections and predictions can include methods from machine learning algorithms in order to incorporate artificial intelligence in real-time disruption management. The approach for deeper insights further gives the possibility of broadening the research scope, as implementations of real-time disruption management can be assessed against efficiency indicators in a transport system. In this way, the potential of proactive recovery actions from disruption management can be identified. Field tests can also provide support for the generalisability of the developed concepts and ideas.

References

Adhitya, A., Srinivasan, R. & Karimi, I.A. (2007), "A model-based rescheduling framework for managing abnormal supply chain events", *Computers & Chemical Engineering,* Vol. 31 No. 5, pp. 496-518.

Aeolix (2017), Aeolix vision document, http://aeolix.eu/wp-content/uploads/sites/11/2017/05/AOELIX-brochure-A5-no-marks.pdf, *Vol.*

Barratt, M. (2004), "Understanding the meaning of collaboration in the supply chain", *Supply Chain Management: An International Journal,* Vol. 9 No. 1, pp. 30-42.

Batalden, B., Leikanger, P. & Wide, P. (2017), "Towards autonomous maritime operations", 2017 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), 26-28 June 2017, pp. 1-6.

Behdani, B. (2013), *Handling disruptions in supply chains: An integrated framework and an agent-based model,* Doctoral thesis, TU Delft.

Bendul, J.C. & Skorna, A.C.H. (2016), "Exploring impact factors of shippers' risk prevention activities: A european survey in transportation", *Transportation Research Part E: Logistics and Transportation Review,* Vol. 90 No. 206-223.

Berg, E., Knudsen, D. & Norrman, A. (2008), "Assessing performance of supply chain risk management programmes - a tentative approach", *International Journal of Risk Assessment and Management,* Vol. 9 No. 3, pp. 288-310.

Blackhurst, J., Craighead, C.W., Elkins, D. & Handfield, R.B. (2005), "An empirically derived agenda of critical research issues for managing supply-chain disruptions", *International Journal of Production Research,* Vol. 43 No. 19, pp. 4067-4081.

Bode, C., Wagner, S.M., Petersen, K.J. & Ellram, L.M. (2011), "Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives", *Academy of Management Journal,* Vol. 54 No. 4, pp. 833-856.

Brehmer, B. (1992), "Dynamic decision making: Human control of complex systems", *Acta Psychologica,* Vol. 81 No. 3, pp. 211-241.

Bryman, A. & Bell, E. (2011), *Business research methods,* Oxford University Press, USA.

Christopher, M. & Lee, H. (2004), "Mitigating supply chain risk through improved confidence", *International Journal of Physical Distribution & Logistics Management,* Vol. 34 No. 5, pp. 388-396.

Christopher, M. & Peck, H. (2004), "Building the resilient supply chain", *The International Journal of Logistics Management,* Vol. 15 No. 2, pp. 1-14.

Crainic, T.G., Gendreau, M. & Potvin, J.-Y. (2009), "Intelligent freight-transportation systems: Assessment and the contribution of operations research", *Transportation Research Part C: Emerging Technologies,* Vol. 17 No. 6, pp. 541-557.

Crainic, T.G. & Laporte, G. (1997), "Planning models for freight transportation", *European Journal of Operational Research,* Vol. 97 No. 3, pp. 409-438.

Dunke, F., Heckmann, I., Nickel, S. & Saldanha-Da-Gama, F. (2018), "Time traps in supply chains: Is optimal still good enough?", *European Journal of Operational Research,* Vol. 264 No. 3, pp. 813-829.

Eisenhardt, K.M. (1989), "Building theories from case study research", *The Academy of Management Review,* Vol. 14 No. 4, pp. 532-550.

European Commission. 2017. *A european strategy for low- emission mobility* [Online]. European Commission (Ed.). Available: https://ec.europa.eu/clima/policies/transport_en [Accessed 13.06.2017 2017].

Fan, Y. & Stevenson, M. (2018), "A review of supply chain risk management: Definition, theory, and research agenda", *International Journal of Physical Distribution & Logistics Management,* Vol. 48 No. 3, pp. 205-230.

Feldman, Z., Fournier, F., Franklin, R. & Metzger, A., (2013), "Proactive event processing in action: A case study on the proactive management of transport processes (industry article)" in Proceedings of the 7th ACM international conference on Distributed event-based systems, in Arlington, Texas, USA, ACM, pp. 97-106

Fernández, E., Bogado, V., Salomone, E. & Chiotti, O. (2016), "Framework for modelling and simulating the supply process monitoring to detect and predict disruptive events", *Computers in Industry,* Vol. 80 No. 30-42.
Flick, U. (2014), *An introduction to qualitative research,* Sage publiations,
Flyvbjerg, B. (2006), "Five misunderstandings about case-study research", *Qualitative Inquiry,* Vol. 12 No. 2, pp. 219-245.
Giunipero, L.C. & Aly Eltantawy, R. (2004), "Securing the upstream supply chain: A risk management approach", Vol. 34 No. 9, pp. 698-713.
Goel, A. (2010), "The value of in-transit visibility for supply chains with multiple modes of transport", *International Journal of Logistics Research and Applications,* Vol. 13 No. 6, pp. 475-492.
Goffin, K., Raja, J.Z., Claes, B., Szwejczewski, M. & Martinez, V. (2012), "Rigor in qualitative supply chain management research: Lessons from applying repertory grid technique", *International Journal of Physical Distribution & Logistics Management,* Vol. 42 No. 8/9, pp. 804-827.
Halldórsson, Á. & Aastrup, J. (2003), "Quality criteria for qualitative inquiries in logistics", *European Journal of Operational Research,* Vol. 144 No. 2, pp. 321-332.
Heckmann, I., Comes, T. & Nickel, S. (2015), "A critical review on supply chain risk – definition, measure and modeling", *Omega,* Vol. 52 No. 119-132.
Hishamuddin, H., Sarker, R.A. & Essam, D. (2013), "A recovery model for a two-echelon serial supply chain with consideration of transportation disruption", *Computers & Industrial Engineering,* Vol. 64 No. 2, pp. 552-561.
Ho, W., Zheng, T., Yildiz, H. & Talluri, S. (2015), "Supply chain risk management: A literature review", *International Journal of Production Research,* Vol. 53 No. 16, pp. 5031-5069.
Ivanov, D., Dolgui, A., Sokolov, B. & Ivanova, M. (2017), "Literature review on disruption recovery in the supply chain", *International Journal of Production Research,* Vol. 55 No. 20, pp. 6158-6174.
Ivanov, D., Sokolov, B. & Dolgui, A. (2014), "The ripple effect in supply chains: Trade-off 'efficiency-flexibility-resilience' in disruption management", *International Journal of Production Research,* Vol. 52 No. 7, pp. 2154-2172.
Jacobsson, S., Arnäs, P.O. & Stefansson, G. (2017), "Access management in intermodal freight transportation: An explorative study of information attributes, actors, resources and activities", *Research in Transportation Business & Management,* Vol. 23 No. 106-124.
Jiang, L., Wang, Y. & Yan, X. (2014), "Decision and coordination in a competing retail channel involving a third-party logistics provider", *Computers & Industrial Engineering,* Vol. 76 No. 109-121.
Ketokivi, M. & Choi, T. (2014), "Renaissance of case research as a scientific method", *Journal of Operations Management,* Vol. 32 No. 5, pp. 232-240.
Knemeyer, A.M., Zinn, W. & Eroglu, C. (2009), "Proactive planning for catastrophic events in supply chains", *Journal of Operations Management,* Vol. 27 No. 2, pp. 141-153.
Li, N., Chen, G., Govindan, K. & Jin, Z. (2018), "Disruption management for truck appointment system at a container terminal: A green initiative", *Transportation Research Part D: Transport and Environment,* Vol. 61 No. 261-273.
Mason, S.J., Mauricio Ribera, P., Farris, J.A. & Kirk, R.G. (2003), "Integrating the warehousing and transportation functions of the supply chain", *Transportation Research Part E: Logistics and Transportation Review,* Vol. 39 No. 2, pp. 141-159.
Maxwell, J.A. (2013), *Qualitative research design: An interactive approach,* Sage publications,
Mckinnon, A.C. & Ge, Y. (2006), "The potential for reducing empty running by trucks: A retrospective analysis", *International Journal of Physical Distribution & Logistics Management,* Vol. 36 No. 5, pp. 391-410.
Meyer, G.G., Buijs, P., Szirbik, N.B. & Wortmann , J.C.H. (2014), "Intelligent products for enhancing the utilization of tracking technology in transportation", *Internation Journal of Operations & Production Mangement,* Vol. 34 No. 4, pp. 422-446.
Mishra, M., Sidoti, D., Avvari, G.V., Mannaru, P., Ayala, D.F.M., Pattipati, K.R. & Kleinman, D.L. (2017), "A context-driven framework for proactive decision support with applications", *IEEE Access,* Vol. 5 No. 12475-12495.

Nel, J., De Goede, E. & Niemann, W. (2018), “Supply chain disruptions : Insights from south african third-party logistics service providers and clients”, *Journal of Transport and Supply Chain Management,* Vol. No. 1, pp. 1.
Neves-Moreira, F., Amorim, P., Guimarães, L. & Almada-Lobo, B. (2016), “A long-haul freight transportation problem: Synchronizing resources to deliver requests passing through multiple transshipment locations”, *European Journal of Operational Research,* Vol. 248 No. 2, pp. 487-506.
Norrman, A. & Jansson, U. (2004), “Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident”, *International Journal of Physical Distribution & Logistics Management,* Vol. 34 No. 5, pp. 434-456.
Otto, A. (2003), “Supply chain event management: Three perspectives”, *The International Journal of Logistics Management,* Vol. 14 No. 2, pp. 1-13.
Pedrosa, A.D.M., Näslund, D. & Jasmand, C. (2012), “Logistics case study based research: Towards higher quality”, *International Journal of Physical Distribution & Logistics Management,* Vol. 42 No. 3, pp. 275-295.
Perego, A., Perotti, S. & Mangiaracina, R. (2011), “Ict for logistics and freight transportation: A literature review and research agenda”, *International Journal of Physical Distribution & Logistics Management,* Vol. 41 No. 5, pp. 457-483.
Séguin, R., Potvin, J.Y., Gendreau, M., Crainic, T.G. & Marcotte, P. (1997), “Real-time decision problems: An operational research perspective”, *Journal of the Operational Research Society,* Vol. 48 No. 2, pp. 162-174.
Sheffi, Y. (2015), Preparing for disruptions through early detection, *MIT Sloan Management Review, Cambridge, Vol.* 57
Sheffi, Y. & Rice Jr., J.B. (2005), A supply chain view of the resilient enterprise, *MIT Sloan Management Review, Cambridge, Vol.* 47
Snyder, L.V., Atan, Z., Peng, P., Rong, Y., Schmitt, A.J. & Sinsoysal, B. (2016), “Or/ms models for supply chain disruptions: A review”, *IIE Transactions,* Vol. 48 No. 2, pp. 89-109.
Steadieseifi, M., Dellaert, N.P., Nuijten, W., Van Woensel, T. & Raoufi, R. (2014), “Multimodal freight transportation planning: A literature review”, *European Journal of Operational Research,* Vol. 233 No. 1, pp. 1-15.
Stefansson, G. & Lumsden, K. (2008), “Performance issues of smart transportation management systems”, *International Journal of Productivity and Performance Management,* Vol. 58 No. 1, pp. 55-70.
Sternberg, H. (2011), *Waste in road transport operations - using information sharing to increase efficiency,* Doctor of Philosophy, Chalmers university of technology.
Świerczek, A. (2014), “The impact of supply chain integration on the “snowball effect” in the transmission of disruptions: An empirical evaluation of the model”, *International Journal of Production Economics,* Vol. 157 No. 89-104.
Tang, C.S. (2006), “Perspectives in supply chain risk management”, *International Journal of Production Economics,* Vol. 103 No. 2, pp. 451-488.
Tomlin, B. (2006), “On the value of mitigation and contingency strategies for managing supply chain disruption risks”, *Management Science,* Vol. 52 No. 5, pp. 639-657.
Van Belle, J., Valckenaers, P. & Cattrysse, D. (2012), “Cross-docking: State of the art”, *Omega,* Vol. 40 No. 6, pp. 827-846.
Van Der Spoel, S., Amrit, C. & Van Hillegersberg, J. (2017), “Predictive analytics for truck arrival time estimation: A field study at a european distribution centre”, *International Journal of Production Research,* Vol. 55 No. 17, pp. 5062-5078.
Wagner, S.M. & Bode, C. (2008), “An empirical examination of supply chain performance along several dimensions of risk”, *Journal of Business Logistics,* Vol. 29 No. 1, pp. 307-325.
Wandel, S., Ruijgrok, C. & Nemoto, T. (1992), Relationships among shifts in logistics, transport, traffic and informatics-driving forces, barriers, external effects and policy options, *Lund, Sweden, Vol.*
Wieland, A. & Wallenburg, M.C. (2012), “Dealing with supply chain risks: Linking risk management practices and strategies to performance”, *International Journal of Physical Distribution & Logistics Management,* Vol. 42 No. 10, pp. 887-905.

Wieland, A. & Wallenburg, M.C. (2013), “The influence of relational competencies on supply chain resilience: A relational view”, *International Journal of Physical Distribution & Logistics Management,* Vol. 43 No. 4**,** pp. 300-320.
Wilson, M.C. (2007), “The impact of transportation disruptions on supply chain performance”, *Transportation Research Part E: Logistics and Transportation Review,* Vol. 43 No. 4**,** pp. 295-320.
Witkowski, K. (2017), “Internet of things, big data, industry 4.0 – innovative solutions in logistics and supply chains management”, *Procedia Engineering,* Vol. 182 No. 763-769.
Woxenius, J. (2012), “Directness as a key performance indicator for freight transport chains”, *Research in Transportation Economics,* Vol. 36 No. 1**,** pp. 63-72.
Yin, R. (2014), *Case study research: Design and methods,* Sage publications,
Yu, G. & Qi, X. (2014), *Disruption management : Framework, models, and applications,* World Scientific Publishing Co Pte Ltd, Singapore, UNITED STATES.
Zhen, X., Li, Y., Cai, G. & Shi, D. (2016), “Transportation disruption risk management: Business interruption insurance and backup transportation”, *Transportation Research Part E: Logistics and Transportation Review,* Vol. 90 No. 51-68.