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Information exchange and disruption risk in multimodal maritime supply chains

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SUMMARY

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Title:	Information exchange and disruption risks in multimodal maritime supply chains
Department:	School of Business
Year:	2011
Master's Thesis:	Lappeenranta University of Technology, 72 pages, 13 figures, 4 tables and 5 appendixes
Supervisor and examiner:	Professor Kirsimarja Blomqvist Professor Jukka Hallikas

Keywords: knowledge management, information sharing, supply chain management, supply chain risk management

Supply chains are becoming increasingly dependent on information exchange in today's world, and any disruption can cause severe repercussions to the flow of materials in the chain. The speed, accuracy and amount of information are key factors. The aim in this thesis is to address a gap in the research by focusing on information exchange and the risks related to it in a multimodal wood supply chain operating between the Baltic States and Finland.

The study involved interviewing people engaged in logistics management in the supply chain in question. The main risk the interviewees identified arose from the sea logistics system, which held a lot of different kinds of information. The threat of breakdown in the Internet connection was also found to hinder the operations significantly. A vulnerability analysis was carried out in order to identify the main actors and channels of information flow in the supply chain. The analysis revealed that the most important and therefore most vulnerable information-exchange channels were those linking the terminal superintendent, the operative managers and the mill managers.

The study gives a holistic picture of the investigated supply chain. Information-exchange-related risks varied greatly. One of the most frequently mentioned was the risk of information inaccuracy, which was usually due to the fact that those in charge of the various functions did not fully understand the consequences for the entire chain.

TIIVISTELMÄ

Tekijä:	Anna Rumpu
Tutkielman nimi:	Information exchange and disruption risk in multimodal maritime supply chains
Osasto:	Kauppatieteet
Vuosi:	2011
Pro gradu -tutkielma:	Lappeenrannan Teknillinen yliopisto 72 sivua, 13 kuvaa, 4 taulukkoa, 5 liitettä
Ohjaajat:	Professori Kirsimarja Blomqvist Professori Jukka Hallikas
Hakusanat:	tietojohtaminen, informaation jakaminen, toimitusketjujen riskienhallinta

Toimitusketjut ovat nykyään aikaisempaa pirstoutuneimpia, samalla toimijoiden määrä kansainvälisissä toimitusketjuissa on lisääntynyt merkittävästi. Nykytilanne asettaa toimitusketjujen johtamiselle sekä tiedonvaihdon eri osatekijöille, tiedonkulun nopeudelle, tiedon tarkkuudelle ja määrälle, entistä suurempia vaatimuksia. Tilanne lisää huonon tiedonkulun aiheuttamien riskien mahdollisuutta, siksi tiedonvaihdon riskien ehkäisemisellä ja hallinnalla merkittävän roolin toimitusketjujen johtamisessa.

Tämän työn tavoitteena oli tutkia ja määritellä tiedonvaihtoa eri näkökulmista, sekä tutkia siihen liittyviä riskejä multimodaalisessa toimitusketjussa Baltiasta Suomeen. Aineisto kerättiin haastatteluilla sekä kyselylomakkeilla. Tutkimuksessa saatiin kokonaisvaltainen kuva tutkitusta toimitusketjusta. Toimitusketjussa oli useita eri tiedonvaihtomenetelmiä sekä toimijoita, joilla oli erilainen näkemys tutkitusta toimitusketjusta ja erilaiset mahdollisuudet käyttää eri tiedonvaihtomenetelmiä. Tiedonvaihtoon liittyvät riskit vaihtelivat paljon, yksi useimmin mainituista riskeistä oli tiedon epätarkkuus, joka johtui yleensä siitä, että toimitusketjun toimintojen vastuussa olevilla henkilöillä ei ollut oikeaa ymmärrystä epätarkan tiedon seurauksista koko toimitusketjulle.

Tämän lisäksi tutkimukseen tehtiin haavoittuvuusanalyysi, joka paljasti toimitusketjun tärkeimmät toimijat sekä tiedonvaihdon polut. Tärkeimmiksi ja samalla haavoittuvimmiksi tietojenvaihdon poluiksi paljastuivat terminaaliesimiehen, operatiivisten johtajien sekä tehtaan johtajien välillä.

TABLE OF CONTENTS

FIGURES

LIST OF TABLES

1 Introduction

Supply chains nowadays are very long and complex, with a high density of information in the different functions. Several drivers are causing these functions to be divided among a growing number of actors, and this decentralizes the knowledge in the chain. There is increasing dependence on information exchange between the members, and new methods (e.g., ICT and mobile solutions) are being used to fill the gaps. However, increasing dependence on these new solutions poses new challenges related to risk management. The more the functions are divided among a growing number of actors, the less knowledge there is about what goes on beyond the companies' own functions. (Christopher and Lee, 2004)

Supply chains require increasingly highly coordinated flows of goods, services, information and money within and across national boundaries (Mentzer et al., 2001). According to Jüttner (2005), a disruption affecting an entity anywhere in the chain may have a direct effect on a corporation's ability to continue operations. The vulnerabilities of one actor on account of a lack of information, for example, exposes the whole chain to various risks. Hence, it is important to investigate cross-border supply chains in the selection and implementation risk-management strategies (Manuj and Mentzer, 2008).

Research has shown that many organizations are poorly prepared in terms of managing supply-chain-related risks. Investor reactions to disruptions have clearly been significant in that firms announcing major problems in the supply chain have seen their shareholder value drop by approximately 10 percent on average (Handfield and McCormack, 2008; Hendricks and Singhal, 2003). This illustrates the potential effect of disruption. Supply-chain disruptions have become a significant issue for many companies, and managing them is likely to play an increasingly important strategic role (Reyes et al., 2009). Although practitioners are becoming in-

creasingly aware of supply-chain vulnerability and risk, the concepts are still in their infancy (Jüttner, 2005; Manuj and Mentzer, 2008). Recent scientific publications in the field have called for a systematic analysis of vulnerability in particular (e.g., Peck et al., 2003; Waters, 2007).

The main aim in this study is to assess the information exchange and the risks of its disruption in wood supply chains operating between the Baltic States and Finland. In order to achieve this aim various information-exchange methods are investigated and possible disruptions identified. The theoretical framework is based on complementary approaches in the literature on knowledge management, knowledge transfer and information exchange, supply chain management, and supply chain risk management, for example, as well as on the findings from interviews, questionnaires and group discussions. Iterative rounds similar to the Delphi method were used to verify the interview data. A social-network analysis was also carried out in order to illustrate the network relationships of the actors in the multimodal supply chain under investigation with regard to information exchange, and to identify the most important information-exchange channel.

1.1 Background of the study

This study is part of the STOCA (Study of cargo flows in the Gulf of Finland in emergency situations) project at The Northern Dimension Research Centre (NORDI) at Lappeenranta University of Technology. The project is funded by the European Union (EU) and The National Emergency Supply Agency (NESA). The goal of the research is to assess the current and future business environment of cargo flows in the Gulf of Finland from both an environmental and an economic perspective.

The research conducted for this thesis is part of a larger research project and some of the results have been published or accepted for publication in various international forums.

The forest industry has an important position in Finland, accounting for approximately 19 percent of its export trade value. In terms of land logistics, every third large or medium-sized truck serves the industry (Rumpunen, 2010). The supply chains in question belong to complicated international supply networks, which require constant information exchange in order to ensure the undisrupted flow of materials. Given the increasing amount of competition in the field, the information exchange is becoming more and more valuable among the growing numbers of actors involved within these networks. The regional and international wood-supply networks are formed regionally and internationally in Finland, and serve competing mills, competing organizations, and the whole industry at the same time. One of the sources of wood supply for Finnish forest industries is the Baltic States. These cargo flows operate in the Baltic Sea Region in the form of a multimodal supply chain, in which room for improvement has recently been noted.

The case organization in focus belongs to a large global corporation with production units worldwide. The units and interviewees were not randomly selected, but were chosen from different units representing the best and most comprehensive expertise in the supply chain under study, which extends across many different organizations and units. The informants thus included members of the supply organization, the logistics organization, the mill, and the forwarding company represented in this study. The cargo flows in focus operate in the Baltic Sea Region in the form of a multimodal supply chain, and they are vital for the case organization’s mills in Finland.

1.2 The objective of the study and the research problems

Finland as a northern country with small markets is highly dependent on exports. Given the great distances its cargo flows are particularly vulnerable to various disturbances, and here shipping is in a unique position. Sea transport accounts for approximately 82 percent of Finnish cargo-flow volumes, and the Gulf of Finland is in a special position with the three biggest

ports of Helsinki, Sköldvik and HaminaKotka on its shores (Finnish Customs, 2011).

The main objective of this research is to find out how disruptions in information exchange affect the multimodal wood (round wood, chips, sawdust) supply chain from the Baltic countries (mainly Estonia) to mills in Finland.

The main research question in this study is:

How can knowledge management enhance information-exchange-related risk management in supply chains?

The following sub-questions are also addressed:

1. How is information exchange organized?
2. What types of risks are involved in the process?
3. How can knowledge management enhance risk management in information exchange?

1.3 Exclusions and the level of analysis

The focus in this study is on the methods of information exchange currently in use, and the possible risks that may cause disruption in the multimodal supply chain operating from the Baltic States to Finland. It concerns neither past methods nor future states. Moreover, the word organization does not refer to the whole corporation, and means smaller units within a large corporation. Many separate units operate in several countries in the supply chain in question, including procurement and logistics units, and mills.

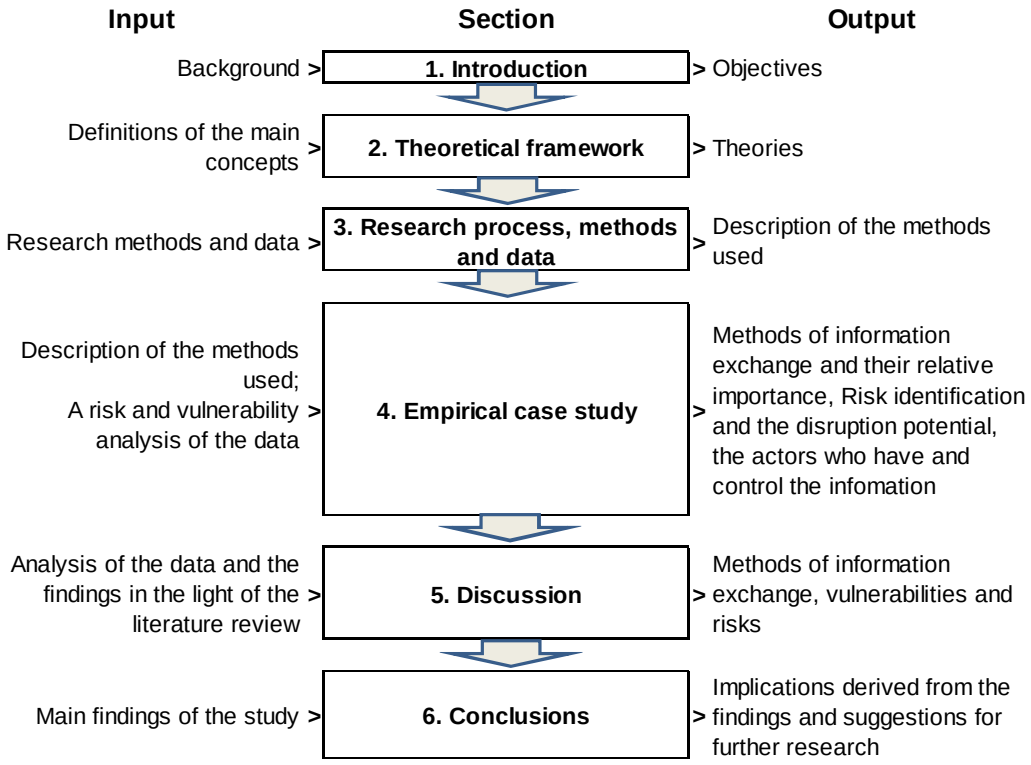
For convenience, the term information exchange as used in this thesis includes information sharing. Furthermore, the focus is on the disruption

risks inherent in information exchange, not on the differences between information exchange and information sharing.

1.4 Structure

This introductory Chapter 1 gives the background of the study, sets out the research questions, and discusses the limitations and the level of analysis. Chapter 2 describes the theoretical framework and the main concepts, namely knowledge, knowledge management, knowledge transfer, information exchange, supply chain risk and supply chain risk management, in a review of the state-of-the-art literature.

Figure 1 The structure of the thesis



Chapter 3 describes the research and data-collection methods. Chapter 4 comprises the empirical part of the study, beginning with a description of the supply chains under study and of the most important information-exchange methods used in them. The findings from the interviews are

presented, the information-exchange-related risks and potential disruptions are assessed, and the various network roles are introduced and analyzed. Chapter 5 comprises a discussion of the findings in the light of the theoretical framework, and draws some conclusions. Finally, Chapter 6 summarizes the conclusions of the study and gives suggestions for further research. Figure 1 illustrates the structure of the thesis.

2 Theoretical framework

The theoretical part of this study describes the main concepts employed as portrayed in the state-of-the-art literature. These include knowledge, and knowledge management and transfer, and information exchange and quality, which are also discussed in the light of previous research. The focus then shifts to the concept of supply chain risk management, and the role of information exchange in it. The concept of risk is defined as a quantitative formula and is thereafter discussed in a supply-chain context, including outcomes whenever possible. Finally, supply chain risk management is defined. In order to familiarize herself with the present body of knowledge in the scientific literature the author conducted an article search in journals specializing in supply-chain and logistics management, as well as knowledge management. The databases used for the literature review included Sciencedirect, Emerald and Inderscience. Several other publications and reports were consulted via Google Scholar, for example, in order to shed light on the background of the concepts.

2.1 Knowledge and knowledge management

Liebeskind (1996) defines knowledge as valuable information the validity of which has been established through tests of proof, thereby distinguishing it from opinion, speculation, beliefs, and other types of unproven information. According to Kogut and Zander (1992) and Grant (1996), knowledge consists of information (know what) and know-how. “Know

what" is explicit knowledge (information and facts that can be codified) and "know how" is tacit knowledge (knowledge that can be observed through application or acquired through practice). Information in this context signifies knowing what something means, and know-how refers to how to do something. Explicit knowledge can be articulated and is easy to transfer, whereas tacit knowledge is difficult to articulate and slow or uncertain to transfer (Kogut and Zander, 1992). Tacit knowledge potentially offers more sustainable advantages because it is difficult to imitate, and the process of accumulating and leveraging knowledge is more likely to create new sources of advantage (Choo et al., 2007).

Alavi and Leidner (2001) refer to knowledge as a broad and abstract notion, which is nowadays treated as a significant organizational resource. This perspective builds upon the resource-based theory of the firm. Knowledge-based resources are usually socially complex and generally hard to imitate. The knowledge-based view implies that the role of the firm is to create, acquire, and deploy organizational knowledge in order to achieve superior performance. In other words, knowledge assets may produce long-term sustainable competitive advantage. (Nonaka, 1994; Alavi and Leidner, 2001)

According to von Krogh (1998) and Hackbarth (1998), knowledge management (KM) refers to "identifying and leveraging the collective knowledge in an organization to help the organization compete and to increase innovativeness and responsiveness". Knowledge management is a dynamic and continuous organizational phenomenon and therefore an organization and its members may be involved in multiple knowledge-management-process chains at the same time (Alavi and Leidner, 2001). According to Argote et al. (2003), knowledge management comprises three dimensions: knowledge creation, retention and transfer. The focus is on the properties of a particular unit, which may be an organization, an individual, or a population of organizations, in terms of how the units are connected to each other and what the social relationships between them

are. The relationships are classified on several dimensions, including intensity of connection, communication or contact frequency, and social similarity, all of which can affect the knowledge-management process.

2.2 Knowledge transfer

Argote and Ingram (2000) define knowledge transfer as a process through which one unit (group, department or division) is affected by the experience of another, and describe the creation and transfer of knowledge in firms as a basis for competitive advantage. The extent to which a firm achieves competitive advantage from its knowledge-based assets depends how well it is able to utilize its existing knowledge to create new knowledge (Alavi and Leidner, 2001).

Sharing information is an effective way of transmitting personal knowledge within groups. This kind of knowledge is transmittable because a set of values has been learned, providing a shared language in which to communicate. (Kogut and Zander, 1992) The ability to transfer knowledge from one unit to another has been found to contribute to the organizational performance of firms A significant component of the knowledge organizations acquire may be tacit (embedded in the individual members) and not easily articulated (Nonaka, 1991).

According to Walsh and Ungson (1991), there are five knowledge repositories in organizations: (1) the individual members, (2) the roles and the organizational structure, (3) the organization's standard operating procedures and practices, (4) its culture, and (5) the physical structure of the workplace. The knowledge repositories change when knowledge transfer occurs, and they also reflect its outcomes. Within McGrath and Argote's (1993) framework, however, knowledge is embedded in the three basic elements of an organization: its members (people), its tools (technical components) and its tasks (goals and intentions), and the various subnetworks formed by combining all three. It is therefore possible to move

knowledge by moving the networks in which it is embedded. The social network also plays an important role in knowledge transfer because it can link organizational units to new sources of knowledge. (Argote and Ingram, 2000)

Social relations have a significant, even direct role in effective knowledge transfer. In other words, social relationships provide individuals with the opportunity to create, retain, and transfer knowledge. Significant relationships could comprise a trans-active memory system or consensus about who knows what. As a result of observation the individual learns who knows what and how to search for relevant knowledge and information. By making knowledge more proximate, informal ties promote learning. Informal connections allow people to benefit from knowledge accumulated by close contacts and associates (Argote et al., 2003). Informal networks serve a similar function (Argote and Ingram, 2000).

2.3 Information exchange and information quality

Current business environments are remarkably dynamic. In facilitating dynamic action and decision-making, information exchange and information quality are very important aspects of coordination operations in supply chains (Fiala, 2004). Information therefore has great value. Information sharing in supply chains relates to the extent to which information is communicated between the partners (Li and Lin, 2006).

Information within the supply chain has become a vital element in terms of integration, performance and successful implementation (Chen et al., 2011). Furthermore, its performance is crucially dependent on its members' ability to coordinate their decisions, and the role of information sharing is vital in that respect. Furthermore, the more easily available the information is, the easier is the decision-making and the higher the likelihood of better performance (Chen, 2003). It is suggested in several studies that information sharing improves the coordination of physical move-

ment within the supply chain, and of the decision-making (Clark and Scarf, 1960; Gustin et al., 1995; Closs et al., 1997; Whang, 1995).

Available information is a key ingredient for a seamless supply chain and its management. Information exchange is a tool that makes available undistorted and up-to-date data at every step within the process, and makes it easier to deal with problems such as supply uncertainty. There may be delays as the information moves up through the supply chain, a phenomenon known as the bullwhip effect (Fiala, 2004; Kaipia, 2007.) Effective information exchange can reduce or even eliminate this effect. By exchanging information with the other parties involved an organization can improve the efficiency of the supply chain, and respond to customer needs more quickly. Information has become a key driver of enhanced supply-chain performance in facilitating the better matching of supply with demand. Information flow and information sharing thus help to keep all actors in the supply chain updated and hence assist the decision-making. Therefore, in the long run, information exchange will bring the organization competitive advantage. (Li and Lin, 2006; Ryu et al., 2009; Fu and Zhu, 2009; Tang and Musa, 2010)

An overflow of information may be harmful, however. It is certainly important to share information in the supply chain, but the quality (what, when, how and with whom) of what is shared matters even more. Information quality is defined as “the degree to which the information meets the needs of the organization” (Monczka et al. 1998; Forrester, 1962), and according to Li and Lin (2006) includes aspects such as accuracy, timeliness, adequacy, and credibility. Monczka (1998) adds completeness and compatibility across all users to the list. Information availability also has a clear impact on the planning result and is critical to the effectiveness of the decision-making (Kaipia, 2007).

Organizations with timely and accurate information at their disposal are better able to cope with various uncertainties in the supply chain (Ryu et

al., 2009). According to Minahan (2005), the success of supply management depends very much on the ability to access, organize, analyze and utilize data. The use of the Internet and of enterprise resource planning solutions helps supply networks in terms of information visibility, and has reduced the information-transaction time. It has also reduced the incidence of inaccuracy and redundancy. The immense usefulness of these systems has exposed yet another weakness, however, namely information disruption (Tang et al., 2010).

Given that knowledge is acknowledged to be an organizational resource, there is also considerable interest in information systems, referred to as knowledge management systems (KMS). The objective of such systems is to support the creation, transfer and application of knowledge in organizations. IT tools play a significant role in organizational knowledge-management processes. (Alavi and Leidner, 2001)

Advanced information technologies (IT) such as the Internet, intranets, extranets and data warehouses play an important role from the perspective of the knowledge-based view of the firm, facilitating the management of large-scale intra- and inter-firm knowledge. Advances in communication and information technologies therefore hold great potential. (Alavi and Leidner, 2001) Although IT solutions can help to reduce coordination and transaction costs, as well as the risks related to the bullwhip effect, however, risk management with regard to information flow is yet to become an established aspect of supply chain management (Faisal et al., 2007).

2.4 Risk and supply chain vulnerability

Risk is typically defined in the literature on supply chain management as purely negative, leading to undesired results or consequences (Harland et al., 2003; Manuj and Mentzer, 2008; Paulsson, 2004, Ref. “The Royal Society, 1992”). *Risk* is defined in this study as unreliable and uncertain re-

sources creating interruption in the supply chain (Tang and Musa, 2010; Waters, 2007).

A standard formula for the quantitative definition of supply chain risk is:

Risk = P(Probability) * I(Impact)

Thus risk is defined as the product of the probability (P) of loss times the significance of its consequences (I) (Mentzer et al., 2001).

According to Waters (2007), vulnerability in the supply chain reflects its susceptibility to disruption and is a consequence of the risks to which it is exposed. Jüttner et al. (2003) describe vulnerability as exposure to serious disturbance, arising from risks both within and external to the chain. In other words, it reflects the propensity of risk sources and risk drivers to outweigh risk-mitigating strategies, thus causing adverse consequences in the chain in addition to jeopardizing its capacity to effectively serve the end customer. How sensitive a supply chain is to these disturbances is measured in terms of its vulnerability, and how vulnerable it is depends on its structural agility and resilience. It is here that risk management plays a crucial role.

2.5 Supply chain management and multimodal logistics

The supply chain is defined as a system of suppliers, manufacturers, distributors, retailers and customers within which material, financial and information flows connect the participants in both directions (Fiala, 2004). According to Lysons and Farrington (2006), there is no single, unique definition of supply chain management (SCM). Tan (2001) defines it as a holistic and strategic approach to operations, materials and logistics management. According to Minahan (2005), the role of procurement in the strategic operations of enterprises has increased notably, and procurement and supply management are now major contributors of value across

the organization. SCM falls within three categories: it is a management philosophy, the implementation of a management philosophy, and a management process (Lysons and Farrington, 2006). Multimodality with regard to the management of logistics supply chains refers to the combination of various modes of international transport including ship, rail and road, primarily through the use of containers (UNCTAD, 1993). Multimodal logistics supply chains have two main characteristics: firstly, there may be more than one means of transport from one place to another, and secondly, in order to transfer from one means to another, the place should have additional facilities for loading/unloading shipments and transferring them to/from transport modes of different types (Hu, 2011).

2.6 Supply chain risk management

Given the increasing complexity of supply chains and the demands placed on them, disruptions have become more common in recent years. It is therefore essential to be able to identify the possible risks, and this is now a key risk-management activity. In reality it is almost impossible to list all possible risks that could affect the supply chain. (Giannakis and Louis, 2010) The personnel responsible for the organization´s supply-chain activities usually have the best knowledge of both the organization and its operations, but do not necessarily have the capability to identify risks as such. Organizations cannot rely on personal knowledge, and need more formal risk-identification arrangements (Waters, 2007). The Cranfield University report (2002) lists ten ways of managing supply-chain risks: through diversification, stockpiling, redundancy, insurance, supplier selection, supplier development, contractual obligation, collaborative initiatives, rationalization of the product range, and localized sourcing. Diversification means multiple sourcing, whereas stockpiling refers to the use of a buffer against eventualities, and redundancy to maintaining excess production, storage, handling, and transport capacity. Supplier selection implies the more careful assessment of supplier capability and risks, and supplier development means working closely with suppliers and sharing information.

The risks can also be managed through contractual obligations (imposing legal obligations with penalties). Rationalizing the product range may entail excluding products with supply problems, and localized sourcing may help to reduce the risks arising from bottlenecked transport networks or intermodal transport transfer by shortening transport distances. Figure 2 depicts the relationship between risks, vulnerability and risk management in the supply chain.

Given the increasing prevalence of disruptions in the supply chain, it is important to assess the risks and their possible effects on the actors involved. Risk assessment begins with the selection and definition of the different categories, which can then be weighed, compared and quantified (Singhal et al., 2009; Blackhurst et al., 2008). According to Handfield and McCormack (2008), the severity of a disruption in the supply chain can be defined as the number of nodes within the supply network whose ability to ship and/or receive goods and materials has been effected by an unplanned, unanticipated event. All supply chains carry some risk, but the variability is a function of multiple factors including the density, criticality and node configuration of the network.

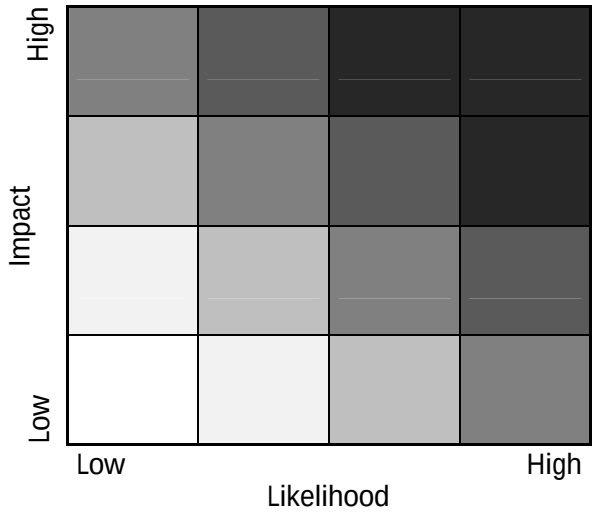
Risks in the supply chain may be operational or low-probability–high-consequence (LP–HC) events. Operational risks occur regularly, but they are considered minor. They do not cause serious disturbances in themselves, but if they occur simultaneously or cause a snowball effect they may have serious implications. LP–HC events as described by Tang (2006) and Zinn et al. (2009) can unexpectedly disrupt the flow of material in the supply chain at any time.

Supply chains may be vulnerable to both external and internal risks. External risks are those that are linked to environmental events (storms, floods), economic causes (strikes), political matters (wars, embargoes), and social factors, whereas internal risks derive from interactions between organizations in the supply chain. (Lysons and Farrington, 2006) The

Cranfield University report (2002) lists five types of supply-chain risks associated with a lack of ownership, chaos, decision-making, the JIT relationship (JTI = just in time), and inertia. Tang and Musa (2010) also mention risks associated with information accuracy, attributable to poor information accessibility, a lack of information efficiency, and data inaccuracy.

According to Thun and Höenig (2011), internal supply chains are more likely to incur risks than external supply chains because the majority of external risks are highly exceptional (e.g., wars or terrorist attacks), whereas internal risks (e.g., changes in customer demands) cannot be regarded as uncommon. Furthermore, external risks have a higher impact because their occurrence normally has severe consequences. The risks can be demonstrated on two dimensions - ‘‘probability” and ‘‘impact’’ - based on a Likert-type scale. (Thun and Höenig, 2011) Norrman and Lindroth (2002) developed a risk matrix, as shown in Table 1 (adapted from Norrman and Lindroth, 2002; Thun and Höenig, 2011).

Table 1 A risk-probability-impact matrix



The role of risk management is to handle the possible risks. This involves taking the necessary actions to reduce the consequences or probability of the unwanted situation or occurrence, and following a process in which conscious decisions are made to accept a known risk. Risk management

can also mean, “to take actions to shift the odds in your favor” (Paulsson, 2004, 79, Ref. The Royal Society, 1992).

The aim of supply chain risk management is “to collaboratively with partners in a supply chain deal with risks and uncertainties caused by, or impacting on, logistic related activities or resources” (Paulsson, 2004, 80, Ref. Norrman and Lindroth, 2002). The process starts with the identification of probable risks and their possible impact on operations. The first task is to identify the direct risks, such as the loss of critical raw materials or process capability, and the second is to assess the potential indirect consequences of these risks in every part of the supply chain. (Lysons and Farrington, 2006)

Figure 2 The main concepts involved in supply chain risk management

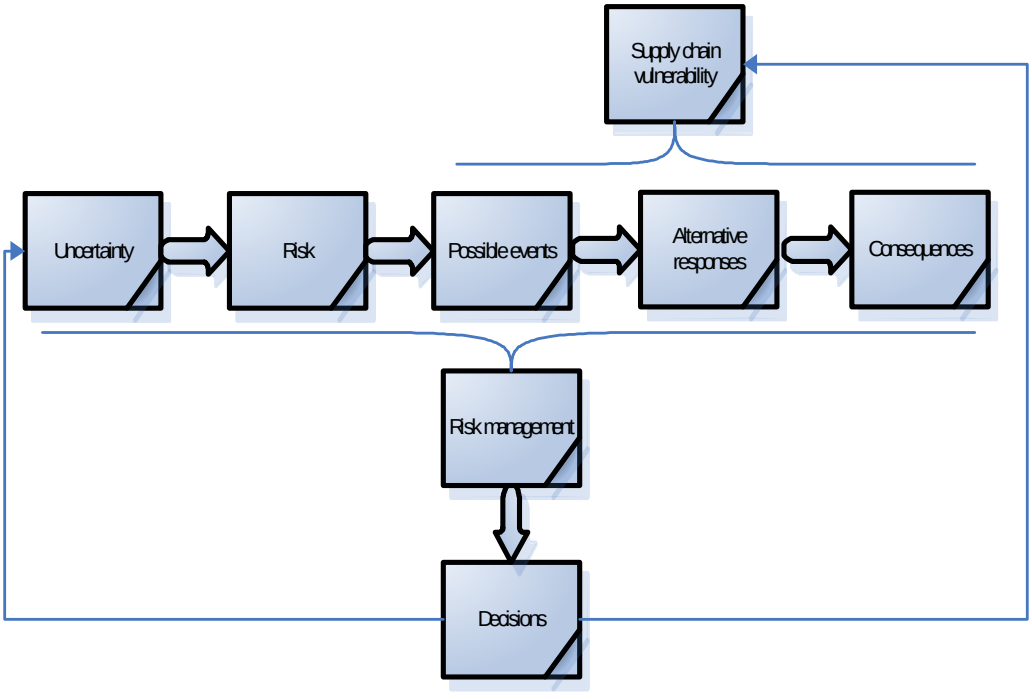
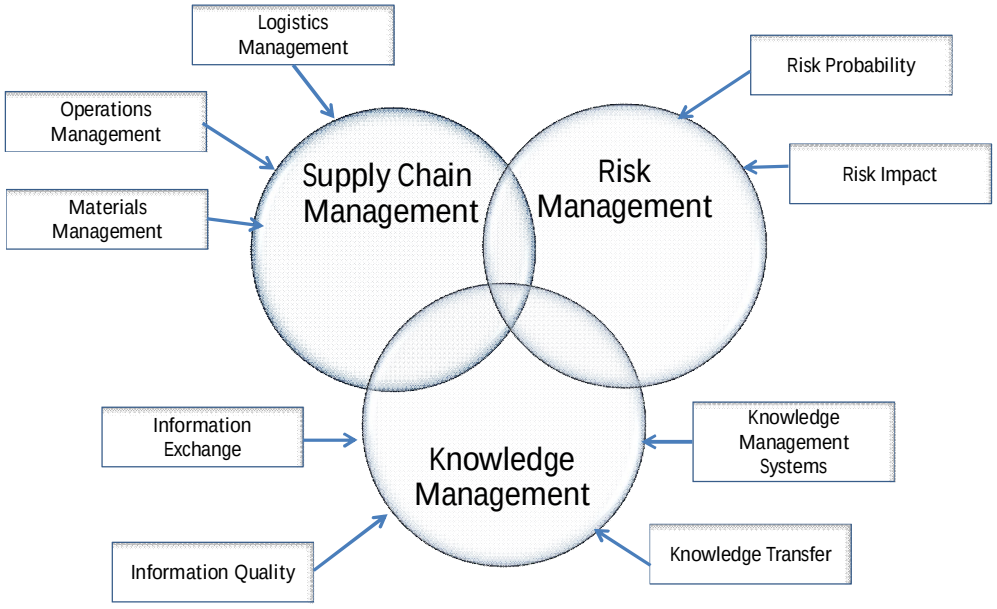


Figure 2 (adapted from Vilko et al., 2011; Waters, 2007) depicts the relationship between supply-chain risks, vulnerability and risk management.

Figure 3 Connections between the main theoretical concepts



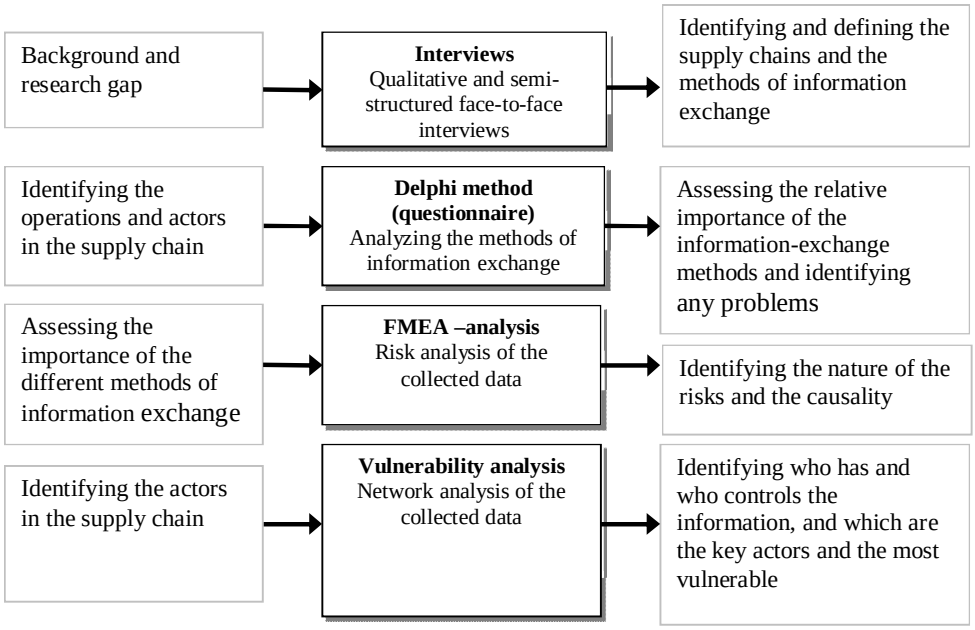
As mentioned above (Ryu et al., 2009), timely and accurate information is useful in terms of managing risks in that it helps the organization to cope with the various uncertainties inherent in the supply chain. The use of the Internet and various planning solutions has cut down transaction time and reduced the levels of inaccuracy and redundancy. Nevertheless, the risk of information disruption remains. (Tang et al., 2010)

Figure 3 depicts the connections between supply chain management, risk management, knowledge management and information management, and describes the notions attached to them.

3 Research process, methods and data

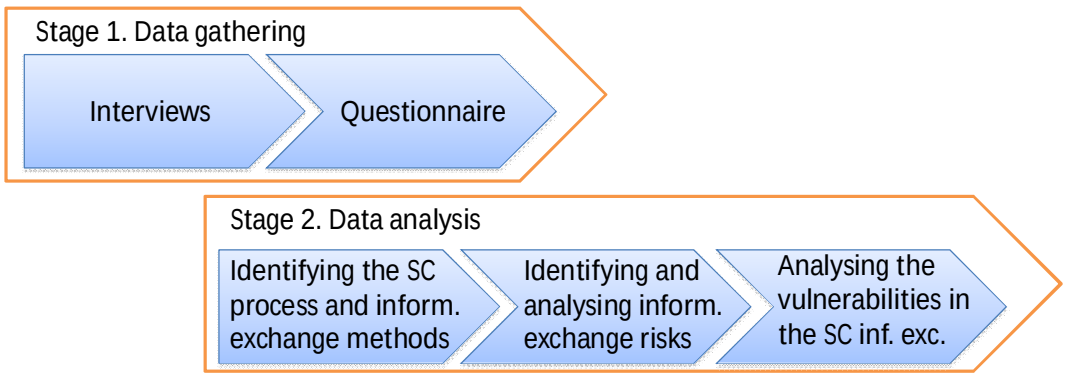
This chapter describes the research process, the methods used and the data-collection procedure. It includes a brief introduction of the case organization and some information about the interviews. The quantitative survey provided valuable background information whereas the qualitative research gave deeper, more specific insights. Figure 4 summarizes the research methods that were applied.

Figure 4 Research methods



This study followed a two-stage research process (Figure 5), the first stage of which was to gather data in qualitative interviews with people responsible for logistics-related tasks, and further from an Internet-based questionnaire designed to expand and verify the interview data. The second stage comprised the data analysis. The first step in this process was to identify the path of the supply chain and the methods of information exchange adopted, the second was to identify and analyze the information-exchange risks, and the final stage was to analyze the vulnerabilities.

Figure 5 The research process



3.1 Qualitative research

The study was based on qualitative case research in which the research subjects were studied in their natural setting in a real-life context. Given that neither the phenomenon not the context was evident, an approach was chosen that would make sense of both through the interpretation of the meanings people bring to them (Yin, 1984). The researcher also believed that a qualitative approach would better serve the purpose because it facilitates in-depth and detailed study of the subject (Alasuutari, 1999). The perspective is usually that of the informants. The sampling is generally discretionary, although the samples may be small and therefore not necessarily of statistical value. According to Alasuutari (1999), qualitative research typically requires no hypothesis setting in advance, and the researcher should not make any assumptions concerning the subject.

The study sample was not very big, and was by no means statistical. The research method used was therefore purely qualitative.

3.1.1 The case study

Case-study methodology was used in the research. A case study is an empirical inquiry investigating a contemporary phenomenon within its real-life context, especially if the boundaries between the phenomenon and the context are not evident (Yin, 1984). In terms of a research strategy it is

comprehensive. One of its advantages is that it allows the phenomenon to be observed in its natural setting as the actual practice is followed. In other words, case-study research allows investigation of the “hows” and “whys” of a phenomenon within a real-life context (Schiele and Krummaker, 2011). Its limitations include the cost and the time required for the research, as well as the limited generalizability of the findings. According to Eisenhardt (1989), case studies allow a combination of data-collection methods, including interviews, questionnaires and archives, and the evidence may be qualitative, quantitative or both.

3.1.2 Interviews

Methods of data collection in qualitative research include in-depth interviewing, observation, group discussions and narratives (Alasuutari, 1999). In the present study it was gathered through qualitative interviews with nine individuals employed in three different companies (the case company and two others in a related field of business). The interviewees represented a range of functions related to logistics and planning. Their positions in the organizations and units varied, but all had an extensive understanding of their company’s operations and an overview of the supply chain’s activities. The researcher considered it essential for the interviewees to have a wide perspective on the operations of the supply chain and on the risks in order to produce an accurate analysis, and therefore considered suggestions about good interviewee candidates during the interviews. The interviews were conducted in Finnish or English.

The interviews were recorded and the audio files were then transcribed to text files, and finally analyzed. At the beginning of each interview the interviewees were promised anonymity and their permission to use a recorder was solicited. They were all told that this study would be part of the STOCA research project and that the research paper would be a public document. The names of the interviewees are not revealed here. The interviews were semi-structured and discursive, and there were no pre-

determined response options. The themes and questions were discussed at random in order to facilitate a natural conversational style and to allow the lead of the interviewees to be followed. All interviews were conducted face-to-face, and lasted about two hours. The interviewees were asked to describe their own activities in the supply chain in question, and to take into account the processes in a broader sense.

3.2 Quantitative research

Quantitative research methodology concerns the way in which research based on various observations and measurements should be carried out. The main strengths of quantitative data are that it can be summarized and subjected to statistical analysis. Quantitative evidence can identify relationships that may not be obvious to the researcher. (Nummenmaa, 2004) The quantitative approach offers various methods for analyzing and processing the collected data. Quantitative analysis was used in this study to summarize, describe and model the data, and also in the drawing of conclusions. On the qualitative level, a survey was conducted in order to assess the importance of the different methods of information exchange, and a group discussion took place.

3.2.1 Survey

An Internet-based questionnaire and a group discussion served to quantify and verify the interview data in iterative rounds similar to the Delphi method (see e.g., Fowles, 1978). After the first round of the interviews the interviewees were sent a webropol questionnaire, the items in which were based on the interviews. The purpose of the questionnaire was to obtain a clearer picture of the impact factors related to information sharing and its possible disruption in the supply chain under study. The Delphi approach facilitated identification of the most significant information-exchange methods, and the ones that were most vulnerable to potential disruption. The

questionnaire is not shown in this thesis because it would reveal all the methods of information exchange in use.

3.2.2 The Delphi method

A method similar to the Delphi method was used to quantify and verify the interview data: after the interviews the interviewees were sent an Internet-based questionnaire, and a group discussion was organized. The Delphi method was developed in the 1940s, and its use spread to include technological forecasting and the evaluation of complex social problems in the 1960s (Gordon and Helmer, 1964; Weaver, 1971; Sackman, 1974; Landeta, 2006). Dalkey and Helmer (1963) describe the method as a group technique employed in order to obtain a reliable group opinion using a panel of experts.

The Delphi method is typically characterized as a repetitive process. The experts in the group have to be consulted at least twice on the same question so that they can reconsider their responses in the light of the information they receive from the other experts. It also maintains the anonymity of the participants, or at least of their responses. Controlled feedback is also a feature of the method. The exchange of information between the experts is not free, but is carried out via a study-group coordinator who is able to eliminate all irrelevant information. All the opinions are taken into account in the final answers. The questions are formulated in such as way that the answers can be processed quantitatively and statistically. (Weaver, 1971; Sackman, 1974; Landeta, 2006)

The Delphi method has its strengths: it goes some way to resolving the problems that are inherent in traditional group-opinion-based interaction and can reduce the influence of timid or dominant personalities in the group; it allows more extensive observation because of the repetition; it produces statistical results, is flexible in terms of methods, and is simple to execute. There are also some weaknesses, however, including the time

required to carry out the rounds and the difficulty of ascertaining accuracy and reliability in terms of who is considered an expert or the biases the different experts may have (which could affect the results) (Gordon and Helmer, 1964; Weaver, 1971; Sackman, 1974; Landeta, 2006).

3.3 Data analysis

The aim in the interviews was to identify the process in the multimodal maritime supply chain under study step by step, then to establish what kind of information was being exchanged, and finally to assess the potential disruption risks.

Failure Mode and Effect Analysis (FMEA) was used to identify the risk-evaluation criteria based on the data gathered in the interviews. FMEA is a tool that facilitates the recognition, prioritization, and elimination of potential failures, problems, errors and risks. The Risk Priority Number (RPN) index, which is used to measure the degree of risk and the severity, comprises three indicators: Occurrence (O), Severity (S), and Detection (D). FMEA proceeds in two stages. The first stage involves identifying the potential risks and assigning a value to their Severity, Occurrence and Detection. The company should then correct its actions during the second stage, after which the RPN has to be re-calculated. (Hu et al., 2009)

Software facilitating social network analysis was used to conduct a supply-chain-vulnerability analysis based on the responses to the webropol questionnaire. The aim was to find out who had and who controlled the information in the supply chain, and to identify the most crucial actors. This also revealed who shared information with whom, and which relations were the most important among the actors. The analysis also illustrated the vulnerabilities in the network.

Social Network Analysis is a research method emphasizing relations between actors in the network, the aim being to make visible that which is

not apparent to the “naked eye”, and to evaluate the location of the actors (Kadushin, 2005). The nodes in the network are the people and groups and the links show the relationships or flows between them. The method also produces a visual analysis of human relationships that helps to make them visible. (SNA, 2011)

According to Axelsson and Easton (1992), a “network involves sets of two or more connected exchange relationships". Markets can be described as systems of social and industrial relationships among customers, suppliers, competitors, family, and friends. Thus, from a network perspective the nature of relationships established between various parties will influence strategic decisions, and the network will involve resource exchange among different members (Sharma, 1993). Furthermore, the power of the individual actors is not an individual attribute, but arises from their relations with others (Hanneman and Riddle, 2011).

The measures arising from social network analysis give an insight into the various roles and groupings involved: who are the connectors, mavens, leaders and bridges, where the clusters are and who is in them, who is at the core of the network, and who is on the periphery. Two nodes are connected if there is regular communication or other forms of interaction. (SNA)

Hanneman and Riddle (2011) and Freeman (1979) refer to three basic centrality approaches in SNA: degree, closeness, and betweenness. Each of these describes the locations of actors in terms of of how close they are to the "center" of the action in the network, for example. Centrality illustrates the degree of control over information exchange the actors in the network have (the nearer to the center they are, the higher their level of control). (Freeman, 1979)

Degree in this context means that the more ties an actor has the more power he or she may hold. Actors who have more ties have more oppor-

tunities because they have choices and are therefore less dependent on any one fellow actor. Those who are closer to more actors than any other actor will have more power, and those who have shorter paths to other actors or who are more reachable by other actors due to the shorter path lengths will have favorable positions. Each actor in a circle network lies between another pair of actors, and those closer to the middle of the chain lie on more pathways, thus again being in an advantaged position in terms of betweenness. (Hanneman and Riddle, 2011)

Degree centrality refers to the number of ties an actor has to other actors in the network, although having the same number of ties does not necessarily make the actors equally important. Those who have more ties to other actors may be in an advantageous position. An actor with many ties may have alternative ways in which to satisfy needs, and hence is less dependent on other individuals.

Freeman and Bonacich represent two different approaches to degree centrality. Freeman argues that actors who have more connections are more likely to be powerful because they can directly affect more other actors, whereas according to Bonacich, an actor who is connected to central actors is likely to be more influential. However, if the actors to whom you are connected are well connected they are not highly dependent on you, whereas if they are not, then they will be dependent on you. Bonacich argues that being connected to connected others makes an actor central but not powerful. The more connections the actors in your neighborhood have, the more central you are, and the fewer connections they have, the more powerful you are. (Hanneman and Riddle, 2011)

Closeness centrality is the degree of closeness between an actor and all the other members in the network (directly or indirectly). It reflects the ability to access information through the members, emphasizing the distance of any actor from everyone else in the network by focusing on the distance from each actor to all the others. Degree centrality measures are open to

criticism because they only take into account the immediate ties that an actor has, or the ties of his or her neighbors, rather than the indirect ties. (Hanneman and Riddle, 2011; Wasserman et al.,1994) A number of slightly different measures can be used (path distances, reach and eigenvector) depending on the meaning one attaches to being "close" to others. Path distance is one way of calculating how far away each actor is from all the others in the network, farness being the sum of the distance. (Hanneman and Riddle, 2011) Not all network paths are equal however, and the shorter ones are considered more important. They also have horizons beyond which they cannot be seen or influenced. The key paths have one or two steps, and on rare occasions three. It is therefore important to know who is in the neighborhood of your network, who are you aware of, who you are able to reach, and who is the only person able to reach everyone else in two steps or less. (SNA, 2011) The average path length is defined as the average number of steps along the shortest route for all possible pairs of network nodes. It is a measure of the efficiency of information or mass transport in a network. Reach refers to how close each actor is to all the others, and which actors can reach them in one, two or three steps, for example (Hanneman and Riddle, 2011). The eigenvector approach is used to find the most central actors (i.e. those at the smallest distance from others). The location of each actor with respect to each dimension is called an "eigenvalue," and the collection of such values is called the "eigenvector." Eigenvector centrality is a measure of the importance of a node in a network (Rybski et al., 2009; Bonacich, 2007; Hanneman and Riddle, 2011). The closeness and eigenvalue approaches refer to the closeness of the connections to all other actors, but only by the "most efficient" path. In some cases, however, power or influence may be expressed through all of the pathways that connect an actor to all the others. (Hanneman and Riddle, 2011)

Having more than one channel makes an actor less dependent and therefore more powerful (Hanneman and Riddle, 2011). Betweenness centrality is the extent to which a node lies between other nodes in the network. It

takes into account the connectivity of the node's neighbors, and gives a higher value to nodes that bridge clusters. This measure reflects the number of people who are connected indirectly through their direct links. (Wasserman et al., 1994) The more one specific actor depends on any other actor to make connections, the more power the other specific actor has. It is the centrality of the relations are most central, rather than which actors. (Hanneman and Riddle, 2011)

According to Rybski et al. (2009), human interaction is another measure of linkage that can be used in network analysis.

3.4 Validity and reliability

Reliability can be defined in terms of the measurement repeatability of an event and the stability of the system, and is stronger the less that chance can affect the results. Validity refers to the data - the extent to which it measures what it should have measured and that a balance is achieved between theoretical and conceptual definition. Errors related to the study design, the researcher, the collection, quality and analysis of the data, the presentation of the results, and the conclusions may undermine the reliability of qualitative research. (Lotti, 1982)

The researcher believes that the thesis material in this case is reliable given that the interviewees were motivated to respond and were very familiar with the field. She has done her best to dismiss her own preconceived ideas and to deal with the subject and the material objectively.

4 The empirical case study

This chapter reports the empirical case study and the data analysis. The supply chains in question are introduced in the first section, section 2 de-

scribes the methods of information exchange used in the processes, and section 3 assesses their relative importance.

4.1 The case supply chains

Step by step process maps of the supply chains, based on the interviewees' descriptions, were drawn up in order to give a systematic understanding of the phenomenon. The maps facilitated deeper operation-level examination without losing the holistic understanding of the overall process.

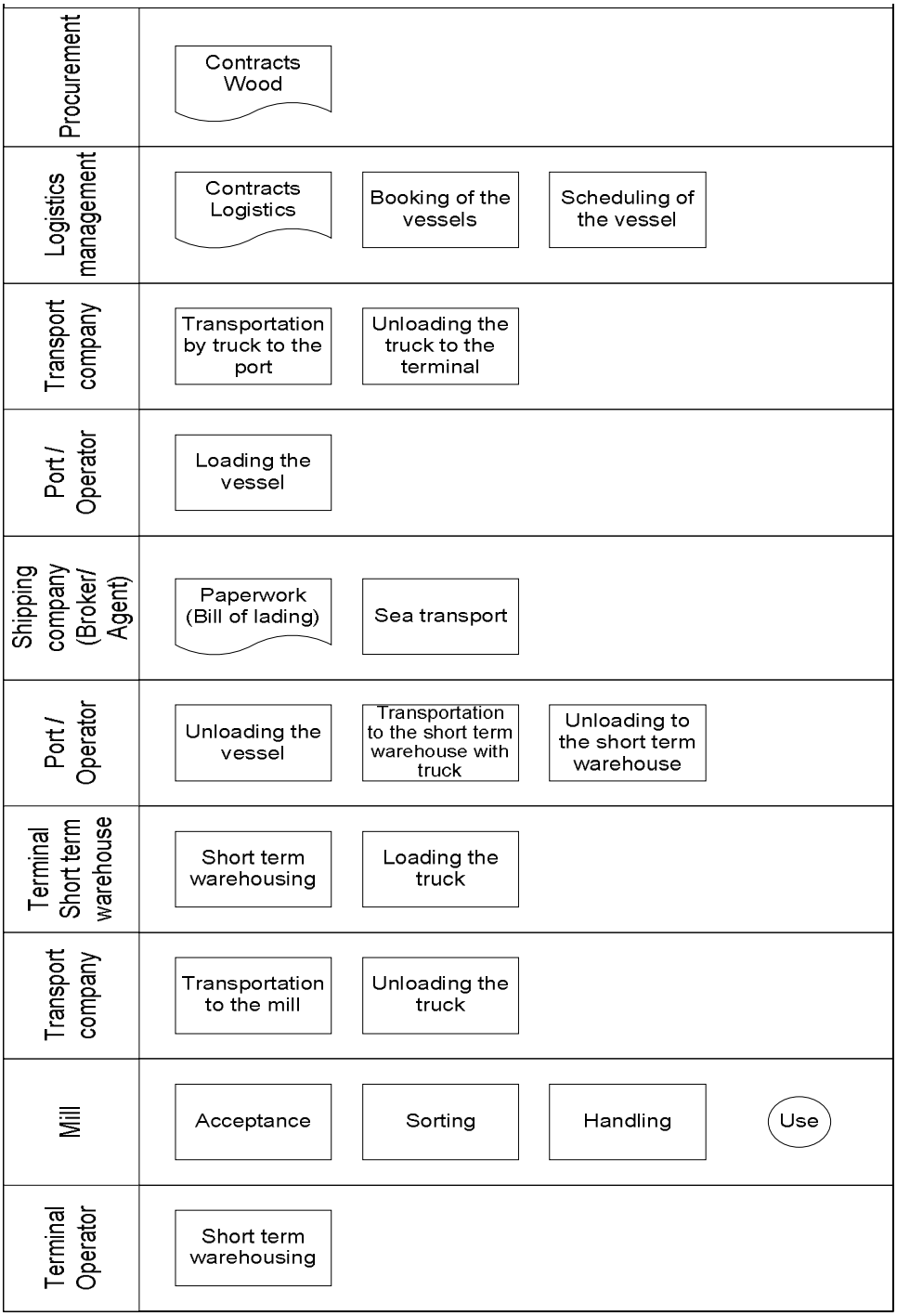
The interviewees identified three wood-supply-chain processes that were typically in use: (1) an international inter-modal maritime supply chain in the Baltic Sea Region (Figure 7); (2) a supply chain mainly comprising railroad transportation from Russia to Finland (Figure 7); (3) road transportation, both regional and international (Figure 8). The left-hand side columns in Figures 6, 7, 8 and 9 list the organizations, or the various departments, and the right-hand-side columns indicate the main functions of the different actors and the related documents (paperwork). The process maps are be to read from top to bottom and from left to right. In order to ensure the anonymity of the case organization the names of the departments are not mentioned.

The three supply chains under investigation were equally important to the case company, although they varied substantially in their nature. The maritime supply chain turned out to be the most economical delivery method in terms of cost. The raw-material quantities per vessel were significantly larger compared with railroad and road transport, one vessel having the capacity to deliver between 4,000 and 5,000 cubic meters of raw material at a time.

The first chain to be analyzed was the maritime supply chain. Information timeliness was considered important because of the reasonably quick transport times. According to the interviewees the scheduling of the

vessels and the predictability of their arrival times were challenging, but still manageable. The arrival frequency varied a lot: the vessels were normally scheduled to arrive frequently, one at a time, but occasionally there were peaks when several ships came in at the same time.

Figure 6 The maritime supply chain



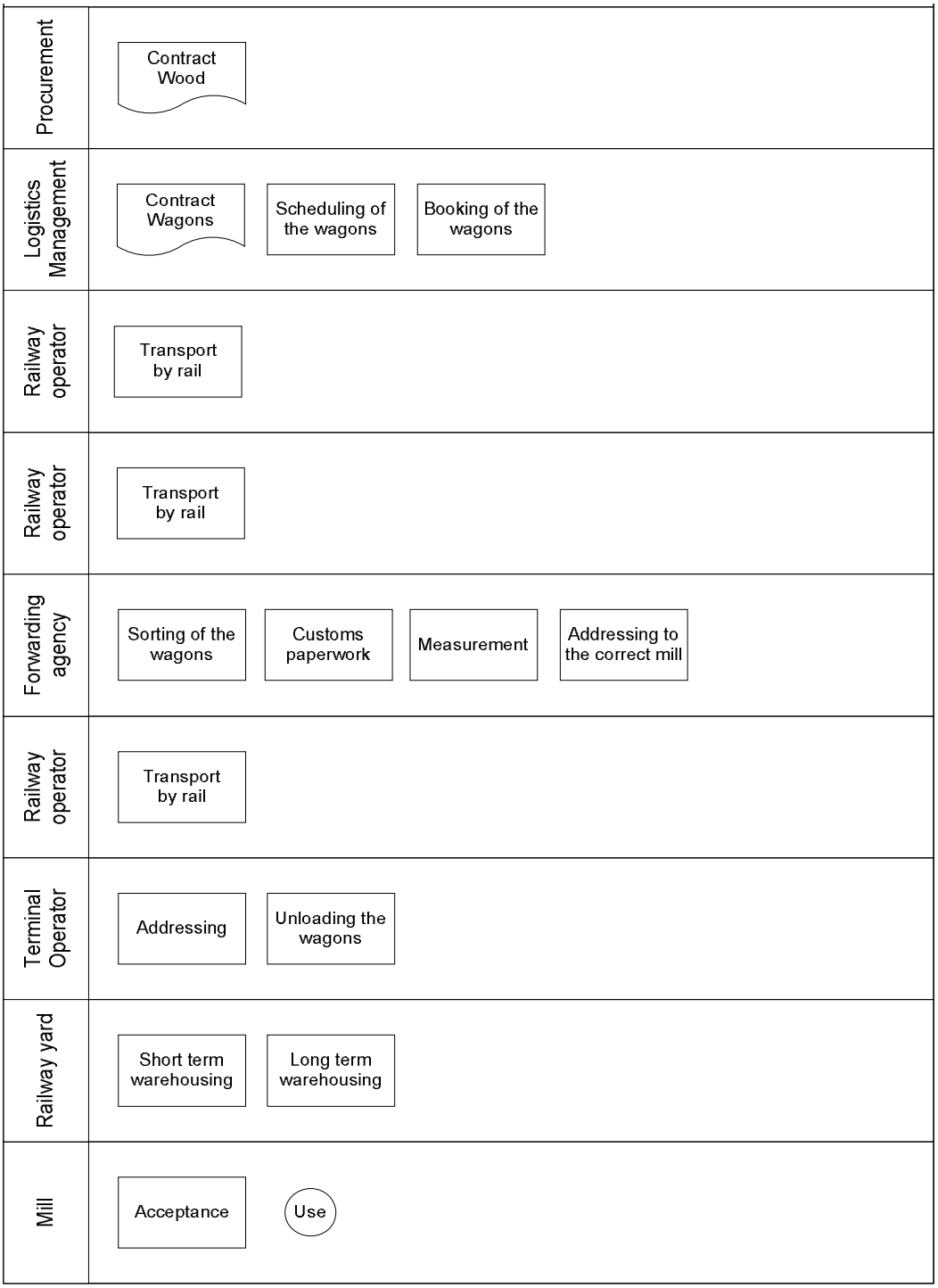
The maritime supply chain was international, with a higher number of process phases than the road and rail chains. One of its disadvantages turned out to be that deliveries would become difficult or even stop during the winter months. The winter conditions in the Baltic Sea and the closing of the Saimaa Canal from December to February limited vessel deliveries to the mills to a significant extent.

Figure 7 depicts the second of the supply chains under investigation, involving international railroad transport. It appears more straightforward and has fewer phases than the maritime supply chain. The predictability of the train arrivals, the frequency of the services and the schedules were considered better, but worse than in the road-transport chain. The quantities of raw materials per wagon and per train were far smaller than per vessel, but considerably more than per truck.

In the case of raw-material deliveries by railroad the lack of up-to-date information (schedules, quantities, even assortments) from Russia appeared to complicate the mills' production planning and scheduling.

The studied railroad supply chain incorporated many phases and three different organizations (Figure 7). According to the interviewees, organizational borders and even interpersonal relations had a big effect on information exchange in terms of how well information concerning the schedules, the quantities and the assortments was forwarded. Overall the international aspects seemed to increase the challenges when compared to domestic transportations. Even though there seemed to be some desire to increase railroad deliveries in the future, the limited number of wagons and track capacity will restrict both development and growth.

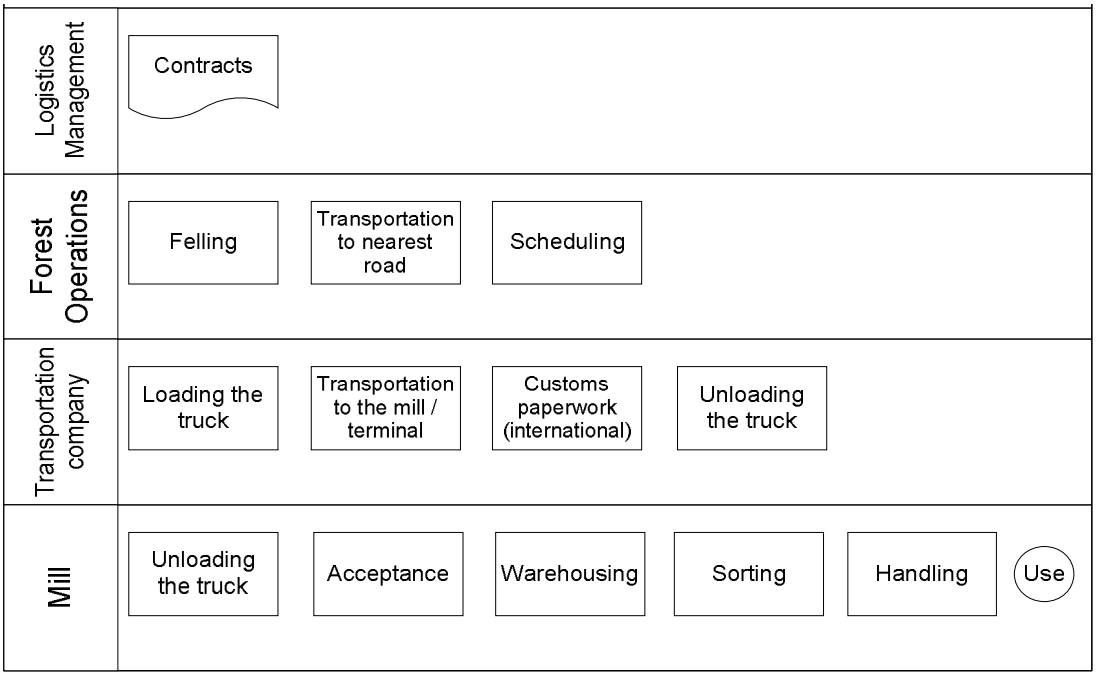
Figure 7 The international railroad supply chain process



The deliveries made by road (Figure 8) were typically regional and from areas near the mills, and were both domestic and international (from Russia to Finland). Of the supply chains under investigation, road transport was considered the most flexible. It allowed the mills to compensate for

the unpredictable changes in vessel schedules and rail deliveries, and thus to keep smaller stocks in the mills. Secondly, the truck capacity was considered an advantage: there were plenty of trucks and the loading and unloading were not confined to any particular areas or schedules.

Figure 8 The truck supply chain



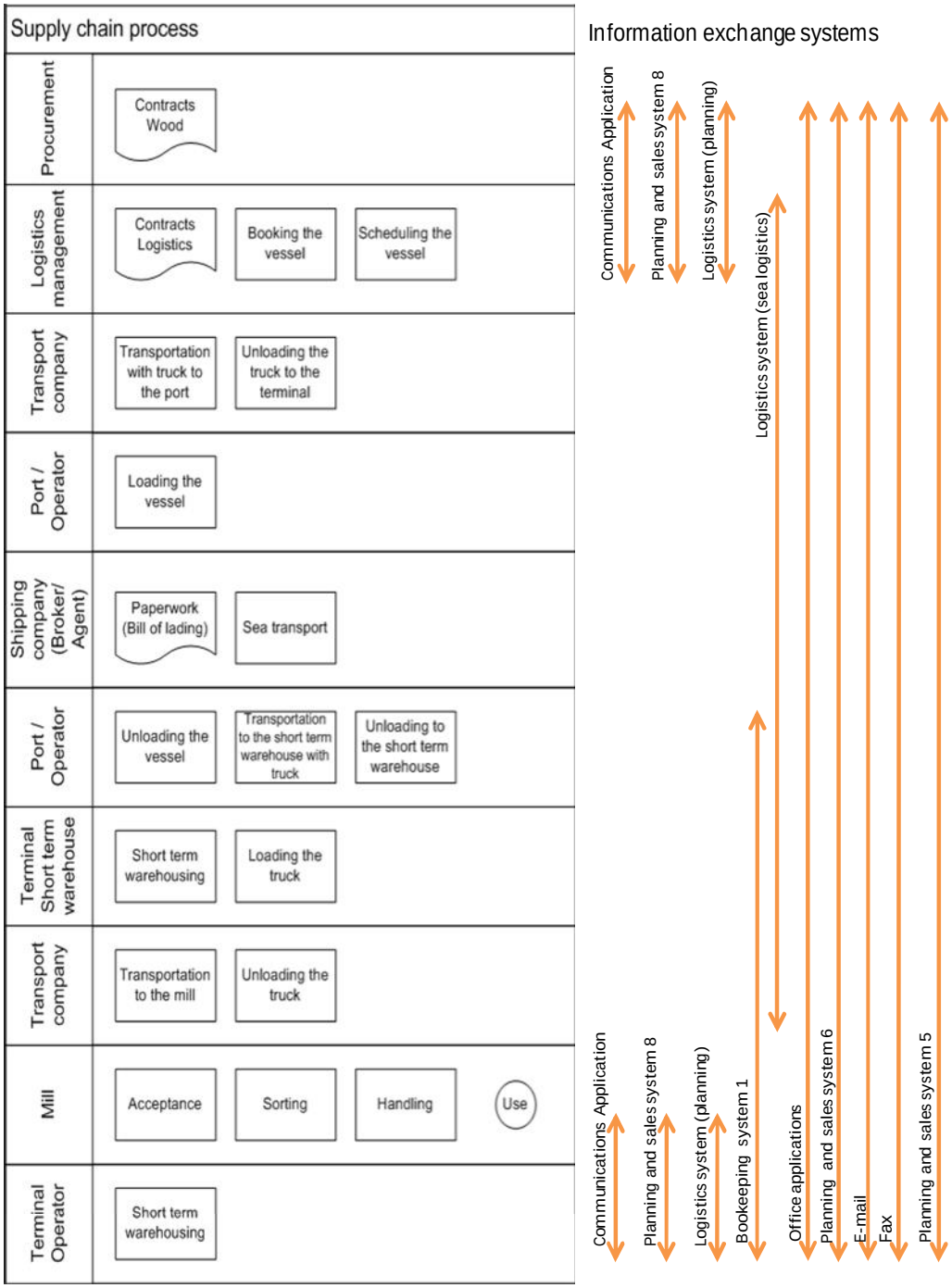
In terms of information exchange, of the supply chains in question domestic road transport was considered the most simple and trustworthy. In the case of international deliveries, however, the predictability was considered to be quite poor because of the customs formalities at the border and the actions of the transportation companies. According to the interviewees, one of the disadvantages of road transportation was related to frost heaving, when deliveries from the forest are very limited.

4.2 Information exchange in multimodal maritime supply chains

It appeared from the interviews that the maritime supply chain with its many phases was the most sensitive to disruptions in information exchange, and the risks are therefore analyzed in more depth here.

The first column in Figure 9 lists the different departments of the organizations, and the middle column sets out the main functions of the supply chain.

Figure 9 Systems of information exchange in the maritime supply chain



The most commonly used information-exchange systems are presented on the right-hand side of the map, the aim being to illustrate the extent to which the different systems are used. In order to ensure the anonymity of the interviewees and the companies, the system names are not mentioned in the figure.

The interviews revealed the following information-exchange activities:

* Acquiring background information
* Making bookings (truck, vessel, wagon)
* Making changes
* Issuing confirmations
* Having discussions/negotiations
* Improving/developing things
* Meeting
* Planning
* Scheduling

The most frequently used form of information exchange was the acquisition of background information (accounting for 18.8% of the total). Planning (14.6%), issuing confirmations (13.9%) and scheduling (13.9%) also featured strongly, whereas there were lower occurrences of making bookings (6.3%), making changes (6.9%), holding meetings (6.9%), and improving/developing things (7.6%). The respondents were given the opportunity to add to the list and to indicate whether they used the given methods for other purposes than those listed in the questionnaire, but no such reports were received. However, it is worth noting that the usage part of the questionnaire did not elicit the extent to which the individual actors used the different systems, only asking them to indicate whether they used the particular system in the given operations or not. In other words, how many of the operations a particular system covered remained unclear.

Some of the units used their own planning and sales systems, and in many cases alongside the systems that were in common use in many other units, too. The interviewees therefore mentioned many different planning, sales and logistics systems.

Table 2 Methods of information exchange

Information-exchange method	Description
Bookkeeping system 1	Invoice handling, payment data and financial reporting
Bookkeeping system 2	Invoice handling
Bookkeeping system 3	Invoice handling and financial reporting
Coffee-table discussions and one's own network	Discussions with colleagues; a social network of colleagues and partners
Communications Applications	The organization´s internal instant messaging system
EDI Messages	Electronic Data Interchange messages, structured data transmission between organizations by electronic means
E-mail	Bookings, information concerning raw-material demands, changes in schedules, raw-material quality and assortments
Fax	Confirmations, wagon data from Russia
Logistics system (planning and operating)	Planned and delivered volumes, and freight contracts: rail, truck and vessel deliveries
Logistics system (planning)	Planned and delivered volumes, and invoice handling: rail, truck and vessel deliveries
Logistics system (sea logistics)	Planned and delivered volumes, schedules, quality, assortment and destination information and also freight contracts: vessel deliveries
Meetings (face-to-face and group telephone)	Group telephone meetings weekly or monthly, face-to-face meetings when needed
Office applications	Excel, Word and PowerPoint
Telephone	Problem solving and double checking
Planning and sales system 1	Mill(s) system including planned volumes, orders and schedules
Planning and sales system 2	Mills´ system including planned volumes, orders and schedules
Planning and sales system 3	Invoicing information and mill´s production programs and plans
Planning and sales system 4	Invoicing information and mill´s production programs and plans
Planning and sales system 5	Corporation-level information on all planned raw-material volumes globally
Planning and sales system 6	Bookkeeping, planned and delivered volumes: rail, truck and vessel deliveries
Planning and sales system 7	Product and sales information: quantities, prices, invoices and loading orders
Planning and sales system 8	Information about planned and delivered volumes, payments and freight contracts: rail, truck and vessel deliveries
Reporting system	Mill´s reporting system

The informants interviewed for this study had varying opinions about the importance of the different methods of information exchange. The most important seemed to be the Sea logistics system, which carried information about the logistics operations, and also about many things related

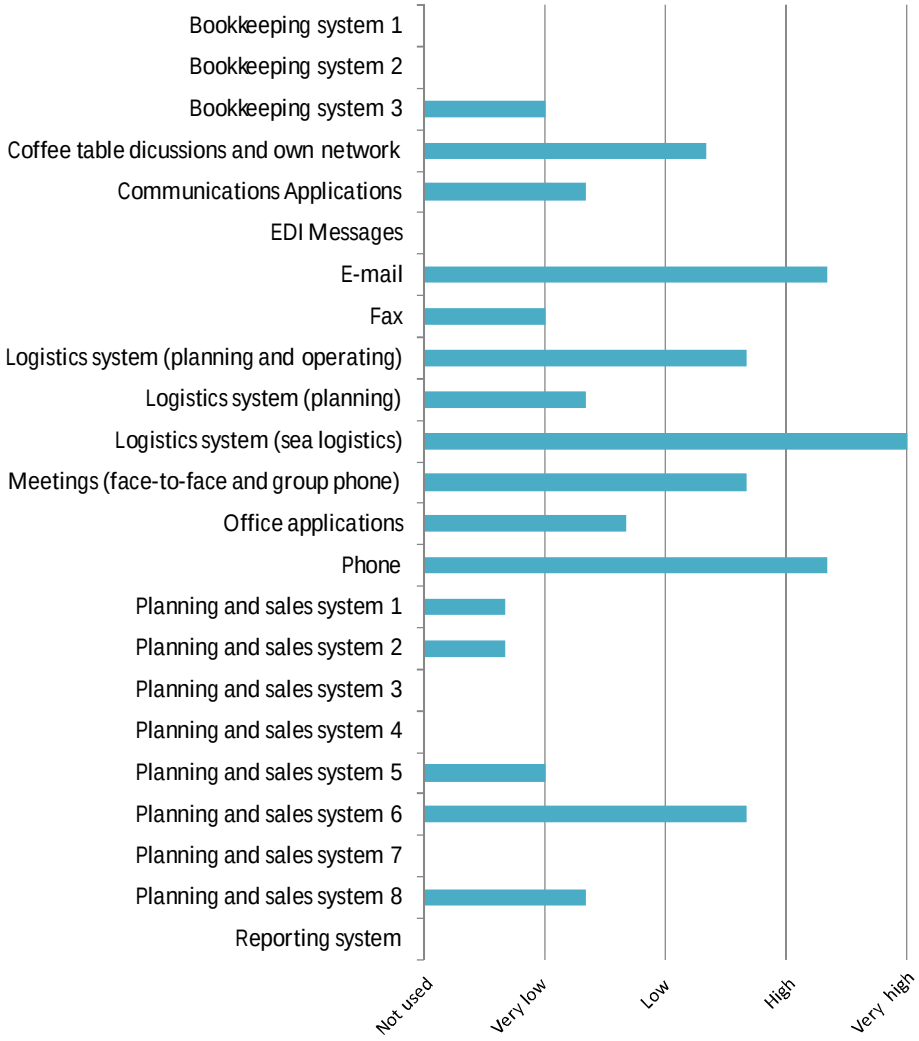
to them. Email, Telephone, and Planning and sales system 6 were also mentioned in most of the interviews. One surprising discovery was that if there were sudden changes the relative importance of the systems changed. The information systems in use were not geared to handling sudden changes, and problems were typically solved by telephone or email, which then became the primary method of exchanging the new information, the importance of which increased in conditions of change or high uncertainty. The significance of personal knowledge was surprisingly high. The tacit knowledge acquired through long work experience in the operations of the supply chain was considered highly important. To the interviewees' ways of thinking the significance of the knowledge should not be overlooked. The vulnerability of the information systems was considered one of the most serious risks in the supply chains. Information exchange between the parties involved depended on different systems within the chain, and modern technologies were utilized.

The interviewees gave a holistic account of the information exchange that was taking place, thus the aim of the questionnaire was to verify the results and enhance understanding of their significance from the perspective of the whole supply chain. In order to assess their relative importance, the methods were coded in the questionnaire as follows: 0 = not used, 1 = very low usage, 2 = low usage, 3 = high usage, and 4 = very high usage. The resulting importance factors are presented in Figure 10.

The length of the bars in the figure indicates the extent to which the information-exchange method in question was used: a short bar, or no bar at all indicates zero or minimal usage. The questionnaire results confirmed the findings from the interviews that the Sea logistics system carried the most importance, which was very high in comparison with the other methods. The second most important methods were email and the telephone, and their significance as information-exchange tools was equally high. Next came Planning system 6, followed by the Logistics system (planning and operating) and meetings (face-to-face and by telephone). Planning

system 6, which included planning, logistics, invoicing and bookkeeping, was not in use in all units, but nevertheless its importance was significant in the supply chain as a whole.

Figure 10 The importance of the different information-exchange systems according to the interviewees



The interviewees considered the so-called “Coffee-table discussions”, informal discussions with colleagues, and “one’s own network” (a social network of colleagues and partners) of prime importance in terms of acquiring background information, for example, followed by Office applications (i.e. Excel, Word and PowerPoint).

On the next level of importance were the communication application, the logistics system (planning) and Planning system 8. The communication application was the organization´s internal instant-messaging system, the significance of which was also quite high when it was used only internally. The logistics system (planning) and Planning system 8 were systems holding information on some of the planned and delivered volumes, and also freight contracts, and were rated as rather important even if only some of the members of the studied supply chain had access to them.

Planning system 5 was the organizational planning system storing all the projected raw-material volumes globally, and was rated 10th in importance of all the methods of information exchange. Bookkeeping system 3, which included invoice handling and financial reporting, was rated next in importance, and the fax was considered equally significant. Planning and sales systems 1 and 2, which were the mills´ systems holding information on planned volumes, orders and schedules, were also mentioned as being of significance.

4.3 Disruption in information exchange: a risk analysis

The risks in the maritime wood supply chain mentioned in the interviews were explored in two steps. The first step was to identify the risks in terms of the process levels illustrated earlier in Figure 6.

The FMEA (Failure Mode and Effect Analysis) framework was used in order to investigate the potential failure modes and their causes and effects in the supply chain processes. FMEA allows the identification and analysis of potential failure modes in a system, as well as of actions that could eliminate or reduce the likelihood of failure (Chuang, 2002). According to the interviewees, in addition to information disruption, inaccuracy was among the most significant risks in the supply chain under investigation.

4.3.1 Risk identification

The second step in the analysis was to categorize and assess the risk factors mentioned by the interviewees. The risk-probability-impact matrix as set out in Figure 11 summarizes the results of the risk analysis, giving a holistic view on the risk of disruption in information exchange categorized by each method of exchange used. The descriptive, but not explicit, rating of the risks illustrates the tool and its feasibility in assessing their effects. In the questionnaire the participants were asked to describe the likelihood and impact of disruption attached to each method of information exchange, coded as: 0 = non-existing, 1 = very low, 2 = low, 3 = high and 4 = very high. The risks were then calculated by multiplying the likelihood and the risk-impact values.

From the results it was possible to rank the importance of the methods of information exchange used (Figure 11) in terms of the impact of disruption and the likelihood of its occurrence attached to each method. The risk values listed in Table 3 were also scaled for the purposes of comparison. The right-hand risk column shows the total weight of each risk and the percentage value relative to other types of information-exchange disruption. The bottom row summarizes the total weight of each category.

Table 3 Risk analysis

Information exchange method	Likelihood	Impact	Risk	
Bookkeeping system 1	0.0	0.0	0.0	0%
Bookkeeping system 2	0.0	0.0	0.0	0%
Bookkeeping system 3	0.7	0.7	0.4	1%
Coffee-table discussions and one's own network	2.0	2.0	4.0	9%
Communications Applications	1.7	1.0	1.7	4%
EDI Messages	0.0	0.0	0.0	0%
E-mail	2.3	3.0	7.0	16%
Fax	0.7	0.3	0.2	0%
Logistics system (planning and operating)	1.7	1.7	2.8	6%
Logistics system (planning)	1.0	1.0	1.0	2%
Logistics system (sea logistics)	3.0	3.3	10.0	22%
Meetings (face-to-face and group phone)	1.7	2.0	3.3	7%

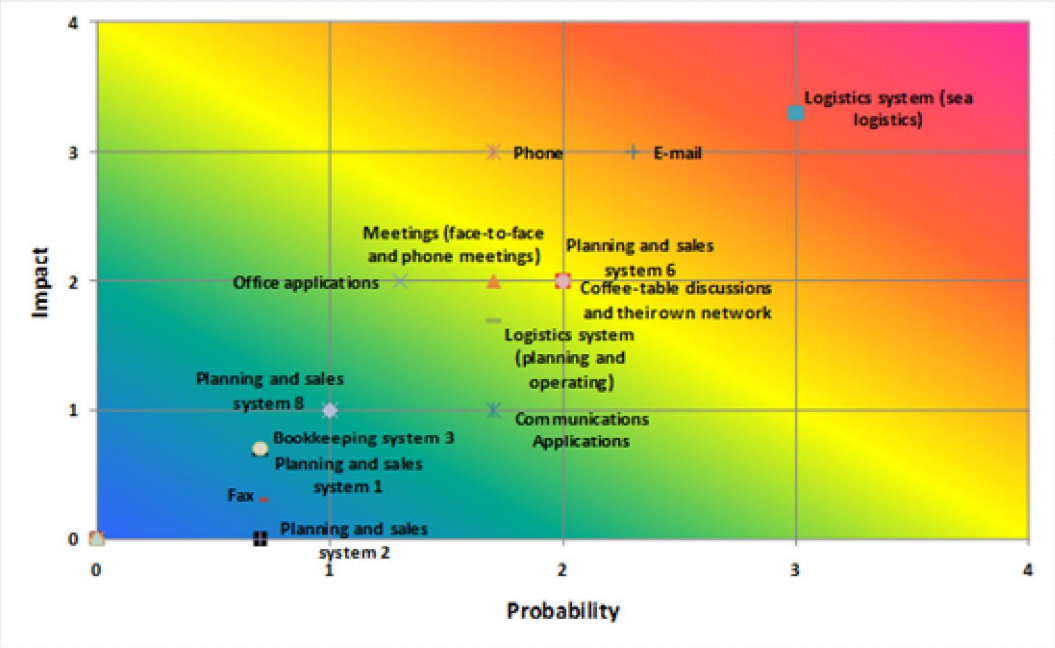
Office applications	1.3	2.0	2.7	6%
Phone	1.7	3.0	5.0	11%
Planning and sales system 1	0.7	0.7	0.4	1%
Planning and sales system 2	0.7	0.0	0.0	0%
Planning and sales system 3	0.0	0.0	0.0	0%
Planning and sales system 4	0.0	0.0	0.0	0%
Planning and sales system 5	1.0	1.0	1.0	2%
Planning and sales system 6	2.0	2.0	4.0	9%
Planning and sales system 7	0.0	0.0	0.0	0%
Planning and sales system 8	1.0	1.0	1.0	2%
Reporting system	0.0	0.0	0.0	0%
TOTAL	23.0	24.6	44.6	100%

The risk column in the matrix shows that the highest single disruption risk in the investigated supply chain concerned the logistics system that operated sea traffic. It accounts for 22 percent of the risk and could therefore be seen as the most vulnerable method. Given that risk analysis determines the vulnerabilities of the different information-exchange methods, their relative importance seems to follow somewhat similar lines. The sea logistics system was considered the most important and, at the same time, the most vulnerable method. This is in line with the importance assessments given by the interviewees, but at the same time highlights both the likelihood and the severity of possible disruption. Email was rated the second highest disruption risk at 16 percent, followed by the telephone at 11 percent. Email and the telephone were both mentioned in the interviews as tools for exchanging new information and solving problems, and it was therefore not surprising that the disruption effects were considered rather high. Planning system 6, informal “Coffee-table discussions” and the interviewees´ own network of colleagues and partners each accounted for nine percent of the disruption risk, whereas face-to-face and telephone meetings accounted for seven percent.

The risk-identification table (Table 4) illustrates the potential failure modes, the potential failure effects and the potential causes step by step in the supply chain. The interviewees were also asked in the Webropol questionnaire how they would improve the organization’s information-exchange

methods. According to their responses, they considered it essential for the Sea logistics system and Planning and sales system 6 to “discuss” with each other, in other words they believed that system integration, especially with regard to the daily vessel schedules and the daily information, was very important.

Figure 11 Disruption risk analysis



Furthermore, in their view the logistics planners (in the Baltics) should share information concerning the changes (e.g., in schedules) more efficiently and faster via email and the telephone, for example. In addition, the planning figures in the Sea logistics system and in Planning and sale system 6 should show the same planned wood amounts on the monthly level.

Table 4 Risk identification table

Supply-chain step	Potential failure mode	Potential failure effects	Potential causes
Loading a vessel	Wrong raw material loaded and shipped	Lack of essential raw material	Wrong reported quality of raw materials
Sea transport	Mill´s production is delayed	Loss of reputation / customers	Lack of essential raw material

Unloading a vessel	Problems scheduling vessel unloading	Costs and time losses (vessel waiting time)	Slow information exchange
Transfer to short-term warehouse	Wrong raw material assortment	Lack of storage space and extra costs for sorting	Inaccurate data in the logistics system (unreported schedule changes)
Handling in the mill	Uncertainty in planning	Lack of foresight	Poor input of raw-materials information into the logistics system

4.3.2 Disruption risk

It appeared from the interviews that the risk of information accuracy was one of the most significant factors related to the poor information exchange in the case supply chain. According to Tang and Musa (2010), the risk emanates from poor information accessibility, a lack of information efficiency, and data inaccuracy. As Christopher and Lee (2004) state, key operational data (inventory reports, production and shipment plans, capacities and backlogs) should be easily available to all key actors in the supply chain, it should be accurate and timely, and any updates should be incorporated as soon as possible. The case supply chain had a logistics planning system of which most of its users approved. However the interviewees mentioned that information concerning quality, correct volumes, wood assortment, and destinations was not always accurate. The risks related to information accuracy arose for many reasons. According to the interviewees, one of the main ones was the lack of system integration. There was no connection between the logistics system and the systems of the procurement organizations and the mills. Therefore the information did not transfer automatically, and the data had to be inputted manually into many separate systems. As a consequence, the human factor played a big role in that the employees did not always understand the “big picture”, in other words the linkage between the whole supply chain and all of its actions. Interpersonal relations, or rather poor interpersonal relations, may cause information disruption.

Information concerning changes in schedules was not always accurate in the logistics system, and was not always conveyed as speedily as it should have been. Given the short distances in the Gulf of Finland in particular, the need for very rapid information exchange is paramount. The vulnerabilities of an IT-based society were evident in the breakdowns in Internet and email connections, which constituted one of the most significant risks related to information exchange. The main Sea logistics transport planning system was Internet-based, therefore the Internet connection was vital. Organizational borders were also recognized as potential causes of disruption.

Several interviewees mentioned the tacit knowledge related to the management of complex supply chains. Knowledge that was essential in order to manage the flows could be lost if the management personnel changed. Some of the interviewees mentioned that it could easily take from one to two years to acquire the required level of knowledge about the supply chain to be able to operate efficiently in its operations.

The above-mentioned facts are potential sources of difficulty in supply chains. According to some interviewees, incorrect or inaccurate information on raw-material quality, correct volumes, the wood assortment and the destinations caused general confusion and uncertainty. The extra work, time loss, and especially extra costs were also of great concern to the terminal and the mill. Port and terminal workers could not plan their work schedules because the storage space may not have been adequate. A lack of raw materials also constituted a risk.

4.3.3 Supply chain vulnerability

According to Asbjornslett (2008), the difference between a risk analysis and a vulnerability analysis is in the focus: vulnerability analysis focuses on the survival of the system, whereas risk analysis targets the human and environmental impact of an accidental event. An analysis of supply chain

vulnerability was therefore conducted in order to identify the essential actors and links in terms of the information exchanged. Social network analysis was considered a solid method for mapping the actor relationships and shedding light on the information flows in the system. The analysis was used to identify the crucial actors in the supply network and the most vulnerable paths in terms of information exchange. Network analysis has been used previously to illustrate the relationships and connections between identified actors in a supply chain network (see Yu et al., 2008; Hallikas et al., 2008; Vilko et al., 2011).

4.3.4 The roles of the actors

The network analysis was conducted in three phases. First the interviewees were shown the process map of the supply chain under investigation (Figure 6), about which they were free to comment, and were asked to identify the actor roles and to explain the main responsibilities of each. Second, a group discussion was conducted involving two actors in the focal supply chain and one expert in supply chain risk management in order to verify the data. The final stage was to conduct a social network analysis based on the results.

Thirteen different actor types were identified: brokers, drivers, forwarding agents, logistics managers, the mill manager, operations and planning managers, operative managers, the railway operator, shipping companies, stevedores, the terminal superintendent, transportation companies, and the user group. The logistics managers, the mill manager, the operations and planning and operative managers, the terminal superintendent and the user group were part of the focal company, whereas the other actors were from other companies in related fields of business, but acting in the case supply chain. Logistics managers are responsible for planning and scheduling deliveries to and from the mill, and mill managers are responsible for production, needs assessment and operations. Both operations and planning managers and operative managers organize the planning of

the operations and the scheduling of deliveries. The terminal superintendent manages mill logistics (into and out of the mill) and warehousing, and the user group organizes mill production and scheduling more widely. Brokers sell maritime shipping services, transportation companies and drivers take care of land transportation (trucking), forwarding agents usually take care of the documentation (tolls etc.), and stevedores are responsible for loading and unloading the vessels. The shipping companies are responsible for maritime transportation, and the railway operator for rail transportation.

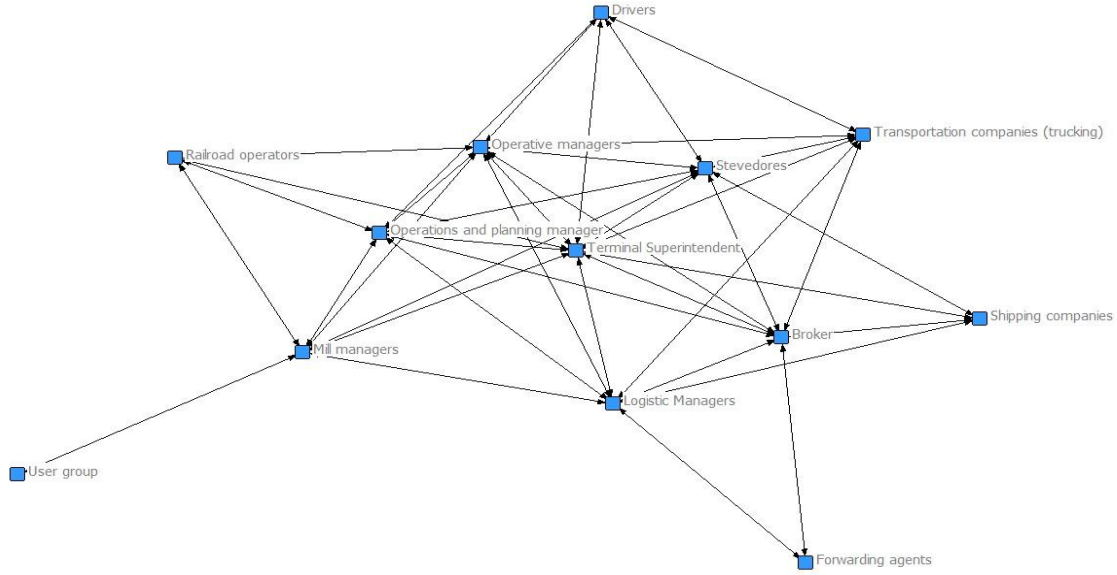
4.3.5 The network structure

In order to obtain a holistic view of the information exchange between the different actors in the supply chain, each pair was mapped according to the results of the interviews and the group discussion. The interviewees were asked to describe the relationships and the information exchange between each member, and then to rank them as follows: 0 = non-existent, 1 = low, 3 = medium, 9 = high. The group discussion thereafter verified the results.

The following measures were chosen for closer examination: betweenness centrality, the eigenvector, the average recipient distance, two-step reach, degree centrality (Bonacich power), and the degree of centrality. They were chosen because they give a good picture of the actors who have the best ties to other actors in the network, and of those who are able to reach other actors on shorter paths, or who are more reachable by other actors. They also reveal how close any actor is to all the other members and actors who connect the node's neighbors in the supply network. In other words, the measures were chosen in order to illustrate the connectors, leaders, bridges, clusters (what they are and who is in them), the people at the core and those on the periphery of the network in question.

Figure 2 maps the network. The node sizes are not set, in other words all nodes are depicted as being the same size. In the network maps comprising appendixes 2, 3, 4 and 5 the node sizes vary according to the different measures: Appendix 2 by Degree, Appendix 3 by Betweenness, Appendix 4 by Closeness, and Appendix 5 by the Eigenvector.

Figure 12 Network map



As Figure 12 shows, the connections between the actors varied somewhat. It appears that the operative managers, the terminal superintendent, the operations and planning manager and the logistics managers have the most important positions in the network. Even though some actors are positioned beyond the core, they still play a relatively important role in the supply chain as a whole. For example, the user group determines the whole production planning and scheduling of the mills.

4.3.6 Network analysis

The table in Figure 13 summarizes the actors' network positions on the following six measures: betweenness centrality, the eigenvector, average recipient distance, two-step reach, degree centrality (Bonacich power),

and degree of centrality. Here they indicate the level of information exchange and therefore illustrate which actors possess greater amounts of information and through which actors most of the information flows.

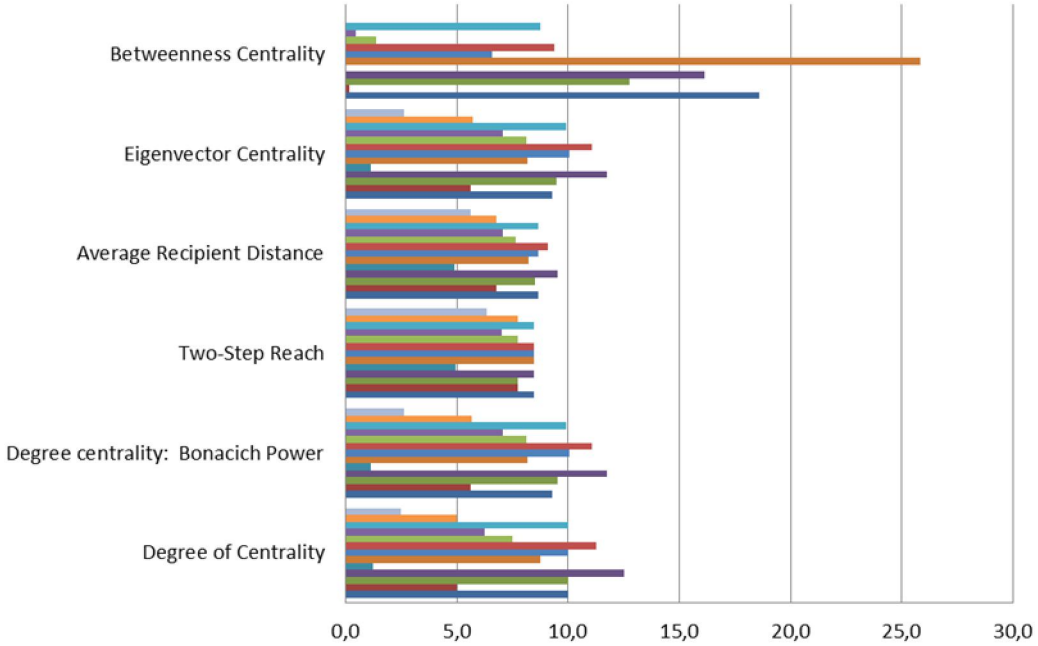
The first measure, betweenness centrality, reflects the number of people who are indirectly connected through their direct links. It assigns measures to the nodes based on their position between separated clusters of “gatekeepers” in the network, and was used to illustrate the actors with the most control over information exchange. Eigenvector centrality was used to measure the importance of the nodes, and average recipient distance was used to identify the network paths, and which ones are more important. The fifth measure, two-step reach, was used to ascertain the efficiency of information or mass transport in the network in terms of which actors can reach everyone else in two steps or less. The last measure, degree centrality (Bonacich power), was used to assess the level of information an actor possesses based on information exchange with other network actors.

According to the network analysis, the terminal superintendent had the highest degree of centrality (12.5%), degree centrality - Bonacich power (11.7%), average recipient distance (9.5%) and eigenvector centrality (11.7%), and together with five other actors (stevedores, operative managers, operations and planning managers and logistics managers) had the highest degree of two-step reach (8.5%).

The terminal superintendent had also quite a high degree of betweenness centrality with (16.1%, the third-highest score) as well as the most important nodes in the network. The network paths were also the most significant. He had the highest score in terms of efficiency of information, being able to reach everyone in two steps or less. Finally, he had the best level of information in terms of information exchange with other actors. This indicates that he possessed and controlled most of the information in the network.

Operative managers came second to the terminal superintendent in almost every category. They were all on the same level in two-step reach and had the fifth highest level of betweenness (9.4%), behind the mill managers, the terminal superintendent, the brokers, and the logistics managers.

Figure 13 Network analysis



	Degree of Centrality	Degree centrality: Bonacich Power	Two-Step Reach	Average Recipient Distance	Eigenvector Centrality	Betweenness Centrality
Forwarding agents	2,5	2,6	6,3	5,6	2,6	0,0
Railroad operators	5,0	5,7	7,7	6,8	5,7	0,0
Stevedores	10,0	9,9	8,5	8,6	9,9	8,8
Drivers	6,3	7,1	7,0	7,1	7,1	0,5
Transportation companies (trucking)	7,5	8,1	7,7	7,6	8,1	1,4
Operative managers	11,2	11,1	8,5	9,1	11,1	9,4
Operations and planning manager	10,0	10,1	8,5	8,6	10,1	6,6
Mill managers	8,7	8,2	8,5	8,2	8,2	25,8
User group	1,2	1,1	4,9	4,9	1,1	0,0
Terminal Superintendent	12,5	11,7	8,5	9,5	11,7	16,1
Broker	10,0	9,5	7,7	8,5	9,5	12,7
Shipping companies	5,0	5,6	7,7	6,8	5,6	0,2
Logistic Managers	10,0	9,3	8,5	8,6	9,3	18,6

The mill managers had the highest degree of betweenness centrality at 25.8 percent, although the logistics managers, the brokers, and the terminal superintendent achieved high scores on this dimension (see Figure 13). Betweenness centrality reflects the number of people who connect indirectly through their direct links, and assigns measures to the nodes based on their position between the separated clusters of “gatekeepers”. All this implies that they had the most control over the flow of information, and that they had a powerful role among the groups of network actors.

Drivers, transportation companies, shipping companies and stevedores were in the middle in all categories. All of them had some information, but the user group and the forwarding agents seemed to have the least amount on all measures. Some of the actors seemed to have no control over the information, and they were usually positioned in more logistics-based functions or in higher organizational positions.

The network analysis identified the most important actors and thereby also the most vulnerable information-exchange paths in the case supply chain. It appears that the terminal superintendent, the operations and planning managers, the operative managers, and the logistics managers held the most important positions in the network. The most significant and therefore the most vulnerable information-exchange paths were between the terminal superintendent, the operative managers and the mill managers. Furthermore, information exchange between the logistics managers and the actors mentioned above was considered vital and therefore vulnerable.

Given the high amount of information exchange between the terminal superintendent, the operative managers, the mill managers and the logistics managers, and their influential position in the network, it is important to ensure that the information flow is not disturbed.

5 Discussion

This chapter summarizes the findings from the empirical study and the literature review. The main aim of this thesis was to find out how knowledge management can enhance the management of risk related to information exchange in supply chains. This chapter provides some answers to the research questions, building on findings related to the main research question as well as to the sub-questions have been given also in the Chapters four.

5.1 Summary

This research began with collecting the data with the interviews. The supply chain process maps were made after a systemic studying supply chain process with help of the data collected from the interviews. The three supply chains studied were discovered to be equally important to the studied company. However the nature of each chain varied substantially. The supply chain processes are illustrated in the Figure 6 (maritime supply chain), Figure 7 (railroad supply chain) and Figure 8 (truck supply chain). In the interviews it was discovered that the maritime supply chain was the most sensitive for information exchange disruptions because of its many phases, and therefore the multimodal maritime supply chain was chosen to be studied more in-depth in this thesis.

The interviews revealed there to be a number of information exchange methods (Table 2), and that the actors had different perspectives on the multimodal maritime supply chain, and different levels of access to these methods. Figure 9 depicts the functions of the information exchange in different phases of the process. It was found that the importance of different information-exchange methods varied to different extents. Some of the systems were integrated and some were seriously lacking in this regard. Poor integration with regard to some methods was mentioned as one of

the key problems that had to be compensated for through the use of other methods. The methods of information exchange used in the multimodal maritime supply chain were reviewed, and then systematically evaluated from different perspectives.

The use of qualitative interviews to map the process, and to identify the information-exchange methods and risks seemed to provide a good basis on which to develop the questionnaire that was used to assess the importance of the different methods, and to calculate the risk of possible disruption. The responses to the questionnaires were subjected to FMEA analysis in order to determine the nature of the risks and their causality. Information-exchange disruptions in the supply chain were studied more closely with a view to identifying the vulnerabilities and dependences.

5.2 The results

The main research question of this thesis was:

> *"How can knowledge management enhance information-exchange-related risk management in supply chains?"*

Tacit knowledge (acquired through long work experience) and social skills together with a good network of partners were found to be important ways to manage information-exchange-related risks in the studied supply chains. Also several different kinds of information systems, which were acting also as data banks, had an important role in case organization's supply chain risk management. With help of the knowledge management the causality, assessment and management of the possible vulnerabilities and risks related to information- exchange could be identified.

The first sub-question was:

“How is information-exchange organized?”

In the supply chain studied in this thesis were used several methods to exchange information. Altogether 22 different kinds of methods were identified, i.a. bookkeeping, logistics, reporting, planning and sales systems, email, telephone, fax, EDI-messages, meetings, office and communications applications, coffee table discussions and actors’ own networks. The exchange methods were listed and described in the table 2. Some of the systems under study seemed to have a broader reach over the whole supply chain than others: for example, the mills’ high logistics management systems were beyond the reach of many of the actors.

The second sub-question was:

“What types of risks are involved in the process?”

The risks involved in information exchange varied. One that was frequently mentioned related to the accuracy of the information. Inaccuracy could usually be traced to the early stages of the supply chain when those in charge do not have a clear understanding of the consequences that inaccurate information could have on the system as a whole. Wong and Acur (2010) support these findings, claiming that the current literature often assumes that decision makers are rational, competent and consistent, which is contrary to real life. Managers in a complex environment such as an international supply chain may lack the cognitive capacity to understand the consequences of a particular decision. (Heiner, 1983; Senge, 1990)

The probability-impact matrix (Figure 11) was drawn up to illustrate the risks along two dimensions, ‘‘probability” and ‘‘impact’’ (see Norrman and Lindroth, 2002; Thun and Höenig, 2011). The risk values (Table 3) were also scaled for comparison. The highest risk appeared to arise from the sea logistics system, which holds a huge store of information. If the system were to go down, replacing it would an almost insurmountable task

while maintaining the same level of efficiency. Email connections were also considered to be susceptible to high risk and disruption in that disruption would clearly hinder the operations. The telephone was used extensively in the supply chain in order to exchange information and to ensure its arrival, maintain good personal connections with the other actors, and most importantly as an aid in extenuating circumstances. The possible risks and consequences are illustrated in Table 4, and the drivers of the disruption risk and the vulnerabilities of the information-exchange methods used are illustrated in the risk analysis (Table 3), which also shows the possible disruption risks.

According to Tang and Musa (2010), the risk of disruption to information systems may be internal or external, related to ill-managed systems or natural disasters (including the resulting power cuts). The risk should be considered in terms of the most serious effect of disruption on planning. This was the case in the case supply chain: disruption in the information system (i.e. a lack of accurate information and poor integration) caused uncertainty in the planning processes.

In table 4 (risk identification table) were presented the possible effects due to the information exchange disruption. As potential effects were identified lack of essential raw material, loss of reputation and/or customers, extra costs and time losses (vessel demurrages), lack of storage space and extra costs for sorting and lack of foresight.

Moreover, although the deficiencies and the lack of ability to input information were noted, putting things right presented its own unique challenges. The information needed in the supply chain did not always coincide with the system's capabilities, and as in many other cases, email and the telephone were used as backup. This made additional work for the managing personnel. Given that integrated systems allow firms to respond more quickly to problems and requests, the lack of integration is likely to be a severe disadvantage. Furthermore, a seamless supply-chain system

facilitates processes and reduces lead times with suppliers (Wu et al., 2005). As Banomyong (2005) states, the role of an integrated logistics system is to support the whole supply chain in the production, consumption and distribution of goods and services. The interviewees echoed this sentiment, suggesting that one of the main reasons for the lack of information accuracy was the lack of system integration. The results of this study were also in line with the findings of Wong et al. (2009), according to which the potential value of IT-enabled transport logistics lies in improving business performance, but the adoption of IT is not conducive to inter-organizational coordination that requires the involvement and cooperation of the partners in the supply chain.

The third sub-question was:

> *"How can knowledge management enhance risk management in information exchange?"*

In addition to the technical risks related to various methods of information exchange, human-related factors played a significant role. Once again, although the problems were noted, resolving them was challenging. Managing the flow appeared to be fairly information-intensive. The knowledge acquired through long experience in the supply chain, combined with a good network of partners, enabled the actors to compensate for possibly inaccurate information, thereby emphasizing the significance of system knowledge. These results also reflect Argote and Ingram's (2000) findings that, according to previous studies, as they gain experience of working together, dyads and small groups improve their performance by acquiring knowledge about who knows what. Research has also shown that the nature of the social ties interacts with the characteristics of the knowledge being transferred and thus affects the outcomes. Moreover, social networks enable organizational units to link to new sources of knowledge and to interpret it. In the present case, too, the interviewees considered the so-called "Coffee-table discussions", informal discussions with colleagues,

and their “own network” (a social network of colleagues and partners) important in terms of obtaining background information, for example. The results of the interviews therefore support the findings of Argote and Ingram (2000) and Argote et al. (2003).

The lack of cognitive capacity (ergo the cognitive barriers) to understand the whole supply chain functions of the operational-level actors caused disturbances in the supply chain. With help of the knowledge management could be improved systemic motivation and causal understanding so that a holistic picture of the information sharing and its necessity could be addressed to all actors in all levels of the supply chain.

The additional network analysis gave a deeper view of the information exchange between the supply-chain members, and was therefore used to identify the key actors and their connections (see i.a. Vilko et al., 2011; Yu et al., 2008) in terms of information exchange (the Network map, Figure 12, and the centrality measures, Figure 13) and the relations among them. The centrality and betweenness analyses revealed “who has” and “who controls” the information and its exchange. According to Wassermann and Faust (1994), it is characteristic of inter-organizational networks for one or more actors to exert more power over other members due to their network centrality. Those with the highest degree of centrality in the case supply chain were the terminal superintendent and the operative managers, which is only natural given that they handle most of the material flow. Surprisingly however, the mill managers achieved the highest scores on betweenness centrality even though it appeared from many of the interviews that they did not have much control within the information-exchange system. The principle of betweenness applies to actors who are between other actors, and also describes their dependency. Strong betweenness facilitates their power or Broker position in the network. (Yu et al., 2008)

6 Conclusions

Chapter 6 summarizes the theoretical findings and the managerial implications of this study, and gives suggestions for further research.

6.1 Theoretical findings

Supply chains are becoming more and more complex and disintegrated, which makes them increasingly dependent on information exchange between the members. Proper information exchange ensures the stable flow of goods and materials among growing numbers of actors by enabling better predictability. The potential risks are serious, and a disruption or delay in information exchange could have devastating effects as supply-chain schedules in general are being trimmed as much as possible. In shedding light on the methods of information exchange used and the risks involved in a multimodal supply chain involving the transportation of wood from the Baltic States to Finland, this thesis contributes to the literature in this field.

Research on risk management reported in the current literature focuses on either knowledge management or supply chain management, and the simultaneous study of these three theories has thus far been missing. The aim in the present study was to narrow this gap. The scientific literature reports a number of studies on supply chain risk management from the information-exchange perspective. This thesis contributes to the discussion in assessing the methods of information exchange and the associated disruption risks in the supply chains of an international conglomerate. It strengthens some of the findings from earlier research, but also brings out new aspects of risk management in supply chains, particularly with regard to disruption in information exchange, which still lacks empirical investigation.

6.2 Managerial findings

Information exchange was evaluated systematically from various angles. The analysis revealed a number of information-exchange methods that are available in varying degrees to the many actors with their different perspectives on the supply chain. Some of the systems seemed to have a broader reach over the whole supply chain than others. The importance of the different information-exchange methods varied to different extents. Some of the systems were well integrated, whereas there were serious gaps in others. Inadequate integration was mentioned as one of the key reasons for turning to alternative methods.

Disruptions in information exchange were studied in more detail in order to identify the vulnerabilities and dependences in the supply chain. The highest risk appeared to arise from the sea logistics system, which holds a huge store of information. If the system were to go down, replacing it while still maintaining the same level of efficiency would be an immensely difficult task. The implication is that even if one system has broad and powerful capabilities it can pose a serious risk in terms of “putting all one’s eggs into the same basket”. Moreover, the case organization is forced to carry large stocks and accept backlogs, and to tolerate extra costs due to the need for overtime work as well as to uncertainty within the supply chain, and all because of poor information exchange. Therefore information sharing has an essential role in supply chain coordination.

Currently the actors have limited visions of the fragmented supply chain and have their own specific areas of responsibility. It would be essential for those operating on the functional level to gain a broad understanding of the activities of the whole chain in that it would help to build up resilience against information-exchange disruptions. The fact that the most commonly used methods of information exchange were also the most vulnerable makes it vital for the actors in the supply chain to ensure their continuing use and functionality through reliable channels in order to ensure interrup-

tion-free and problem-free operation. Furthermore, co-operation in the supply chain could make it easier to combat the risks. In other words, a holistic understanding of the activities throughout the chain is a prerequisite for effective risk management.

The research findings also show that the nature of the social ties in the chain interacts with the characteristics of the knowledge being transferred and thus affects transfer outcomes. Organizational units could therefore use social networks to link sources of knowledge and facilitate the interpretation of new knowledge.

6.3 Further research avenues

An organization's ability to deliver and interpret supply chain information is also connected to organizational cognition and cognitive processes. Connecting systemic and organizational cognitive perspectives to risk management may help in the development of new approaches to information exchange. There is thus a need for further research on systemic and cognitive interpretations of the management of risk in supply chains.

The study reported here provides a holistic view of the risks involved in information exchange in a supply-chain context. As a case study, however, it has some limitations in terms of generalizability given the small size of the sample and the subjective nature of the data. There is thus a need for further empirical research employing more extensive data. Additional data could be obtained by increasing the number of participating units and actors in railroad and land-transport supply chains and focusing on a different geographical area. It would also be fruitful to calculate and categorize other risks related to information exchange.

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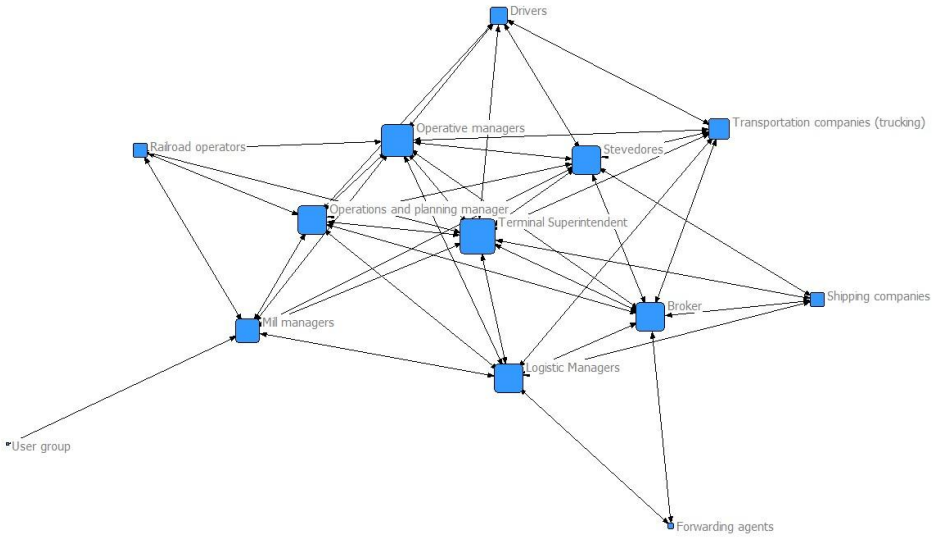
APPENDIXES

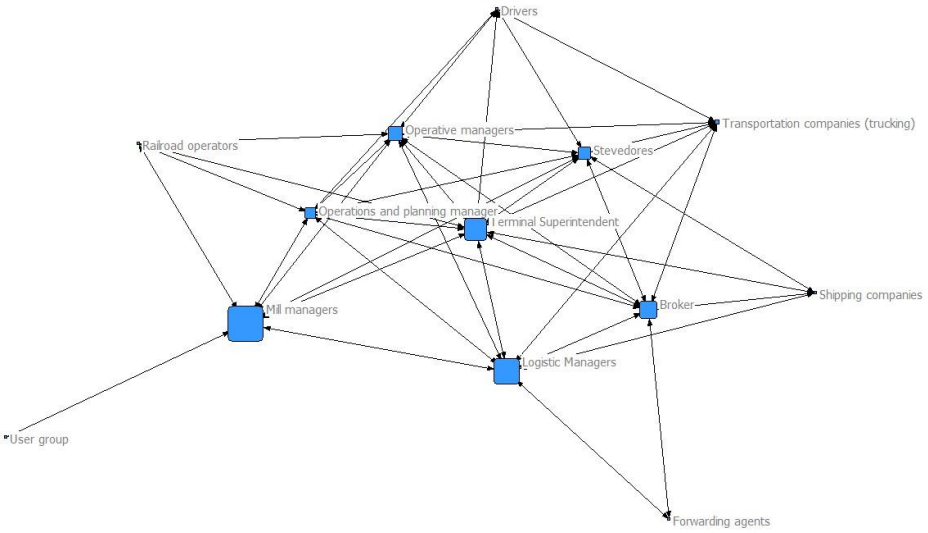
Appendix 1: Centrality Measures

	Degree	BonPwr	2Step	ARD	Eigenvector	Between
Logistic Managers	0,667	4,047	1	0,833	0,44	0,121
Shipping companies	0,333	2,445	0,917	0,653	0,266	0,001
Broker	0,667	4,139	0,917	0,819	0,45	0,083
Terminal Superintendent	0,833	5,113	1	0,917	0,556	0,105
User group	0,083	0,495	0,583	0,472	0,054	0
Mill managers	0,583	3,563	1	0,792	0,388	0,168
Operations and planning manager	0,667	4,381	1	0,833	0,477	0,043
Operative managers	0,75	4,813	1	0,875	0,524	0,061
Transportation companies (trucking)	0,5	3,541	0,917	0,736	0,385	0,009
Drivers	0,417	3,076	0,833	0,681	0,335	0,003
Stevedores	0,667	4,315	1	0,833	0,47	0,057
Railroad operators	0,333	2,48	0,917	0,653	0,27	0
Forwarding agents	0,167	1,137	0,75	0,542	0,124	0

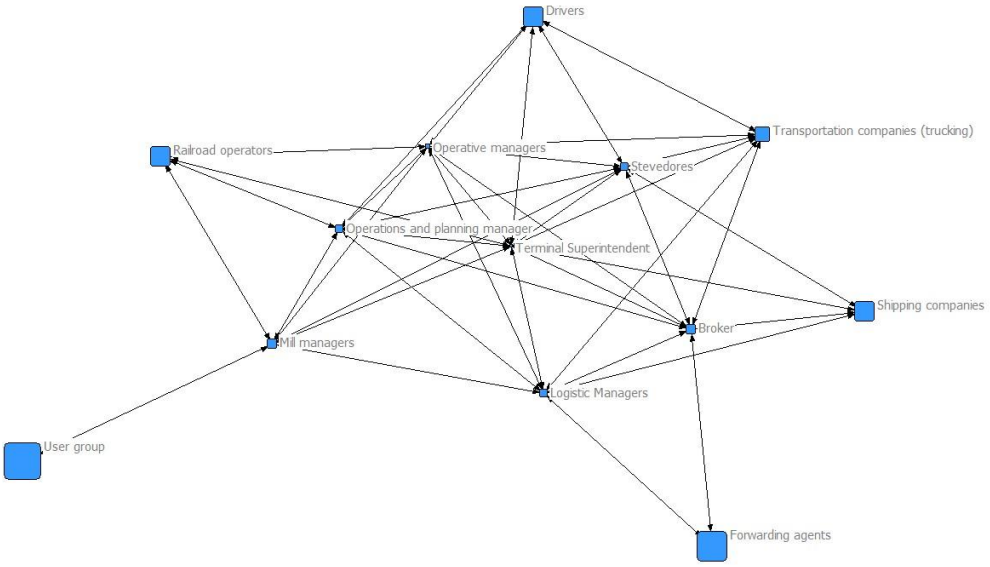
Appendix 2: Network node sizes by Degree



Appendix 3: Network node sizes by Betweenness



Appendix 4: Network node sizes by Closeness



Appendix 5: Network node sizes by Eigenvector