



Risk assessment in multimodal supply chains

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ABSTRACT

Complexity and disintegration are emerging as major challenges in supply-chain risk management. It has become more difficult to identify risks as supply-chain operations have fallen into the hands of outside service providers, and are therefore less visible. The risks, their identification and impact depend on the position of the companies in the chain, and on the level of analysis they can carry out. In this paper we present preliminary research concepts and findings concerning the identification and analysis of risks in multimodal supply chains. Our research approach is holistic, and incorporates perspectives from different parts of the chain. The multimodal maritime supply chain in focus runs from the Gulf of Finland to the Finnish mainland. We map the process and the structure, and present a new framework for categorizing the risks in terms of their driver factors in order to assess the overall impact on the performance of the supply chain. Finally, we analyze the risk impacts in terms of delays in the chain by means of Monte-Carlo-based simulation.

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1. Introduction

Global supply chains are formed by a multitude of companies acting as part of a long and complex logistics system. The continuing disintegration and the specialization of operations have made the chains vulnerable to disturbances coming from both inside and outside the system. The visibility of operations outside the companies' own functions has decreased, and with it the ability to identify risks threatening them and the whole supply chain. Harland et al. (2003) found that less than 50% of the risks were visible to the focal company in the supply chains they examined. The risks that are identified are typically related to the companies' own functions. In most cases, in terms of business impact, risks of disruption are much greater than the operational risks (Tang, 2006). There is therefore a need for a broader view of the supply chain that would facilitate proper risks identification.

Managers selecting a supply-chain-management strategy should first understand the sources of uncertainty and find the way of reducing the level that suits them best (Cucchiella and Gastaldi, 2006). Integrated and seamless logistics can play a crucial role in facilitating global supply-chain processes (Banomyong, 2005). Yet, in practice, greater integration increases dependency between companies and exposes them to more risks (Hallikas et al., 2004). Indeed, the increasing amount of risk in the supply chain is a current focus

of interest in logistics (Minahan, 2005). According to Jüttner (2005), any approach to managing risks from such a perspective must have a broader scope than that of a single organization, and provide insights into how the key processes should operate across at least three organizations. Hence, in assessing supply-chain vulnerabilities companies need to identify the risks not only to their own operations but also to all other entities, as well as those caused by linkages between organizations. A disruption affecting an entity anywhere in the supply chain can have a direct effect on a corporation's ability to continue operations, get finished goods to the market, and provide critical services to customers. For example, a ten-day shutdown of 29 US ports cost the US economy one to two billion dollars per day, which illustrates the effects that such disruptions can have (Park et al., 2008; Jüttner, 2005).

Multimodal container transportation is playing an increasingly important role in global supply chains and trade. Container transportation has expanded significantly over the last 10 years, and the trend shows no sign of slowing down. According to the World Trade Organization, the world's container-shipping capacity tripled in the last decade (World Trade Organization, International Trade Statistics, 2010), which illustrates the significance of multimodal maritime supply chains as part of a global logistics system. Even though there have been several studies on supply-chain risk management, however, very few of them focus on the multimodal maritime supply chain. Given that supply risks, and further the likelihood of disruption, are emerging as a key challenge in supply-chain management, the ability to identify the parts of the chain that are more prone to disruption is becoming a critical first step in managing the frequency and impact of disruptions that may endanger the security of supply (Trkman and McCormack, 2009;

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Singhal et al., 2009). The limited information sharing and collaboration that is typical in the supply chain limit the visibility of risks to some practitioners. There is thus a need to provide a more holistic view by studying the processes involved as an integrated system.

The Gulf of Finland (GoF) is the most important transport route accommodating Finnish cargo flows. Finland's major ports are on its shores, and are in a key position as far as security of supply is concerned. The risks affecting GoF supply chains could have a devastating effect on the downstream organizations, and furthermore endanger Finnish business life and the livelihood of the people. The sources and impacts of the risks should therefore be studied, and that is precisely where the contribution of this paper lies. The aim is to present an assessment of risks and their effects in a multimodal maritime supply chain. A case study was conducted, the purpose of which was to systematically analyze and evaluate the risks affecting a multimodal maritime supply chain between the Gulf of Finland and the Finnish mainland in terms of the nature of their impact. The study is based on literature focusing on risks and supply-chain risk management, and on the findings from interviews. Most of the research was carried out in three overlapping phases. The interviewees were identified and the interviews conducted in the first phase. The risk analysis comprising the second phase involved an expert group of researchers and practitioners in the field. In the final phase, the risk impact of time delay was evaluated by means of simulation in order to obtain a more in-depth perspective on the possible consequences.

The paper continues with a literature review covering the key concepts of supply-chain risk management and multimodality. The following, empirical part of the study begins with a description of the operational area, the study methods, and the process of the case supply chain. The uncertainties are identified and assessed, and a risk analysis follows in which the simulation results illustrate the delay impact of the risks. The conclusions are presented and discussed in the final section.

2. Literature review

Supply chains in the modern world are complicated networks that stretch over longer and longer distances, which makes them vulnerable to a variety of risks. Global supply chains require highly coordinated flows of goods, services, information and money within and across national boundaries (Mentzer et al., 2001). Events affecting one entity or process may interrupt the operations of other members of the chain. Hence, it is important to investigate cross-border supply chains in the selection and implementation of risk-management strategies (Manuj and Mentzer, 2008).

Supply-chain management entails proactive relationship formation and integration among various tiers in the chain (Trkman et al., 2007). Company management should take the supply chain into account in order to construct a holistic understanding about the sources of risks. Jüttner et al. (2003) define supply-chain management as the identification and management of the risks involved through coordinated action among the members in order to reduce vulnerability as a whole. Supply-chain risk management entails identifying the potential sources of risk and implementing appropriate actions to avoid or contain vulnerability. Jüttner et al. (2003) describe vulnerability as exposure to serious disturbance, arising from risks both within and external to the supply chain, and supply-chain vulnerability as the propensity of risk sources and risk drivers to outweigh risk-mitigating strategies, thus causing adverse consequences and jeopardizing the supply chain's ability to effectively serve the end customer. How sensitive a supply chain is to these disturbances is measured in terms of its vulnerability. How vulnerable it is to disturbances

depends on its structural agility and resilience, and in this (risk) management plays a crucial role.

The vulnerability of a supply chain does not assign probability, and it is therefore essential to identify the risks. This is a key activity on which all other aspects of supply-chain risk management are based. In reality, it is virtually impossible to list every conceivable risk, and identification highlights the most significant ones that affect the supply chain. Inter-organizational people usually have the most intimate knowledge of their own organization and its conditions, but not necessarily the capability to identify risks. Organizations cannot rely on personal knowledge and informal procedures, but need more formal arrangements (Waters, 2007).

As many authors acknowledge (i.e., Caridi et al. 2009; Al-Mudimigha et al., 2004), one of the key factors in risk identification is visibility in the supply chain, which is beneficial in terms of efficiency (e.g., Smaros et al., 2003), productivity, and the effective planning of operations (e.g., Petersen et al., 2005). Christopher and Lee (2004) describe visibility as the actors' knowledge of what goes on in other parts of the chain.

The literature on supply-chain management usually defines risk in purely negative terms, and as leading to undesired results or consequences (Harland et al., 2003). A standard formula for the quantitative definition of supply-chain risk is

$$\text{Risk} = P(\text{Loss}) \times I(\text{Loss})$$

where risk is the function of the probability (P) of loss and the significance of its consequences (I) (Manuj and Mentzer, 2008).

Hetland (2003) and Diekmann et al. (1988), on the other hand, view risk as the implication of an uncertain phenomenon. Waters (2007) explains the difference: risk occurs because there is uncertainty about the future, which means that unexpected events may occur. Knight's (1921) distinction between certainty, risk and uncertainty is probably the best known and most used typology of uncertainty for risk management. In his definition of risk Knight coined the terms (quantitative) "measurable" uncertainty and (non-quantitative) "unmeasurable" uncertainty when there is only partial knowledge of outcomes in the form of beliefs and opinions.

Although awareness of supply-chain vulnerability and risk management is increasing among practitioners, the concepts are still in their infancy and there are insufficient conceptual frameworks and empirical findings to give a clear sense of the phenomenon of risk management in global supply chains (Jüttner, 2005; Manuj and Mentzer, 2008). Much of the earlier research has neglected the crucial division of risks as originating either within a chain or in the outside environment. In order to make such a distinction, the sources of uncertainty need to be separated (Trkman and McCormack, 2009).

Supply-chain disruptions may have long-term negative effects on a firm's financial performance (Tang, 2006). Risks come in many forms. Firstly, they may be operational and considered minor in terms of consequences, but they occur regularly. They may cause disturbances in the supply chain that are not perceived to be serious, but if they occur simultaneously or create a snowball effect they have serious consequences. Secondly and more commonly, they may be disruptive, described by Tang (2006) and Knemeyer et al. (2009) as low probability-high consequence (LP-HC) events. Such events may unexpectedly disrupt the flow of material at any time.

There are numerous categorizations of supply-chain risks in the literature, and their applicability depends on the chain in question. Blackhurst et al. (2008) argue that the most important step in the process of risk assessment is the selection and definition of the categories, which can be weighted, compared and quantified. The current literature offers many options, some of which are industry-specific and others are more general. Mason-Jones and Towill (1998)

and Jüttner et al. (2003) specify three risk groups: *internal risks*, which arise from the organization, *supply-chain risks*, which are external to the organization but within the supply chain, and *external risks*, which are external to the supply chain and arise from the environment. Manuj and Mentzer (2008), having conducted an extensive literature review, present a generic framework for the categorization of risk in global supply chains into the following broad classes: supply risks, operational risks, demand risks, security risks, macro risks, policy risks, competitive risks, and resource risks. This categorization highlights the generic business aspects of risk, and separates the source vulnerability in an appropriate manner.

According to the Finnish National Emergency Supply Agency (NESA, 2010), the security of supply means “the capacity to maintain the basic activities that are indispensable for safeguarding the population’s living conditions, for sustaining the functioning of critical infrastructures, and the material preconditions for maintaining national preparedness and defence in case of serious disturbances and emergency situations.” Ensuring capacity and delivery are thus the key elements. In highly disintegrated and specialized supply chains this means safeguarding the livelihood of the companies involved. Some of the current security reports take this into consideration (i.e. Willis and Ortiz, 2004; Kwek and Goswami, 2003) with reference to the costs and vulnerabilities of multimodal transportation, for example, but suggest further research on the system risk involved.

Different authors define intermodal and multimodal transportation slightly differently, and it seems that many attempt to attribute different names to what is basically the movement of goods by at least two modes of transport (Banomyong, 2000). Crainic and Kim (2007) define intermodal transport as “the transportation of a person or a load from its origin to its destination by a sequence of at least two transportation modes, the transfer from one mode to the next being performed at an intermodal terminal”. The European Conference of Ministers of Transport (2002), on the other hand, defines intermodal transportation as “a movement of goods in one and the same loading unit or vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes”. The concept is very general, and thus means different things to different people. However, it typically refers to a multimodal chain of container transportation (Crainic and Kim, 2007).

Multimodal supply chains are international transport combinations of various modes of transport such as ship, rail, and road, primarily through the use of containers. Containers ensure the transport of unitized cargo from its origin to its final destination, efficiently and with minimum risk (UNCTAD, 1993). There are two prominent characteristics of multimodal transport chains: first, there may be more than one means of transport from one place to another; secondly, in order to transfer from one means to another, the place should have additional facilities, such as loading/unloading containers and to/from transport tools of different types (Hu, 2011). The costs and risks of multimodal transportation have attracted the attention of some authors, and various models have been created to enable logistics practitioners to choose the most cost-effective and risk-free mode or combination of modes (Christopher, 2005; Yan et al., 1995; Barnhart and Ratliff, 1993; Minh, 1991).

As the amount of multimodal transportation is growing, so is its importance in international trade. There are more than two billion containers transporting cargo in the world (Hu, 2011). According to Beresford et al. (2011), the choice of transport mode, or combination of modes, may have a direct impact on the efficiency of a multimodal supply chain. The recent rapid rise in container-transport volumes has brought shorter delivery times, but has also exposed actors in the chains to various risks. Complicated and combined transportation has increased inter-organizational dependency.

Organizations therefore need to understand the holistic picture in order to ensure proper resilience against the various risks in multimodal supply chains.

3. Empirical study and methods

The focus in the empirical part of the study is on the supply chain between the Gulf of Finland and the Finnish mainland in terms of the risks involved and their impact. The study was conducted as part of a Study of Cargo Flows in the Gulf of Finland in Emergency Situations (STOCA) project, the aim of which is to assess cargo flows in the Gulf of Finland in emergency situations.

The supply chain in question runs between southern Finland and the Gulf of Finland, with an approximate length of 200 km including both maritime and land transport. The Gulf of Finland is situated between Finland, Estonia and Russia. It is approximately 400 km long, varies in width from 60 to 135 km, and has an average depth of only 37 m (Finnish Maritime Administration, 2009). The volume of transported cargo in the Gulf has grown substantially during the last decade, and thus far there have been fewer accidents attributable to traffic density than the average worldwide (VTT, 2002; Finnish Maritime Administration, 2009). The inland leg of the supply chain is located in southern Finland, which has the highest density of roads and railways in the country and about half of the total population (Population Register Centre, 2010). The infrastructure is in good condition and the GNP is the highest in the country (Statistics Finland, 2010).

The supply chains between the Gulf of Finland and the mainland are extremely important in terms of Finnish security of supply in that sea transportation comprises 85% of the country’s import and export cargo flows. The Gulf is of strategic importance with the three biggest ports on its shores (Kujala et al., 2009). Finland as a northern country with small markets and great distances is particularly vulnerable, and here the ports on the Gulf are in a unique position. If a port is unable to receive cargo, supply-chain disruptions, or at least delays, will be likely. Disruptions in the downstream supply chain may also affect GoF supply chains in the case of a disaster in or near any of the ports.

The choice of supply chain and of the case companies was made in collaboration with the National Emergency Supply Agency, the role of which is to ensure the security of supply in Finland. The supply chain in question is responsible for transporting containers carrying various goods of high significance for both business life and the population in general, and there would be serious disruption if their free flow was disturbed for a long period of time. These goods include time- and temperature-sensitive products such as fresh food and medicine, and other everyday articles. The interviewees were selected from the companies best representing their field and with high significance in their area of operations. All of the companies were part of the multimodal maritime supply chain and were acting in various roles, representing shipping companies, ports and port operators and administrators, customs, road and rail transportation, insurance companies and international logistics operators. The first interviews were with representatives of port administration and the operators, which seemed to be in a key position in the supply chain. The interviewees had a range of duties related to supply-chain and risk management. They varied in terms of position, but all had an extensive understanding of their company’s operations. It was considered essential for them to have a wide perspective on supply-chain operations and risks in order to ensure accuracy in the analysis. For this reason the companies were contacted and asked to name the person who would be most suitable given the scope of the research, and further suggestions were given in the earlier interviews. Researchers with different specialization

backgrounds conducted the interviews so as to end up with as broad a view of the subject as possible, and to ensure the reliability of the study and its viability as a basis for further work.

The qualitative interviews that comprised the primary method of data collection during the first phase of the empirical research process identified the uncertainties in the multimodal supply chain. In qualitative research the subjects are studied in their natural settings in a real-life context. Given that neither the phenomenon nor the context was evident, this approach was considered appropriate in terms of making sense of the phenomena by interpreting the meanings people attach to them to them (Yin, 1989). It was also assumed that the qualitative approach would best serve this research purpose because it facilitates in-depth and detailed study of the phenomenon from the perspective of the interviewees. It typically entails no prior hypothesis setting, and the researcher should have no prior assumptions (Voss et al., 2002). Sampling is generally discretionary, but the numbers may be small and the results not necessarily of statistical value.

Twenty-two persons from different companies were interviewed face-to-face. At the beginning of each one the interviewee was promised anonymity and permission to use a tape recorder was solicited. The sessions were recorded and the audio files then transcribed to text files to facilitate later examination. The interviews, which were semi-structured, focused on supply-chain risks and their impacts, and a discovery-oriented approach was used in order to tap into the professionals' experience and knowledge (Zaltman et al., 1982; Yin, 1989). The style was discursive, and there were no predetermined response options. Themes and questions were discussed at random to enable a natural conversational style and allow the lead of the interviewees to be followed. In order to obtain a holistic view of the operations the interviewees were asked to describe their own activities in the case supply chain and to take into account the processes on a broader level. The aim was to focus on the process in order to determine what factors influenced the chain and what kind of risks were involved in the different stages. This systematic approach allowed a holistic understanding of the supply chain and the potential risks and consequences to emerge.

During the interview process expert panel discussions involving three to six persons were conducted in iterative rounds similar to the Delphi method (see e.g., Fowles, 1978). The purpose was to verify and analyze the interview data and finally to determine the risk likelihood and impact values. The interviewers set up the sessions, and their role was to present the preliminary findings and guide the discussion in a holistic direction. The panel comprised researchers in the logistics field as well as practitioners in the port sector, who had been interviewed. The selected organizations are the major actors in the supply network in question, and have the best knowledge about the risk probabilities and impacts. Every risk driver was considered separately and the causality of the unwanted events was recognized. Overall consensus about the risk factors was reached following discussion of the different viewpoints on the supply-chain process. Of the interviewees, the port operators and administration personnel seemed to have the best knowledge about the delay effects, and they were used in the simulation. The perspective of the study could therefore be assumed to represent the port more than other operations, although a wide perspective on the supply-chain process was basis of the discussions.

Once determined, the risk probabilities and impacts were evaluated in a simulation of the delay effect. The simulation model was constructed in order to investigate the variation in the distribution of possible supply-chain outcomes, their likelihood, and their subjective values (March and Shapira, 1987). Simulation modeling has been applied in the research on supply chains to investigate sources of uncertainty (Petrovic, 2001), and is especially well suited in cases

in which there is a lack of statistical data on the phenomena in question. The Monte Carlo approach was used here as a basis on which to investigate the connection between risk events and their delay implications.

4. Identifying the supply chain and the risks

The uncertainties observed by the practitioners varied between the companies, but some were mentioned in every interview. The identification of the supply-chain and the overall risk were on a lower level in the smaller companies (e.g., trucking) than in those operating from a wider perspective. Furthermore, the personal differences between the managers and in interpretation were significant, and companies in a more operational role seemed to have difficulties in forming a general view. The scale of conceptual understanding and comprehension of the risks varied highly between the interviewees. The smaller logistics companies with no clear risk management typically had a lower level of knowledge, and tended to respond to risks as they occurred. Some of the trucking companies had their own simple methods of identification and response, such as simple feedback forms filled in by employees and analyzed by managers. The larger logistics companies in control of a global supply chain practiced risk management on a higher level through the use of strategic-management tools such as modified Failure Mode Effect Analysis.

The interviews were conducted during different phases of the supply-chain process as follows: with three shipping companies in the Maritime transport phase, with nine companies in the Port operations phase (e.g., port operators, port administration, port security, warehousing companies, and customs), and with ten companies representing land transportation and all other activities including rail and road transportation companies, rail and road transport agencies, warehousing, insurance companies, as well as locally and globally acting logistics operators. The chart of the transport supply-chain process presented in Fig. 1 was created in order to identify the risks associated with the supply chain under investigation. It shows the higher-level steps in the process and allows in-depth focusing on each stage without losing the connections between the stages.

The interviewees involved in port operations also had their own views of the risks. Their responses varied according to their position and background, but to a lesser extent than among the other actors interviewed, and were more comprehensive. The actors responsible for security typically did not consider the market risk to be relevant, whereas those responsible for development and traffic perceived it to be higher compared to terrorism, for example. The 9/11 disaster was still affecting business in every interviewee's opinion, and most mentioned the International Ship and Port Facility Security (ISPS) Code that came into force in 2004. Overall, in the view of the port-operations-related companies interviewed, employee strikes, fire, and electricity or IT blackout constituted the most severe risks.

The interviews also revealed interesting information about the routes to and from the port, and not only the narrow shipping lanes but also the land routes. The port managers were aware of the risks, but only a few of them had been assessed properly. If these vital routes were to be blocked, the capacity of the port would be significantly lower and its operations disrupted. This would have an instant effect on cargo flows in the Gulf of Finland. Given the specialization in the biggest ports, the transferring of cargo that requires special handling equipment would be difficult.

As far as the logistics operators and the Finnish export industry were concerned, the availability of empty containers constituted a risk. Finnish industry is export-oriented and the use of multimodal container transportation is common. Currently companies depend

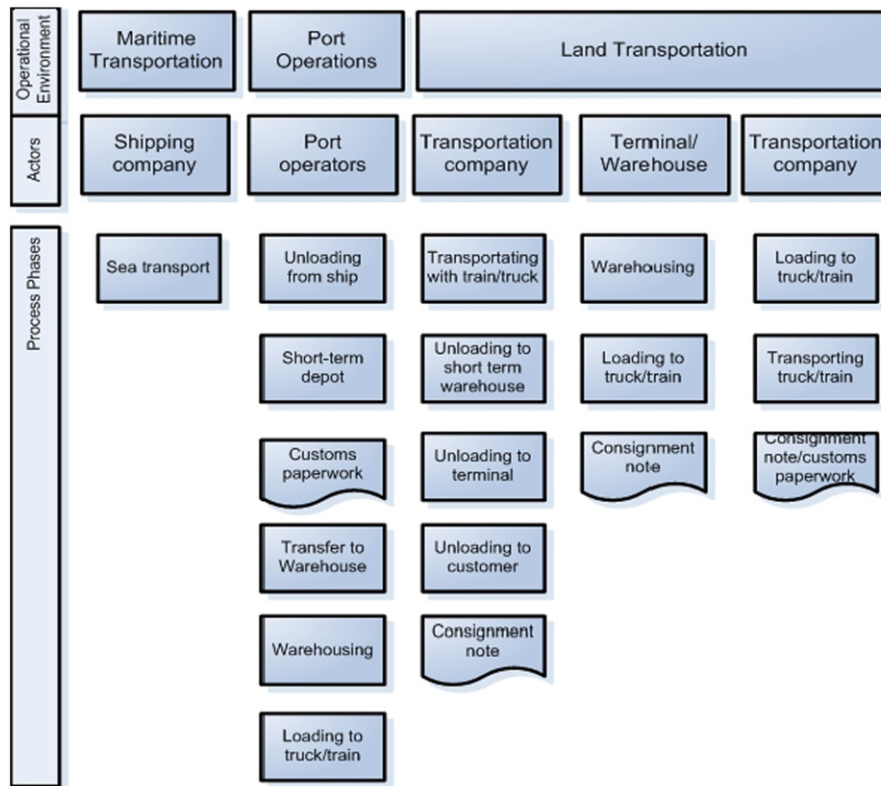


Fig. 1. The supply-chain process.

on the Russian transit containers that become available after being unloaded. Given the high accessibility of these containers the rates have been typically lower than in the rest of Europe, but availability dropped during the financial crisis and the rates went up. Some companies have even had to order empty containers from Europe to ensure their supply.

A surprising revelation in the interviews was the poor state of preparedness for disruption in some companies, no matter how insignificant they were considered to be and how little co-operation there was between the organizations operating in the same supply chain. The co-operation and the communication were usually only on the level that was compulsory or necessary in order to conduct business. The perspectives of the operators on different levels of the supply chain in question raised the most serious concerns. The global logistics operator had the widest perspective on multimodal supply-chain management, whereas the smallest operator seemed to have difficulties in forming a general view. The benefits of co-operation on the international level were clearly understood, as were its inhibitors: intense competition was also seen as a risk. There is still a lot of suspicion in the logistics and transportation fields, and this has a negative effect on co-operation and visibility in the supply chain.

5. Risk analysis

The risks were analyzed in terms of their effects on the supply chain. Some of the investigated organizations had severe problems in forming a holistic view, and clear overestimations as well as underestimations were evident in their assessment of the risk impact beyond their own functions. Expert panel discussions were held in order to verify the risk values. The first of these took place during the interview process in order to discuss the preliminary findings from the interviews conducted thus far and

to explore the different viewpoints. The expert panel consisted of logistics field researchers and port operations experts in the case supply chain. The researchers' role in the discussions was to present the data and guide the discussion in a holistic direction. Consensus was finally reached about the risks, their categorization and impact. A summary of this analysis is presented in Table 1. The risk drivers found from the supply chain were classified by source. We found that an adaptation of Manuj and Mentzer's (2008) risk source classification with its wide perspective on supply-chain risk management provided a solid framework for our case; the classification is both qualitative and quantitative, taking into account both the direct and indirect impacts, and this facilitates in-depth understanding of the risk sources without losing the holistic view. The risks were categorized as follows: *Supply Risks*, *Security Risks*, *Operational Risks*, *Macro Risks*, *Policy Risks* and *Environmental Risks*. No risk sources fitting the *Demand Risks*, *Competitive Risks* and *Resource Risks* classification were identified in the group discussions. Having identified the risks and made their semi-quantitative assessment, the expert panel turned to the delay impact, which was modeled in the form of triangular distributions representing the minimum, the most likely and the highest impact.

Risk effects can be categorized in three different types: *time-based*, *finance-based* and *quality-based*. Time-based effects either delay or disrupt the material flow of the supply chain. In this case the disruption was identified as a breakdown in the chain such that the goods do not reach their destination by the time they are expected by the final customer. There are no clear time limitations on the delay due to the fact that it had significantly different consequences in different stages of the chain. Maritime transportation could be delayed for days or even a week without serious consequences, but if a truck is 30 min over its time window in a terminal, the whole downstream supply chain is affected. The risk impact in this case varied highly depending on the

Table 1
Risks and their effects as identified in the study.

Risk likelihood and effects	Likelihood	Time		Financial Quality		
		Delay	Disruption	Costs	Damage	Risk
Supply Risks						
Hazardous materials	1	3	1	3	1	8
Stoppage with cargo on board	3	1	0	1	1	9
Lack of intermodal/multimodal equipment	0	1	0	1	0	0
Bottlenecks in the transportation routes	3	3	0	1	0	12
Capacity problems in railroad traffic	0	3	0	0	0	0
Problems with customs clearance	0	3	1	0	1	0
Employee strikes in ports	3	9	1	9	1	60
The permits of the transportation company	0	0	0	1	0	0
Oil spills	0	1	1	3	0	0
Bottlenecks in the Ro-Ro/Ropaxs-capacity	0	1	0	0	0	0
Operational Risks						
Ship collision or sinking in the approach lane	0	1	0	1	0	0
Lack of skilled workers	1	3	0	0	0	3
The condition of cargo-handling equipment	1	1	0	0	3	4
Carelessness and a lack of motivation among the workforce	1	1	0	1	3	5
Interpretation problems with documents, contracts and permits	0	1	0	1	0	0
Security Risks						
Organized Crime (infiltrating into the SC)	1	0	3	3	1	7
People-smuggling	1	1	0	1	0	2
Information systems	3	3	1	3	0	21
Drunken drivers	0	1	0	0	1	0
Infringement of traffic regulations	0	1	0	0	0	0
Outside interference in the SC	1	3	1	3	1	8
Spying and espionage	0	0	0	3	0	0
The ownership of the Finnish merchant fleet (supply security)	9	1	0	0	0	9
The applications of the transported good	1	1	0	3	0	4
Invoice inspection in transit traffic	0	0	0	0	0	0
Energy supply	0	9	3	3	1	0
Demonstrations (Eco-terrorism)	1	3	0	3	0	6
Water supply	1	1	0	3	1	5
Problems in telephone connections	1	1	0	1	0	2
Breakdown at a critical railway crossing or yard	0	9	1	1	0	0
Commercial and administrative linkage (foreign ownership)	3	1	0	0	0	3
The order organization's financial problems	1	3	1	3	0	7
Terrorism	0	9	3	9	1	0
Customs clearance	0	1	0	0	0	0
Macro Risks						
Financial Crisis	3	0	0	3	0	9
Finland's small and unattractive markets	3	1	0	1	0	6
Fierce competition in the transportation sector	9	0	0	1	0	9
Policy Risks						
Russian customs	3	3	0	1	0	12
Railway operators' attitude towards free markets	1	0	0	0	0	0
Environment Risks						
Nuclear disaster in nearby plants	0	9	1	1	1	0
Oil catastrophe in the GoF/shipping lane/port	0	1	0	1	0	0
Ice conditions in winter	9	3	0	1	0	36
Fire	3	3	3	3	9	54
Regional infectious diseases	1	3	1	1	0	5
Climate change	1	1	0	1	3	5
Natural forces (weather changes, storms, floods, etc.)	1	1	0	0	1	2
Finland's geographical position and dependence on sea traffic	3	0	0	3	0	9
Long distances	1	1	0	3	0	4
Toxic waste in the bottom of the lane (dredging)	0	1	0	0	0	0
Fog in the shipping lane	1	1	0	0	0	1
Slipperiness in wintertime	9	1	0	1	1	27

goods. For example, if a time- and temperature-sensitive food or medicine shipment were to be late the impact would extend from hours to a couple of days, whereas a week's delay on a spare part destined for a warehouse would not necessarily have any negative consequences.

Risk likelihood and impact were evaluated on a scale of 0,1,3,9, where 0 implies zero likelihood or no impact and 9 denotes a very high likelihood or impact. The scale is adapted from the Quality Function Deployment design method (see e.g., Akao,

2004), which is commonly used in the context of new product/service development.

The financial effects on the supply chain are the costs attributable to additional management and fees attributable to some of the risk drivers. Finally, quality-based effects result from damage to the transported goods or the transportation equipment.

The risk analysis framework illustrated in Table 1 summarizes the analysis findings and provides a holistic view on supply-chain risk drivers and impacts. It is clear from the right-hand side Risk

column in the matrix that the highest single risk factors in the case supply chain are *employee strikes in the ports, fire, and ice conditions in winter*. These are calculated as a sum product of likelihood multiplied by the risk-impact measures. In terms of each impact category, the analysis shows that time delay is the most serious, followed by finance/cost and further by quality/damage and disruption. These measures are calculated as sum products of likelihood multiplied by each risk-impact category. If the study had addressed the issue from the business perspective, for example, the category weights would most likely have been different.

A Monte-Carlo-based simulation was then carried out in order to evaluate the overall risk impact of delay. The delay data revealed severe inconsistencies among the interviewed companies. Those connected to port operations seemed to be most affected and their perspective was adopted. The delay values were those reported by three actors.

6. Simulation

The qualitative assessment of risk provides a solid general framework within which to identify the most serious risks in the supply chain. As a further step, time delay was used as a quantification measure. The simulation model was based on the delay impact of the identified risks, the aim being to investigate variation in the distribution of possible supply-chain outcomes, their likelihood, and their subjective values (see e.g., [March and Shapira, 1987](#)). The advantage of the simulation approach is that one measure (time) can be used for modeling risk impact and probability. Unlike direct expert assessment ([Table 1](#)), it identifies extreme risk scenarios because the distributions allow the assignment of a range of values to a single variable (e.g., minimum, most likely, maximum). Given the lack of statistical data on supply-chain disruptions, we used the previously mentioned expert panel in assigning input values for the simulation, and Monte-Carlo-based simulation software for calculating the risks and uncertainties. The risk-likelihood measures assigned to each driver were first translated into probability measures in the expert panel discussion conducted with handpicked supply-chain actors. The probability measures reported below are based on these actors' experiences. The probabilities set in the study for each linguistic measure are presented in [Table 2](#), and reflect the risk-occurrence experiences of the actors in the selected supply chain.

Risk probabilities were assigned to each risk driver. The delay impact of each risk driver on supply-chain performance, in other words the delay caused by the risk driver in the case of its occurrence, was similarly assigned. Delay impacts were modeled as probability distributions. [Table 3](#) shows the selected part of the risk-analysis framework showing the risk probabilities and impact (delay). The time delays are modeled as triangular distributions, which have been used in earlier supply-chain simulation studies (see e.g., [Beamon and Chen, 2001](#)). Here, the experts evaluated the minimum, maximum and most likely value of a time variable. The analysis was based on the Monte Carlo simulation method, which randomly selects values from the distribution and uses several iteration rounds. In this case, 10,000 iteration rounds were used in

Table 2
Risk likelihood measures.

Linguistic scale	Assigned probabilities (<i>p</i>)
0=Minor	0.0001
1=Small	0.00023
3=Moderate	0.0013
9=High	0.01

Table 3

Delay likelihood and impact in the studied supply chain.

	Likelihood of occurrence	Delay (days)		
		Min.	Most likely	Max.
Supply Risks				
Hazardous materials	0.00023	2	5	7
Stoppage with cargo on board	0.0013	0	0	0
Lack of intermodal/multimodal equipment	0.0001	0.5	1	2
Bottlenecks in the transportation routes	0.0013	1	2	3
Capacity problems in railroad traffic	0.0001	1	4	14
Problems with customs clearance	0.0001	1	7	170
Employee strikes in ports	0.0013	1	7	20
The permits of the transportation company	0.0001	0	0	0
Oil spills	0.0001	0	1	7
Bottlenecks in the Ro-Ro/Ropaxs-capacity	0.0001	0	0.5	1
Operational Risks				
Ship collision or sinking in the approach lane	0.0001	0	1	7
Lack of skilled workers	0.00023	0	1	3
The condition of cargo-handling equipment	0.00023	0	1	2
Carelessness and a lack of motivation among the workforce	0.00023	0	1	7
Interpretation problems with documents, contracts and permits	0.0001	0	1	3
Security Risks				
Organized Crime (infiltrating into the SC)	0.00023	0	0.5	1
People-smuggling	0.00023	0	0	1
Information systems	0.00023	0	1	7
Drunken drivers	0.0001	0	0.5	1
Infringement of traffic regulations	0.0001	0	0.5	1
Outside interference in the SC	0.00023	0	0	0
Spying and espionage	0.0001	0	0	0
The ownership of the Finnish merchant fleet (supply security)	0.01	0	0	1
The applications of the transported good	0.00023	0.5	1	2
Invoice inspection in transit traffic	0.0001	0	1	2
Energy supply	0.0001	0	1	5
Demonstrations (Eco-terrorism)	0.00023	0	0.5	1
Water supply	0.00023	0	0.5	1
Problems in telephone connections	0.00023	0.5	1	2
Breakdown at a critical railway crossing or yard	0.0001	0.5	1	3
Commercial and administrative linkage (foreign ownership)	0.0013	0	0	1
The order organization's financial problems	0.00023	1	150	365
Terrorism	0.0001	2	165	365
Customs clearance		1	2	14
Macro Risks				
Financial Crisis	0.0013	0	0	0
Finland's small and unattractive markets	0.0013	0	0.5	2
Fierce competition in the transportation sector	0.01	0	0	0
Policy Risks				
Russian customs	0.0013	0.5	1	2
Railway operators' attitude towards free markets	0.00023	0	0	0
Environment Risks				
Nuclear disaster in nearby plants	0.0001	0	30	160
Oil catastrophe in the GoF/shipping lane/port	0.0001	0	1	30
Ice conditions in winter	0.01	0.5	5	9
Fire	0.0013	0	2	30
Regional infectious diseases	0.00023	0	2	5
Climate change	0.00023	0	0	0

Table 3 (continued)

	Likelihood of occurrence	Delay (days)		
		Min.	Most likely	Max.
Natural forces (weather changes, storms, floods, etc.)	0.00023	0	0.5	2
Finland's geographical position and dependence on sea traffic	0.0013	0	0	0
Long distances	0.00023	0	0	0
Toxic waste in the bottom of the lane (dredging)	0.0001	0	0	1
Fog in the shipping lane	0.00023	0	0	0.5
Slipperiness in wintertime	0.01	0	0.5	2

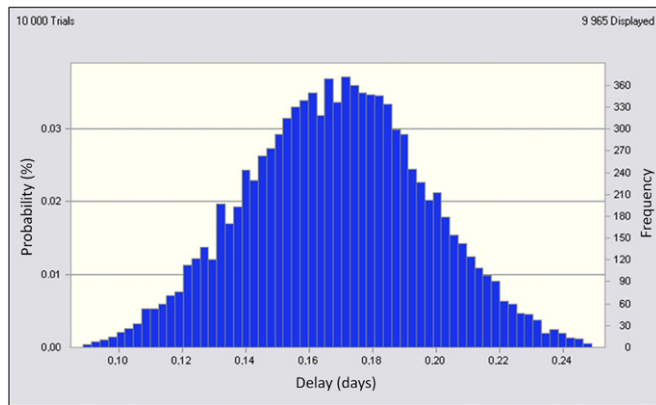


Fig. 2. The simulation results of the delays in the supply chain (min 0.08; mean 0.17; max 0.27).

order to ensure the existence of uncertain conditions. The case supply-chain process was modeled in a single simulation.

Fig. 2 shows the outcome of the simulation when time delay was used as a measure. Multiplying the probability measures of the risk drivers by the delay distributions (impact) allows calculation of the risk weights. Each risk probability is multiplied by the delay impact and presented as a distribution. In accordance with the Monte Carlo simulation procedure, the sum weight of all the risk factors gives the risk profile of the selected drivers in any case situation. It appears from the detailed simulation report that the delay impact could vary between 0.08 and 0.27 days, which would seem to be sufficient to take the probability measures into the model. It is worth noting that the simulated delay variation in the case supply chain without the effect of the identified risk-driver probabilities was between 197 and 1022 days.

The contribution of the variance sensitivity chart in Fig. 3 is to show the essential risk drivers of delay variation. According to the simulation analysis, *ice conditions* (38.4%), the *order organization's financial problems* (37.5%), *fire* (9.0%), *terrorism* (6.5%) and *strikes* (3.4%) constituted the major risk drivers in the case supply chain. Connecting the delay-probability distributions to the identified risk-event probabilities makes it possible to analyze the actual resilience of the supply chain in question. As shown, the supply-chain delay in the simulated case is 0.17 days on average. The outcome describes the control of the supply chain and is strongly connected to the identified risk events and their probabilities in the maritime supply chain under investigation. In other case environments the diverse risk-event probabilities might result in a totally different delay-outcome distribution.

In terms of risk management in multimodal supply chains, the simulation approach has many advantages with regard to risk analysis. For example, it facilitates connection between the

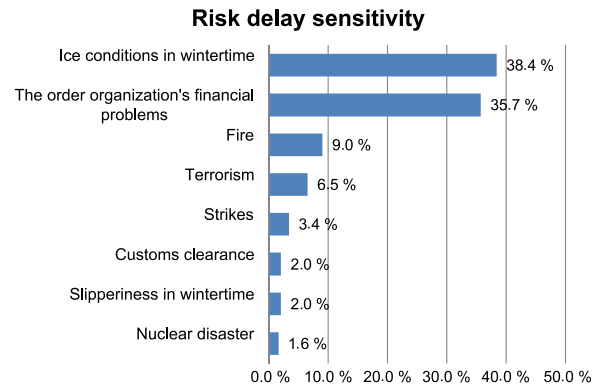


Fig. 3. The sensitivity analysis of risk drivers in the supply chain.

drivers and the impact of uncertain risk. Another outcome is a sensitivity analysis of the drivers causing the most uncertainty in the supply chain rather than a prioritized list of risks. Ultimately, this allows the selection of any performance indicator (e.g., delay) in the supply-chain system as a unit of analysis without losing the connection with the larger set of risk drivers.

7. Discussion and conclusions

This study broadens the perspective on risk management in multimodal maritime supply chains in considering both the needs of the supply chain and the security of supply to the end customers. The main objective was twofold: first, to identify and assess the risks affecting the cargo flows in the case multimodal maritime supply chain from the perspective of risk management, and secondly, to analyze the impact of the risks in terms of delay. A review of the current literature on maritime supply chains and supply-chain risk management gave a holistic understanding of the field. The empirical part of the research was carried out in two sequential but overlapping stages. Representatives of organizations comprising part of a supply chain originating in the Gulf of Finland and ending up on the Finnish mainland were interviewed in the first stage of the case study. These interviews were semi-structured and exploratory. The second stage involved mapping and evaluating the identified risks according to their outcomes in the supply chain. Thirdly, a simulation model was constructed based on the delay impact of the identified risks in order to investigate any variation in the distribution of possible supply-chain outcomes, their likelihood, and their subjective values (see e.g., March and Shapira, 1987).

Given the background of the interviewees, neither the conceptual clarity of the risk nor the risk sources and drivers were taken into consideration; the interviewees rather responded with tales of cause and effect. In this respect the findings reflect those reported by Peck (2005) and Zsidisin (2003), who note that practitioners perceive risk as a multi-dimensional construct. The low-hierarchy trucking companies seemed only to have some idea about their functions in the supply chain and how any disruption would affect it. Their perspectives were typically narrow, single-functioned and logistics based, although there were significant individual differences (Skjøtt-Larsen et al., 2007). The risks imposed on different parts of a multimodal supply chain depend on numerous factors, and many of the practitioners thought their company's business was somewhat different with regard to the other companies. Effective risk management clearly requires a holistic understanding. Increasing visibility and co-operation in the supply chain would improve the identification of risks and thus make them easier to manage.

Some of the logistics operators who were interviewed had taken steps in this direction, but a lack of trust seemed to prevent more extensive co-operation and information sharing. The risks identified as the most severe, namely strikes, fire and ice conditions in winter, affected the whole chain and most parts of it, and co-operation would therefore be most beneficial in this context. The most significant source of risk seemed to relate to supply, as well as to the operational environment, and the main effect in most cases was a time delay: in other words, the greatest impact is on cargo that is time-sensitive. For companies applying proper risk management the ability to mitigate or respond to these risks could prove to be a key benefit in the intense competition of present-day logistics.

The expected outcome of the vulnerability analysis is the top-down analysis of supply-chain risk drivers and their impact, and a more in depth investigation into the connection between risk exposure and supply-chain performance measures such as time. This paper connects both of these in exploring risks in a multimodal supply chain. Risk drivers and uncertainty in supply chains are often analyzed separately, but this study presents an integrated framework. Exposure in terms of likelihood and impact provides a solid structure on which to explore risks in different parts of the chain. Simulation with its inherent sensitivities sheds light on the drivers of risk and their impact on supply-chain performance. The delay impact was used to model risk exposure on the case supply chain in this study. However, it may be extremely difficult to obtain data for simulation applications, in which case expert opinions would be invaluable.

We believe that this study provides valuable information for practitioners and researchers alike. It illustrates the value of a holistic view to actors in the supply chain attempting to assess the risks facing them. On the national or regional level it enhances understanding of such risks, their likelihood and consequences, which gives a good basis on which to prepare for and respond to them in order to ensure the security of supply.

The viewpoint adopted and the methods used will enhance current research and arouse more discussion. The approaches to risk analysis adopted in the study rely on the expert knowledge of a few people and on subjective assessment. The case-study method therefore imposes limitations. The study also has limitations in terms of generalizability, given the size of the sample and the subjective nature of the data. There is thus a need for further empirical research employing a more extensive data set, or a comparative study involving some other geographical location. It would also be useful to analyze the financial and qualitative aspects of risk and its effects in the supply-chain context.

References

- Akao, Y., 2004. QFD: Quality Function Deployment—Integrating Customer Requirements into Product Design. Productivity Press.
- Al-Mudimigha, A.S., Zairib, M., Ahmed, A.M.M., 2004. Extending the concept of supply chain: the effective management of value chains. *International Journal of Production Economics* 87 (3), 309–320.
- Banomyong, R., 2005. The impact of port and trade security initiatives on maritime supply chain management. *Maritime Policy & Management* 32 (1), 3–13.
- Banomyong, R., 2000. Multimodal Transport in South East Asia : A Case Study Approach. Ph. D. Thesis, Cardiff University.
- Beamon, B.M., Chen, V.C.P., 2001. Performance analysis of conjoined supply chains. *International Journal of Production Research* 39 (14), 3195–3218.
- Beresford, A., Pettit, S., Liu, Y., 2011. Multimodal supply chains: iron ore from Australia to China. *Supply Chain Management: An International Journal* 16 (1), 32–42.
- Barnhart, C., Ratliff, D.H., 1993. Modeling intermodal routing. *Journal of Business Logistics* 14 (1), 205–223.
- Blackhurst, V.J., Scheibe, P.K., Johnson, J.D., 2008. Supplier risk assessment and monitoring for the automotive industry. *International Journal of Physical Distribution & Logistics Management* 38 (2), 143–165.
- Caridi, M., Crippa, L., Perego, A., Sianesi, A., Tumino, A., 2009. Do virtuality and complexity affect supply chain visibility? *International Journal of Production Economics* 127 (2), 372–383.
- Christopher, M., 2005. *Logistics and Supply Chain Management: Creating Value-adding Networks*. 3rd ed. Prentice-Hall, Harlow.
- Christopher, M., Lee, H., 2004. Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management* 34 (5), 388–396.
- Crainic, T.G., Kim, K.H., 2007. Intermodal Transportation. *Handbook in Operations. In: Barnhart, C., Laporte, G. (Eds.). Research and Management Science: Transportation*, vol. 14 (8), pp. 467–537.
- Cucchiella, F., Gastaldi, M., 2006. Risk management in supply chain: a real option approach. *Journal of Manufacturing Technology Management* 17 (6), 700–720.
- Diekmann, J.E., Sewester, E.E., Taher, K., 1988. *Risk Management in Capital Projects*. Construction Industry Institute, Austin, TX.
- European Conference of Ministers of Transport, 2002. ECMT Annual Report 2001. OECD Publishing.
- Finnish Maritime Administration, 2009. Merenkulun liikenne ja tavaravirtojen arviointi Itämerellä. Obtained through the Internet: <<http://portal.fma.fi/portal/page/portal/79BFF35B49105D2EE040B40>> [accessed 14/01/2010].
- Fowles, J., 1978. *Handbook of Futures Research*. Greenwood Press, ISBN: 978-0837198859.
- Harland, C., Brenchley, R., Walker, H., 2003. Risk in supply networks. *Journal in Purchasing and Supply Management* 9 (2), 51–62.
- Hetland, P.W., 2003. Uncertainty Management. In: Smith, N.J. (Ed.), *Appraisal, Risk and Uncertainty*, Thomas Telford, London, pp. 59–88, (Chapter 8).
- Hallikas, J., Karvonen, I., et al., 2004. Risk management processes in supplier networks. *International Journal of Production Economics* 90 (1), 47–58.
- Hu, Z.-H., 2011. A container multimodal transportation scheduling approach based on immune affinity model for emergency relief. *Expert Systems with Applications* 38 (3), 2339–2632.
- Jüttner, U., Peck, H., Christopher, M., 2003. Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications* 6 (4), 197–210.
- Jüttner, U., 2005. Supply chain risk management: understanding the business requirements from the practitioners perspective. *International Journal of Logistics Management* 16 (1), 120–141.
- Knemeyer, A.M., Zinn, W., Eroglu, C., 2009. Proactive planning for catastrophic events in supply chains. *Journal of Operations Management* 27 (2), 141–153.
- Knight, F.H., 1921. *Risk, Uncertainty and Profit*. Houghton Mifflin company, Boston and New York.
- Kujala, P., Hänninen, T., Ylitähti, J., 2009. Analysis of the marine traffic safety in the Gulf of Finland. *Reliability Engineering and System Safety* 94 (8), 1349–1357.
- Kwek, K.-H., Goswami, N., 2003. Cost and Productivity Implication of Increased Security in Sea Trade Processes, The Logistic Institute, Asia Pacific National University of Singapore. Research White Papers.
- Manuj, I., Mentzer, J., 2008. Global supply chain risk management. *Journal of Business Logistics* 29 (1), 133–155.
- March, J., Shapira, Z., 1987. Managerial perspectives on risk and risk taking. *Management Science* 33–11, 1404–1418.
- Mason-Jones, R., Towill, D.R., 1998. Total cycle time compression and the agile supply chain. *International Journal of Production Economics* 62 (1–2), 61–73.
- Mentzer, J., DeWitt, W., Keebler, J., Min, S., Nix, N., Smith, C., Zacharia, Z., 2001. Defining supply chain management. *Journal of Business Logistics* 22 (2), 1–24.
- Minahan, T., 2005. *The Supply Risk Benchmark Report*. Aberdeen Group, Boston, MA.
- Minh, H., 1991. International intermodal choices via chance-constrained goal programming. *Transportation Research A* 25 (6), 351–362.
- NESA, 2010. Security of Supply in Finland. Overview of Security of supply. Obtained through the internet: <<http://www.nesa.fi/security-of-supply/overview/>> [accessed 16/7/2010].
- Park, J., Gordon, P., Moore, I., J.E., Richardson, H.W., 2008. The State-by-State Economic Impacts of the 2002 Shutdown of the Los Angeles-Long Beach Ports, Growth and Change. Gattton College of Business and Economics, University of Kentucky 39 (4), 548–572.
- Petersen, K.J., Ragatz, G.L., Monczka, R.M., 2005. An examination of collaborative planning effectiveness and supply chain performance. *The Journal Of Supply Chain Management* 41 (2), 14–25.
- Petrovic, D., 2001. Simulation of supply chain behaviour and performance in an uncertain environment. *International Journal of Production Economics* (71), 429–438.
- Population Register Centre of Finland, 2010. Suomen asukasluvu vuodenvaihteesta 2009–2010. <[http://www.vaestorekisterikeskus.fi/vrk/home.nsf/files/Asukasluvu_2009_2010/\\$file/Asukasluvu_2009_2010.htm](http://www.vaestorekisterikeskus.fi/vrk/home.nsf/files/Asukasluvu_2009_2010/$file/Asukasluvu_2009_2010.htm)> [accessed 13.12.2010].
- Singhal, V., Hendricks, K., Zhang, R., 2009. The effect of operational slack diversification, and vertical relatedness on the stock market reaction to supply chain disruptions. *Journal of Operations Management* 27 (3), 233–246.
- Skjøtt-Larsen, T., Schary, P., Mikkola, J., Kotzab, H., 2007. *Managing the Global Supply Chain* Third edition Copenhagen Business School Press.
- Smaros, J., Lehtonen, J.M., Appelqvist, P., Holmstrom, J., 2003. The impact of increasing demand visibility on production and inventory control efficiency. *International Journal of Physical Distribution & Logistics Management* 33 (4), 336–354.
- Statistics Finland, 2010. Etelä-Suomen katsaus. Multiprint Oulu, Finland, 136 p.
- Tang, C., 2006. Perspectives in supply chain risk management. *International Journal of Production Economics* 103 (2), 451–488.

- Trkman, P., McCormack, K., 2009. Supply chain risk in turbulent environments—a conceptual model for managing supply chain network risk. *International Journal of Production Economics* 119 (2), 247–258.
- Trkman, P., Stemberger, M., Jaklic, J., Groznik, A., 2007. Process approach to supply chain integration. *Supply chain management—An international Journal* 12 (12), 116–128.
- UNCTAD, 1993. Containerization and standards, UNCTAD, Geneva, UNCTAD/SDD/MT/2.
- Voss, C., Tsikritsis, N., Frohlich, M., 2002. Case research in operations management. *International Journal of Operations & Production Management* 22 (2), 195–219.
- VTT, 2002. Statistical Analyses of the Baltic Maritime Traffic. Research Report Technical Research Center of Finland.
- Waters, D., 2007. *Supply chain risk management: vulnerability and resilience in logistics*. Kogan Page Limited ISBN-13: 978-0-7494-4854-7.
- Willis, H., Ortiz, D., 2004. Evaluating the Security of Global Containerized Supply Chain, TR214. RAND Corporation, Santa Monica, CA.
- World Trade Organization, 2010. International Trade Statistics 2010. (available at <http://www.wto.org/english/res_e/statistics_e/its2010_e/its10_toc_e.htm>).
- Yan, S., Bernstein, D., Sheffi, Y., 1995. International pricing using network flow techniques. *Transportation Research B* 29 (3), 171–180.
- Yin, R., 1989. *Case Study Research: Design and Methods*. Sage, Thousand Oaks, CA.
- Zaltman, G., Lemansters, K., Heffring, K., 1982. *Theory Construction in Marketing: Some Thoughts on Thinking*. Wiley, New York.