Lappeenranta
University of Technology

Lauri Lättilä

IMPROVING TRANSPORTATION AND WAREHOUSING EFFICIENCY WITH SIMULATION-BASED DECISION SUPPORT SYSTEMS

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium of the Student Union House at Lappeenranta University of Technology, Lappeenranta, Finland on the 30th of June, 2012, at noon.

Acta Universitatis
Lappeenrantaensis 478

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ISBN 978-952-265-252-2

ISBN 978-952-265-253-9 (PDF)

ISSN 1456-4491

Lappeenranta University of Technology
Digipaino 2012

Abstract

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Lappeenranta 2012
88 p., 1 Appendix

Acta Universitatis Lappeenrantaensis 478
Diss. Lappeenranta University of Technology

ISBN 978-952-265-252-2
ISBN 978-952-265-253-9 (PDF)
ISSN 1456-4491

Transportation and warehousing are large and growing sectors in the society, and their efficiency is of high importance. Transportation also has a large share of global carbon-dioxide emissions, which are one the leading causes of anthropogenic climate warming. Various countries have agreed to decrease their carbon emissions according to the Kyoto protocol. Transportation is the only sector where emissions have steadily increased since the 1990s, which highlights the importance of transportation efficiency.

The efficiency of transportation and warehousing can be improved with the help of simulations, but models alone are not sufficient. This research concentrates on the use of simulations in decision support systems. Three main simulation approaches are used in logistics: discrete-event simulation, systems dynamics, and agent-based modeling. However, individual simulation approaches have weaknesses of their own. Hybridization (combining two or more approaches) can improve the quality of the models, as it allows using a different method to overcome the weakness of one method.

It is important to choose the correct approach (or a combination of approaches) when modeling transportation and warehousing issues. If an inappropriate method is chosen (this can occur if the modeler is proficient in only one approach or the model specification is not conducted thoroughly), the simulation model will have an inaccurate structure, which in turn will lead to misleading results. This issue can further escalate, as the decision-maker may assume that the presented simulation model gives the most useful results available, even though the whole model can be based on a poorly chosen structure.

In this research it is argued that simulation- based decision support systems need to take various issues into account to make a functioning decision support system. The actual simulation model can be constructed using any (or multiple) approach, it can be combined with different optimization modules, and there needs to be a proper interface between the model and the user. These issues are presented in a framework, which simulation modelers can use when creating decision support systems. In order for decision-makers to fully benefit from the simulations, the user interface needs to clearly separate the model and the user, but at the same time, the user needs to be able to run the appropriate runs in order to analyze the problems correctly.

This study recommends that simulation modelers should start to transfer their tacit knowledge to explicit knowledge. This would greatly benefit the whole simulation community and improve the quality of simulation-based decision support systems as well. More studies should also be conducted by using hybrid models and integrating simulations with Graphical Information Systems.

Keywords: simulation, transportation, warehousing, decision support systems, efficiency

UDC: 65.012.2:004.4:004.94:658.286:658.78

Articles

The thesis consists of an introductory part and the following articles:

(1) Lättilä, L. and Hilmola, O-P. (2012). Forecasting long-term demand of largest Finnish sea ports. *International Journal of Applied Management Science,* 4(1), pp. 52 - 79

(2) Lättilä, L. (2011). Modelling seaports with agent-based modelling and system dynamics. *International Journal of Logistics Systems and Management*, 10(1), pp. 90 -109

(3) Hilletofth, P., Lättilä, L., Ujvari, S. and Hilmola, O-P. (2010). Agent-based decision support for maintenance service provider. *International Journal of Services Sciences*, 3(2/3), pp. 295 - 314

(4) Lättilä, L., Saranen, J. and Hilmola, O-P. (Submitted). Decision support system for AS/RS investments: Real benefits out of Monte Carlo simulation. *Submitted for referee process in Int. Journal of Manufacturing Technology and Management*

(5) Lättilä, L., Hilletofth, P. and Lin, B. (2011). Hybrid simulation models: when, why, how?, *Expert Systems with Applications*, 37(12), pp. 7469 - 7975.

(6) Lättilä, L. and Saranen, J. (2011). Multimodal transportation risk in the Gulf of Finland region, *World Review of Intermodal Transportation Research*, 3(4), pp.376 - 394

Contribution of the author

(1) Main author. Gathered most of the data, created the simulation model and conducted the statistical analyses required for the paper. Participated in all stages of preparing the paper.
(2) Sole author
(3) Constructed the simulation model presented in the paper, as well as the mathematical model. Analyzed the results of the model and wrote the sections regarding the model and its results.
(4) Main author. Worked with the case company and constructed the simulation models with them. Analyzed the results, participated in all stages of preparing the paper.
(5) Main author. Did most of the literature review. created the analyses, and wrote most of the paper.
(6) Main author. Participated in the interviews, constructed the simulation models and participated in all stages of preparing the paper.

Acknowledgements

This project was made possible with the help of many different persons. First and foremost I would like to thank my advisor Professor Olli-Pekka Hilmola for providing feedback and support during the whole process. Professor Markku Tuominen played a significant role by assisting in getting adequate funding and giving moral support during my years at the department. Professor Jukka Hallikas and Professor Tuomo Kässi played likewise an important role in guiding me towards choosing doctoral studies while I was still doing my Master's degree.

I would also like to thank Professor Chee Wong from Hull University Business School and Professor Albert Tan from Malaysia Institute of Supply Chain Management for giving insightful remarks and comments, which were vital in improving the quality of this thesis. The thesis would have lacked many important issues without your comments. In addition, I owe thanks to Professor Wladimir Segercrantz for working as the opponent for the thesis.

A significant amount of work in this thesis was done during the STOCA and Mopo – projects. Juha Saranen, Milla Laisi, Bulcsu Szekely, Jouko Karttunen and Ville Henttu from LUT Kouvola, and Jyri Vilko from LUT Nordi worked closely with me during these projects. The personnel from Kotka Maritime Research Centre and Estonian Maritime Academy should also receive my thanks. In addition, Per Hilletofth and Sandor Ujvari should receive my thanks for our joint-work in Högskolan i Skövde. During my short visits I started to take my first steps towards multi-method simulations, which in retrospect can be seen to be one of the most important steps in my career.

I had also the possibility to work with researchers from Hull University Business School in 2011. It opened my eyes regarding academia and allowed me to have insightful discussions on various topics. I would not have thought about using Operations Research to analyze piracy before visiting your research institute.

I should not forget other persons in LUT Kouvola. Even if we have not done that much work together, it does not mean that we have not had interesting discussions. The personnel at the Department of Industrial Management have also provided a lot of support during these years. A lot of interesting work was especially done with Samuli Kortelainen, but working also with other persons from different laboratories has given me a broader view about science in general. Pirkko Kangasmäki requires a special mentioning from the faculty as she is able to keep everything in order from the side of administration.

My academic writing skills have improved significantly by participating in various writing courses. Angappa Gunasekaran, Binshan Lin, and Eelko Huizingh allowed me to have a better understanding over the publication process. Sinikka Talonpoika polished the language of the thesis and improved the overall readability of the work. Many basic readability issues would have gone unnoticed without your work.

Financially I would like to thank the Finnish Doctoral Program in Industrial Engineering and Management (Tuotantotalouden valtakunnallinen tutkijakoulu), Finnish funding Agency for Technology and Innovation (TEKES), and European Union's European Regional Development Fund (Central Baltic Interreg IV A Programme 2007–2013) for providing the main funding for the research project. Research Foundation at Lappeenranta University of Technology (Both the general fund, and Lauri and Lahja

Hotinen Fund) and the Society for Viipuri School of Economics (Tuomo Rönkkö Fund) also provided financial support during this process.

Life is not only about working. The players at Louhi gaming club and WT practitioners (especially coaches Simo Sairanen, Jonne Härkänen, and Artem Kotchkin) have allowed me to have something else to think about than my work. Exploring civilizations through the ages and getting bruised have allowed me to concentrate properly at work and provided me with additional energy to finalize this work.

Finally, I would like to thank my family and friends. Without my parents, Hannu and Sirpa, I would not be writing these acknowledgements. Despite our constant fighting when we were younger, my brother Ville has provided me a totally different view on academic studies. This has helped me to put everything into perspective. Finally, my fiancée Anja made sure that the morale at the home front stayed high, regardless of me spending more time at work than at home during the final six months of this project. Thank you.

Lappeenranta, June 2012

Lauri Lättilä

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LIST OF ABBREVIATIONS

DSS	Decision Support System
ABM	Agent-Based Modelling
SD	System Dynamics
DES	Discrete-Event Simulation
IS	Information Systems
IT	Information Technology
MIS	Management Information System
SIMDSS	Simulation-Based Decision Support System
SCM	Supply Chain Management

PART I: OVERVIEW OF THE THESIS

1 INTRODUCTION

1.1 Motivation for the Research

Transportation and warehousing play a major role in modern society. Their share of the GDP in USA and Europe is between 7 to 8 percent (COM 2009; Wilson 2010) and they also work as a catalyst for economic growth (Quinet and Vickermann 2004). Logistics as a whole is a major source of costs for companies (in Finland the total cost of logistics is about 12 – 14 % of the total revenue (Solakivi et al. 2010)). According to many studies (Cap Gemini 2007; Selviaridis and Spring 2007; Marasco 2008; Hilletofth and Hilmola 2010; Hilmola and Tan 2010), logistics is currently heavily outsourced. Outsourcing provides many advantages to logistics, improved efficiency being one of the reasons for it (Razzaque and Sheng 1998). According to Li et al. (2006) good supply chain management practices may directly impact the competitive advantage of organizations. Efficiency improvements are a major factor in logistics, which can be seen especially in the development of cycle time requirements during the last 50 years (Hesse and Rodrigue 2004). As the efficiency of logistics has already improved significantly, and supply and demand are more integrated, novel approaches are required for further improvements.

In most cases transportation and warehousing are constantly running processes. In some cases, like humanitarian aid, the supply chain is established quickly and effectiveness is very important (Kovács and Spens 2007). These situations require different types of decision-making. Gorry and Scott Morton (1971) have analyzed the requirements for a management information system (MIS) from two perspectives. The first perspective is the level of the decision. The decision can be operational control, management control, or strategic planning. The second perspective is the type of the decision. The problems can be structured (there is a procedure to solve the problem), unstructured (no procedures exist), or semi-structured (there are some structured and unstructured elements). The information system (IS) to support the decision will depend on these two perspectives. This is also true for transportation and warehousing. As they are in many cases constantly running processes, the decisions will be operational and structured. This will have an impact on the type of the decision support system.

The efficiency of transportation and warehousing can be improved with different optimization methods, or with simulation. The purpose of optimization is to find the best possible solution to a problem (Hillier and Lieberman 2005). The purpose of simulation is to improve or understand a system by creating a computer imitation of the system (Robinson 2004). Simulation in itself does not guarantee improvements, but it can be combined with other methods (Ivanov 2009). Simulations are also frequently used with logistics (Saranen 2009). Some minor details may also have a great impact on real world results (Ujvari and Hilmola 2006), and mathematical models may not be able to include these in the decision-making. According to Min and Zhou (2002,) one important aspect in future supply chain modelling is to create model-based decision support systems (DSS) utilizing communication- and knowledge- discovering techniques. Visual aids (Graphical Information Systems) should be combined to the models as well. Simulations should not be used in all cases (Banks and Gibson 1997). In transportation and warehousing many problems have mathematical methods which are able to provide an answer to the decision-makers. These methods include, for instance, vehicle routing problems (Laporte 1992), scheduling (Cordeau et al. 1998), transportation problems (Camm et al. 1997), and network optimization (Zhang & Yang 2004). However, there are many advantages that are associated with simulations only (Banks 1998; Robinson 2004). Many different types of simulation approaches are also available. According to Jahangirian et al. (2010), the most widely used approaches in business and manufacturing are Discrete-Event Simulation (DES), System Dynamics (SD), Agent-Based Modelling (ABM), and hybrid simulations. Even with these four approaches, it is possible to create a wide spectrum of different types of simulation models. Choosing the most suitable simulation approach is an important task in any simulation project (Banks et al. 2005). When the model becomes a part of a DSS, it may be even more critical, as the user is not an expert in the subject matter regarding simulations. The modeller needs to choose the correct approach, or otherwise the decision support system might give bad advice to the user. Also, the user is rarely a modeller, which makes it necessary to separate the user from the actual model.

Table 1 shows some recent samples of the use of simulations in transportation and warehousing problems. All the major approaches have been used, but some publications do not discuss at all why a certain approach has been chosen (Eksioglu et al. 2010; Henesey et al. 2009; van der Vorst et al. 2009). Some publications (Cagliano et al. 2011; Park et al. 2011) discuss the advantages of individual approaches, but these discussions tend to be short. Also, only few publications (van Dam et al. 2009) compare multiple models which use different approaches to analyze the same problem. Hybridization (Sun et al. 2010) can overcome the problems of individual approaches, but the number of publications concerning hybrid models is still a small one. In addition to combining multiple simulation approaches, it is possible to combine simulation with other approaches (Frayret et al. 2007). The choice of the simulation approach is an important one, and more research is needed to create guidelines for choosing the appropriate approach when modelling specific problems.

Table 1: Some applications of simulations in transportation and warehousing

Author	Journal	Field of study	Method
Cagliano et al. (2011)	Journal of Manufacturing Technology Management	Fashion	SD
Eksioglu et al. (2010)	Forest Products Journal	Furniture industry	DES
Frayret et al. (2007)	International Journal of Flexible Manufacturing Systems	Forest products	ABM & optimization
Henesey et al. (2009)	Autonomous Agent and Multi-Agent Systems	Container terminal	ABM
Park et al. (2011)	Automation in Construction	Concrete supply chain	SD
Sun et al. (2012)	Advanced Engineering Informatics	Seaport	Hybrid (DES & ABM)
van Dam et al. (2009)	Computers & Chemical Engineering	Oil refinery	SD & ABM
van der Vorst et al. (2009)	International Journal of Production Research	Food supply chain	DES

Uncertainty is a feature of modern supply chains. According to Davis (1993), it is possible to estimate the impact of uncertainty with the help of modelling. In Hewlett Packard, about

40 % of inventory is due to necessary minimum stock. This includes work in process, pipeline, review periods, etc., and this type of inventory is needed to handle the daily operations, even without any supply or demand variation. The rest of the inventory is due to uncertainty. Most of the uncertainty comes from demand variation, while only a small fraction comes from supply and production uncertainty. According to van der Vorst and Beulen (2002), there are four inherent characteristics for supply chain uncertainty: (i) supply; (ii) demand and distribution; (iii) process; and (iv) planning and control. This uncertainty can be analyzed on a more detailed level by analyzing the sources from the perspective of quantity, quality, or time. These sources are supply chain configuration, supply chain control structure, supply chain information system, and supply chain organizational system. All these four categories can be managed and improved. However, estimating the best possible system is a difficult task due to the interconnectivity of the parts. Also, even if uncertainty can be reduced by better systems, it cannot be totally eliminated. This needs to be taken into account in decision-making, or costly mistakes may occur.

1.2 Research Objective

The objective of this thesis is to enhance the knowledge in the use of multi-method simulations in transportation and warehousing DSSs. The overall research question is: "*How can transportation and warehousing efficiency be improved with simulation-based decision support systems?*" The study consists of six publications where simulation has been used as the main research method. The simulations concentrate on transportation and warehousing issues, and different approaches have been used in different publications. The research problem can be approached with the help of sub-questions:

1) What are the advantages and disadvantages of different simulation approaches?
2) Where can hybridization of different simulation approaches offer additional insights?
3) What other approaches can be combined with simulations in order to have more useful decision support systems?
4) How can uncertainty be included in decision support systems?

In addition to the individual publications, the research question is further analyzed with more advanced simulation models, used as parts of DSSs.

1.3 Scope and Limitations of the Study

The framework of this thesis is presented in Figure 1. The main focus of the study is on simulation-based DSSs (SIMDSS) in transportation and warehousing. Transportation and warehousing are the actual physical handling of goods in various supply chains. They can be seen to be sub-sections of logistics, which is a sub-section of supply chain management (SCM). This issue is discussed more thoroughly in Section 2.1.

The purpose of Operations Research is to find optimal (or near optimal) solutions to operational issues (Hillier and Lieberman 2005). Transportation and warehousing are important parts in all supply chains, and their operational efficiency is of high importance to organizations. As such, improving the processes leads to significantly higher profits for organizations. Simulation is one of the possible tools in Operations Research.

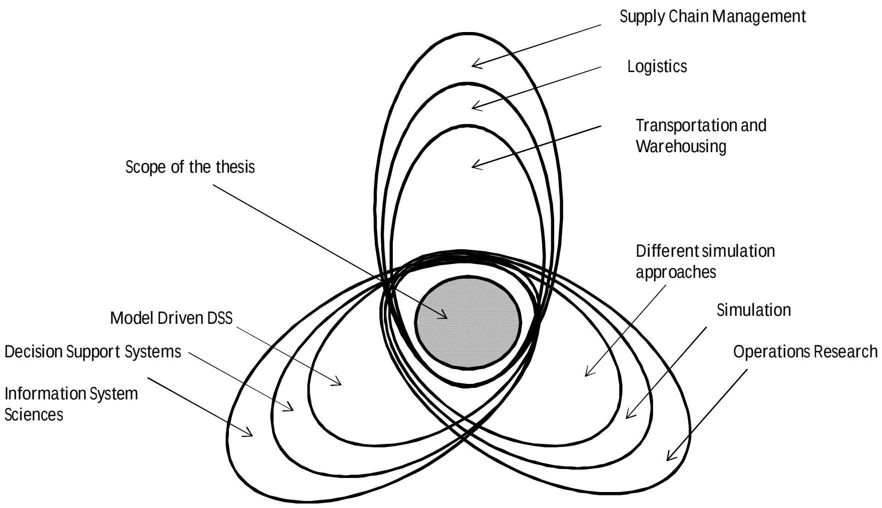

Figure 1: The framework of the thesis

This study also analyzes the simulation models from the DSS perspective. DSS is a subset of information systems, which concentrates on enhancing the actual decision-making process (Power 2002). Simulation modelling requires very high expertise in modelling, and most problem domain experts do not have adequate knowledge in constructing these models. The modeller will co-operate with the expert and create a DSS, which will help the manager to make better decisions.

1.4 Organization of the Thesis

This thesis consists of two parts; the first one provides an overview of the study, and the latter one contains the actual scientific publications. Figure 2 shows the outline of the thesis. The first part is divided to eight sub-sections. The first sub-section clarifies the motivation for the research, discusses the framework and the research questions, as well as provides an overview of the structure of the thesis. Sections two to four discuss transportation and warehousing, simulations, and DSS. Each section contains an overview of the topic and current practices. The fifth section discusses the methodology of the research, while the sixth section presents the findings of individual publications. Section seven synthesizes the results obtained in the individual publications and proposes a framework to be used with simulation-based DSS in transportation and warehousing. The final section summarizes the thesis and discusses potential further avenues for research.

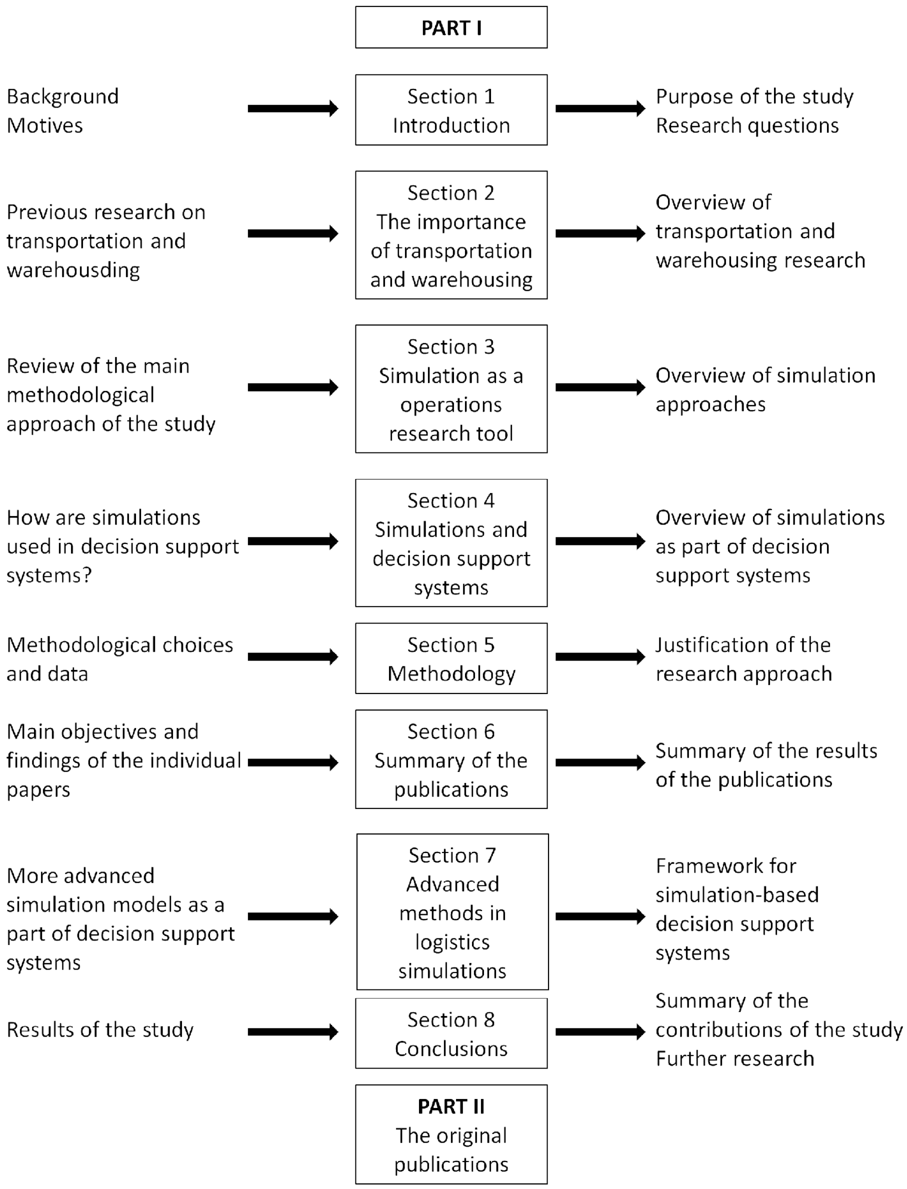

Figure 2: Outline of the thesis

2 THE IMPORTANCE OF TRANSPORTATION AND WAREHOUSING

2.1 Definitions

According to the Council of Supply Chain Management Professionals (CSCMP 2010), supply chain management consists of the planning, management, and coordination of all activities from procurement, conversion, and all logistics management activities. Logistics (CSCMP 2010) is the part of supply chain management which plans, implements, and controls the actual transportation and warehousing of goods and information. Logistics management (CSCMP 2010) integrates and optimizes logistics with other functions, such as sales, marketing, and manufacturing. According to these definitions, logistics is part of logistics management, which in turn is part of supply chain management. The direct quotes for these definitions are presented in Appendix.

According to Hesse and Rodrigue (2004), logistics integration has evolved due to improvements in information and communication technologies. The timely supply of raw materials and effective organization of distribution have improved step by step from the 1960s. The evolution of logistics integration is presented in Figure 3. This is also in line with the definitions of CSCMP (2010).

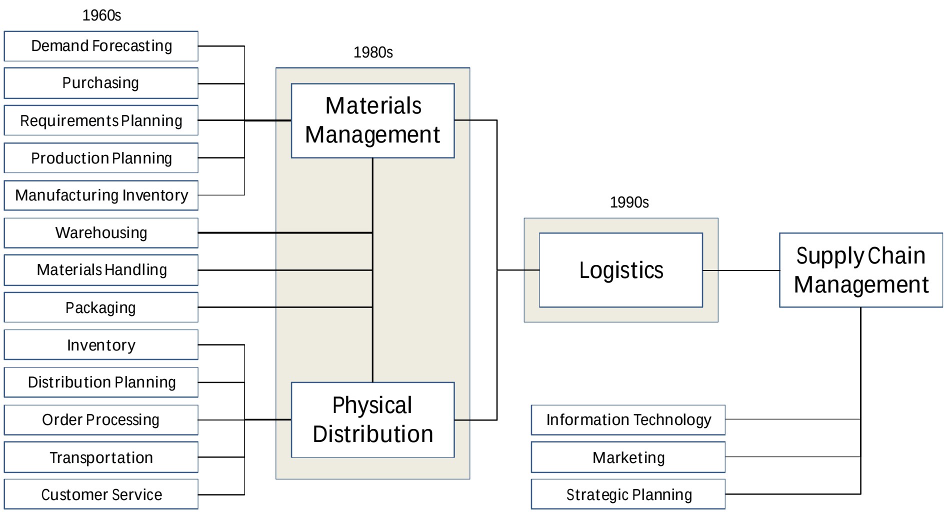

Figure 3: Evolution of logistical integration (Hesse and Rodrigue 2004)

Larsson and Halldorsson (2004) have surveyed the use of the words “Supply Chain Management” and “Logistics” among leading educators in different parts of the world. They have identified four different categories, which can be used to describe the relationship between logistics and SCM. The first one is the traditionalist view, where SCM is a part of logistics, generally seen to be inter-organizational logistics. The second one, re-labelist, sees SCM to be equal to logistics, but it has been simply renamed. In the unionist view, logistics is a part of supply chain management. In the last category, intersectionist, SCM is seen to be a broad strategic issue, while logistics covers mainly operational issues. In this thesis, the unionist view has been chosen. The definitions for logistics and SCM by CSCMP (2010) confirm with this view. However, according to Vafidis (2007), the issue between logistics and SCM is not very clear cut. SCM can be seen to be both too narrow and too broad, simultaneously.

In this thesis, the main focus is on transportation and warehousing, which are only one part of logistics. Transportation is seen as the physical flow of goods. It does not regard the larger process of transportation planning, which includes the management of transporters, integration between partners, and information flows. Warehousing considers the storing of goods. It is part of the larger process of warehouse management, which includes picking, shipping, and planning. The use of a SIMDSS is part of the planning process for both transportation and warehousing.

2.2 The Impact of Transportation and Warehousing on Society

Transportation and warehousing are important parts of the modern society. They have been able to make the world more interconnected, and generally the amount of trade has grown faster than the general GDP (WTO 2011). The financial crisis which began in 2008, dropped the volume of exports by 12 per cent in 2009, while the global GDP dropped only by 3 per cent. However, in 2010 the trade increased again by 14 per cent while the GDP grew only by 4 per cent. According to Wilson (2010), business logistics accounted for 7.7% of the whole US GDP in 2009. In the EU the transportation sector accounted for 7% of total GDP (COM 2009). In the EU countries, the growth of the turnover (excluding inflation) in the transportation sector was between 14.4% in Germany and 409% in Romania during the years 2000 – 2009 (Eurostat 2011). The global relative growth of the GDP and trade are presented Figure 4.

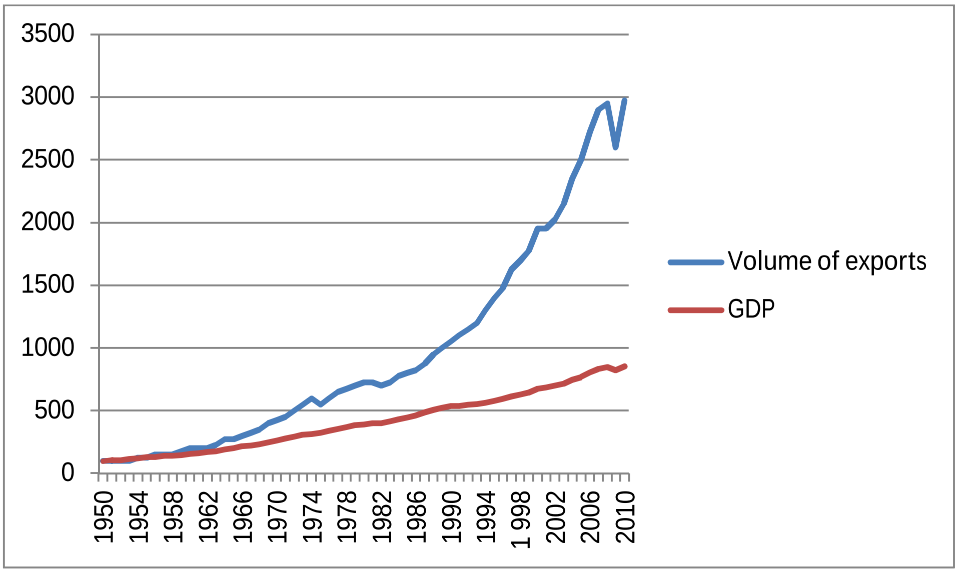

Figure 4: Indices for GDP and global exports. 1950 = 100. (WTO 2011)

In the European Union, over 5% of total employment is due to transportation (COM 2009). According to US Census (2010), the transportation and warehousing sector employed 4 438 903 persons in the United States during the year 2008. The sector employed 3 462 472 persons in 1998, so overall the number of personnel increased by 28.2%. During the same time-period, the total employment in all sectors increased only by 11.8%. The fact that the growth of the transportation and warehousing sector was over double compared to all sectors combined, shows that transportation and warehousing is still a vital industry despite its long history (the use of canals as a transportation route began in the late 18th century and their growth rate peaked in 1836 (Ausubel and Marchetti 2001)). In Finland the total logistics costs of an industrial or retail organization are 12 – 14 per cent of the total revenue (Solakivi et al. 2010). Logistics costs consist of transportation, warehousing, capital investments due to stocking, logistics management, packaging, and others (Solakivi et al. 2010). Warehousing investment and operating costs account for 22 to 24 percent of the total logistics cost in the USA and Europe (Baker and Canessa 2009).

Transportation has also a great impact on the atmosphere. According to the European Commission (2009) and UIC (2009), the CO_2 emissions have increased steadily for the whole 1990s and early 2000s. All other sectors have decreased their emissions during the same time-period. One challenge for the 21st century is to decrease the environmental impact of transportation (COM 2009). This can be achieved by improving the efficiency of operations and shifting to low-carbon transportation modes.

One important issue in transportation is the chosen transportation mode. In the European Union the vast majority of tonne kilometres are transported by road (Eurostat 2011). Figure 5 shows the development of the modal- split in EU-15 area during the last 15 years.

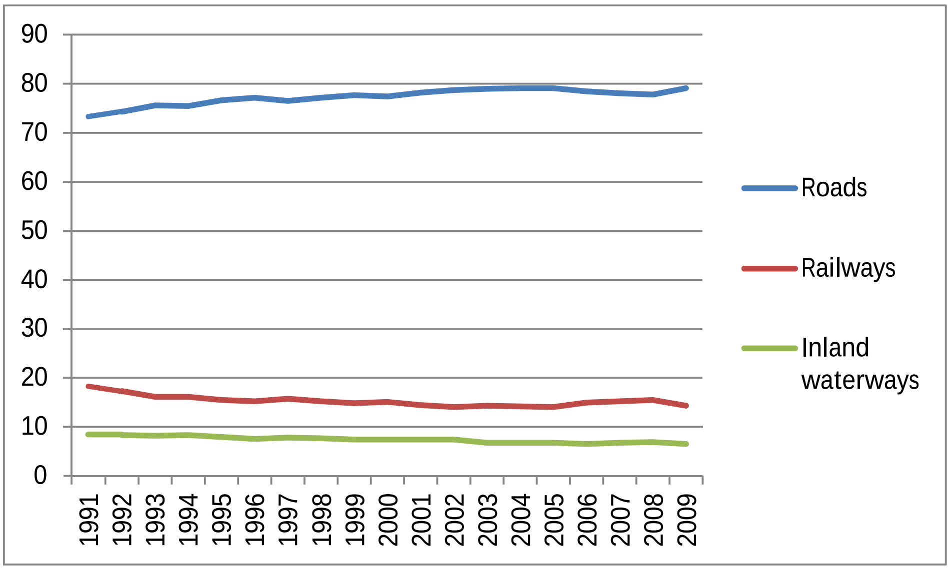

Figure 5: Modal split in the EU-15 area (Eurostat 2011)

As can be seen in Figure 5, the relative share of rail transportation has slightly decreased during the last 15 years, while road transportation has increased its share. Companies use multimodal transportation over long distances, but over short distances unimodal road transportation has smaller total costs (Rutten 1998). The research of multimodal transportation is still relatively new and offers many challenges to companies (Bontekoning et al. 2004; Macharis and Bontekoning 2004).

2.3 Transportation and Warehousing as Part of Supply Chain Management

As stated in Section 2.1, this thesis views logistics as a smaller part of SCM. Also transportation and warehousing are subsections of logistics and can be regarded as the most important parts in international supply chains (Tuzkaya and Önüt, 2009). According to various studies (Cap Gemini 2007; Selviaridis and Spring 2007; Marasco 2008; Hilletofth and Hilmola 2010; Hilmola and Tan 2010), logistics and warehousing are currently heavily outsourced to third-party logistics service providers. According to Bask (2001), logistics services can be seen to be a triad between the logistics service provider, the buyer, and the seller. This is presented in Figure 6. The logistics service provider does the actual transportation and possible warehousing, but relationship management can be seen to be a part of SCM.

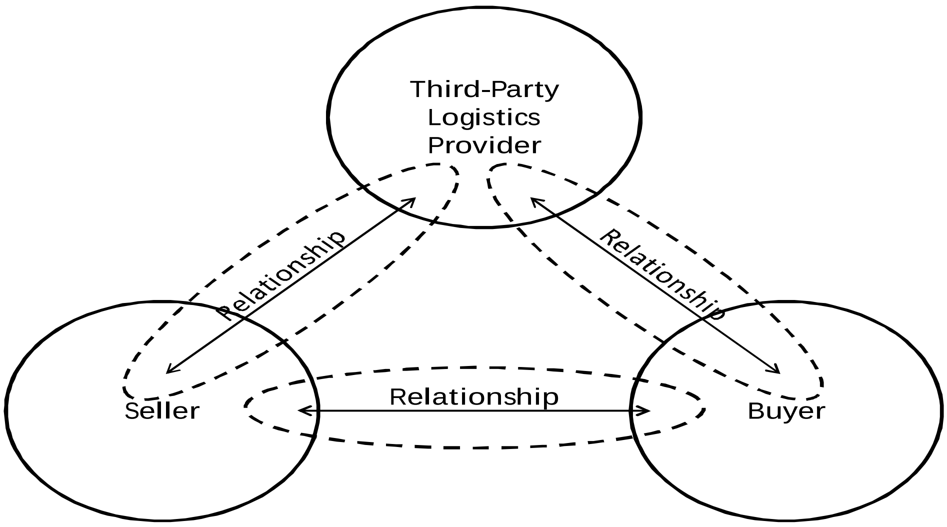

Figure 6: Three dyadic relationships (Bask 2001)

Sanchez-Rodriguez et al. (2008) have expanded Bask's framework to include various uncertainties in transportation. Uncertainties can come from five different sources, which are:

- Uncertainty related to suppliers
- Uncertainty related to customers
- Uncertainty related to carriers
- Uncertainty related to control systems
- External uncertainty.

Sanchez-Rodrigues et al. (2010) conducted a focus group study to find out the major uncertainties in transportation supply chains. Four different clusters were then constructed according to the focus groups:

- Delays
- Demand and information issues
- Lack of coordination
- Delivery constraints.

Sanchez-Rodrigues et al. (2010) state that these clusters come from two different root causes: an unclear framework in terms of the key performance indicators (KPIs) of transport, and not the best supply chain relationships. These two issues are of high importance, if smooth transportation processes are to be ensured. According to van der Vorst and Beulen (2002) and Germain et al. (2008), uncertainty is an inherent part of supply chains.

Transportation and warehousing are a part of a process called postponement and speculation (Bucklin 1965). Speculation means that the actor chooses to shift the risk on itself by speculating on what is going to be needed in the future. Postponement is the opposite of this. According to Pagh and Cooper (1998), there are four different generic strategies for supply chain postponement, as presented in Figure 7.

		Logistics	
		Speculation Decentralized inventories	Postponement Centralized inventories
Manufacturing	Speculation Make to inventory	The full speculation strategy	The logistics postponement strategy
	Postponement Make to order	The manufacturing postponement strategy	The full postponement strategy

Figure 7: Postponement and speculation and generic supply chain strategies (Pagh and Cooper 1998)

The proper strategy needs to be chosen according to the product characteristics, market and demand, and the scale and capabilities of manufacturing and logistics. Manufacturing postponement is more or less an issue of internal warehousing, but the chosen distribution network will impact heavily on what kind of warehousing will be required and in which parts of the chains.

Fisher (1997) has approached the issue of choosing the right supply chain according to the characteristics of the product. Functional products have predictable demand, while innovative products have unpredictable demand. According to Fisher (1997), innovative products should have a responsive supply chain, while functional products should have an efficient supply chain. Christopher et al. (2006) have a similar approach and also take into account the supply characteristics. Their framework is presented in Figure 8.

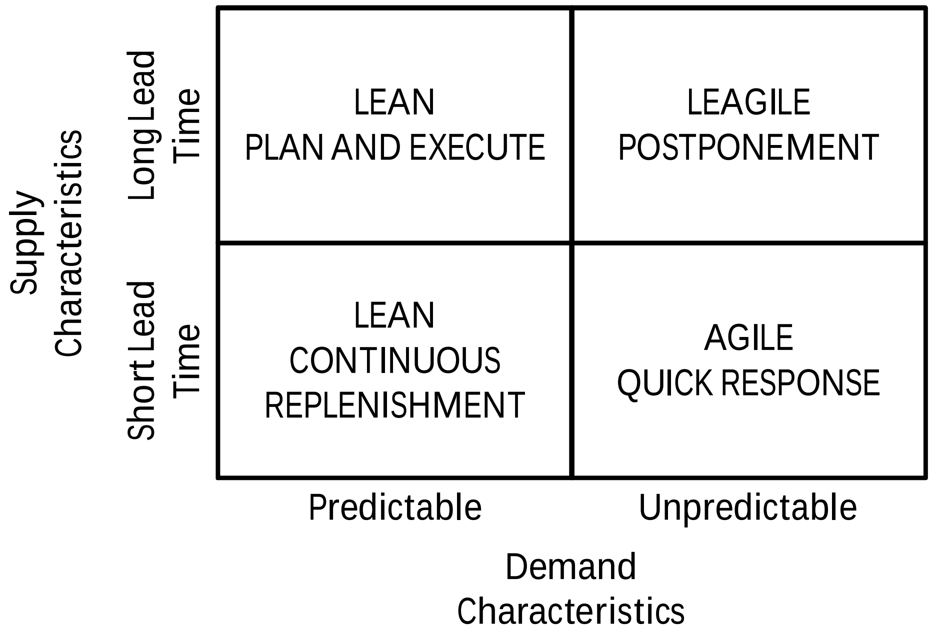

Figure 8: Pipeline selection strategy (Christopher et al. 2006)

A good overview of the characteristics of different types of supply chains can be found in Hilletofth (2009). Hilletofth has developed a way to create differentiated supply chain strategies, consisting of four steps, which are:

(1) Developing a segmentation model
(2) Understanding the market we serve
(3) Understanding the capabilities to serve the market
(4) Developing necessary supply chain solutions.

Different supply chains have different requirements for transportation and warehousing. Also, as Sanchez-Rodrigues (2010) point out, one of the key sources of uncertainty in transportation comes from an unclear framework in terms of transport KPIs. The transportation and warehousing of an organization need to take the chosen supply chain strategy into account and try to minimize the costs for the company to stay competitive in the marketplace.

Postponement in itself does not indicate where the actual warehouses should be located. Network design is the part of supply chain management dealing with this issue. The effect of centralizing warehouses was first discussed by Maister (1976). Combining warehouses makes it possible to have a smaller safety stock for the same availability to customers. This follows the “square root law”, e.g. total inventory in the system is proportional to the square root of the number of warehouses desired. Zinn et al. (1989) have later expanded the model to include the cross-correlation between different warehouses and the uncertainty of demand. Later the discussion has expanded to cover many different aspects in the actual location design. Figure 9 shows a generic supply chain network (modified from Melo et al. 2009).

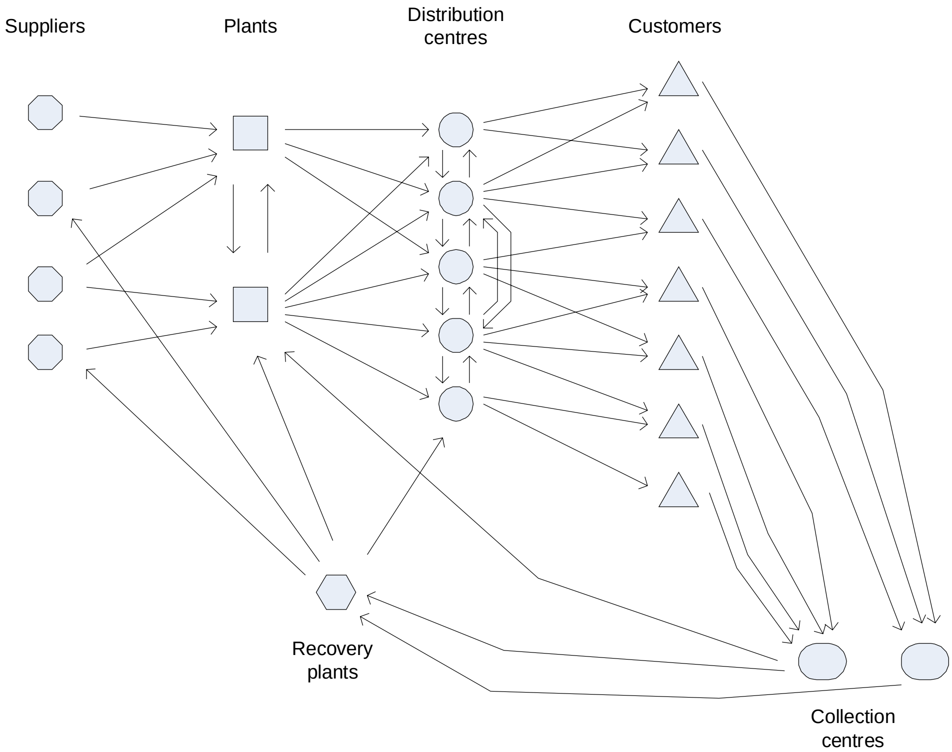

Figure 9: A generic supply chain network (modified from Melo et al. 2009)

In a recent literature review, Melo et al. (2009) have analyzed studies concentrating on facility location and supply chain management. In their review they divide the methods according to the number of layers, number of products, number of periods, and type of data (deterministic / stochastic). As such, there are many different ways to approach the problem. It is also possible to make other divisions, e.g. according to capacity, inventory, procurement, production, routing, and transportation modes. In addition to these, there are multiple methods for solving the problem. Melo et al. (2009) also point out that many other issues can be included in the problem, such as financial aspects, risk management, and others. Overall, it can be argued that the network design problem is multi-faceted and complex to solve.

In addition to the network design, it is important to decide the correct amount of goods to be transferred between different locations. This is the so-called lot-sizing and consolidation problem. According to Aissaoui et al. (2007), this problem can be approached with various kinds of assumptions. The problem can contain either a single item or multiple items. In single item problems only one product is analyzed, while multiple item problems contain more than one product. In addition to the number of items, it is possible to analyze only one period or multiple periods. Finally, the problems might include discounts. Aissaoui et al. (2007) have analyzed the problem from the supplier selection perspective, but the same method can be used to analyze different parts of the supply chain. The problem becomes more difficult, if the issue is analyzed from both the buyer's and the vendor's perspective (Ben-Daya et al. 2008). It can be stated that this problem is multi-faceted and complex as well.

The ecological impact of industrial activity has started to receive increasing attention recently. Srivastana (2007) points out that most of the green supply chain issues have been analyzed from the perspective of compartmentalized operation strategy areas. Srivastana continues by stating that the Operations Research tools are a good way to analyze green supply chains, as the problem area is a complex one. According to Rao and Holt (2005), a green supply chain can create competitive advantage which will lead to higher economic performance as well. As such, not only preserving the environment, taking environmental issues into consideration can improve the performance of the organization as well.

3 SIMULATION AS AN OPERATIONS RESEARCH TOOL

3.1 Operations Research

Simulation belongs to a larger group called Operations Research, which can be seen to have begun during the Second World War, when scientists conducted research on military operations. Since then, the same approach has been used in other organizations as well, with the purpose of finding the best solution to a specific problem. Typically, mathematical models are constructed, validated, and optimized to reach the solution. According to Hillier and Lieberman (2005) some of the most widely used tools in Operations Research are:

- Linear programming
- Network optimization
- Dynamic programming
- Integer programming
- Nonlinear programming
- Metaheuristics
- Game Theory
- Decision Analysis
- Markov Chains
- Queueing Theory
- Inventory Theory
- Markov Decision Processes
- Simulation.

Simulation models use mathematical or logical constructs and calculate the final solution. Simulation in itself does not optimize the solution for the problem, it simply runs the model according to the specifications (Robinson 2004). However, simulations, heuristics, and optimization often work in conjunction (Ivanov 2009). A simulation model may be based on some heuristics, which are then improved using an optimizer. Design of Experiments is also frequently done with simulations (some recent examples include Chen et al. 2009; Longo 2010; Bottani and Montanari 2010; Tiacci and Saetta 2011). Simulations are also frequently used to enhance learning, where the main purpose is not to improve a system (Haapasalo and Hyvönen 2001).

According to the January-February 2009 Statement of the Editor-in-Chief of Operations Research Journal (OR –2009 EIC), a high percentage of submissions to the journal use either simulation or stochastic models as their main methodology. This indicates an increased interest in solving more relevant problems and modelling the behaviour of various systems more precisely.

3.2 Simulations

Robinson (2004, p.4) has defined simulation as "Experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system". Others (e.g. Banks et al. 2005) offer a relatively similar definition. Robinson (2004) has also compared simulation with other modelling approaches and identified three main differences, which are summarized in Table 2.

Table 2: Simulation versus other modelling approaches (Modified from Robinson 2004)

Modelling variability	Many traditional modelling approaches do not contain stochastic elements, which can have a big impact on the results.
Restrictive assumptions	Simulation does not require restrictive assumptions that do not exist in the real system, but are included in other modelling approaches.
Transparency	It is easier to get buy-in from a model with an animated display of the real system compared to equations or large spreadsheet models.

The simulation process contains many phases. According to Banks et al. (2005), most processes are relatively similar to each other. Some differences may occur due to different simulation approaches, but generally speaking the processes are the same. Figure 10 shows the simulation process as a flowchart.

The simulation process begins by formulating the problem. The policymaker and analyst must agree on a good problem articulation in the very beginning of the project. It is also important to set the overall objectives and create an overall plan before modelling begins (Sterman 2000, Banks et al. 2005, North and Macal 2007).

After the formulation of the problem, the model has to be conceptualized. Depending on the chosen simulation approach, there are different methods to accomplish this. In System Dynamics, causal loop, model boundary, and policy structure diagrams are usually formed (Sterman 2000). In Agent-Based Modelling, the potential agents in the model and how they make their decisions need to be considered (North and Macal 2007). In Discrete-Event Simulation, the potential entities in the system, events, activities and delays are considered (Banks et al. 2005). This needs to be conducted before the actual computer simulation model can be created.

Data collection occurs during the whole simulation project as the model is refined and modified. The data may already exist in databases, it can be gathered from public sources, or needs to be gathered from the real system. When the conceptual model is ready, it is translated to a computer model. Here the modeller needs to choose the appropriate program and start writing the actual code. (Banks et al. 2005; North and Macal 2007)

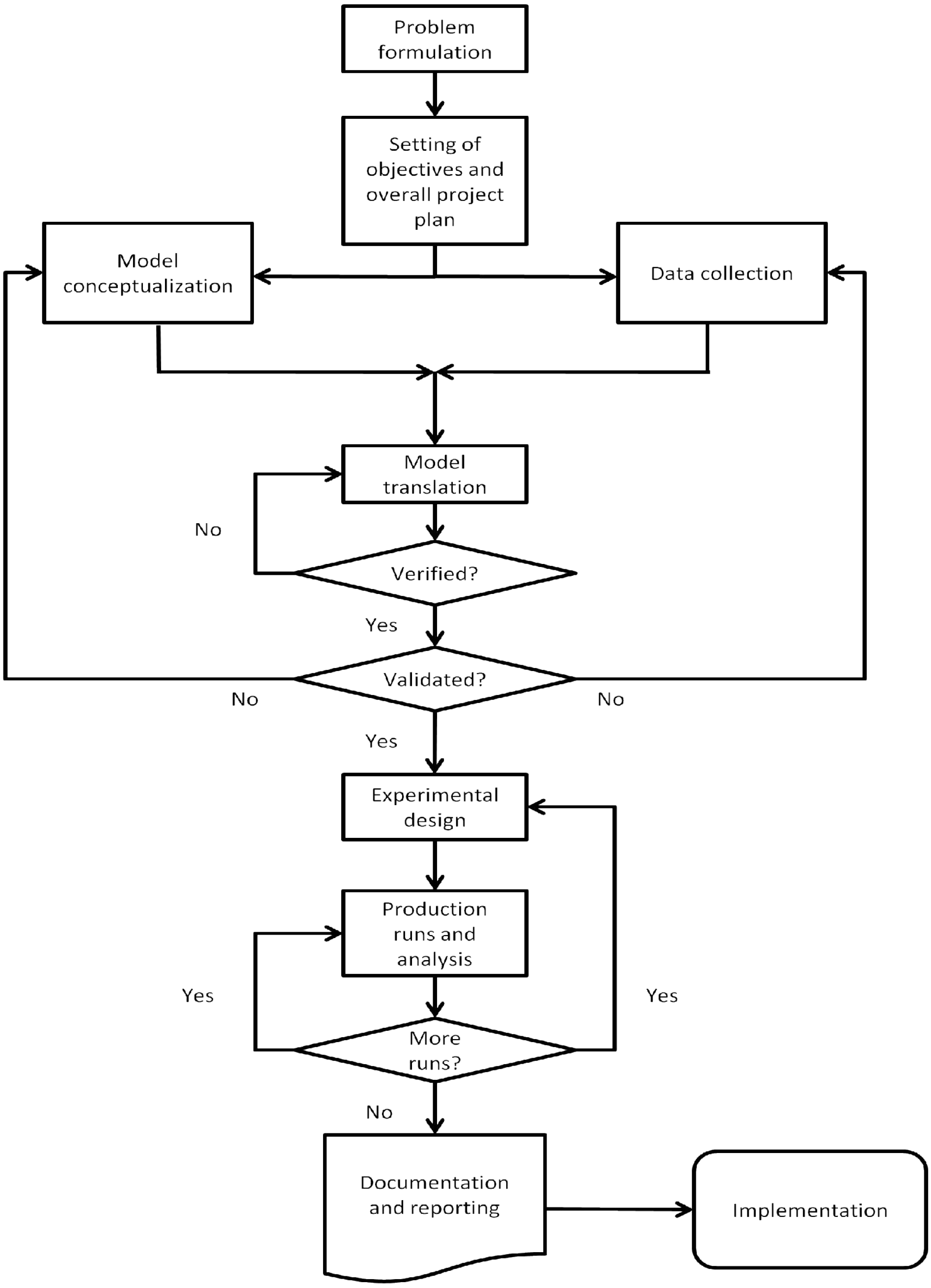

Figure 10: Simulation process (Banks et al. 2005)

Verification and validation are important issues in simulation modelling. Verification means that the model does what it is supposed to do, and validation means that the model represents the system (Banks et al. 2004). According to North and Macal (2007), potential ways to conduct verification are: documentation, structured code walk-throughs, structured debugging walk-throughs, unit testing, formal methods, test cases and scenarios, model logging, and rapid prototyping. North and Macal also present ways for doing practical validation. These include requirements validation, data validation, face validation, process validation, model output validation, agent validation, and theory validation. Both verification and validation are large issues, and according to Sterman (2000), true validation and verification is impossible, as models are always some sort of abstractions from some person's mental models, and thus all models are wrong. More information about the issue can be found in Balci (2003) or North and Macal (2007).

Experimental design consists of choosing the alternatives to be simulated. This is more or less an iterative process in conjunction with the analysis phase. The alternatives are different policies concerning the system. Experimental design may change only some operational aspects of the system (required safety stock), modify capacity (including a new machine), or even change the whole operational rules (e.g. production strategy change from make-to-stock to make-to-order). Many other items need to be chosen as well (such as the initialization period, the length of simulation runs, and the number of replications), and after that the results are analyzed. The analyst then decides whether more runs are required or not. (Banks et al. 2005, Sterman 2000)

During the construction it is strongly recommended to make documentation about the process (Banks et al. 2005). This includes making comments on the source code so that it is possible to come back to the model later on and make changes. Also, during the project it is advisable to make progress reports to other stakeholders about what has been done and to introduce the prototypes. Collaborative modelling is also possible, but it might not be possible if the actual coding takes a lot of time (Sterman 2000, North and Macal 2007).

The final implementation phase depends heavily on the successfulness of the previous steps. The more the users or decision-makers have taken part during the whole process, the more likely the model is taken into real use. (Banks et al. 2005)

3.2.1 Advantages of simulation

According to Banks (1998), there are many advantages associated with simulations. The potential benefits are presented in Table 3. According to Robinson (2004), simulations have four advantages. The first advantage is fostering creativity, as simulations allow trying out ideas in a risk-free environment. The second advantage is knowledge creation and understanding. Simulation can work as a catalyst, allowing people to think about a problem in a different way, which helps them to understand the system better. The third advantage is visualization and communication. A visual simulation is a good way to communicate ideas to others. It makes buy-in easier to achieve when the proposed system can be presented in a visual environment. The last advantage is consensus building. Simulations allow parties with differing opinions to share their concerns on an objective platform and to test ideas, which helps in creating consensus between the parties.

Table 3: Advantages of simulation (Banks 1998)

Choose correctly	Testing every aspect of a change before committing resources
Compress and expand time	Short time periods can be analysed thoroughly or long time periods can be expanded to short ones
Understand why	Allows analyzing why a certain phenomenon occurs in a system
Explore possibilities	Allows comparing different policies
Diagnose problems	Allows diagnosing problems by understanding underlying interactions in the system
Identify constraints	Possibility of performing bottleneck analysis to discover the causes of delays
Develop understanding	Aid in clarifying to others how a real system works
Visualize the plan	3D simulations may be able to notice problems which cannot be noticed in a 2D environment
Build consensus	It is possible to achieve buy-in with simulations, as potential changes can be modelled, tested, validated, and presented visually
Prepare for change	Allows creating what-if –scenarios, which test how the system performs in potential future situations
Invest wisely	The cost of a simulation study is only a fraction of the total amount of investment required in expensive machinery or facilities
Train the team	Simulations can be used to provide training
Specify requirements	Allows testing potential requirements for a single machine in a complex environment in order to meet certain criteria

Overall, simulations seem to have a lot of advantages. Some of the advantages can be achieved with other methods as well (such as linear optimization, queuing theory), but when systems become more complex, it is more difficult to construct analytical models about the problem.

3.2.2 Disadvantages of simulation

Simulation is not a tool without any disadvantages. According to Banks (1998), there are four disadvantages with simulations, which are:

- Model building requires special training
- Simulation results may be difficult to interpret
- Simulation modelling and analysis can be time-consuming and expensive
- Simulation may be used inappropriately.

Robinson (2004) presents relatively similar disadvantages:

- Expensive software
- Time-consuming
- Data-hungry
- Requires expertise

- Overconfidence.

Combining these two lists, it is possible to see that there are five disadvantages associated with simulation:

- Requires special training
- Simulation modelling and analysis are time-consuming and expensive
- It is difficult to interpret simulation results
- Simulations require a lot of data
- Simulation may be used inappropriately and people may have overconfidence in the results.

Proper training and good project management help avoid most of the problems. An expert in simulation modelling knows that there are problems that should not be simulated, which prevents directing resources to unfruitful application of simulations. Also, the modeller will know the "limits" of the model, which decreases the chance of overconfidence. Even good simulation projects will always be time-consuming, expensive, and require a lot of data.

3.2.3 When to use simulation

Banks et al. (2005) provide a comprehensive list of the purposes of using simulations:

- Simulation allows studying the interactions of a complex system
- Different changes can be simulated and their effects on the system observed
- Important knowledge is generated during the designing of a simulation model
- Varying inputs can generate information about the most sensitive variables
- Can be used as part of teaching to enforce ideas from analytical methods
- Can be used to experiment on new designs or policies
- Can be used to verify analytic solutions
- Can help estimate requirements for a machine
- Can be used as part of training without on-the-job instructions
- Plans can be animated with the help of simulation
- Modern systems are too complex to be analyzed without the help of simulations.

Banks et al. (2005) have also summarized some frequent topics in the main Discrete-Event Simulation conference, the annual Winter Simulation Conference. The areas include manufacturing, semiconductor manufacturing, construction engineering and project management, military applications, logistics, supply chain and distribution, transportation modes and traffic, business process simulation, and health care. On the other hand, in the main System Dynamics simulation conference, the annual conference of the System Dynamics Society, the topics include governance, business application, complexity, conflict and defence, economics, education, energy, strategy, etc. As such, it is clear that simulations can be used in a wide area of applications, and different approaches have advantages in different areas.

3.2.4 When not to use simulation

Banks and Gibson (1997) have defined 10 rules which indicate when simulation may not be an appropriate tool. These rules are:

- The problem can be solved by using "common sense analysis"
- The problem can be solved analytically (using a closed form)

- It is easier to change or perform direct experiments on the real system
- The cost of the simulation exceeds the possible savings
- There are no proper resources available for the project
- There is not enough time for the model results to be useful
- There is no data – not even estimates
- The model cannot be verified or validated
- Project expectations cannot be met
- The system behaviour is too complex or cannot be defined.

The first three rules indicate that an “easier” solution is available by either making direct experiments with the system or by constructing an analytical model of the problem. Rules four to nine can be seen to be project management issues. Simulation modelling usually takes a long time, and requires a lot of data and a high amount of expertise from the modellers. The last rule concerns the human aspect of operations. In an extreme situation people may not work according to normal operational rules and it might be impossible to anticipate every work procedure taking place in these situations.

3.3 Simulation Approaches

Many different types of simulations can be created, as it is possible to code the whole source code for the required model. However, modellers usually use platforms, which provide a versatile way to conduct simulations. On the other hand, most programs only allow for one type of simulation, and all approaches have their own advantages. Jahangirian et al. (2010) have analyzed in a recent survey the use of simulations in manufacturing and business. The most widely used approaches are Discrete-Event Simulation (DES), System Dynamics (SD), Hybrid models (combining two or more approaches in one model), and Agent-Based Modelling (ABM). Three simulation approaches (SD, DES, and ABM) are presented in this section.

3.3.1 System Dynamics

The field of SD originates from the late 1950s when Jay W. Forrester work on the bullwhip effect of supply chains (Forrester 1958). SD tries to understand dynamic complexity, whereas in optimization the interest is in detailed complexity (Sterman 2000). In detailed complexity, the complexity arises from the number of potential combinations existing in the solution space. According to Sterman (2000), dynamic complexity has many different sources, as presented in Table 4.

SD uses stock-and-flow diagrams to create the actual simulation models. As the name of the diagram indicates, the main elements used in SD are stocks and flows. Stocks represent accumulations in the model and provide important information to various parts of the model. Flows, on the other hand, shift the entities between stocks and the boundary of the model. The boundaries of models are sources and sinks, which are basically stocks with infinitive capacity. In addition to these, different auxiliary variables help to store certain information during the simulation. The models themselves are simply a large collection of differential equations. (Sterman 2000)

Table 4: Reasons for dynamic complexity (Sterman 2000)

Dynamic	Everything changes through time
Tightly coupled	Everything inside a system is connected to other actors and even the natural world
Governed by feedback	Each action creates changes in the system, which then interact back to the original actor
Nonlinear	Systems tend to be nonlinear. Production can never be negative, no matter how much inventory exists
History-dependent	Path-dependence exists in many situations
Self-organization	Dynamics of systems emerge through interaction in the internal system
Adaptive	Agent rules in complex systems change over time
Counterintuitive	Cause and effect are separated in time, which makes learning difficult
Policy resistant	Systems are too complex to understand, which makes obvious solutions fail
Characterized by trade-offs	Long-term effects tend to differ from short-term effects, which may make good decisions perform poorly initially

As mentioned in Section 3.1.3, SD is currently used in a wide variety of areas. SD began from the analysis of supply chains and it is still a widely used method in analyzing supply chains. Some recent applications are summarized in Table 5.

Table 5: Recent applications of System Dynamics in supply chain management

Source	Field of study
Fan et al. (2010)	Supply system for military weapon maintenance
Samuel et al. (2010)	Healthcare services
Cagliano et al. (2011)	Fast-fashion warehouse management
Park et al. (2011)	Supply chain for mixed concrete trucks
Dégrés et al. (2008)	Steel industry
Sanders et al. (2007)	Seaports and investment dynamics

The table shows only some samples of recent applications of SD in supply chain management. It can be applied in various situations and environments. Even though the approach was developed in the 1950s, it is still a valid approach to analyze supply chain systems.

3.3.2 Discrete-Event Simulation

As the name implies, DES uses discrete events, which are executed during the simulation. The history of DES goes back to the 1950s. According to Nance (1996), the first simulator was the General Simulation Program (GSP). An important concept during the simulation is clock time. Different events occur according to a calendar. Whatever the next event, the system will activate the event as soon as the clock time reaches the next active event in the calendar. White and Ingalls (2009) have provided an overview of DES. The most important concepts in DES are presented in Table 6.

Table 6: Major concepts in Discrete-Event Simulation (White and Ingalls 2009)

Concept	Description
Inputs	Actions of environment on the system
Outputs	Measured quantities
State	Internal condition of the system
Entities	Dynamic entities which flow through the structure
Attributes	Unique characteristics of an entity
Activities	Processes and logic in the model
Events	Conditions occurring during the simulation, causing a change in the state of the system
Resources	Anything which has a constrained capacity
Global variables	Variables containing information about the system
Random number generator	Generates randomized values to be used during the simulation
Statistics collector	Collects statistics on the conditions

Usually DES uses queues and servers (Banks et al. 2005). The entities enter the model through a source and go into a queue. As soon as a server is available, the entity gets processed after a delay. After a delay the entity can go into another server and may end up in a queue.

According to Jenkins and Rice (2009), resource models can be categorized according to the complexity of the servers and clients. Five different levels are presented in Table 7. The more intelligence is included in the model, the more features it needs to have. Servers and clients are still important issues in DESs, but the more computational power there exists, the easier it is to have more intelligence inside the models. Like SD, DES is a widely used approach to analyze supply chains. The yearly conference, Winter Simulation Conference, attracts over 500 participants each year and the main area of interest is in DES. Since 1998, one of the tracks has been logistics, and it still gathers a good number of papers. Some recent applications are presented in Table 8.

Table 7: Features in resource models (Jenkins and Rice 2009)

Level I	Simple servers, simple clients, and FIFO queues
Level II	Simple decision making
Level III	Advanced service scheduling
Level IV	Advanced queuing
Level V	Advanced entities

Table 8: Recent applications of Discrete-Event Simulation in supply chain management

Source	Field of study
Scmitt and Singh (2009)	Disruption risks
Mobini et al. (2011)	Forest biomass supply logistics
Brito et al. (2010)	Steel plant maritime logistics
Longo (2010)	Inspection in a container terminal
Eksioglu et al. (2010)	Furniture industry supply chain
Persson and Araldi (2009)	Integration of SCOR and DES in automotive industry
van der Vorst et al. (2009)	Food supply chain

As the table shows, DES can be used in many different contexts. The main ideas in the models are queues and servers, but it is possible to make complex transportation and warehousing networks if intelligence is included in the models.

3.3.3 Agent-Based Modelling

ABM is a relatively new approach in simulations. The roots can be seen to go back to von Neumann machines, but ABM started to gather more interest in the 1990s when the computers became more powerful (Macal and North 2005). Cellular automata also played a role on the development of ABM. One of the earliest applications was Schelling's segregation model (Schelling 1969; 1971). In the model the environment consists of a grid, and each square represents one potential location for a household. Each household will check the number of neighbours who have the same condition as they have (this can be race, income level, education, etc.). The model then contains a threshold value, which indicates whether a household will move to a new location, if too many neighbours do not share the same characteristics. The dynamics of the whole system then emerges from each actor's decisions. The emergent behaviour drives the model towards segregated environments, where only one characteristic is dominant. Similar approaches have later been presented by Conway in the Game of Life (first appeared in Scientific American, Gardner 1970) and Epstein and Axtell (1996) in their Sugarscape model.

According to Macal and North (2006), there are four reasons behind the growing interest in ABM. The first reason is that observed systems are becoming more complex in terms of interdependence. Different parts of the system are even more connected. The second reason is that some systems have been too complex to model with other approaches. The third reason is the organization of data at finer levels of granuility in databases, and the fourth reason is the increase in computational power. However, most of the work is still on a conceptual level and few empirical models exist (Davidsson et al. 2005; Hilletofth et al. 2010; Chen & Cheng 2010).

There are some basic principles in ABM. As the name implies, agents are the main area of interest. The agents belong to one or more environment. Each agent will gather information from its local environment and will then make its autonomous decisions. The decisions lead to interaction with other agents and the environment. Each agent also has some sort of goal which it tries to achieve. (Wooldridge and Jennings 1995)

Many different ways to classify agents have been presented. The different approaches are summarized in Table 9. As can be seen in the table, there are many ways to classify agents, and Schieritz and Milling (2003) conclude that there is no agreement about the issue on the subject. Schieritz and Milling have provided a good overview of the different classifications of ABM.

Table 9: Different classifications for Agent-Based Modelling

Source	Approach
Wooldridge and Jennings (1995)	Computer science
Macal and North (2006)	Practical modelling
Nwana (1996)	Software perspective
Shehory (1998)	Software architecture
Haeyes-Roth (1995)	Artificial intelligence

As ABM is the newest approach of the simulation, there are not many studies containing an empirical case that has been simulated. A vast majority of research is still on the conceptual level. Table 10 presents some recent applications of ABM in SCM.

Table 10: Recent applications of Agent-Based Modelling in supply chain management

Source	Field of study
Henesey et al. (2009)	Container terminal system
Govindal et al. (2006)	Seaport security
Vidal and Huynh (2010)	Seaport container terminal
Frayret et al. (2007)	Forest product industry
Sun et al. (2012)	Seaport container terminal

Even though the number of empirical models using ABM is still small, there are no reasons why it should not be used more in the future as modellers become more proficient with the approach. Transportation and warehousing can greatly benefit from ABM principles, and it is possible to analyze systems which were too complex to analyze with more traditional approaches.

4 SIMULATIONS AND DECISION SUPPORT SYSTEMS

Decision-making has always been an important part of organizations. In the beginning of the 1960s, Simon (1960) approached decision-making from the perspective of different types of decisions. Some decisions are programmed, which means that they are repetitive and routine, and a procedure to solve them exists. On the other end of the spectrum are non-programmable problems, which do not have a predefined procedure for dealing with them. Gorry and Scott Morton (1971) expanded Simon's framework with Anthony's (1965) framework of planning and control system, where the focus was on the type of the problem, e.g. whether the problem was an operational control, management control, or strategic planning problem. Gorry and Scott Morton's (1971) framework is presented in Figure 11.

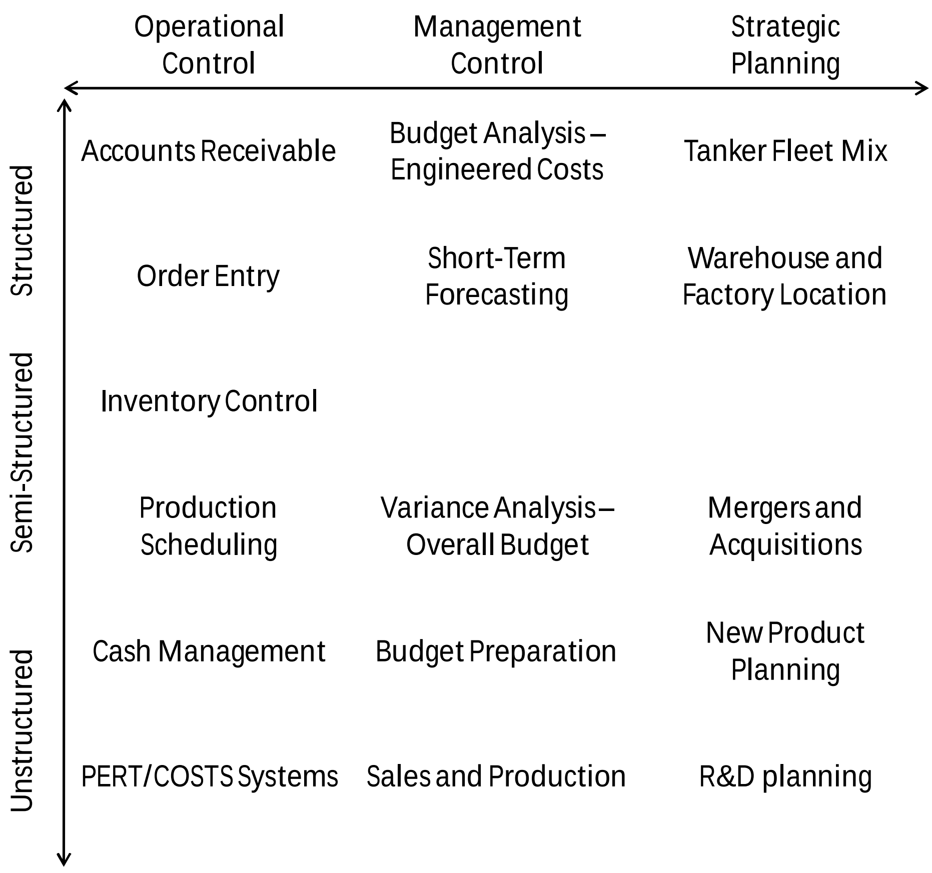

Figure 11: Information Systems framework (Gorry and Scott Morton 1971)

Different types of decisions will require a different type of decision support as well. Decision support systems (DSS) are a special case of Information Systems (IS), which enhance the decision-making process of managers. The first DSSs began to appear in the 1960s (Power, 2002). According to DeLone and McLean (1992), the organizational impact of IS comes from the individual impact of the use of IS, as presented in Figure 12.

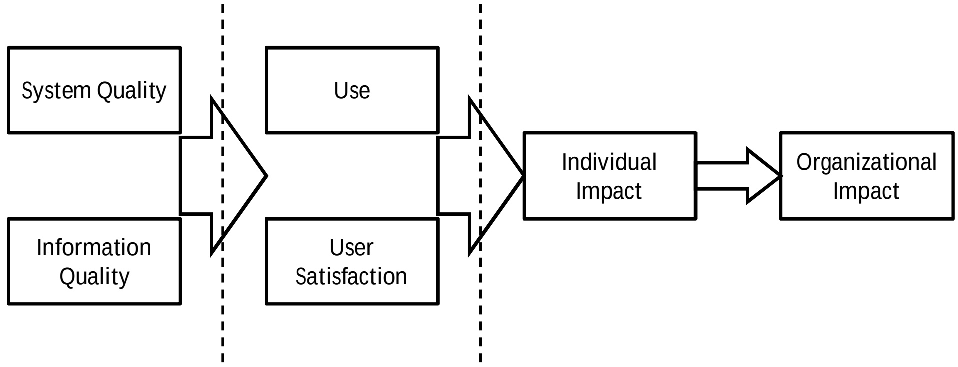

Figure 12: The impact of Information Systems (DeLone and McLean 1992)

The individual impact will depend on the use of the system and user satisfaction, while these are dependent on the quality of both the system and the information. This is especially true for DSS. By using a DSS the user(s) can create better decisions, but the quality of the decisions will depend on the quality of the DSS and the quality of the information.

Legris et al. (2003) have expanded the technology acceptance model of Davis (1989) by analyzing the literature regarding the use of information technology (IT). The modified acceptance model is presented in Figure 13. In the framework the use of IT depends on the intention of use, which in turn is dependent upon the perceived usefulness, the perceived ease of use, as well as the subjective norm of technology usage. Experience and voluntariness also impact the intention to use. The user satisfaction can be seen to come from the perceived usefulness and perceived ease of use. Many issues have an impact on the perceived usefulness (experience, subjective norm, image, job relevance, output quality, and demonstrability of results), and it can be seen to be the system quality and information quality in the framework of DeLone and McLean (1992).

According to Sprague (1980), one key difference between Management Information Systems (MIS) and DSS is that DSS concentrates on enhancing the decisions made by the user, while MIS concentrate on providing information. Below MIS, there is Electronic Data Processing (EDP), which concentrates on automating tasks. MIS aggregate information from EDP, and a DSS then uses various MIS in the actual decision-making process. Sprague (1980) separates three different technology levels in DSS. A Specific DSS is the module which is used to help the actual decisions. A DSS generator is used to generate Specific DSS from appropriate sub-modules. DSS Tools are the final class, which are used to facilitate the generation of specific DSS or DSS generators.

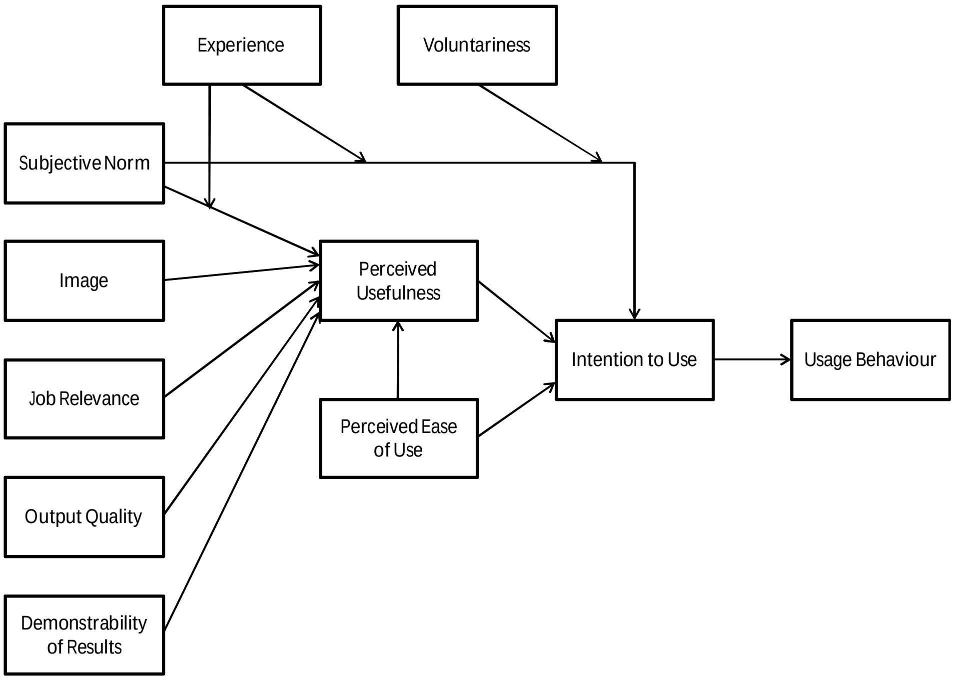

Figure 13: Information technology acceptance model (Legris et al. 2003)

The DSS decision-making process consists of seven phases (Courtney 2001), as presented in Figure 14. The process starts with problem recognition. After the problem has been recognized, it needs to be properly defined. Alternatives can be generated when the definition is known and the decision-making model can be developed. The different alternatives provided by the model are analyzed and a decision is then made. Finally, the decision needs to be implemented. This follows the decision process first proposed by Simon (1960). Courtney (2001) has expanded the model to include more decision-makers and their mental models, but this is mostly an issue with Group Decision Support Systems.

According to Arnott and Pervan (2008), there are eight key issues in the DSS discipline. These are presented in Table 11. In order to improve DSS research, Arnott and Pervan (2008) make six suggestions which would improve the quality of DSS research. Firstly, more case studies should be undertaken. Secondly, the design science tradition needs to be continued, but greater attention needs to be paid to the rigor of projects. Thirdly, research problems should be based on long-term professional relevance. Fourthly, DSS research needs more funding from the industry. Fifthly, attention needs to be paid to the effective development and implementation of data warehouses and business intelligence systems. Last, the theoretical foundation of projects needs to be expanded to include judgment and decision-making.

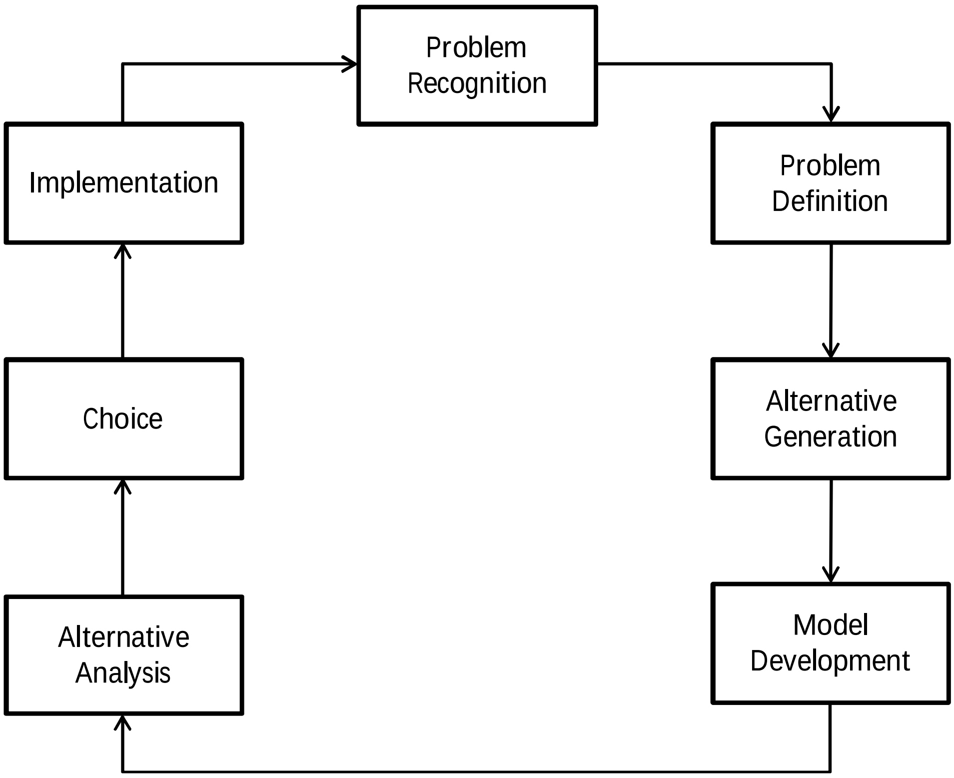

Figure 14: DSS decision-making process (Courtney 2001)

Table 11: Key issues in the DSS discipline (Modified from Arnott and Pervan 2008)

Key issue	Comment
Professional relevance	Most research is disconnected from practice
Research methods and paradigms	Positivist research view and a small number of case studies
Theoretical foundations	No foundation in judgment and decision-making in most papers
Role of the IT artefact	Focus on the IT artefact is declining
Funding	Low competitive grant success and low industry support
Inertia and conservatism	Old types still dominate research agendas
Exposure in ‘A’ journals	Need to increase exposure in IS ‘A’ journals other than DSS
Discipline coherence	Comprises three isolated sub-fields

According to Power (2002), there are five different dominant DSS components: Communications-driven DSS, Data-driven DSS, Document-driven DSS, Knowledge-driven DSS, and Model-driven DSS. Communications-driven DSS improve communication and collaboration between different participants, and they can also be called Group Decision Support Systems. Data-driven DSS emphasize the use of large amounts of structured data. They are especially used to present time-series of both internal and external data. Document-driven DSS concentrate on managing a large amount of documents. The purpose is to provide document retrieval and analysis techniques with the help of storage and processing technologies. Knowledge-driven DSS contain some kind of artificial intelligence which recommends actions to the users. It can use various rules or data mining techniques to achieve this. Model-driven DSS emphasize the access to a model and its manipulation.

According to Shim et al. (2002), model-driven DSS consist of three phases: formulation, solution, and analysis. During the formulation phase the actual problem is translated to an algebraic form. In the solution phase the model is optimized, and in the final phase the actual results of the model are presented to the user. The formulation phase will also impact on how the solution is obtained. The Operations Research tools presented in Section 3.1 are potential ways of how model-driven DSS can be formulated and solved. Most of the methods use a mathematical programming approach, e.g. a collection of mathematical functions is created and the minimum or maximum value is then obtained by using various algorithms.

Simulations are widely used in DSS. Some recent papers about the topic are summarized in Table 12.

Table 12: Recent applications of simulation-based decision support systems

Source	Field of Study
Mahdavi et al. (2010)	Job shop manufacturing system
Petering (2011)	Seaport container terminal
Fagerholt et al. (2010)	Maritime transportation
Acar et al. (2010)	Supply chain management
Kuhn Jr et al. (2010)	Airline market share
Fröhling et al. (2010)	Multiple plant transportation and recycling planning
Armaneri et al. (2010)	Project management

Simulations are used in DSS, as many problems cannot be solved in a closed loop, analytical form (as discussed in Section 3.2). Different types of problems (Figure 11) require different types of simulation models (Section 3.3), and the use of simulations should always be critically considered due to their limitations (Section 3.2.4).

5 METHODOLOGY

In this chapter, the six publications constituting Part II of this thesis are presented. The individual publications analyze different sub-questions of the research, which answer the main question: "*How can transportation and warehousing efficiency be improved with simulation-based decision support systems?*" Table 13 summarizes the position of the publications against the research questions.

Table 13: Research questions and publications of the study

Research questions	P I	P II	P III	P IV	P V	P VI
1) What are the advantages and disadvantages of different simulation approaches?		X	X		X	X
2) Where can hybridization of different simulation approaches offer additional insights?		X			X	
3) What other approaches can be combined with simulations in order to have more useful decision support systems?	X	X	X			
4) How can uncertainty be included in decision support systems?	X	X	X	X		X

The seventh main section (Advanced methods in logistics simulations) of the introduction will also analyze these sub-questions and answer the main question. The background of the research and the chosen methodology are discussed in the next two sub-sections.

5.1 Background of the Research

All the individual publications were written in the years 2008 to 2011, and many of the publications were done during different projects. The first article was based on preliminary work preceding a larger EU-funded STOCA project. The purpose of the STOCA project was to study how cargo flows in the Gulf of Finland react to emergency situations. The project consisted of many partners from Finland and Estonia. The simulation software used in the first publication was constructed using Vensim, and the statistical analyses were conducted using SPSS. The second publication was constructed during the STOCA project, and it utilized a program called Anylogic as well as Vensim. The data for the first two publications were gathered from public sources (including Statistics Finland, Finnish Port Association, IMF, Port@Net, etc.). The sources are generally considered to be of high quality, and due to the abundance of data, there was no need to gather any first-hand data. The work was conducted in Kouvola Research Unit of Lappeenranta University of Technology.

The third publication was developed in co-operation with the University of Skövde. The work was a part of a project called "Information Fusion Research Program at University of Skövde, Sweden". The author visited the Swedish university for two weeks, and the main simulation model was constructed during this time. A Swedish maintenance operator provided data from their own databases, which was then used in the simulation model.

The model was presented to the case company and the results were included in their decision-making. The company has since expanded their service portfolio to a decentralized maintenance network.

The fourth article was based on a small project conducted in a Finnish SME company. The company provides automatic loading solutions, and during the project various Excel-based simulation models were constructed. The models were based on expert opinions, and the sensitivity analyses were conducted using @Risk. The company is planning to use the models in their own marketing efforts, which increases the validity of the models.

The fifth article was based on a literature review. The literature review was done during other projects as well and was expanded for the final article. The article was based on various previous works, as experience from different simulation approaches had been accumulated during different projects.

The final article was also mostly written during the STOCA project. The models were one the main tasks during the research, as well as experimenting with ABM. The author participated in various interviews with logistics operators, created the simulation models and communicated about the results during the project. The web-pages of the project have gathered over 2000 visits.

5.2 Methodological Approach

This thesis concentrates on the effective use of simulations as a part of DSS. Neilimö and Näsi (1980) have proposed a framework where a scientific approach can be studied from two dimensions. The first one is theoretical-empirical, and the second one is descriptive-normative. The framework contains four different research approaches, a conceptual, nomothetical, decision-oriented, and action-oriented approach. Lukka (1991) has expanded the framework to include a constructive approach in the possible research approaches. The usability of the constructions can be tested by implementing the solution and analyzing its performance. The constructive research process contains six phases (Kasanen et al., 1993)

(1) Find a practically relevant problem
(2) Obtain an understanding of the topic
(3) Construct a solution to the idea
(4) Demonstrate that the solution works
(5) Show the theoretical connections and research contribution
(6) Examine the scope of applicability of the construction.

Simulation modelling can be either axiomatic or empirical (Bertrand and Fransoo 2002). Axiomatic research studies idealized systems, while empirical models are more concerned about creating a model that fits the actual data. Within the empirical field it is still possible to conduct either descriptive or normative studies. As such, empirical modelling is nomothetical, action-oriented, or constructive.

The publications included in this thesis can be positioned in the expanded framework, as presented in Figure 15. Publication one (PI) contains a model which is used to forecast the long-term demand for Finnish seaports. The model solves a relevant problem, as it explains how the demand will develop in the future. The publication can be seen to be nomothetical by its approach.

Publication two (PII) shows how simplified models about seaports can be constructed with the help of System Dynamics and Agent-Based Modelling. The models contain actual empirical data from seaports, and they are analyzed in the publication. The publication gives suggestions for the preferability of the modelling approaches, and as such it can be classified mostly as decision-oriented, despite having empirical data.

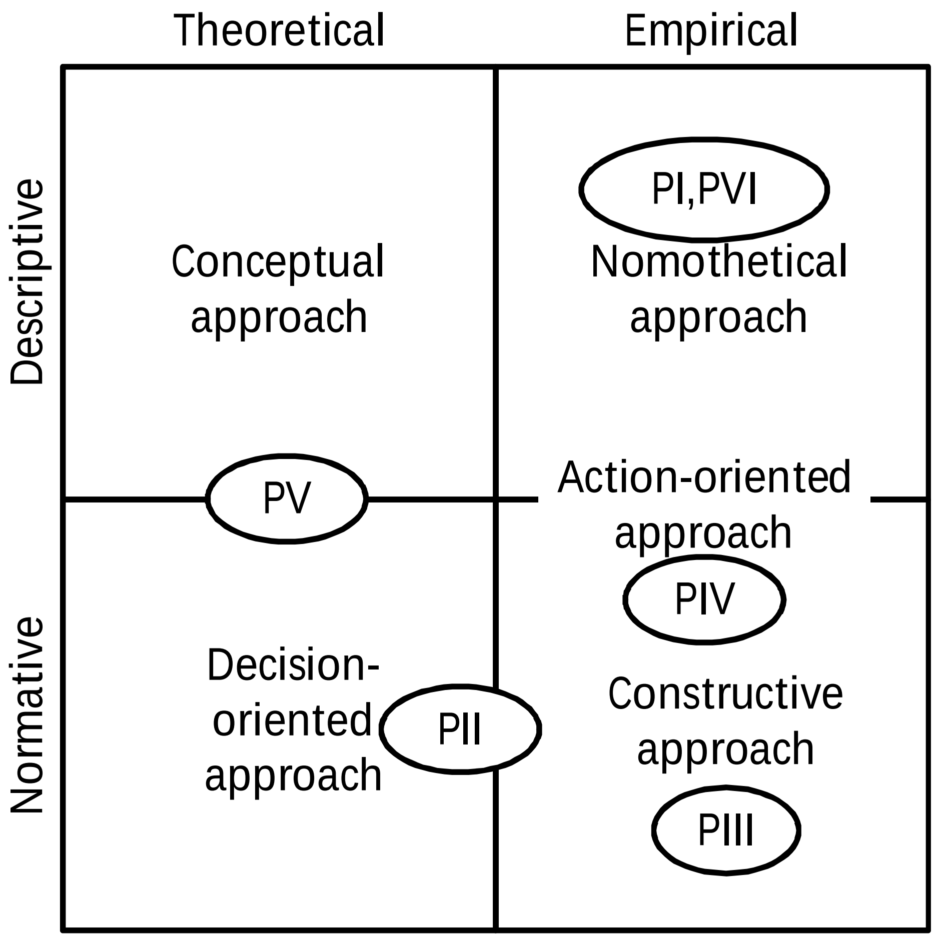

Figure 15: Classification of the research articles in the Neilimo and Näsi framework (1980) expanded with Lukka's (1991) constructive approach

Publication three (PIII) concerns a case company which required help in analyzing their current service strategy. The simulation model used data from the case company and suggestions were made to alter their services. Since then the company has modified their services and found the model to be of high value. This publication follows the constructive approach.

Publication four (PIV) also concerns a case company. The author worked together with the case company and created a model to help the company with its current bottlenecks in sales. This research can be seen to be action-oriented and constructive.

Publication five (PV) does not contain an empirical case, as it analyzes the literature regarding current gaps in the knowledge about using hybrid simulation models. The publication gives suggestions for the of hybrid models and can be seen to have both a conceptual and a decision-oriented approach.

Publication six (PVI) estimates the impact of crises on supply chains. This is a relevant problem, as the area is sensitive to interruptions, and supply chain risks have started to raise more interest in the academic literature. The publication discusses the functionality of supply chains, which have been analyzed with the help of simulations. This can be seen to be a nomothetical approach.

In five of the six articles, a quantitative approach has been used. Simulations are always dependent on the person who constructs the model. The scientific paradigm can be seen to be postpositivist (Guba and Lincoln 1994). Simulations have earlier been analyzed from the critical realism perspective (Mingers 2000). These form the philosophical background of this thesis. The actual simulation projects were similar to the process presented by Banks (2005). However, implementation was not used frequently, as in many of the simulation projects there was no clear customer and thus no actual implementation.

6 SUMMARY OF THE PUBLICATIONS

6.1 Forecasting Long-Term Demand of Largest Finnish Sea Ports

The objective of this publication was to study how the forecast for the development of demand for Finnish seaports could be done by combining regression and ARIMA – models with System Dynamics (SD). The article suggests using industrial production as an explanatory variable instead of using GDP. Also, the demand for some seaports is heavily influenced by the growth of the Russian GDP, as a lot of the traffic in Finnish seaports is transit traffic through Russia.

6.1.1 Literature review

According to the literature review, seaport demand is usually forecasted only for general goods cargo. Only one publication was found to forecast the demand for liquid or dry bulk goods as well. When the demand for many seaports is evaluated, a judgmental or analytical method is used, and the main area of interest is the competition between different seaports. When the demand for only one or a few seaports is forecasted, simulation or statistical methods are used to make the estimates.

Statistical methods have been previously used for forecasting national demand. Maloni and Jackson (2005) have used exponential smoothing to make their forecasts, while Lehto et al. (2006) and the United Nations (2007) have used the GDP as an explanatory variable. It should also be noted that of the ten publications that were found, only three created a forecast for future periods and none of these created estimates for individual seaports.

6.1.2 Empirical Study

This research was a part of a larger research project, and it was started by gathering expert opinions. According to the experts, exchange rates, the GDP, age distribution, industry production, and inflation were potential explanatory variables which could be used to explain the development of demand in Finnish seaports regarding imports and exports. Regarding transit-transport, exchange rates, the Russian GDP, Russian Natural Gas Exports, Russian Oil Exports, and Russian Trade Balance were potential explanatory variables. All these are presented in Table 14.

Table 14: Potential dependent and independent variables according to expert opinions

Dependent Variable	**Potential explanatory, independent variables**				
Imports / Exports	Exchange rates	Finnish GDP	Age distribution	Industry production	Inflation
Import / Export Transition	Exchange rates	Russian GDP	Natural Gas Exports	Oil Exports	Russian Trade Balance

Regression models were constructed by using the independent and dependent variables. It was noticed that the Finnish exports and imports can be best explained by using industrial production as an explanatory variable. Also, an autoregressive variable was included in many of the models, as autocorrelation existed in the residuals of the models according to Durbin-Watson –statistics.

Transit exports (mostly freight originating from Russia and going through Finland) could not be explained with the help of any of the variables. As such, it was simulated in the model by varying these transits between specific levels. Import transition (mostly containers and cars from European seaports going through Finland to Russia), on the other hand, could be explained by using the Russian GDP as an explanatory factor. The Russian GDP could also be explained with the help of Russian oil exports. As the amount of Russian data was relatively small, it was not possible to include autoregressive variables into the models. However, the amount of transit traffic was relatively small compared to the total traffic and as such, the whole model did not suffer too much from possible autocorrelation.

The demand was divided to individual seaports by using historical data to see how large proportion of the Finnish total demand each of the largest seaports had. Also the share of liquid bulk, dry bulk, and general goods cargo was analyzed. This data was used to get the mean value and standard deviations for the shares, and these were used in the simulation model. The total demand was then calculated by summing up all of the individual demands. Four different scenarios were constructed, where the Finnish industrial production and Russian oil exports grew in a linear or non-linear fashion.

6.1.3 Conclusions and contribution

The article presents how SD simulation can be combined with regression or ARIMA models. The publication also shows that national demand can be analyzed at individual seaport level. The methodology could be expanded to other countries as well, and it would be especially interesting to see whether the demand of other countries' seaports could be explained by using industrial production instead of the more traditional GDP as an explanatory factor.

The model for exports and imports was very stable even during the financial crisis of 2008 and 2009. Industrial production could also be forecasted in the short term by using the information regarding orders at hand as an explanatory variable. However, transit traffic differed from real values during 2009. This could be the result of the heavy deflation of the Russian currency. Also, the port of Saint Petersburg lost a significant volume of its total demand, which most likely took away some of the advantages provided by the Finnish route to Russian markets.

6.2 Modelling Seaports with Agent-Based Modelling and System Dynamics

The objective of this publication was to analyze how individual seaports could be modelled with the help of SD and Agent-Based Modelling (ABM). This publication presents two different simulation cases where the same seaport is modelled and analyzed using different simulation approaches. The publication does not create individual forecasts for the seaport, but uses a predefined demand for the seaport.

6.2.1 Literature review

Seaports are regarded an important part of global supply chains. However, they are rarely well integrated in the chains. The efficiency of individual seaports is an important factor when their competitiveness is estimated. Mathematical models are frequently used to analyze the performance of seaports. However, simulations might be able to grasp some important aspects with a great impact on the final results. Discrete-Event Simulation has been the most widely used approach to study individual seaports, but the amount of detail has been extremely high in all these models.

Some SD and ABM have been constructed previously, but all these models have used a high level of detail as well. A large model boundary is generally seen to be more preferable than a high level of detail.

6.2.2 Empirical study

In the study, the port of Kotka was simulated, as it is one of the most important seaports in Finland (the situation strengthened during 2011 as the seaports of Hamina and Kotka merged to form the largest container seaport in Finland (Port of Kotka, 2011). As SD works on the aggregate level, it does not contain information regarding individual entities. Queuing theory was used in conjunction with SD. As seaports were seen to be one node in larger global supply chains, they were analyzed as an M/M/1 system. Data of the capacity of the seaport was estimated with the help of a database where all ships give information regarding their stay in the seaport. Using the capacity utilization and information regarding actual demand, it was possible to calculate the potential maximum capacity. A capacity expansion module was also included to ensure that adequate capacity existed in the system.

The ABM simulates individual ships and cranes. There is a fixed number of cranes in the seaport and as the ships arrive to the seaport, they reserve the cranes. The cumulative amount of capacity of the cranes is equal to the amount of capacity in the SD model. The simulation model also contains a capacity expansion model in order to cope with increase in demand. Unlike the SD model, the ABM does not require queuing theory to calculate the average utilization and waiting times.

There are differences between the simulation models. The ABM invests a lot more resources on new capacity compared to the SD model. One possible reason could be the additional randomness in the ABM. Also, the M/M/1 may not be the best way to represent a seaport. It is quick to construct the SD model, but an M/M/m, or even a M/G/m, should be used to represent the seaport. The ABM takes more time to construct, but the largest hindrance comes from the longer simulation time. An ABM might also be easier to present to the subject matter experts. A queuing system is based on predefined equations and approximations, while an ABM is constructed using “logical” pieces.

6.2.3 Conclusions and contribution

ABM was seen to be a more versatile approach to modelling seaports than SD. SD cannot work alone and calculate the waiting times for the ships. ABM seems to be a very promising avenue to study large logistical systems. Also, as ABM is able to grasp complex events, it might be more suitable to analyze complex emergency situations in the logistical context. It is difficult to compare the models presented in the publication to earlier studies, as all previous works have been constructed on a very high level of detail.

6.3 Agent-Based Decision Support for Maintenance Service Provider

The third publication uses an ABM to analyze the current service system of a maintenance service provider. The purpose was to increase the current understanding about the problem domain and to form a basis for better decision-making. An ABM of the service environment was constructed and the performance of the system was improved with the simulation model. Several types of data gathering methods were used to gather information about the service system, and the model concentrated on the service of one particular machine.

6.3.1 Literature review

ABM can be used as a part of decision support systems. The decision-maker sets/edits the parameters of the simulation model. The results of the model are then analyzed by the decision-maker, and future decisions can be made. The decision-maker's decisions are implemented in the real system and it creates a feed-back loop back to the decision-maker.

According to research, there are many benefits associated with ABM. It can incorporate information regarding the impact of unscheduled factors, which normally need to be excluded in many other mathematical modelling approaches. The emergent behaviour of the simulation models can also help the managers to understand the impact of their own decisions on the whole system. This can enhance the decision-makers' instincts. The models also allow finding the highest leverage points of the system. The system can be improved by concentrating on these high impact areas. Finally, it may be possible to make better forecasts on the basis of the results.

6.3.2 Empirical study

After discussion with the personnel of the case company, it was decided that there were two different types of engineers available, mechanical and electrical engineers. The simulation model includes these two types of engineers and two different types of tasks. The first tasks are corrective tasks, which occur suddenly and need to be addressed quickly. The other class is scheduled maintenance. These tasks are not immediate, but if they are disregarded, acute tasks would occur. A certain number of engineers would work on the corrective tasks, while some would only work in planned tasks. According to historical data, different probability distributions were included in the simulation model. The model contains some key statistics, which are gathered during the simulations and can be used to analyze how well the system performs in different situations.

A mathematical model of the system was also constructed. The model was based on queuing theory, and the purpose was to compare the results of the ABM to the mathematical model. Most of the results were relatively close to each other. However, the waiting time in the ABM was clearly shorter. It is possible that as the mathematical model was based on certain distributions, this would have caused the differences between the models. Total accuracy is not the goal of simulation, and it is possible to understand the system even without totally accurate results.

The model increased the interest in more sophisticated decision support systems in the case company. The company has started to discuss about modifying their service portfolio, as the model showed its current modus operandi to be unsuitable for its current situation. The model will be expanded in the future to incorporate other service operations into it. . Also, as the model is decentralized by structure, it is possible to study a more flexible structure in the future. It will most likely be easier to incorporate it to the ABM as compared to the mathematical model.

The simulation model also clearly demonstrated the difference between the response times in different locations. As response time is critical, and a vast amount of time is spent in driving to different locations, a decentralized service system seemed to be a more favourable one. It was also evident that customers with one-time corrective tasks are much more difficult to handle than long-time customers with a high number of planned service operations.

Buy-in can be achieved a lot easier with the ABM than with a mathematical model. A Graphical User Interface and animation can be shown to the company's employees, and it is easy to explain separate parts of the model to the potential users. The largest drawback of a simulation model is the longer construction time. However, a simulation model can be expanded to study more complex situations, while mathematical models have certain limitations. The model will be expanded in the future to analyze a decentralized service depot system.

6.3.3 Conclusions and contribution

The publication emphasizes the potential benefits that can be achieved by using ABM in decision support systems. The case company perceived the model to be of high value and shifted the potential focus of company towards a decentralized service structure. The publication is also one of the first publications about using ABM in the maintenance-service providing industry with real-life data. The model was also used as part of decision-making, which indicates that the constructed model was a good one.

The publication stresses the importance of travel time and the amount of personnel in the response time. A centralized solution has a high amount of travel as customers are further away from the service depot. Also, it is easier to control the demand when a higher number of customers require planned tasks instead of corrective tasks. In order to have a fast response time, adequate capacity needs to exist in the system. Further avenues of research include testing different scenarios by expanding the model or by connecting it to other decision-support systems.

6.4 Decision Support System for AS/RS Investments: Real Benefits of Monte Carlo Simulation

In this publication, a simulation model was constructed, where the financial impacts of an Automated Warehousing and Retrieval System (AS/RS) are estimated. Detailed planning is needed in warehousing automation projects, as they incur heavy investments. Automated warehouses can increase flexibility and space utilization, and reduce spoilage and administration costs. The warehousing sector is an important employer as well, and it is under the influence of fierce outsourcing activity.

6.4.1 Literature review

Complex supply chain networks require advanced activities in transportation and warehousing. The employment of the warehousing sector grew heavily (380%) in the US between 1998 and 2005 (Bowen 2008). The revenues of the main automation suppliers increased from 9.5 billion USD (in current USD) to 15.3 billion between 1997 and 2008 (Kulwiec and Forger 1998; Rogers, 2009). In Europe and the US, about 22 to 24 % of the total logistics costs are due to warehousing investments and operating costs (Baker and Canessa 2009).

There are no systematic methods in designing warehouses, and the process differs in each case (Baker and Canessa 2009). The design of warehouses consists of five different areas (Gu et al. 2010), and the optimal design will depend on several design criteria (Peteresen et al. 2005). The prime reasons for choosing automated systems are incorporating growth, reducing operating costs, and improving customer service (Baker and Halim 2007).

Simulations have earlier been used to analyze AS/RS. Analytical methods are also widely used in studying these systems. However, these models have emphasized the actual performance of a specific AS/RS, not the high level configuration estimates.

6.4.2 Empirical study

In this study, the authors worked in close co-operation with an AS/RS provider. The purpose was to construct a model which could make some physical performance estimates and then convert these into financial estimates. During the construction process, some existing sales cases were used to validate the results of the model.

The supplier also provides automated load forming and loading of transportation vehicles. These were incorporated in the model to allow the user to analyze whether additional benefits could be achieved with the help of automated loading. In order to estimate the benefits achievable by using automated loading only, two separate models were constructed.

The automated loading solution provides clear benefits, especially if the potential customer needs to use open-top containers to load their goods. This is because with an automated loading solution it is not necessary to use open-top containers, and the transportation costs of normal containers are significantly lower. Also, fewer goods get damaged during loading, it is possible to load more goods inside one container, and the turn-around time for trucks is smaller. With spreadsheet simulation software it is possible to have estimates for the savings. There are many uncertainties involved in the decisions, and these can be incorporated in the decision-making with the help of simulations.

The AS/RS contains a lot more variables than the unloading system, but the principles are the same. In the AS/RS case study it was shown that inventory costs due to spoilage are among the most important issue when AS/RS are considered. The more expensive the goods, the more financially beneficiary the AS/RS becomes compared to a normal, manual warehouse.

6.4.3 Conclusions and contribution

Combining a Monte Carlo –simulation with a spreadsheet model allowed incorporating additional insights into the investment decisions. It was clear that the most important variable of an automated loading system regarding financial performance was the use of open-top containers. On the other hand, spoilage due to mishandling of goods was most important in an AS/RS investment. The potential users can concentrate on these criteria more thoroughly when considering about investing into these logistical goods handling systems.

This publication concentrated on the initial phase of developing AS/RS, while earlier studies have concentrated on systems that are already online. Spreadsheet models are frequently used in warehousing systems design, which gives further justification for our method. The model could be further expanded by combining it with simulation software or using different design criteria within the model.

6.5 Hybrid Simulation Models – When, Why, How?

The fifth publication discusses the use of hybrid simulation models. As ABM and SD have a common goal, there seems to be a lot of fruitful possibilities in combining these two approaches. There is a relatively small number of publications which use both these methods simultaneously, and five different situations were found where the combination would most likely provide better simulation models.

6.5.1 Literature review

SD and ABM approach the same problems from different points of view. SD uses a top-down approach to study complex systems, while ABM uses a bottom-up approach. SD aggregates individual actors together, while in ABM all the individual actors are modelled separately. SD is rarely used with Expert Systems, but ABM is a more widely used approach.

6.5.2 Empirical study

There are clear differences between SD and ABM. The level of analysis, unit of analysis, crucial mechanism, building blocks, system structure, application, origin of dynamics, and handling of time differ between the approaches. Despite the differences, both approaches try to analyze complex systems.

There seems to be five problematic situations where combining these two methods enables more accurate models. If the actors are heterogeneous, it may be easier to incorporate them into models using Agent-Based principles. Data availability can be an issue with either one of the methods, but parts of the model could be done using an "opposing" view. A flexible structure and complex events can be difficult to simulate with SD, while ABM can take care of these systems. As SD has a long history in modelling policies, it provides a good framework for ABM as well.

There are different ways to create hybrid simulation models. It is possible to program the whole model using a low-level programming language. It is possible to use simply a SD program, or combine a SD program with middleware. Some hybrid simulation model toolsets also exist, and it is possible to even construct own simulation software.

6.5.3 Conclusions and contribution

This publication discusses the potential that can be achieved by creating hybrid simulation models. It analyzes the differences between ABM and SD, identifies the potential situations where one of the simulation approaches has difficulties of coping, and discusses the different ways to achieve hybrid simulation models. The publication also discusses the implications for Expert Systems. As ABM is more widely used with Expert Systems, it may be possible to achieve more realistic behaviour of the models, if the experts are not aware of the local decisions, but know how the system works on the global level. On the other hand, SD-based Expert Systems can incorporate a flexible structure or complex event by incorporating Agent-Based principles to the model.

6.6 *Multimodal transportation risk in Gulf of Finland Region*

In this study, SD is used to analyze interruptions in logistical supply chains. Many nations are heavily dependent on global trade, and these supply chains are dependent on seaports. The Gulf of Finland currently contains a great amount of oil transportation from the seaports of Primorsk (Russia) and Muuga (Estonia). The publication analyzes the impact of an oil spillage in the region. Also, as seaports are dependent on railway transportation, two simulation models are constructed where the impact of an accident in an important rail yard is analyzed.

6.6.1 Literature review

According to the literature review, the single major source of risk in intermodal transportation infrastructure is related to the efficiency of the timing of decisions and their implementation in relation to critical investments of physical resources. The sources of risks can be related to the resources of the system, i.e. labour or information systems, or types of customers served by the system, such as foreign containers and recreational vessels, or external factors, like the weather. As such, no ultimate set of risk sources can be identified. The probability of a risk being realized depends e.g. on the above mentioned factors. It also seems that the duration of the consequences of identified risks is in most cases less than a month. Some SD simulation models analyzing seaports have been constructed, but the overall number seems to be a relatively small one.

6.6.2 Empirical study

During a project called STOCA, many important logistical operators in the Gulf of Finland region were surveyed to find out the main risks in operations. Most of the large Finnish and Estonian seaport personnel were interviewed, as well as some personnel from railway yards and logistics operators. According to the surveys, different ports and railway yards have differing risk profiles, depending on the infrastructure and the cargo handled. The sources of risk include energy supply, information systems, weather conditions, and labour. In addition to these, the form of collaborating firms affects system performance. As multinational firms can change their transportation flows in case of disruptions, local operators can be forced to close down their businesses. Generally, the ports that have specialized to ro-ro and ropax are more flexible compared to the ports that handle containers or liquid bulk. In handling containers or liquid bulk, special loading and unloading devices such as derricks, long leg spiders, pipe and pump systems, indicators of spillage and monitoring cameras are needed. Meanwhile, ro-ro and ropax transportation need only quays and a road connection from the harbour. However, a spillage is a common perceived source of risk.

The publication contains four individual simulation models. Two of the models analyze the impact of an oil spillage in the Gulf of Finland, while the other two studies concentrate on the impact of a major accident in a railway yard. In the first model, the port of Kotka is unable to receive any cargo due to an oil spillage on the Gulf of Finland. The cargo from the seaport is transferred to the seaport of Helsinki. The interviews revealed that the hinterland capacity of Helsinki is near its limit even in the current situation. The simulation model analyzes how well the system would perform with various amounts of hinterland capacity.

The second model analyzes a similar situation on the Estonian coast. However, in this case Helsinki will work as a back-up seaport and the containers will be transferred from Helsinki to Paldinski using roro-ships. The Port of Tallinn is the only one with any real container handling capacity in Estonia, and that is why Helsinki was chosen as the backup. Hinterland capacity in Helsinki is not required, but platforms tend to be in short supply in the short run. As such the model analyzes the impact of varying numbers of platforms.

The third and fourth models analyze the impact of an oil or chemical spillage in the railway yards of Kouvola (Finland) and Tapa (Estonia). Many of the goods transported on railways (raw materials) are expensive to transport using road transportation (in Finland a lot of the cargo includes chemical and oil products, while in Estonia most of the cargo is oil from Russia). In the models we analyze how much income from transit traffic is lost in these cases.

6.6.3 Conclusions and contribution

This publication identifies the major sources for risks in supply chains in the Gulf of Finland regions. The risk profiles differ between the locations, and major sources include energy supply, information systems, weather conditions, labour, and collaboration between partners. Also, as the Gulf of Finland contains a heavy amount of oil traffic, a spillage on the sea would stop the supply chains.

According to the study, the ability of the supply chain to cope with disruptions depends heavily on the excess capacity available in the supporting seaports. This is presented in Figure 16. In Estonia, the Port of Tallinn is the only location with any significant amount of container handling equipment and they are dependent on international co-operation. The railway yards of Kouvola and Tapa are also sensitive to disruptions.

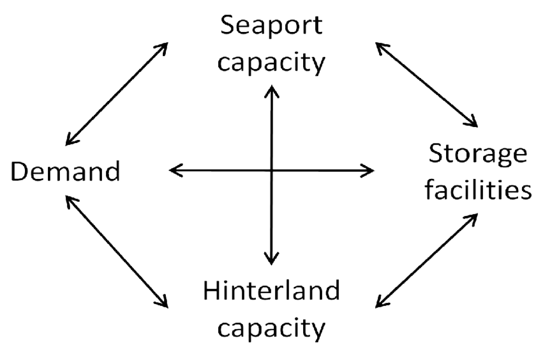

Figure 16: Interplay between seaport demand and capacity

The simulations provide a safe way to analyze how whole logistical systems perform in crisis situations. It was also noticed that SD alone may not be the best way to analyze the systems. Discrete-Event Simulation or ABM may provide more insights into the situations.

7 ADVANCED METHODS IN LOGISTICS SIMULATIONS

7.1 Transportation and Warehousing Simulations

According to Beamon (1998), there are four modelling approaches which can be used to design and analyze supply chains:

- Deterministic analytical models
- Stochastic analytical models
- Economic models
- Simulation models.

Min and Zhou (2002) have proposed a different way to classify supply chain modelling approaches. Their taxonomy includes deterministic and stochastic models as well, but economic models are not included (it should be noted that Beamon (1998) only found one paper using an economic model, so it is only a very minor class at most). Simulations are under hybrid models and the fourth category is IT-driven models including a connection to an Enterprise Resource Planning (ERP) system or a Geographical Information System (GIS).

According to Min and Zhou (2002), it is important to choose the scope of the modelled supply chain carefully. The model should take into account all the important factors, but it should not be too complicated to solve. Min and Zhou continue by stating that there are three main components in supply chain modelling, which are

- Supply chain drivers
- Supply chain constraints
- Supply chain decision variables.

It is possible to define many different types of drivers for supply chains. However, the drivers depend on the type of supply chain. For instance, in humanitarian aid logistics, the efficiency of the supply chain is not a very important aspect, as it is more important to get the help in the disaster area quickly (Kovács and Spens 2007). Also, as discussed in Section 2.3, companies choose different types of supply chains according to their production and market characteristics. Gunasekaran et al. (2001) and Beamon (1999) provide a good overview about performance measures and metrics in a supply chain environment.

Supply Chain Management (SCM) is frequently analyzed with the help of simulations. One of the first major applications of simulation was Industrial Dynamics and it analyzed how bullwhip-effect occurs in supply chains (Forrester 1958). The current literature regarding simulations and SCM is vast. Longo (2010) has analyzed the use of inspection in a container seaport with a simulation model. Chan and Zhang (2010) have studied the impact of collaborative transportation management on supply chain performance. Yoo et al. (2010) have used a hybrid algorithm to optimize a supply chain simulated with Discrete-Event Simulation (DES). Ertem et al. (2010) have analyzed auctions for a humanitarian supply chain with the help of a simulation. Giannakis and Louis (2011) have created a framework for managing disruptions and mitigation of risks in a manufacturing supply chain. These are only recent examples, while Google Scholar (12th of June, 2012) gave 36 100 results, when the search was conducted by using “supply chain management” and “simulation” as keywords.

7.2 *Importance of User Interfaces*

The work presented in the individual publications can be expanded to analyze larger systems. The third publication presented an initial model for a decision support system (DSS). It did not allow much direct interaction from the decision-maker, as it did not contain a proper Graphical User Interface (GUI). It is one possible way to use simulations to run individual scenarios, but it will give additional insights to the users if they are allowed to vary the parameters.

During a project called MobilePort (the purpose of the MobilePort -project is to create a new information centre for a seaport), a simulation model was constructed. The purpose was to create a web-page where individual users could provide their own information and allow the simulation model to analyze their system. The simulation model concerns the use of dry ports, where multimodal transportation is utilized in transporting goods from inland to a seaport. A dry port is an inland terminal where activities typically conducted at the seaport are carried out in the inland terminal instead (Roso 2009). The simulation model calculates the cost and emission savings which can be achieved by using a dry port instead of driving directly to the seaport. More information about the model can be found in Henttu et al. (2010). The user interface of the simulation model is presented in Figure 17.

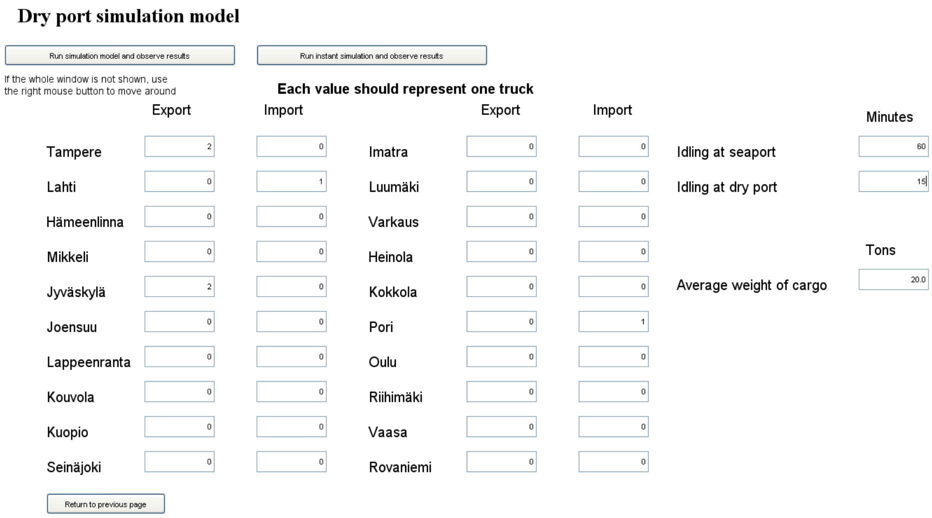

Figure 17: A graphical user interface for a dry port simulation model

As was done in the fourth article, a GUI is used to allow the decision-maker to analyze various potential scenarios. In the model the user can provide information regarding his / her future demand / expected demand to the most important cities as regards the Port of Kotka. As the purpose is to analyze the dry port concept, the basic unit of measure is a truck. Other information includes the amount of idling time at the seaport and idling at an import terminal. The average weight of the cargo will also affect the costs and emissions involved. When the user has provided all the necessary information, he/she can run the simulation model. An example of the simulation model is presented in Figure 18.

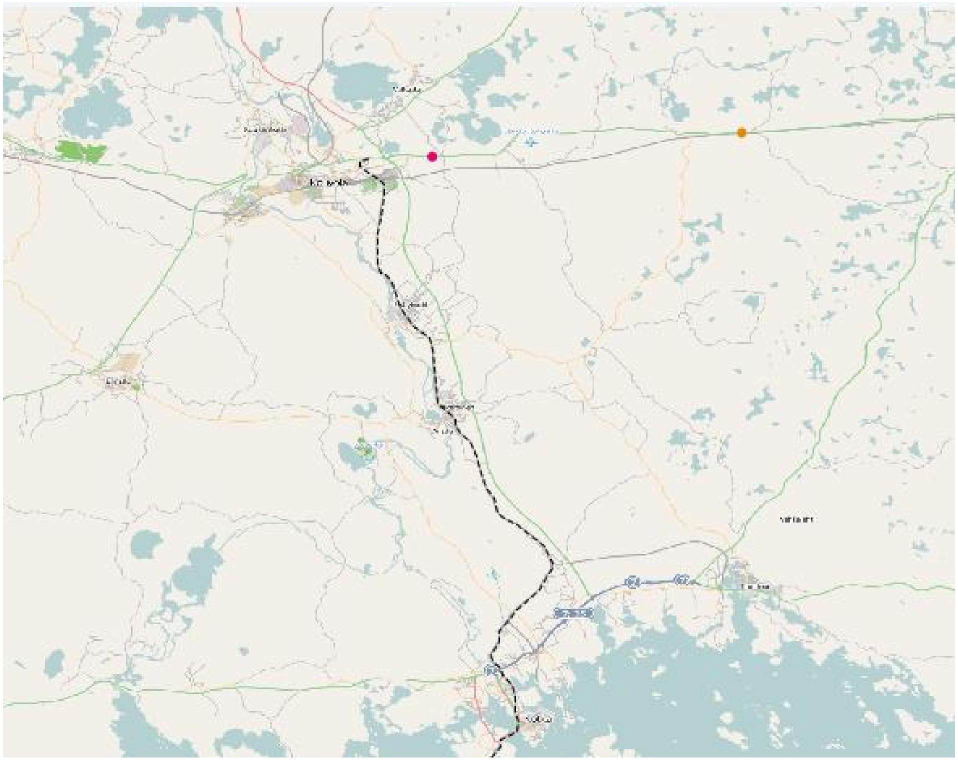

Figure 18: Example of the dry port model during simulation. Map from www.openstreetmap.com

The simulation model runs the model according to the parameters provided by the user. The simulation itself does not provide information for the user, but an additional results page opens after the simulation. This is presented in Figure 19.

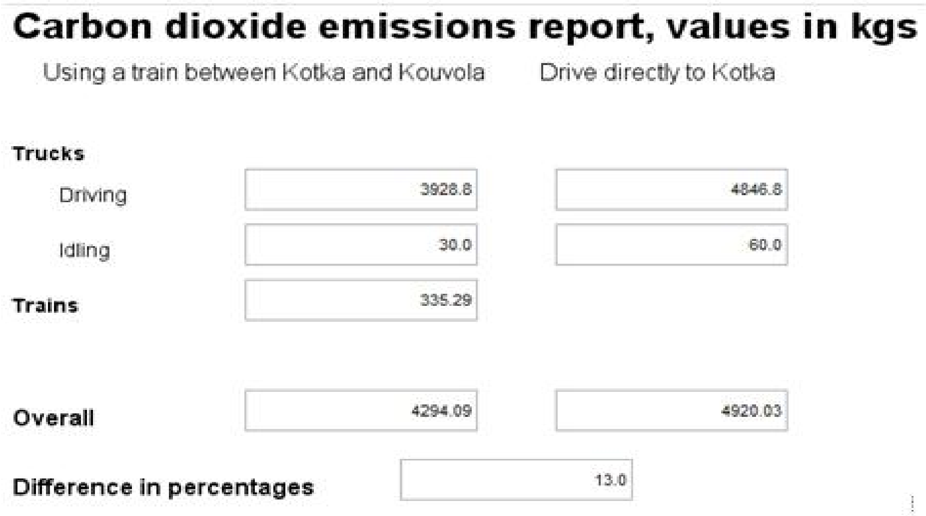

Figure 19: Example of the results page of the dry port model

The results page provides the user with information regarding the results of the model. In this case there are two scenarios which are compared (using and not using a dry port) according to costs and carbon dioxide emissions. The whole construct can be seen to be a DSS, as the user defines the used parameters, after which the simulation model runs through and then provides the actual information for the decision-maker. Without any means of altering the behaviour of the model, the decision-makers will only have a limited view about the problem.

7.3 Importance of Heuristics and Optimization

Another important aspect regarding DSSs is the ability of the system to create good solutions. Simulation is not the only way to improve the results. Other methods include optimization and heuristics. According to Guedes (1995), optimization and heuristics guarantee an improved result, while simulation does not. Simulation can be combined with different optimization and / or heuristics methods which will guarantee better results (Ivanov 2009). Optimization and heuristics are large topics by themselves, and are not discussed more thoroughly in this thesis.

Especially the agents in simulation contain various degrees of intelligence. The intelligence can be realized by using statistical methods, optimization methods, swarm intelligence, or even simple heuristics. However, they may have a great impact on the results of the simulation model. An initial Agent-Based Model (ABM) was constructed during the STOCA project. The model analyzes the impact of a large scale oil-spillage in the Gulf of Finland. The model is somewhat comparable to the first and second simulation models in the sixth publication. The model contains ship agents, which navigate through the Baltic Sea Region. Also, during an oil accident it is possible to use a co-ordinator, who will help individual ships to make better decisions. An example of the model during normal run time is presented in Figure 20.

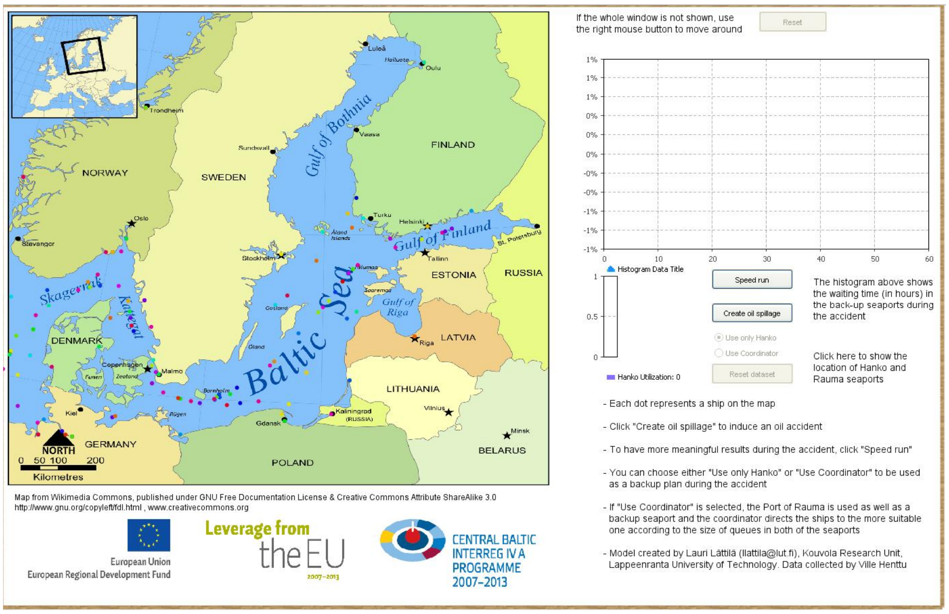

Figure 20: Agent-Based Model of container cargo flows in the Gulf of Finland

Each ship navigates in the Baltic Sea according to their pre-defined route. A similar approach was used in the third publication (Hilletofth et al. 2010). The map provides the route to the locations, and the travelling time is also taken into account in the model. The routes have been gathered from Fossey (2009). The ship will spend a random amount of time in each seaport (triangular distribution with a minimum of 8 hours, mode 12 hours, and maximum of 24 hours), after which it will head to its next destination. No capacity constraints exist in the seaport during the normal situation.

In the sixth publication all the ships were aggregated in just a few stocks. Also, the System Dynamic (SD) model cannot use any graphical information in the decisions due to aggregation. As shown in the second publication, SD cannot create proper queuing models without the help of other methods. As such, it would not have been possible to make a similar model using SD as the main method.

The user can create an oil accident in the Gulf of Finland. The user interface contains a button called “Create oil spillage”. During the oil spillage the ports of Helsinki and HaminaKotka cannot be used. In the normal situation the ships would head towards Hanko, which is the closest seaport with a meaningful amount of container capacity. Hanko is located 120 kilometers south-west from Helsinki. An example of the model during an accident is presented in Figure 21.

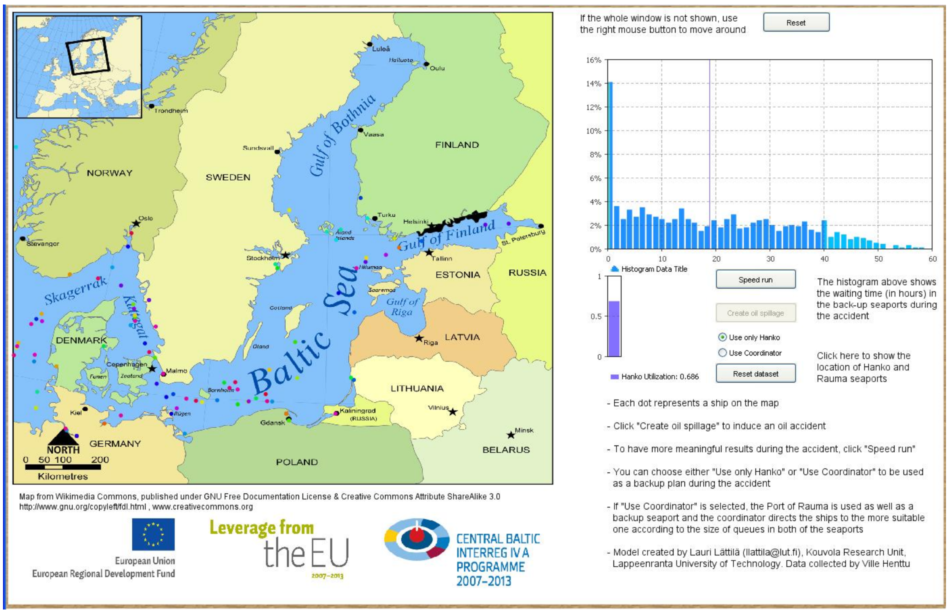

Figure 21: Agent-based simulation model during an oil accident

During the accident there is a fixed amount of capacity available at Hanko seaport. If there are no cranes available, no new ships will be served in the seaport and the ships will wait for their turn outside the seaport. This creates additional delay to the operations. A smaller part of the model shows the excess waiting time, presented in Figure 22.

In this simulation run the waiting time would be almost twenty hours, if only the seaport of Hanko were used. The user can incorporate the coordinator to the model directly in the interface and compare the results. An example of using a coordinator is presented in Figure 23. As can be seen in Figure 23, the waiting time is decreased significantly during the simulation, if a coordinator is used. The coordinator will also start using the Port of Rauma as a potential backup seaport. The Port of Rauma is located in the west coast of Finland. It used to be a large container seaport, but it has lost its volume. The coordinator calculates the length of queue in both seaports, the ships arriving to the seaports, and takes these into account with the available capacity at both seaports. It uses a relatively simple heuristics, but still the situation can be greatly enhanced in the model. There is no reason to assume why using the same principle with different types of logistical simulation models would not enhance the results of the model.

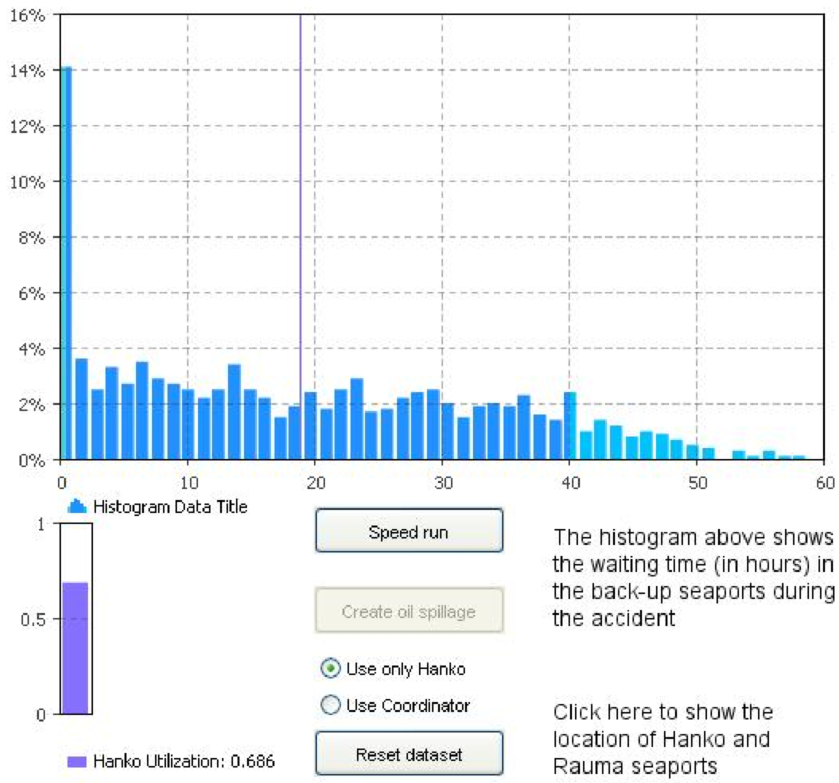

Figure 22: Performance metrics during the simulation without using a coordinator

The results of the model can also be tested statistically. As the distributions are not normally distributed, a non-parametric test has been chosen to be used to compare the situations. Mann-Whitney's U is one of the most widely used non-parametric tests which compare whether the values differ between the two cases. Table 15 shows the results of this test. According to the test, the variables differ statistically significantly between each other. The scenario where the coordinator is used produces clearly smaller waiting times than the scenario without a coordinator.

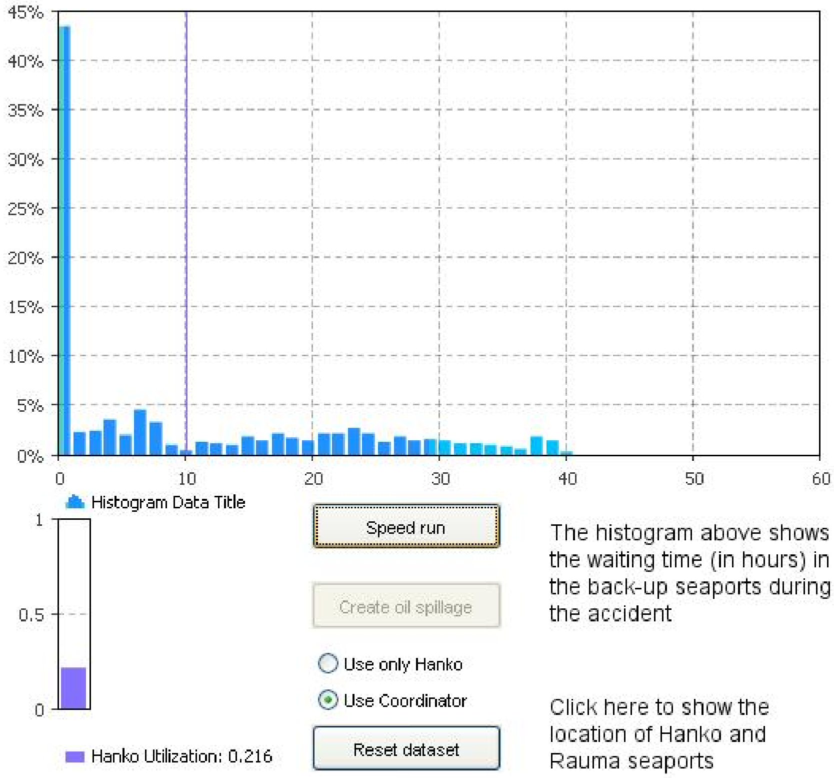

Figure 23: Performance metrics during the simulation by using a coordinator

As the results in both of these cases are run-specific, it is possible to get a broader view of the results by using the Monte Carlo –method with the simulation. A similar approach was used in many of the publications, and it was seen to be of high value in these studies. The simulation model will be run 100 times with oil-accidents of various lengths. The simulation model will then give a histogram about the mean waiting times in different simulation runs at the end of the simulation period. Figure 24 and Figure 25 show the results from the Monte Carlo –method in both situations.

Table 15: Results of the Mann-Whitney test

Ranks

	Chosen scenario	N	Mean Rank	Sum of Ranks
Excess waiting time	No coordinator	1000	1162,49	1162494,50
	Coordinator	1000	838,51	838505,50
	Total	2000		

Test Statistics[a]

	Excess waiting time
Mann-Whitney U	338005,500
Wilcoxon W	838505,500
Z	-12,680
Asymp. Sig. (2-tailed)	,000

a. Grouping Variable: Chosen scenario

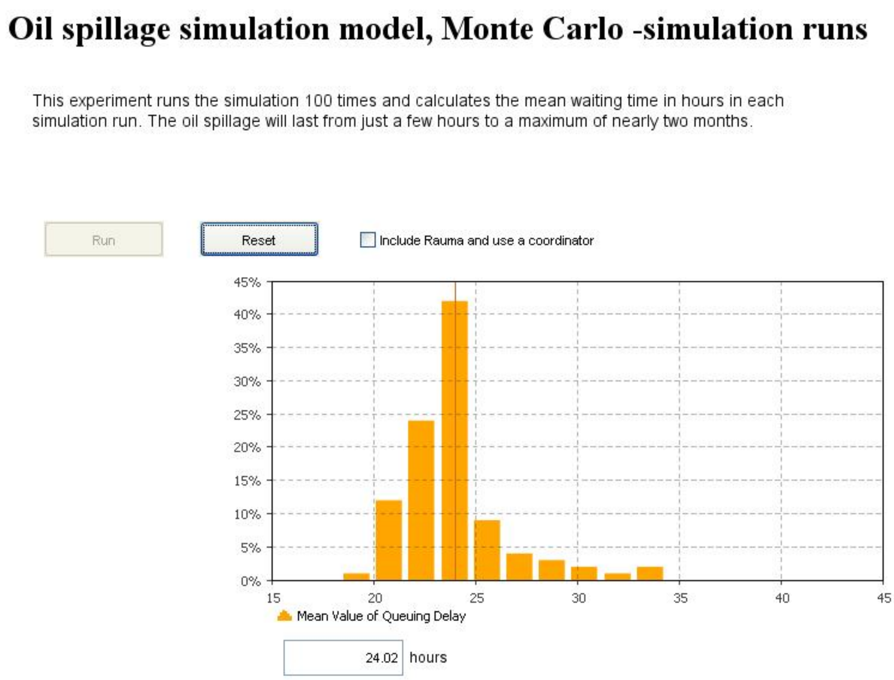

Figure 24: Monte Carlo –simulation run results without using a coordinator

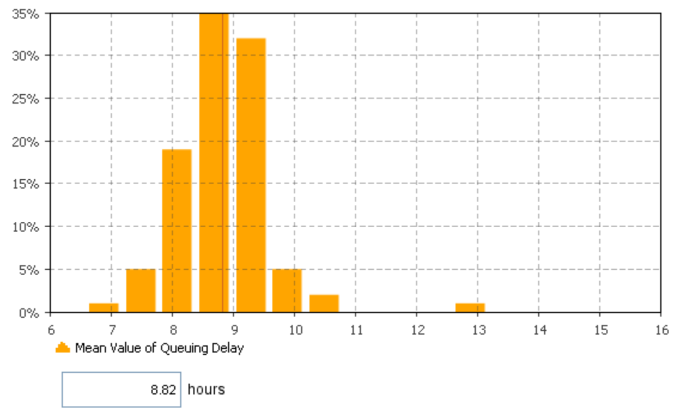

Figure 25: Monte Carlo –simulation run results by using a coordinator

The Monte Carlo runs give additional information regarding the different scenarios. There are clear differences in the performance in the two different scenarios. By using a simple heuristics, the model can make a lot better results. However, at the same time it shows some of the weaknesses related to simulations. Poor defining of some important parts of the model will have drastically different results. If the purpose is to improve the operations, some parts of the model will be more important than others. Miller (1998) has used active nonlinear tests to study the well-known World3 model and found that small changes to certain parameters will have a dramatic impact on the final results. As such, it is necessary to be especially careful with simulation models.

7.4 Estimating the Quality of a Simulation Model

As discussed in Section 4, the organizational impact of Information Systems (IS) comes from the individual impact, which is dependent on the use and user satisfaction of an IS. Many issues have an impact on the use behaviour of IT. One important category has been found to be usefulness. One of the first tests is whether an organization starts to implement a simulation model and its results. According to Kasanen et al. (1993) this would constitute to a weak market test. Whether a strong market test is passed or not is a totally separate issue. Kasanen et al. argue that the performance of the companies implementing the construction should be compared to other companies and see whether systematic efficiencies exist or not. However, it is difficult to compare the results between companies and assume that efficiencies exist due to one particular construction. It is possible that companies using construction X will also more likely use construction Y, which might make the actual contribution to performance. Also synergy efficiencies may exist between different constructions and it is difficult to “control” the sample during comparison. Another issue is a possible bias in reporting the results. If a construct does not work in all cases, this might not be reported. One reason is that in scientific literature it is easier to publish results where statistically significant differences between groups exist (publication bias). If the sample size is grown, it is possible to show statistically significant results even though the actual differences are very small. Thus a large survey could show a statistically significant positive effect when using a specific construct, even though the effect could be small. This does not remove the possible effect of other dependent variables, either. People have also a tendency to look for proof that supports their own view (confirmation bias). Proof of a negative effect of a construct will easily be disregarded due to psychological effects, not mentioning the possibility of pure fraud in reporting the results. Thus, the design for a strong market test requires a lot of work.

If a simulation project is properly conducted, the work does not end when the model is ready. This was discussed above in Section 3.2. The model needs to be implemented in the decision-making as well. If the model shows a positive impact on the results of the company and it is implemented in the decision-making, it is possible to make inferences on whether the construct is a good one or not. If the results of the company improve in a similar fashion as indicated by the model, the construct can be seen to be a good one. This still does not provide information on whether the model provides the best possible DSS for the company, as it is not possible to study “optimality” outside mathematical models. This requires some sort of logic to defend the chosen construct. It can be possible to use the “best practice”, when the construct is done, but according to Cox (1997), in business one always needs to take risks and that requires the use of new practices from time to time.

Simulation can also be used to study other constructs. A “perfect” market test would separate the construct, and everything else should then be controlled. This would allow studying the construct against other older constructs and analyze whether additional benefits can be achieved by a company with using a certain construct. The model could also take into account different types of environments, and a certain construct could be more appropriate in other environments. As discussed in the third publication, the current service structure of company was unfit for its current markets. The centralized structure can be compared against a decentralized structure. The model can then study the usefulness of the possible future service structure and estimate its impact on the results. It could also be possible to study and find out when the structure needs to be expanded.

Several of the simulation models in this thesis were used by case companies. One of the companies clearly changed their own service strategy according to the results of the simulation model (presented in Publication three). Also the case company presented in Publication four is considering using the models in their sales processes. This indicates that the models are able to improve their decision-making and processes, or at least the managers think that the models will improve their operations.

It is more difficult to compare the models presented in Publications one, two, and six, as well as the models in Sections 7.2 and 7.3, as they do not directly influence any operational policies, because they are based on larger projects handling macro-logistical issues. However, the models handling seaports have been well received by the main partner in the project (Finnish National Emergency Supply Agency). Also, the dry port model has been used by many smaller transportation companies. This gives some indication that the models are of good quality.

7.5 Transportation and Warehousing Decision Support Systems

As discussed in Section 2.3, transportation and warehousing are a part of a process called speculation and postponement. An organization needs to choose the proper supply chain strategy according to the demand and supply characteristics (Hilletofth 2009). It is possible to use simulations to analyze the various structures available and to choose the best one. The chosen strategy can then be incorporated into a SIMDSS for more frequent decisions. The constructed DSS will depend on the types of decisions and problems, as discussed in Section 4. When possible postponement strategies are considered, the decisions are strategic by nature. In daily running processes the decisions are operational. The SIMDSS needs to be constructed appropriately, or the user will not have enough confidence towards the system (as discussed in Section 4). This will decrease the user's use behaviour and weaken the quality of the DSS as well. This will have a diminishing effect on the quality of the decisions, which will later on have an impact on organizational performance. When a SIMDSS is constructed, the model should incorporate the constraints, drivers, and decision variables (discussed in Section 7.1).

Simulations in logistics began with SD in the 1950s (Forrester 1958). However, as noted in the fifth publication, it might be advantageous to analyze logistical systems on a more disaggregated level, as the actors are not homogeneous. In transportation and warehousing this means separate warehouses and transportation routes as the delays in transportation will differ between locations. In transportation it is advantageous to use more locations than aggregate everything. However, as SD has a long history in policy analysis, it is possible to use the SD approach to analyze how different parts of the model change their behaviour due to a policy change. On the other hand, it is possible that data is only available at a particular level and this imposes restrictions on the chosen method.

Logistical simulation models can benefit greatly from being incorporated with some sort of map information (which was also done in publication three and in Section 8.2). A Geographic Information System (GIS) could be connected to a simulation model and the model could read the distances between different nodes straight from the map. This would decrease greatly the time required to inserting various distance information to the model manually. It can also allow a higher amount of flexibility for the user interface, if it incorporates only the required nodes in the model.

Monte Carlo –analyses can also provide useful information for the decision-makers. It is possible to incorporate uncertainty and provide confidence intervals for the "voice of the process". Most of the papers in this research (Publications one, two, three, and four), as well as the model presented in Section 8.2, used Monte Carlo –analysis, which provided more insights into the performance of the system being modelled. The fourth publication also studied the sensitivity of the variables to find out the most important variables regarding the output. If a model does not contain stochastic variables, it is possible to make changes in the variables one at a time and compare the simulation runs. This type of an approach was used in the sixth publication. In larger models, a similar approach to the one used by Miller (1994) could be used, or gather data from the outputs of the model and then conduct sensitivity analyses on those variables. As shown in Section 7.2, optimization with simulations is important. If an important part of the model (the most important parts can be analyzed with the help of Monte Carlo –simulations) is poorly simulated, the results of the model can differ greatly. The optimization of a simulation model is a large topic and is not discussed in this thesis.

The contribution of this thesis is presented as a simulation framework in Figure 26. Many parts of the framework have been presented separately earlier, but in this thesis they are presented in a holistic manner. Some of the connections in the DSS are one-way connections (information is only sent one way, represented by a one-way arrow,) while others are two-way ones. The simulation model itself can be constructed by using any one of the simulation approaches or by combining them (Borshchev and Filippov 2004). Simulation models usually use heuristics during the run time, as optimizing each decision would take too long (Ivanov 2009). However, during the initial model setup, or rarely during the simulation, it is possible to use actual optimization methods. Optimization could be used to create an initial solution for the simulation model. As the optimization needs to make more generalizations, the simulation could then test the feasibility of the optimized solution or use heuristics optimization to improve the performance of the system. The heuristics themselves might need optimization as well in order to have a properly functioning simulation model. Heuristics optimization is needed if the DSS needs to be a normative one, e.g. the DSS gives direct suggestions for how to run the daily operations instead of providing a descriptive analysis of how the operations work. The Design of Experiments -approach can also be used to improve the performance of the model (Chen et al. 2009; Longo 2010; Bottani and Montanari 2010; Tiacci and Saetta 2011) and thus the whole system. Also, a part of the simulation model can use more traditional modelling approaches, such as queuing theory or statistics. As queuing theory and statistical methods do not simulate anything, the methods should support the actual simulation model. For instance, queuing theory could be used to estimate the system performance, which then has an impact on a larger SD model.

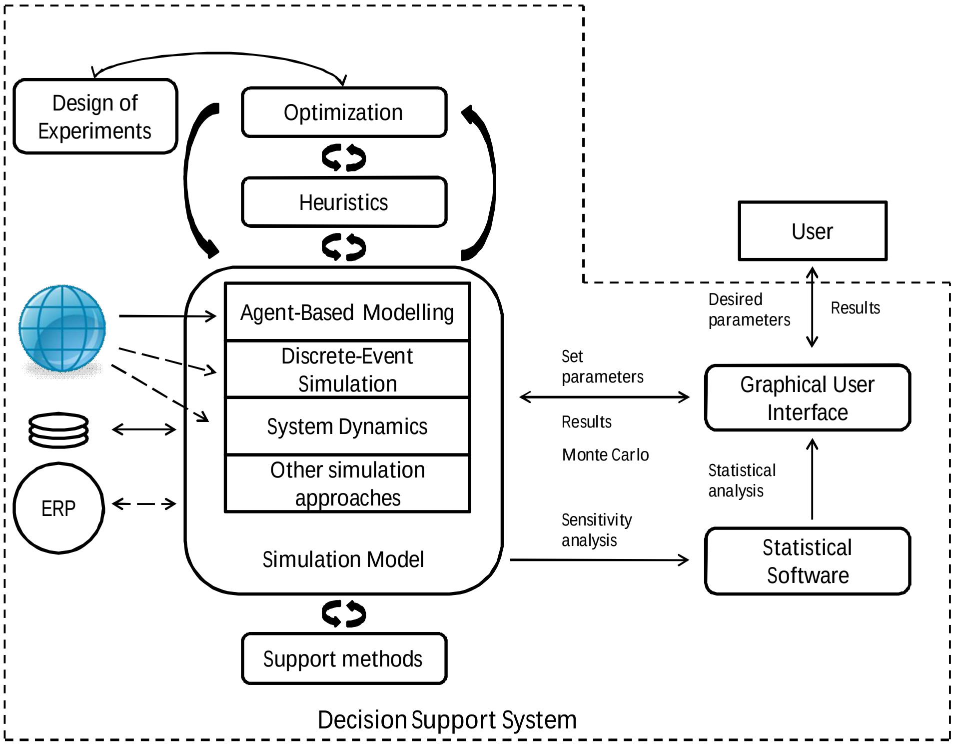

Figure 26: Proposed framework for multi-method simulation-based decision support systems

The simulation model is connected to various databases, depending on the type of the problem. Also, as shown in Section 7.2, especially ABM can greatly benefit from being combined with a GIS or other map data. DES can also benefit somewhat from GIS, but the benefits are smallest for SD. GIS provides a good source of data for the actual simulation model (Min and Zhou 2002). GIS is based on the real system and the simulation model does not modify it directly. However, in some cases a simulation model could be used as a part of daily processes and it could make changes to the different ERP –systems or databases, which are connected to the simulation model.

The user should be able to have some kind of interaction with the model. According to Sprague and Watson (1996), the user interface is the most important component in management support systems. In most cases, the model constructor and user are different persons and thus the interface needs to be usable. A GUI is needed where the user can make the choices which (s)he prefers to use in the simulation. The user interface then makes the changes in the code of the model and incorporates them into the simulation runs, after which it gives the results of the model to the user. A proper user interface has a big impact on the use of the DSS, which in turn affects individual and organizational performance (DeLone and McLean 1992, Legris et al. 2003).

Uncertainty is usually handled with the Monte Carlo -method in simulations (Peidro et al. 2009). It can also be communicated to the user via the user interface. If more thorough sensitivity analysis is needed, it might not be possible to analyze it with the simulation model. In these cases other programs can be used, such as statistical software, to analyze the impact of different variables properly (similar to Design of Experiments). Again, if the user is not an expert with statistics, some kind of an easy way to analyze the results must be provided. It is possible to allow the model to activate statistical software, run the analyses using the software, and then report the results in an understandable form. As can be seen in Figure 26, the user does not need to interact with the system in any other way than by using the graphical user interface. This way the user is allowed to interact with the model without the need for a specialist.

8 CONCLUSIONS

8.1 Theoretical Implications

The main research question of the study was: "*How can the efficiency of transportation and warehousing be improved with simulation-based decision support systems?*" According to DeLone and McLean (1992) the organizational impact is finally dependent on information and system quality, while the use of the system will depend on various factors (Legris et al. 2003). This thesis has proposed a new framework for simulation-based decision support systems (SIMDSS). Different types of problems require different types of decision support (Simon 1960; Gorry and Scott Morton 1971). If an organization is exploring the possibility to change its postponement strategy (Pagh and Cooper 1998, Hilletofth 2009), the decision support system (DSS) will clearly differ from a system supporting a constantly running process. This should be reflected in the chosen simulation approach. The simulation model is only one part of a decision support system, and the user will communicate with the software through a user interface (presented in Figure 26). The quality of the user interface also has a great impact on the usability of the DSS. If the Graphical User Interface (GUI) only provides a small amount of possibilities to impact the simulation runs, the whole system has a lower organizational impact. This is due to the limited number of analyses which can be conducted with the system. However, if the GUI provides good possibilities (enough options and good usability) to impact the model, it will make more thorough analyses possible and have a higher impact on the organizational level as well.

Section 7.1 clearly points out, how important proper GUIs are in designing DSSs. Without a good interface the user might not be able to make the required changes in the simulation model (usually parameters). Also, the GUI needs to act as a "filter" between the model and the user. The GUI will give all of the necessary results for the user without requiring him/her to spend time on compiling them together. The GUI also separates the user from the other parts of the DSS, and so the user is able to concentrate on the actual decisions, while the system gathers all the relevant data. Proper heuristics and optimization need to be used in conjunction with simulation models. If the heuristics are of poor quality, the model will not generate the appropriate behaviour. This will lead to poorer decisions, as the model does not behave as the real system would behave. In section 7.2, a simulation model was presented, where location information was combined with an Agent-Based Model (ABM). This seems to be a very promising avenue for logistics simulations. System Dynamics (SD) cannot benefit that greatly from GIS, but a GIS could provide aggregated information as well, which could be used by a SD model.

The advantages and disadvantages of methods have been rarely discussed in the literature, and in many cases no reasons have been given for why a specific approach has been chosen (see for instance Eksioglu et al. 2010; Henesey et al. 2009; van der Vorst et al. 2009). The first sub- question of this study was: "What are the advantages and disadvantages of different simulation approaches?" As SD works on a highly aggregated level, it has difficulties when the units of analysis differ significantly. However, if the problem domain does not severely suffer by using a high level of aggregation, SD should be used (Publications one and four). ABM, on the other hand, was seen to be a very versatile approach (Publication two, three and five). ABM also allows incorporating more complex events than SD (Publication five). This is also true for Discrete-Event Simulation (DES). ABM also has relatively long run times compared to SD (Publication two). This could make broad analyses more difficult to conduct, as it will take much longer to run all the desired simulation runs.

The second sub-question was: "Where can hybridization of different simulation approaches offer additional insights?". Many studies (Scholl and Phelan 2004; Schieritz and Milling 2003; Borshchev and Filippov 2004) have suggested combining various simulation approaches to create multi-method simulation models. However, only a few hybrid models exist (see for instance Sun et al. 2012). Hybridization was also promoted in this research (Publication two and five). There are many ways to combine SD and ABM (Publication five). It is possible to use SD structures inside agents. At the same time, it is possible to use ABM as only one part of a larger SD model. For instance, some populations could be modelled as agents and then the SD model would calculate some aggregate values from the population to be used in a larger SD structure. ABM and DES were combined in the model presented in Section 7.3. The natural queuing structure of DES can benefit both ABM and SD models if a clear process is involved.

Simulations can be combined with other methods as well (Ivanov 2009). The third sub-question was: "What other approaches can be combined with simulations in order to have more useful decision support systems?" ARIMA models and queuing theory can be combined with SD (Publication one and two). However, it can be argued that time series analyses can be combined with ABM and DES as well. Queuing theory would not be needed if the model is a hybrid one and DES is used to represent the queuing operations. Queuing theory loses its usefulness when the system becomes too complex. It is also possible to combine simulations more directly with optimization methods (Frayret et al. 2007), and this can also improve the quality of the models significantly.

Uncertainty is an inherent characteristic in supply chains (van der Vorst and Beulen 2002; Sanchez-Rodriguez et al. 2008; Germain et al. 2008) The final sub-question, "How can uncertainty be included in decision support systems?", was analyzed in many of the publications. The Monte Carlo –method is one way to cope with uncertainty (Publications one, two, three and four, and Section 7.3). However, in ABM this can take a long time. Another possibility is to use more systematic changes in the variables containing uncertainty (Publication six). It would also be possible to use the Design of Experiments -approach to analyze the impact of important variables. Many simulation studies lack Monte Carlo, even though it is relatively easy to conduct.

8.2 Managerial Implications

The managerial implications of this thesis come from individual studies and the framework presented in the introductory part. The implications of the individual papers are summarized in Table 16. The implications of the papers are discussed briefly below, after which the managerial implications of the introductory part are addressed.

The first publication discusses the importance of industrial production as a means of estimating seaport demand. Generally GDP has been used as the main explanatory factor, but in this study industrial production was shown to be a more appropriate variable in the Finnish context. This is important for logistics managers who operate in seaports. It is also possible to estimate the development of industrial production with the help of industrial orders at hand. This way it is possible to have a six-month forecast for industrial production.

If managers participate in modelling projects, they need to reserve more time for ABM projects. It is very difficult to conduct collaborative modelling, as ABM requires a lot longer time to construct than an SD model. Also, running the model will also take much longer time, in which case the modeller and logistics managers may need to have separate meetings when modifying a model. The third paper emphasizes the use of ABM as a part of DSS. Many situations can be easily represented as agents and it is possible to model them with ABM. ABM also provides a lot more versatility than SD, which can be beneficial when constructing a DSS. In the modelling case, the balance between resource use and customer waiting times were analyzed, and the model clearly points out how centralized service solutions can lead to excessive waiting time for customers, as well as a long time spent on reaching the customers. If an organization provides maintenance services to their customers, they need to take longer driving times into account. Organizations need to consider this issue when promising servicing times for customers.

Table 16: Managerial implications in the individual papers

Article	Implications
P I	National demand can be analyzed at individual seaport level. Industrial production drives the development of demand for Finnish seaports.
P II	Managers need to allow longer time periods when participating in model construction if ABM is chosen as the methodology
P III	ABM can provide a versatile DSS for managers
	Maintenance service providers need to understand the impact of service network structure and individual customer serving time
P IV	Organizations utilizing open-top containers should look into automated loading solutions
	Warehouses with high amount of mishandling of goods should consider automated warehousing systems
P V	Managers should look into hybrid-model Expert Systems to improve decision-making within organizations
P VI	The sources of risk in logistical supply chains include energy supply, information systems, weather conditions and labour
	Simulation can be used as a part of risk management

In the fourth publication, the importance of including uncertainty in investment decisions is highlighted. The paper also points out how the type of container is an important factor when automated loading solutions are considered. These solutions allow using normal containers instead of open-top containers, which are more expensive to transfer overseas. In AS/RS –systems the amount of spoilage is an important factor. In automated storage, the amount of spoilage due to mishandling is greatly decreased, as forklift trucks are more dangerous than handling the material with automated cranes.

The fifth publication concentrates on the use of different simulation approaches in Expert Systems. As individual simulation approaches have difficulties in specific situations, managers need to be aware that hybridization can provide an improved Expert System which will help them to make more informed decisions.

The last paper summarizes interviews which concentrated on risk management in supply chain management. The risk profiles differ according to the actors, but the most frequent risks include energy supply, information systems, weather conditions and labour. The paper also utilizes simulations as a part of risk management. Simulations should be used as a part of risk management, as they are descriptive by nature. They present how systems behave due to external stimuli.

Managers should understand the possibilities which SIMDSS can offer. As simulation should only be used when no other method works well, it can be expected that these are the problems which managers struggle most with. It is possible to have a DSS which is connected to the correct databases, utilizes the best possible approaches, and provides the manager the correct outputs and sensitivity analyses. The manager should be able to achieve these goals without requiring constant participation of a simulation engineer.

8.3 Limitations and Validity

This thesis contains various simulation models, and two of which were constructed for individual case companies. The case companies have used the simulations in their decision-making, and thus it can be seen that the cases have passed the weak market test (Kasanen et al. 1993). As the performance of the case companies has not been compared against their competitors after implementing the simulation models, it is not possible to say that a strong market test has been passed. Some of the simulation models were constructed in a large EU-funded project (STOCA), where the problem owners were not clearly defined. However, the Finnish National Emergency Supply Agency has been satisfied with the models, which indicates that the models are of good quality.

On the other hand, this thesis is limited by the number of simulation cases constructed and analyzed. As such, each model can be seen to be an individual case, and this makes generalization an issue. However, the SIMDSS has been approached from many different types of situations, which can be seen to enable generalizing the results to different transportation and warehousing environments. Another possible limitation can be the selected research approaches. Many of the individual publications are either constructive or action-oriented, in which case the researcher can be too close and have a biased view of the problem domain (Coughlan and Coughlan 2002). It could have been possible to concentrate only on one type of a problem, but in that case it would not have been possible to generalize the results to the larger field of transportation and warehousing.

The individual simulation models also have some limitations. These are summarized in Table 17. Different models were constructed using different approaches, but all of them have some limitations. However, these limitations should not impact the actual results of this thesis. For instance, if feedback is lacking (Publications one, two and three), it only means that the model itself can be lacking some important phenomena. This in itself impacts the validity and verifiability of the models, not the thesis.

Verifiability and validity are always major issues with simulation models. According to Sterman (2000), it is not even possible to validate models. Also, as the famous quote from Box (2012) goes, *"Essentially, all models are wrong, but some are useful"*. Every model will always be some kind of an abstraction from a mental model of a decision-maker, which is an abstraction of reality itself. However, this does not mean that it is not possible to use simulations in decision-making. Decision-makers always have to use some kind of a mental model, and if the constructed simulation models are the best ones, they should be used (Sterman 2000). Some other authors (Balci 2003; North and Macal 2007) have proposed ways to validate and verify models. During the construction processes of the models in this study, the appropriate (SD uses different method than ABM, for instance) methods have been used.

Table 17: Limitations of the simulation models

Article	Method	Limitations
PI	SD & ARIMA combined	No feedback inside the model Industrial production and Russian oil exports were the only external variables, while in reality the seaports are connected
PII	SD & ABM separately	Demand in both models is external The models operate on a high level of abstraction
PIII	ABM	No feedback between preventive and corrective maintenance Only one machine segment Some of the engineers operate on too simple heuristics
PIV	Monte carlo	No dynamic behavior The models are mainly linear
PVI	SD	Only two seaports in both models Concerns only containers No piloting operations
Section 7.2	DES	All cargoes are similar Fixed amount of locations No stochasticity
Section 7.3	ABM & DES combined	Only container ships No piloting operations Does not take the size of ships into account

The validity of the synthesis presented in Section 7, "Advanced Methods in Logistics Simulations", is of higher importance. When this section was written, the models were contrasted in order to find out similarities and differences. This is somewhat similar to cross-case analysis or grounded theory, but in this research the researcher has participated in the cases, which decreases the objectivity of the observer. However, it can be argued that the observer needs to be close to the models, as only the modeller can understand the decisions made during the whole development process, and as such, the SIMDSS framework could have been incomplete without adequate exposure to the models. The SIMDSS framework needs more tests to verify whether it represents SIMDSSs in logistics accurately.

8.4 Further Research

Further research concerning the first publication includes expanding the seaport simulation model to contain information about hinterland development as well. The potential hinterland includes warehouses, railway capacity and needs of road transportation. The driving factors of the model (industrial production and Russian oil exports) should also be analyzed more thoroughly to find out how better short term forecasts could be made.

In the second publication, hinterland logistics is seen to be a possible way to expand the simulation models as well. Emergency situations are another possible avenue for further research. In addition to these, the paper proposes the use of hybrid-simulation models to see whether more useful models can be created.

The model presented in the sixth publication could be improved by analyzing the hinterland logistics more thoroughly. Potential further research includes using other simulation tools (DES or ABM) to analyze the disruptions. The paper also encourages using a similar approach in other geographical areas or similar crisis situations in other than maritime supply chains.

Hinterland logistics is seen to be a possible extension in three different publications. The sixth publication has a very simplistic way of presenting hinterland capacity, so more research should be done regarding seaport hinterland modelling. It is an important factor regarding macro-logistics simulations and should not be overlooked in a DSS either. Otherwise the results of the model might be too optimistic, which could lead to bad decisions by the decision-maker.

In the fourth publication, the potential avenues of research include connecting AS/RS spreadsheet simulation models to other simulation software. The simulation software could then simulate the solution proposed by the spreadsheet model. The spreadsheet model could be expanded to include other design parameters or modify the model to be a standalone application to any computer with spreadsheet software. Spreadsheet connectivity is an important issue, as spreadsheets cannot grasp dynamic behaviour very well. A good visualization is a good way to achieve buy-in, as it is easier to understand a visual representation of a system.

The third paper contains two potential avenues for further research. One possibility is to analyze in which situations the management of the company would find the model to be of best use. Another possibility is to study how the simulation model can be connected to other DSSs. These are both general issues in SIMDSSs. It is possible to improve the quality of DSSs, if it is known in which situations managers generally use simulations. Also, connectivity to other DSSs would greatly enhance the validity of the model.

The suggestions for further research in the fifth publication include the need to have more simulation models with a hybrid approach and then analyzing what was difficult during the construction process. Also, the five interfaces proposed in the publication should be tested empirically to see whether it would improve the quality of the simulation models. In addition, an Expert System containing a hybrid simulation model should be compared against an Expert System with a one-method simulation model to see how much additional benefits hybridization provides in Expert Systems.

This thesis has only briefly analyzed the benefits achievable by combining simulation models with some sort of a GIS. The initial experiences are encouraging, however. Especially ABM seems to benefit greatly in transportation research by using GIS as part of the model. GIS is a powerful tool if it is combined with optimization, and combining all three approaches (GIS, optimization and simulation) will likely yield extremely powerful analyses, which in turn need to be converted to a proper DSS for managers.

Another important issue is the use of various simulation approaches in transportation and warehousing; which simulation approach (SD, DES, ABM) should the modeller use in different situations? This issue was not fully covered in this thesis and needs to be studied further. Also, how great advantages does hybridization provide compared to using a single-method simulation? Hybridization was found to be highly beneficial, but it would be important to know whether the additional advantage justifies the use of multiple approaches, as it generally takes a longer time to construct the models. Generating good “rules-of-thumb” to modellers would help to improve the quality of transportation and warehousing SIMDSS. Modellers themselves have a lot of tacit knowledge about the use of different simulation approaches with different cases, but a lot of work needs to be done to create explicit knowledge. This issue could be pursued by utilizing a focus group consisting of simulation experts who have good knowledge of all the major simulation approaches, as well as some knowledge about different optimization methods.

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APPENDICES

APPENDIX

Definitions by Council of Supply Chain Management Professionals

Supply Chain Management

"*Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology*."

Logistics

"The process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements"

Logistics management

"Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution-strategic, operational, and tactical. Logistics management is an integrating function which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology".

Council of Supply Chain Management Professionals (CSCMP) (2010), Glossary of Terms, <http://cscmp.org/digital/glossary/glossary.asp> [www-document] [accessed 3rd of September 2010] [modified February 2010]

PART II: PUBLICATIONS

Publication I

Lättilä, L. and Hilmola, O-P. (2012)

Forecasting Long-Term Demand of Largest Finnish Sea Ports

International Journal of Applied Management Science, 4(1), pp. 52 – 79

Forecasting long-term demand of largest Finnish sea ports

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Abstract: Investments in large scale logistical infrastructure are significant and they require a long time and as such good forecasts play an important part. In this research, we combine advanced forecasting methods with system dynamics to study the development of Finnish sea ports. We use regression and ARIMA models in conjunction with a system dynamic Monte Carlo simulation model to estimate the development of Finnish sea ports. Based on long-term data, industrial production was found to be the driving factor behind sea port demand development in Finland. GDP is generally regarded as the explanatory variable, but at least in Finland, industrial production drives the growth. Russian oil exports also explain transit traffic through Finland to Russia, and four scenarios were generated to estimate the development of Finnish sea ports.

Keywords: advanced forecasting models; system dynamics; sea port demand; stochastic simulation; Finland.

Reference to this paper should be made as follows: Lättilä, L. and Hilmola, O-P. (2012) 'Forecasting long-term demand of largest Finnish sea ports', *Int. J. Applied Management Science*, Vol. 4, No. 1, pp.52–79.

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1 Introduction

Currently, system dynamics is truly a multidisciplinary method, and simulation technique has been applied in various different branches in five decades time period. Rather interestingly, research dealing in transportation or more specifically sea port demand, has been scarce. In the leading journal of this discipline, *System Dynamics Review* (*SDR*), there has only appeared one research work in its three decades long history, and it dealt with political decisions and transportation mode changes in Germany and Italy (Piatelli et al., 2002); attention focused on the implications of punishment tax policies of transportation mode choices in these two countries. Other publications have mostly taken into account oil transportation issues, e.g., during 70s, Coyle et al. (1977) developed tanker market models for large oil company, and some of the factors incorporated in the model were forced to be built as exogenous, rather than endogenous. However, their research mainly concerned tanker fleet management to ensure oil supply, not ground operations. Thus, other research works have been completed just recently. Dikos et al. (2006) reported research results from tanker freight modelling, where their system dynamics model was able to follow charter prices of tanker transportation. By incorporating different investment decision factors, scrap rate of current tankers, and demand, their model was surprisingly accurate in predicting the level of transport prices in the period 1980–2002. Thus, it should be noted that even this research work was concerned, similarly with Coyle et al. (1977), on strategic level of decision making, not real transportation operations. Similar to these two research works, Ellison and Corbet (2006) simulated the phase-outs of single-hull and double-sided/bottomed, and their effects on the demand of tanker production. Based on their research order intake among tanker producers spikes at 2010, and production follows this with four- to five-year time lag. Instead of these global and really strategic studies, Koskinen and Hilmola (2005) studied Russian oil harbour Primorsk/Koivisto enlargement emphasis, and its affects on the demand of ice-strengthened oil tankers. Their research showed that these special types of tankers are needed to be built in the following ten years, if transports are desired to be secured from environmental hazard during the rough winter periods.

To motivate our study purpose, we can conclude that due to Finland's geographical location, most of the Finnish industrial production gets exported through Finnish sea ports (it is like an isolated island in European landscape). For example, Hämäläinen and Tapaninen (2008) studied the transportation costs of a Finnish paper mill. In their study, the heterogeneity of the European market had a big impact on transportation costs. Therefore, the development and investments of Finnish sea ports plays a crucial role for the whole Finnish industry. The objective of this study is to examine the development of Finnish sea ports during the next 20 years. The research question can be presented as: 'How will the demand for major Finnish sea port system evolve up to year 2030?' For this purpose we have identified four types of demand: imports, exports, import transition, and export transition. In Finland, the presence of Russia has a major impact on import and export transition [Finland is sharing similarities with Singapore, (e.g., Hui and Wan, 2008) not only in logistics sector, but within travel and retail too]. We complete our research work by combining system dynamics, and advanced forecasting methods. As future contains uncertainty, we have used statistical distributions to represent probable future outcomes. This model gives also an opportunity to derive demand top-down to harbour and product group level (e.g., general cargo, bulk or liquid bulk), but this has not been reported over in this manuscript. However, aggregate demand from Finnish sea ports consist uncertainty of each port and three different main product groups (liquid bulk, dry bulk, and general cargo).

This manuscript is structured as follows: in Section 2, we review literature related to forecasting of long-term sea port demand. Our literature survey shows that forecasting in this particular area is either too wide (whole nation or country) or too narrow (only handful of sea ports), and according to our knowledge, we have not identified any research work using methodology and approach, which could develop demand forecasts top-down or bottom-up fashion. In Section 3, we introduce research environment, Finnish sea ports. Although, Finland is a small country, its port system contains numerous different harbours, but handling tons overall is Pareto distributed, and specialisation regarding cargo groups and market areas is progressing between ports. In Section 4, we introduce our system dynamics simulation model, which is based on advanced forecasting models in four different identified sub-groups, and in causalities identified by expert group. Thereafter, in Section 5, we present findings of four different future scenarios; growth is present in following decades, but depends mostly on industrial volume of this country as well as in minor extent on the Russian oil export volume (in Euros; this drives transit import of Finland). Discussion regarding changing conditions of the world is provided in Section 6. Growth of Finnish sea port system could have drawbacks from poor industrial demand development, but most probably it will not have significant downward trend in the future. Some ports might experience problems, if the value of Russian oil export is being hurt by sustainable sales price decline of this raw material. However, this effect is mostly regional and port specific. In Section 7, we conclude our research work, and propose avenues for further research.

2 Literature review – forecasting long-term harbour demand

In the literature review, all of the three words (sea port, container terminal or terminal system) were used to recognise publications regarding the forecasting sea port's demand. Each publication's method was categorised according to either an econometric, simulation, judgmental, or analytical method. Table 1 provides also information, what kind of demand was being forecasted (demand was broken down on three classes, namely liquid bulk, dry bulk, and general goods cargo), and what was the scope of forecasting.

Amount of ports in analysed articles varied; two publications were dealing with only one port, as similar amount of publications were dealing with few, and numerous ports. Three research works did not have any specific port to be forecasted at all, but evaluated overall demand in country or region level. Interestingly, only one work used analytical approach, as Park et al. (2006) used projected data with developed analytical model.

All publications of forecasting national demand have also been completed using some statistical method. Maloni and Jackson (2005) used exponential smoothing to create a forecast concerning US ports. Lehto et al. (2006) studied how overall seaborne transportation of Finland will develop and in here GDP was the driving factor. In the last publication, United Nations (2007) was mostly interested about Asian countries. Similar with the second research work, United Nations (2007) used GDP as a driving factor for port demand. However, rare multi sea port modelling approach was used in the research of Fung (2002). In this research, forecast was built for a historical period (years 1998 to 2000). The purpose was to compare actual realised data on built forecast; the research work did not concern about forecasting any future demand.

Table 1 Analysed research works concerning forecasting of port demand

Authors	*Amount of ports*	*Method*	*Main area of interest*	*Dry*	*Liquid*	*General*	*Port/container terminal*
Fung (2002)	Few	Statistical	Competition			x	Container terminal
Jula et al. (2006)	One	Simulation	Operation procedures			x	Port
Kia et al. (2002)	One	Simulation	Port infrastructure			x	Container terminal
Lehto et al. (2002)	-	Statistical	National demand	x	x	x	Port
Maloni and Jackson (2005)	-	Statistical	National demand			x	Port
McGowan (2005)	Many	Judgemental	Competition			x	Port
Park et al. (2006)	Many	Analytical	Competition			x	Port
Parola and Sciomachen (2005)	Few	Simulation	Other land infrastructure			x	Port
Sanders et al. (2007)	Few	Simulation	Competition			x	Port
United Nations (2007)	-	Statistical	National demand			x	Port

Four publications in Table 1 literature review used simulation, and this approach dominated studies of one and few sea ports. Jula et al. (2006) used a 20-year projected data and developed scenarios through simulation model. Kia et al. (2002) studied the impact of adding additional rail-infrastructure to the port to see how this impacts on the port's ability to serve ships; they used projected forecast and experienced simulation runs with this through defined model. Similarly, Sanders et al. (2007) used a projected forecast and simulation model to test its effects; this study concerned mostly the impact of investments in capacity to the competitive situation in major European ports. Parola and Sciomachen (2005) evaluated the impact of a new rail-line in Northern Italy sea port system including two ports; they also used a predefined forecast and tested simulation model in that environment.

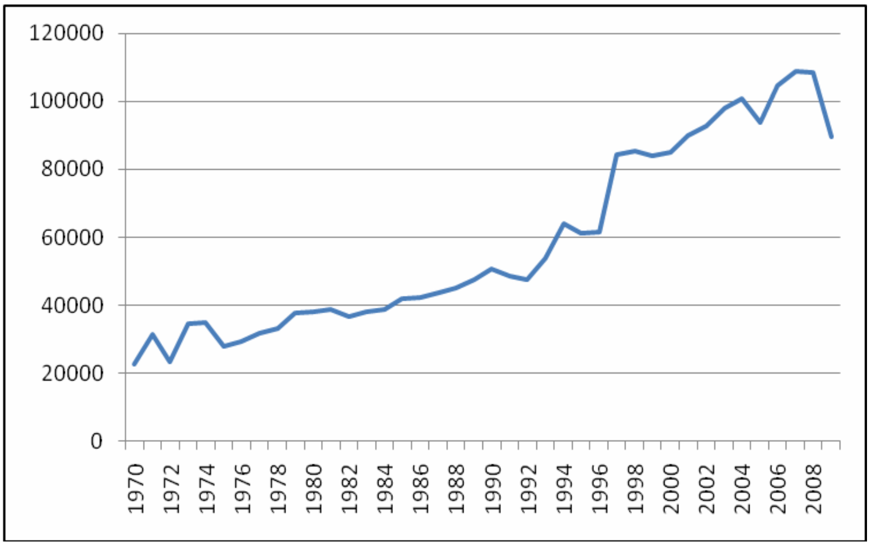
It should be highlighted as a result of literature survey that only three out of ten publications created an actual forecast for the future time periods – none of these concerned specific port(s). Lehto et al. (2006) created demand forecast up to year 2030, while United Nations (2007) created similarly estimate until 2015. Maloni and Jackson (2005), on the other hand, used a simple moving average of volume growth and extrapolate the total demand of US ports for the next ten years. Overall it can be stated that there exist very few publications, which create an actual forecast for the future and all of them are either based on an econometric model about GDP, or on a simple extrapolation.

3 Research environment: Finnish sea ports

Since the 1970s the demand for Finnish sea ports has risen relatively steadily despite a deep depression in the early 1990s (1991–1993; OECD, 2008) as well as very sluggish growth during mid-70s (1976–1977; OECD, 2008). The development of the total demand for Finnish ports is presented in Figure 1. As could be noticed, level of 100 million tons was reached very recently during the economic peak years of 2006–2008. However, challenge for our research work is year 2009 and development onwards; can we develop models to predict for more volatile environment demand, which seems to be here to stay in developed economies.

Finnish ports do not only serve own imports and exports, but some of the harbours handle significant volumes of transit items [e.g., containers for Russian consumer market through ports of Kotka and Hamina, cars for eastern demand through Kotka and Hanko, and some specific Russian raw materials through port of Kokkola (see Hilmola et al., 2007; Märkälä and Jumpponen, 2009)]. However, from overall port handling demand transit transports is taking roughly 5% to 7%.

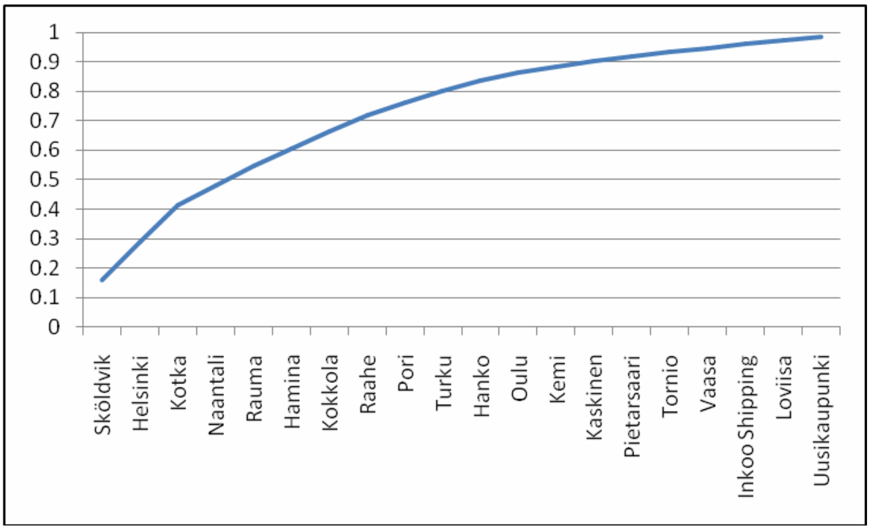
Figure 1 Total annual demand of all Finnish ports (y-axis is in thousand tons) (see online version for colours)



Source: Finnports (2010)

Finnish sea port system is special in a way that the country has numerous ports, and most of these are basically owned by municipalities (some exceptions exist). However, the 12 largest ports take roughly 75% from total demand (for further details see Figure 2). These ports have had at least 70% of all of the demand since the 1990s. Between the years 1990–1996 these ports had at minimum share of 85%, however, since this period the share of top 12 ports has been within the range of 70% to 85%.

Figure 2 Cumulative demand from the major Finnish ports during year 2007 (see online version for colours)



Source: Finnports (2008)

Figure 3 Most important sea ports in Finland divided to pure Finnish demand and transit volumes

	Finnish		Transit (mostly Russia)	
	Export	Import	Export	Import
Liquid bulk	Sköldvik (70%), Hamina (10%), Kotka (7%)	Sköldvik (68%), Naantali (19%), Hamina (3 %)	Kokkola (50%), Hamina (28%), Kotka (19%)	
Dry bulk	Kokkola (51%), Pori (18%), Inkoo (12%)	Raahe (29%), Pori (18%), Kotka (14%)		
General cargo	Helsinki (26%), Kotka (21%), Rauma (19%)	Helsinki (41%), Kotka (18%), Turku (13%)		Kotka (58%), Hanko (20%), Hamina (18 %)
Total (2007) Finnish export / import inc. 12 largest	35.7 mill. tons	44.5 mill. tons	3.5 mill. tons	3.4 mill. tons

Note: Total volume from Finland includes demand of 12 largest ports, but transit overall handling from all of the sea ports.

As generally in Europe, but also throughout the world, specialisation in sea ports has progressed in this country too as is shown in Figure 3. This has occurred in cargo types, but also some harbours have specialised further to serve mostly eastern transit transport (export and import). Regarding three different cargo groups, the largest handling volumes are completed in the following sea ports (year 2007 handling amounts, all Finnish harbours):

1 sea port of Sköldvik, liquid bulk (16.2 mill. tons, 63.5% from liquid cargo)

2 sea port of Kokkola (5.1 mill. tons, 17% from dry bulk cargo) and sea port of Raahe (4.8 mill. tons, 16% from dry bulk cargo), dry bulk

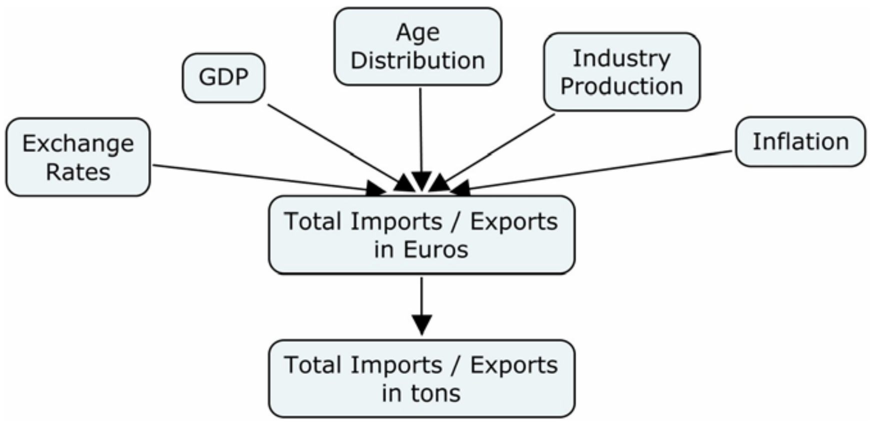
3 sea port of Helsinki (11.6 mill. tons, 24.8% from general cargo) and sea port of Kotka (9 mill. tons, 19.3% from general cargo), general cargo.

4 Constructed stochastic systems dynamics simulation model to forecast harbour demand

As this study was part of a larger research project, the initial expert opinions were gathered prior to this study. The experts consisted of three persons, which have significant experience in Finnish logistics system. Initial discussions resulted into four different models, which were divided in Finnish originating harbour handling demand and transit handling demand. Within these two groups was demand divided in imports and exports.

Expert group assumed that the amount of imports and exports originating from Finland (in Euros) could be explained with the following five variables: exchange rates of Euro (and earlier by Finnish Markka), GDP, age distribution, industry production, and inflation. Modelling logic was decided to proceed in a manner that amount of imports/exports (in Euros) was tried to be explained with these five factors, and then this total sum was converted into handled tons (shown in Figure 4).

Figure 4 Causal diagram of imports and exports (see online version for colours)

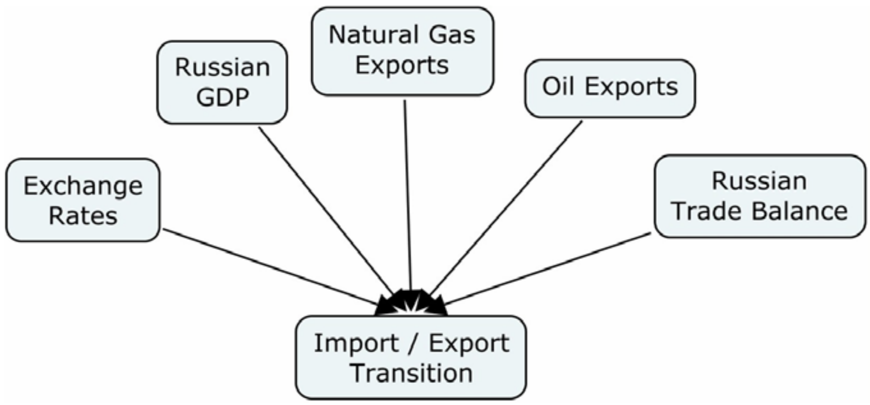


Exchange rates were included in Figure 4 model due to the reason that Finnish own currency Markka was in use until joining the Euro in early 2002. Since Finland is a small country and dependent on exports currency was devalued a quite number of times in our research observation period (Korhonen, 2001). All of these activities to improve competitiveness of export industry (from early 70s until late 90s main export industry was pulp and paper), which in turn is tightly linked to the material handling at sea ports.

Even if Euro brought stability for monetary system, it has shown volatility in previous decade. At minimum 1 Euro was worth 0.85–0.9 USD in 2001, while in year 2007, this rate changed to the level of 1.5 USD. GDP is typically used in sea port handling models, as shown in literature review. Age distribution and ageing population was incorporated due to the argued effects on lower spending after people reach age of 46–47 years age (Dent, 1999), this in turn should affect imports of consumer items. Industrial production volume is motivated by Finnish dependency on exports as concluded earlier (and is different from GDP, since it does not include private/public consumption and investments). Inflation rate is also known from earlier experiences of Germany during 20s as booster of industrial activity, and in turn material handling and investments (Fergusson, 2010); inflation was particularly a problem in Finland during 70s (Korhonen, 2001).

Transition transports (most of this to Russia), on the other hand, was to be explained using exchange rates of Russian Ruble, Russian GDP, Russian natural gas and oil exports, and Russian trade balance. Transition will directly be explained in tons as obtaining information in monetary value is difficult, and could not be considered as entirely reliable (shown in Figure 5). Motivation of including exports of natural gas and oil in explaining Russia's transit transport activity is simply country's long history and current dominance in export of these strategic raw materials (Reynolds and Kolodziej, 2008). In year 2009, Russia was the largest producer of oil in the world, and the second largest of gas (BP, 2010). Russian export trade (and in recent years very strong trade surplus) has developed rather favourably and strongly after the crisis of late 90s (Chiodo and Owyang, 2002). This has been argued to be one major reason for consumption sector growth in recent years (Hilmola et al., 2007).

Figure 5 Causal diagram of imports and exports regarding transit transports (see online version for colours)



The actual forecasts are made using data from years 1970 to 2007 as the financial crisis had a heavy impact on the Finnish maritime cluster. Also, we are interested in long term forecasts (30-year period) where the length of the disruption will be relatively short compared to the whole forecasting period. The forecasts will be compared to the 2008 and 2009 data to see how well the models can operate in discontinuity situations.

4.1 Finnish export model

During export model building phase, numerous models were constructed and compared. The correlations between the variables and their first differences are presented in Appendix 1. We chose to create model for the actual levels as we are interested in the actual handling volumes. Growth rates would need to be translated to the volumes and it would still be necessary to calculate the confidence intervals. Autocorrelation might be an issue with levels, but using autoregressive variables we are able to handle the issue.

For exports and imports, four different models were developed: GDP and industrial production were used as the only explanatory factors for both of these forecasted factors. When a stepwise method was used, the model for Finnish exports consisted of GDP, industrial production, inflation, average age, and amount of pensioners. However, due to multi-collinearity and only a slight increase in the R-squared value, the model which consisted only from industrial production was chosen. Also, when analysing the correlation between GDP and exports, the correlation disappears when industrial production is standardised. The regression models and partial correlations are summarised in Appendix 2. If an autoregressive variable is included in the model, the Durbin-Watson statistic increases from 0.465 to 1.459, so any problem does not exist with the residual's autocorrelation. R-squared rises to 99.4% and the final equation is as follows:

$$\begin{aligned} \textit{Exports in Euros} = {} & -20,226.3 \times (1 - 0.763) + 466.887 \times \\ & \begin{pmatrix} \textit{Industrial production} - 0.763 \times \\ \textit{Industrial production of previous year} \end{pmatrix} + 0.763 \times \\ & \textit{Exports during the previous year (Euros)} \end{aligned} \tag{1}$$

where *Industrial production* is an index gathered by Statistics Finland. The index is gathered using surveys regarding output volumes.

There is a very good and easy to be understood linear connection between exports in Euros and exports in tons. The R-square between these values is 94.1% and the equation is as follows:

$$\textit{Exports in tons} = 0.6076 \times \textit{Exports in Euros} + 14,728 \tag{2}$$

where the *Exports in Euros* are in millions of Euros and the output is in thousand tons.

A one million Euro increase in the total amount of exports in Finland increases the demand for ports in 0.61 thousand tons. As Durbin-Watson for this regression is 1.590, there does not exist any autocorrelation in the residuals.

4.2 Finnish import model

The model for imports contained the same problems as the export model. The different regression models are presented in Appendix 2. GDP, industrial production, average age, amount of pensioners, and the exchange rate between USD and EURO, were the explanatory factors with a stepwise method. Again, only industrial production was chosen as the explanatory factor due to the same reasons; it has a very high coefficient of determination, includes only one independent variable, and is free of multi-collinearity. The regression models can be found in Appendix 1. An autoregressive variable should be included to minimise the effect of autocorrelation.

When including an autoregressive variable into the import model, Durbin-Watson rises from 0.415 to 1.211, but there still might be an issue with autocorrelation. The final R-square is 99.1% and the equation is as follows:

$$\begin{aligned} \textit{Imports in Euros} = & -16{,}624.8 \times (1 - 0.848) + 398.337 \times \\ & \begin{pmatrix} \textit{Industrial production} - 0.848 \times \\ \textit{Industrial production of previous year} \end{pmatrix} + 0.848 \times \\ & \textit{Imports during previous year } (\textit{Euros}) \end{aligned} \tag{3}$$

where *Industrial production* is an index.

Like with the export model, there is a strong connection between imports in Euros and imports in tons. When conducting a linear regression with the model, the R square of the model is 93.5% and the equation is as follows:

$$\textit{Imports in tons} = 9{,}464 + 0.939 \times \textit{Imports in Euros} \tag{4}$$

where the *Imports in Euros* are in millions of Euros and *Imports in tons* is in thousand tons. The Durbin-Watson statistic for the model is 0.941 so an autoregressive variable should be tried out. If one introduces an autoregressive variable in to the model, its R-square will rise to 96.6% and Durbin-Watson to 1.747. Then the model will not have autocorrelation in its residuals and the equation for the model will be as follows:

$$\begin{aligned} \textit{Imports in tons} = & \ 11{,}827 \times (1 - 0.748) + 0.815 \times \\ & \begin{pmatrix} \textit{Imports in Euros} - 0.748 \times \\ \textit{Imports in Euros of previous year} \end{pmatrix} + 0.748 \times \\ & \textit{Imports in tons during the previous year} \end{aligned} \tag{5}$$

where *Imports in tons* is in thousand tons and *Imports in Euros* in millions of Euros.

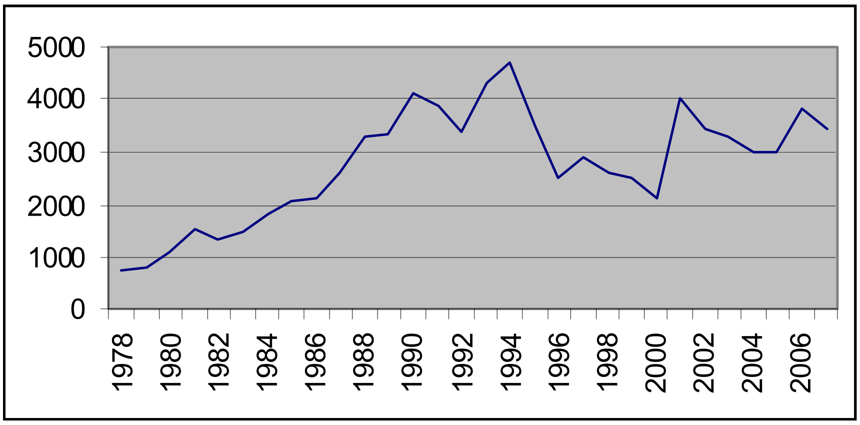
With this model it is possible to estimate the amount of imports in tons without any bias in the variables. In the following demand forecasting simulation model, we have used this as converting equation from import Euros to tons.

4.3 Transit handling models

In our analysis we did not find any variable that had a statistically significant correlation with export transition, so it is not possible to create a meaningful econometric model. It might be that some variables have a significant correlation, if export transition lags those variables in time; that is there is a correlation between export transition and another variable if the independent variable is lagged for one or more time periods (years). Overall only one value had a statistically significant correlation with export transition; the exchange rate of Ruble lagging export transition by two time-periods. This is most likely due to pure random occurrence (as so many variables were lagged) as it is not meaningful to assume export transition to increase after two years of changes in exchange rates. In the simulation model we have assumed that transit exports will keep its current volume, but vary between two and five million tons. Figure 6 shows justification for this within longitudinal perspective.

According to macro economic theory [e.g., Mankiw, (2004), pp.505–507] a country's GDP is function of consumption, investments, governmental consumption, on the top of this net value of exports deducted by imports is being added into sum of these three variables. Due to this we assumed that most important exports drive GDP development in Russia, which in turn is connected on transit import.

Figure 6 Export transition through Finland ('000 tons) (see online version for colours)



Appendix 2 contains all of the tested regression models transition imports. With transition imports to Finland the best model consisted of only using Russian GDP as the explanatory factor. Using more than one independent variable leads to multi-collinearity and the model proposed by the stepwise method was irrational. It gave a negative coefficient for average price of oil even though Russia is heavily dependent on oil exports. As such, the model consisting of only Russian GDP was chosen.

For the model regarding Russian GDP, the model including only the most important Russian export item, oil exports, has an R-square value of 94.8%. When using the stepwise method in regression model building, result also includes only oil exports. In enter method, 'gas exports' variable is statistically non-significant, and there will probably be multi-collinearity. That is the main reason to use the first model, including only oil exports, in the following. Even if the best model has a Durbin-Watson statistics of 0.810, an autoregressive variable should be included in the model. If an autoregressive variable is included in the model, both the autoregressive variable and constant become statistically non-significant. As such, the final model for Russian GDP is:

$$\textit{Russian GDP} = 113.108 + 8.829 \times \textit{Russian oil exports} \tag{6}$$

where Russian GDP is in billions of dollars and Russian oil exports in billions of US dollars.

As we need to convert GDP into transit imports to Russia, following regression model is used:

$$\textit{Transit imports to Russia} = 980.848 + 2.043 \times \textit{GDP} \tag{7}$$

where Russian GDP is in billion dollars (current prices). The R-square of the model is 85.9% while Durbin-Watson is 1.028. If an autoregressive variable is induced to the model, the variable will be statistically not significant so it will not help to improve the model.

So, we use these equations to build up demand estimation model for sea harbour handling in Finland up to year 2030. As could be noticed, we need only a small number of different variables:

1 industrial production in Finland for Finnish imports and exports

2 Russian oil export value for Russian transit import through Finnish sea ports

3 initial values for first forecasting round concerning such measures as Finnish exports and imports as well as Russian GDP.

However, we would like to highlight that the two first mentioned items are needed during the entire forecasting horizon, and we have estimated in the model with two different equations, that these either will follow linear or non-linear development. Tables 2 and 3 show the forecasting models for both the Finnish industrial production and Russian oil exports, respectably.

Table 2 Forecasting the development of Finnish industrial production

Method	*Equation*		*R-square*
Linear model	$3.4085 \times x + 25.993$	(8)	91.34%
Non-linear model	$0.0907 \times x^2 - 0.1269 \times x + 49.562$	(9)	97.54%

Notes: The industrial production is measured as an index with a value of 100 during 1995. *x* is the corresponding year where 1970 is the first year.

Table 3 Forecasting the development of Russian oil exports

Method	*Equation*		*R-square*
Linear model	$10.82 \times x - 17.384$	(10)	91.34%
Non-linear model	$1.4627 \times x^2 - 6.7324 \times x + 20.647$	(11)	97.54%

Notes: The value of Russian oil exports is in billions of dollars. *x* is the corresponding year where 1997 is the first year.

Basically both configurations work well (R-squared values in these assumed development paths range from 86.5% to 98.8%), but more probable is that in the longer time period these two variables will follow linear development.

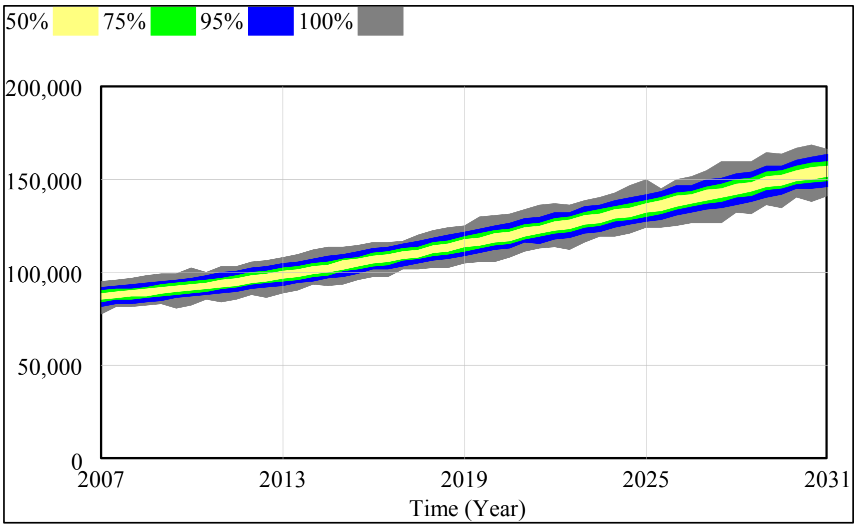
In the following forecasting model, we have concentrated on 12 largest harbours, and start from the assumption that 75% of overall sea port handling demand is concentrated on these harbours (concerning pure Finnish export/import, situation during year 2007). Market share of the 12 largest increases by one percentage point each year within simulation period (during year 2030 it is then 98% from overall handled tons). Transit transports through Finland is assumed to be completed through selected harbours, which all belong into the group of 12 largest.

In the following, we have used system dynamics and Monte Carlo simulation to produce annual demand forecast of 12 largest Finnish harbours (method having similarity with Hilmola and Lättilä, 2008) – stochastic behaviour in the model was built into the model in a manner that each harbour had uncertainty in share of import/export, but also in the division of this demand on the product group level (liquid bulk, dry bulk and general cargo). We used longitudinal data (years 2000–2007) to detect min./max. values and variation for import and export as well as on product groups. Simulation model works in a manner that it firstly sums up all the demand of different 12 harbours together regarding to distinctive product groups, and then the handling of these three groups is summed up together. So, in the following forecasts variation among forecasted handled amounts is due to port market share variation and product group level variation. So, we have assumed that largest sea ports are neutral actors regarding to competing with each others, and future holds considerable uncertainty within product group level demand. It would also be possible to induce competition between the ports, but this would require own competition sub-models. The attractiveness of a port depends on many factors [for a broad literature review and questionnaire results refer to Ng (2006)], so a simple competition model can be difficult, if not impossible, to construct. Used competition models in literature have ranged from logit models (Veldman and Bückman 2003) to spatial-economical models (Luo and Grigalunas, 2003), so the choice of the model would also impact the results. Our forecasting approach used in this research work produces forecasts, which have smaller uncertainty in the beginning, but as could be noticed in the following section, uncertainty increases during the years, and path dependency of port share and product group becomes apparent.

5 Four alternative future scenarios

In the first scenario the growth of both (using scenario technique in futures research is common, and well accepted; e.g., see application for mobile phone services, Heikkinen et al., 2008), the Finnish industrial production and Russian oil exports, were assumed to be linear. The total demand of material handling in Finnish sea harbours with respect of this scenario is presented in Figure 7.

Figure 7 Total sea harbour handling demand in the first linear growth scenario, where the value of Finnish industrial production and Russian oil exports both follow conservative and linear growth (see online version for colours)



The overall demand rises to about 150 million tons at year 2030. This is consistent with the findings of Lehto et al. (2006, p.17). However, based on our assumption, this is only one possible future scenario; Figure 8 shows the harbour handling amounts as the value of Russian oil exports follows non-linear and 'rather strong' growth, and Finnish industrial production is set to follow linear growth still.

Figure 8 Total sea harbour handling demand in the second scenario, where Russian oil export value follows non-linear growth and Finnish industrial production linear (see online version for colours)

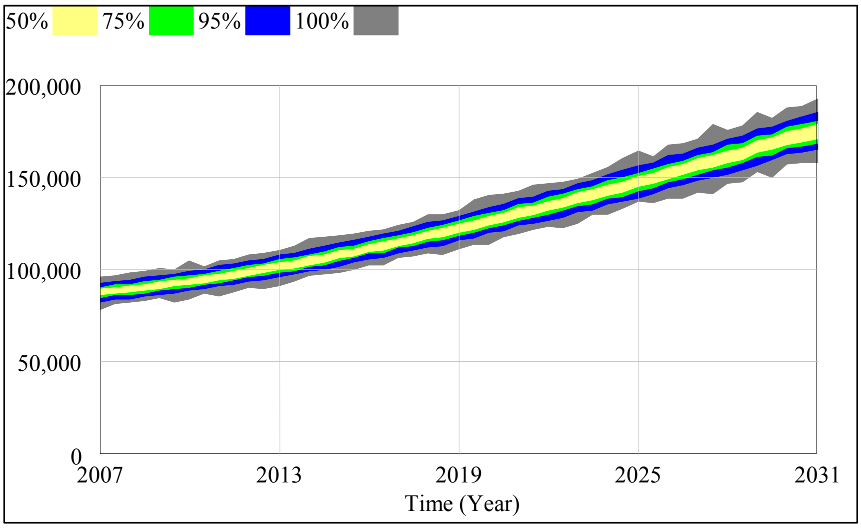
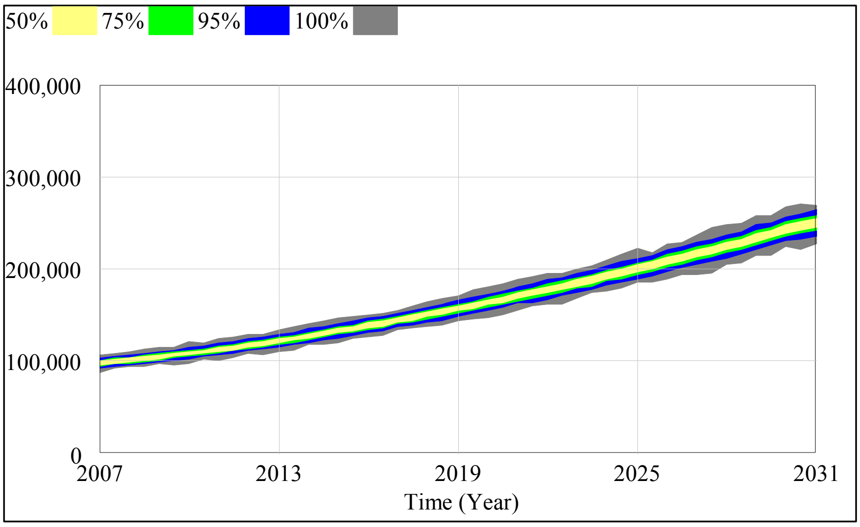


Figure 9 Total sea harbour handling demand in the third scenario, where Russian oil export value follows linear growth and Finnish industrial production non-linear (see online version for colours)

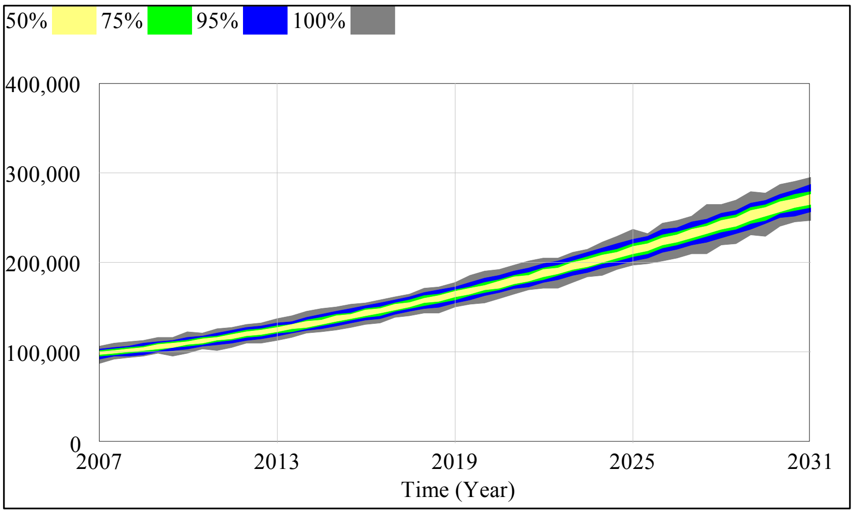


In the second scenario, the total demand rises to about 170 million tons, an increase of 13% (as compared to scenario 1). Notable is the fact that the amount of Russian oil exports is over four times as high as it is in the previous model (during year 2030), but it will only increase 16% of the total demand in sea ports.

In the third model, it was assumed that industrial production increases non-linearly and Russian oil exports linearly. The results of this future scenario are shown in Figure 9, and in this case total demand reaches a value of approx. 240 million tons during year 2030. This is about 60% higher than in the first scenario. So, we could conclude that Finnish harbour handling in the future is more sensitive on changes in industrial production volumes rather than in Russian economy.

In the fourth model both drivers (industrial production and Russian oil exports) were assumed to grow non-linearly, so this case is the most prosperous scenario for harbour handling during the forecasted time period, and results are shown in Figure 10. The total demand shows an impressive value of over 260 million tons during year 2030. This is over 70% higher than in the first scenario.

Figure 10 Total sea harbour handling demand in the fourth scenario, where both Russian oil export value and Finnish industrial production follow non-linear growth (see online version for colours)

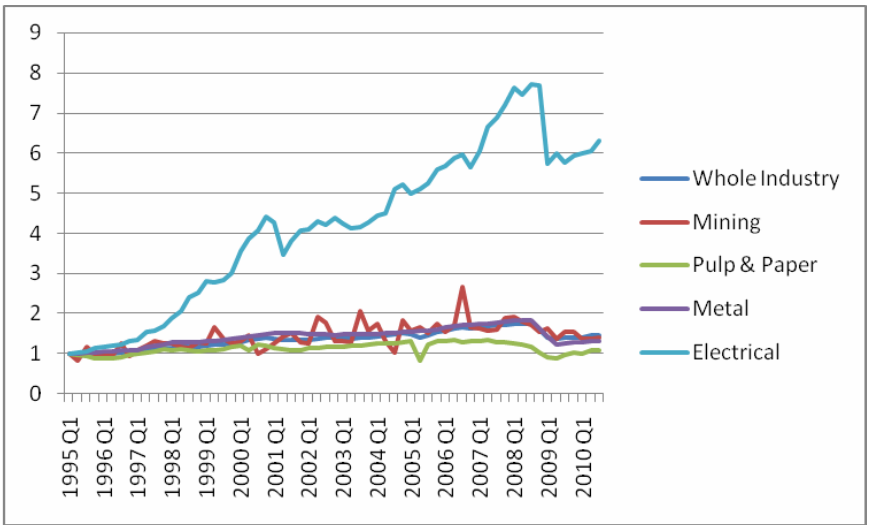


Overall it can be said, that there is a huge impact depending, which kind of growth one allows in the drivers of the model. By choosing a non-linear model we end up having dramatically higher values than in the linear models. However, our results show that industrial production changes in Finland have a major role, and value of Russian oil exports a minor one. Thus, some regions and harbours could face possible future scenarios differently (e.g., harbours serving Russian transit imports).

6 Discussion – relevance of proposed four scenarios

As industrial production explains the development of demand for Finnish sea ports, it seems to be the case that Finnish economy is still very dependent on its major industries (pulp and paper, metal, and electrical). This is further supported by studying the development of industrial production indexes – electrical industry shows impressive growth since the middle of 90s (Figure 11), followed by metal industry (even if recession in Finland was really severe during 90s). As electrical industry products usually demand more time rather than cost sensitive logistical solutions, distribution centres in Central Europe could be reached via sea ports by using trucks. However, metal as well as pulp and paper industries remain to hold their significance in sea ports. Also there exist a possibility that Finnish Lapland will develop into northern mining industry centre, since numerous new mining projects have been inaugurated by internationally well recognised companies (such as Yara, Agnico-Eagle Mines and Northland Resources, as well as new Finnish entrants, such as Talvivaara plc.). Mining volume plans are very significant, maximum is around 50 million tons per year exported by year 2020 (Tervala, 2009). This easily subsides possible negative declining volume effect of other industries.

Figure 11 Industrial production index of Finland during time period of 1995–2010 (see online version for colours)



Source: Business trends: industry and construction (Official Statistics of Finland, 2010)

In the Finnish case, we argue that industrial production drives sea port demand in the forthcoming decades, and port demand could not be explained that accurately by the development of GDP. As Figure 1 (shown in Section 3) show, severe recession during the early 90s affected also sea harbour demand and industrial production, but not in that great extent – in practice growth stopped, but basic demand did not diminish in this situation either. Situation was the same after IT bubble burst during 2001–2002. However, similarly with the whole Europe, ageing population creates next acid test to this model, and Finnish sea ports, as baby boomers start to retire from working life within large scale during following years. This effect combined with global economic meltdown during year 2009 had very serious effect not only on Finnish GDP (–8% from year 2008), but also on total sea port handling (declined by –17.4% from year 2008 and ended up to 89.6 mill. tons).

The model's structure can be tested by using data from 2008 and 2009 to see whether it works in very extreme discontinuous situations. Using 2008 and 2009 industrial production data (some minor differences might exist as the classification for industrial production was changed in 2008) and comparing the demand to real demand we can see how well the model works. The results are presented in Table 4.

Table 4 Model's results with 2008 and 2009 data of Finnish industrial production

Year	*Industrial production (index)*	*Model results, imports (billions of €)*	*Real, imports (billions of €)*	*Difference (%)*	*Model results, exports (billions of €)*	*Real, exports (billions of €)*	*Difference (%)*
2008	182.12	59.55	62.40	4.57	66.00	65.58	0.64
2009	149.11	45.85	43.65	5.03	50.31	45.06	11.63

The model works relatively well during the crisis. The highest error is 11.6%, while the average one is 5.5%. Finnish imports and exports can be well explained even in crisis situations with industrial production. Russian transition is also needed to be checked. The results for this part of the model are presented in Tables 5 through 7.

Table 5 Model's results with 2008 and 2009 data from Russian oil exports

Year	*Russian oil exports (billions of US dollars)*	*Model's results, Russian GDP in billions of current US dollars*	*Real, Russian GDP in billions of current US dollars*	*Difference (%)*
2008	161.15	1535.9	1667.6	7.9
2009	100.59	1001.2	1230.7	18.6

Source: GDP data from World Bank (2010), Russian oil exports from Bank of Russia (2010)

Table 6 Model's results with 2008 and 2009 data from Russian GDP

Year	*Russian GDP in billions of current US dollars*	*Model's results, transition imports in thousands of tons*	*Real, transition imports in thousands of tons*	*Difference (%)*
2008	1,667.6	4,387.7	3,988.9	10.0
2009	1,230.73	3,495.2	1,610.9	117.0

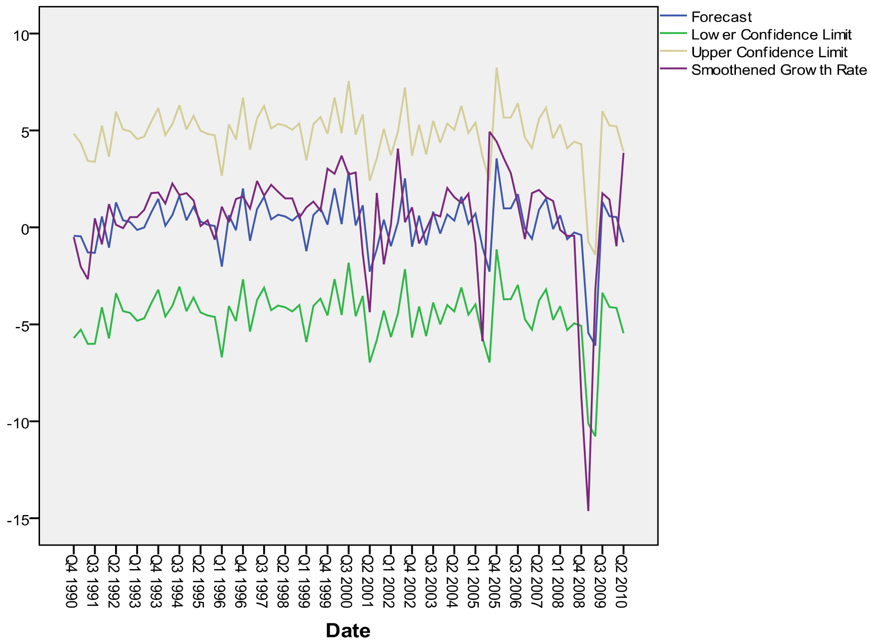
Table 7 Model's transition imports with 2008 and 2009 oil export data

Year	*Russian oil exports (billions of US dollars)*	*Model's results, transition imports in thousands of tons*	*Real, transition imports in thousands of tons*	*Difference (%)*
2008	161.15	4,118.724	3,988.9	3.3
2009	100.59	3,026.365	1,610.9	87.9

The amount of transition imports is much too high according to the model during the crisis (year 2009). The Russian Ruble deflated heavily in the late of 2008 and beginning of 2009 – mostly due to reason that Russian economy is raw material based and these export items are valued in USD (Times, 2008). The exchange rate went from 35 Rubles/Euro to 45 Rubles/Euro. The drop was even heavier against the USD (from 24–25 Rubles/USD to 34–35 Rubles/USD). This makes all imported goods significantly more expensive. Interestingly, also the port of Saint Petersburg lost over 30% of its container demand during year 2009 (Morskoi Port, 2010). This also most likely impacted the usage of the Finnish route to Russia. As transition is a relatively small amount of the total demand, the amount of error created by transition is relatively small. Overall, the model seems to work well in crisis situations.

It is also possible to create short term forecasts for industrial production. A Finnish agency, Confederation of Finnish Industries, conducts business tendency surveys. One of the main areas of interest is the volume of industrial orders in hand. One would assume that the orders in hand would work as an indicator for future total industrial production. The orders in hand was seen to lead industrial production by two quarters and an Arima model was constructed for the growth rate. The forecast is presented in Figure 12.

Figure 12 Forecast for industrial production with a leading indicator (see online version for colours)



The forecast works relatively well for industrial production. Only the dramatic drop in 2008 was not sufficiently estimated by the model. As such, the system dynamic model could be used to make short term forecasts as well.

7 Conclusions

Usually port demand is assumed to follow the development of GDP, and developed models have only one potential scenario to highlight the future demand. In this research work, we have identified four different scenarios, and also used different variables to predict future demand development. This analysis differs greatly from previous studies, since demand forecasting at national/regional level has been built usually with assumed relationship to GDP, or then at sea port level, with analytical and/or simulation model based on made investments and operative characteristics. In this research work, we have completed detailed statistical analysis in the national/regional level, and derived different scenarios from the development of the most important parameters. Our model could also be easily extended to serve the purpose of particular harbours and/or different product groups.

As system dynamics allows the use of stochastic variables, it was possible to include uncertainty in the model. In this study, the uncertainty was included in the individual shares of largest ports and their own demand structure (e.g., how much of their demand arises from liquid bulk, dry bulk, and general goods cargo). Also, it was possible to create four different scenarios with different growth rates. This allowed evaluating the amount of uncertainty in the total growth of the driving factors. The system dynamics model was built using linear and curve-linear regressions and ARIMA models. Both the regressions and ARIMA models had high R-squared and Durbin-Watson values, which correspond that the system dynamic model should have a solid base. The simulation model gave a forecast and its confidence intervals up to year 2030. The model also has the advantage over other studies by giving a forecast for each of the ports.

The system dynamic model can be expanded to include other parts of the logistical systems of Finland. The forecasts for individual ports can be used as driving factors for a sub-model regarding required hinterland logistics. These possibilities include the required warehousing capacity at individual sea ports, amount of railway capacity required in order to cope with the demand of sea ports and the size of the railway yard required at the ports. Also, needs of road transportation capacity and availability within different geographical area could be derived from proposed model. The driving factors (industrial production and Russian oil exports) should also be studied more thoroughly in order to find out whether they have some indicators, which could be used to create a forecast for the driving factors in the short term.

In this study, it was found out that a system dynamics model can be constructed with the help of other advanced statistical methods. This method can be applied to a variety of different situations requiring a forecast. If it is not possible to create a statistical model for one part of the system dynamic model, that part could be constructed with more traditional ways. However, multiple parameter models, which were applied in this research work for handling demand are only directly applicable on more remote sea ports, which are serving own country and possible few other nearby countries. If we think about, e.g., current container transport system, which bases on hub-and-spoke arrangement (very similar to the internet, see e.g., Kaluza et al., 2010), handling volumes are in case of hubs entirely dependent on global economy development, not to case specific factor, like shown in this research (hubs, like Singapore and Rotterdam are connected to so many different economies that models would become too complex with country specific data).

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Appendix 1

Correlations between the variables and their first differences

Correlations

		Import_1000e	*Export_1000e*	*Consumer_price_index_1950=100*	*GDP_at_2000_price_millions*	*Industry_volume_index*	*DM_per_Euro*	*Dollars_per_Euro*	*Yenis_per_euro*	*Pensioners*	*Exports_in_tons*	*Imports_in_tons*
Import_1000e	Pearson correlation	1	.988**	.870**	.978**	.989**	–.733**	.850**	–.741**	.946**	.945**	.967**
	Sig. (two-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	38	38	38	38	38	37	37	37	26	38	38
Export_1000e	Pearson correlation	.988**	1	.887**	.972**	.993**	–.759**	.824**	–.776**	.963**	.970**	.980**
	Sig. (two-tailed)	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	38	38	38	38	38	37	37	37	26	38	38
Consumer_price_index_1950=100	Pearson correlation	.870**	.887**	1	.929**	.889**	–.937**	.695**	–.956**	.967**	.909**	.836**
	Sig. (two-tailed)	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000
	N	38	38	38	38	38	37	37	37	26	38	38
GDP_at_2000_price_millions	Pearson correlation	.978**	.972**	.929**	1	.987**	–.802**	.811**	–.819**	.948**	.954**	.950**
	Sig. (two-tailed)	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000
	N	38	38	38	38	38	37	37	37	26	38	38
Industry_volume_index	Pearson correlation	.989**	.993**	.889**	.987**	1	–.755**	.830**	–.774**	.951**	.967**	.979**
	Sig. (two-tailed)	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000
	N	38	38	38	38	38	37	37	37	26	38	38
DM_per_Euro	Pearson correlation	–.733**	–.759**	–.937**	–.802**	–.755**	1	–.579**	.960**	–.853**	–.798**	–.689**
	Sig. (two-tailed)	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000
	N	37	37	37	37	37	37	37	37	26	37	37

Note: **Correlation is significant at the 0.01 level (two-tailed)

Correlations between the variables and their first differences (continued)

Correlations

		Import_ 1000e	*Export_ 1000e*	*Consumer_price_ index_1950=100*	*GDP_at_2000_ price_millions*	*Industry_ volume_index*	*DM_per _Euro*	*Dollars_ per_Euro*	*Yenis_ per_euro*	*Pensioners*	*Exports_ in_tons*	*Imports_ in_tons*
Dollars_per_Euro	Pearson correlation	.850**	.824**	.695**	.811**	.830**	–.579**	1	–.612**	.607**	.774**	.815**
	Sig. (two-tailed)	.000	.000	.000	.000	.000	.000		.000	.001	.000	.000
	N	37	37	37	37	37	37	37	37	26	37	37
Yenis_per_euro	Pearson correlation	–.741**	–.776**	–.956**	–.819**	–.774**	.960**	–.612**	1	–.828**	–.807**	–.708**
	Sig. (two-tailed)	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000
	N	37	37	37	37	37	37	37	37	26	37	37
Pensioners	Pearson correlation	.946**	.963**	.967**	.948**	.951**	–.853**	.607**	–.828**	1	.959**	.952**
	Sig. (two-tailed)	.000	.000	.000	.000	.000	.000	.001	.000		.000	.000
	N	26	26	26	26	26	26	26	26	26	26	26
Exports_in_tons	Pearson correlation	.945**	.970**	.909**	.954**	.967**	–.798**	.774**	–.807**	.959**	1	.962**
	Sig. (two-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000
	N	38	38	38	38	38	37	37	37	26	38	38
Imports_in_tons	Pearson correlation	.967**	.980**	.836**	.950**	.979**	–.689**	.815**	–.708**	.952**	.962**	1
	Sig. (two-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	38	38	38	38	38	37	37	37	26	38	38

Note: **Correlation is significant at the 0.01 level (two-tailed)

Correlations between the variables and their first differences (continued)

Correlations

		DIFF (Imports_ in_tons,1)	DIFF (Exports_ in_tons,1)	DIFF (Consumer_ price_index_ 1950100,1)	DIFF (GDP_at_ 2000_price_ millions,1)	DIFF (Industry_ volume_ index,1)	DIFF (DM_per_ Euro,1)	DIFF (Dollars_ per_Euro,1)	DIFF (Yenis_per _euro,1)	DIFF (Pensioners,1)	DIFF (Import_ 1000e,1)	DIFF (Export_ 1000e,1)
DIFF (Imports_ in_tons,1)	Pearson correlation	1	.471**	–.198	.395*	.436**	.160	.175	.152	–.047	.301	.307
	Sig. (two-tailed)		.003	.240	.015	.007	.350	.307	.376	.824	.070	.064
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (Exports_ in_tons,1)	Pearson correlation	.471**	1	–.163	.110	.201	.015	.067	.073	–.151	.082	.155
	Sig. (two-tailed)	.003		.335	.518	.233	.931	.699	.671	.471	.628	.358
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (Consumer_ price_index_ 1950100,1)	Pearson correlation	–.198	–.163	1	–.271	–.355*	.041	–.063	–.087	–.328	–.249	–.174
	Sig. (two-tailed)	.240	.335		.105	.031	.814	.716	.615	.109	.138	.302
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (GDP_at_ 2000_price_ millions,1)	Pearson correlation	.395*	.110	–.271	1	.765**	.358*	–.142	.321	.023	.641**	.460**
	Sig. (two-tailed)	.015	.518	.105		.000	.032	.409	.056	.915	.000	.004
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (Industry_ volume_ index,1)	Pearson correlation	.436**	.201	–.355*	.765**	1	.238	–.078	.118	–.011	.750**	.794**
	Sig. (two-tailed)	.007	.233	.031	.000		.162	.652	.493	.958	.000	.000
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (DM_per _Euro,1)	Pearson correlation	.160	.015	.041	.358*	.238	1	–.015	.576**	.164	.295	.176
	Sig. (two-tailed)	.350	.931	.814	.032	.162		.930	.000	.434	.081	.305
	N	36	36	36	36	36	36	36	36	25	36	36

Notes: **Correlation is significant at the 0.01 level (two-tailed) and *correlation is significant at the 0.05 level (two-tailed)

Correlations between the variables and their first differences (continued)

Correlations

		DIFF (Imports_ in_tons,1)	*DIFF (Exports_ in_tons,1)*	*DIFF (Consumer_ price_index_ 1950100,1)*	*DIFF (GDP_at_ 2000_price_ millions,1)*	*DIFF (Industry_ volume_ index,1)*	*DIFF (DM_per_ Euro,1)*	*DIFF (Dollars_ per_Euro,1)*	*DIFF (Yenis_per _euro,1)*	*DIFF (Pensioners,1)*	*DIFF (Import_ 1000e,1)*	*DIFF (Export_ 1000e,1)*
DIFF (Dollars_ per_Euro,1)	Pearson correlation	.175	.067	–.063	–.142	–.078	–.015	1	–.210	–.095	–.032	–.083
	Sig. (two-tailed)	.307	.699	.716	.409	.652	.930		.218	.650	.853	.629
	N	36	36	36	36	36	36	36	36	25	36	36
DIFF (Yenis_per _euro,1)	Pearson correlation	.152	.073	–.087	.321	.118	.576**	–.210	1	.370	.242	.029
	Sig. (two-tailed)	.376	.671	.615	.056	.493	.000	.218		.069	.154	.868
	N	36	36	36	36	36	36	36	36	25	36	36
DIFF (Pensioners,1)	Pearson correlation	–.047	–.151	–.328	.023	–.011	.164	–.095	.370	1	.421*	.167
	Sig. (two-tailed)	.824	.471	.109	.915	.958	.434	.650	.069		.036	.426
	N	25	25	25	25	25	25	25	25	25	25	25
DIFF (Import_ 1000e,1)	Pearson correlation	.301	.082	–.249	.641**	.750**	.295	–.032	.242	.421*	1	.873**
	Sig. (two-tailed)	.070	.628	.138	.000	.000	.081	.853	.154	.036		.000
	N	37	37	37	37	37	36	36	36	25	37	37
DIFF (Export_ 1000e.1)	Pearson correlation	.307	.155	–.174	.460**	.794**	.176	–.083	.029	.167	.873**	1
	Sig. (two-tailed)	.064	.358	.302	.004	.000	.305	.629	.868	.426	.000	
	N	37	37	37	37	37	36	36	36	25	37	37

Notes: **Correlation is significant at the 0.01 level (two-tailed) and *correlation is significant at the 0.05 level (two-tailed)

Appendix 2

Export regression models

Method	*Parameters*	*Coefficients*	*Coefficient of determination*	*Condition index*	*Durbin-Watson*
Enter	Intercept	–40,608.9*	94.4%	7.178	0.259
	GDP	0.626*			
Enter	Intercept	–20,789.9*	98.7%	4.931	0.465
	Industrial production	469.688*			
Stepwise	Intercept	531,657.5*	99.6%	2650	1.730
	Inflation	18.250*			
	GDP	–0.241*			
	Industrial production	732.159*			
	Average age	–20,669.655*			
	Amount of pensioners	0.265*			
Enter	Intercept	579,250.2*	99.6%	3,528	1.795
	Inflation	19.716			
	GDP	–0.203			
	Industrial production	729.751*			
	DM/€	–682.379			
	$/€	1,377.963			
	¥/€	–0.170			
	Amount of pensioners	0.275*			
	Average age	–22,290.9*			

Notes: *Significant at 5% level. When industrial production is controlled, correlation between GDP and exports is –0.463. When GDP is controlled, correlation between industrial production and exports is 0.900.

Import regression models

Method	*Parameters*	*Coefficients*	*Coefficient of determination*	*Condition index*	*Durbin-Watson*
Enter	Intercept	–31,930.2*	95.7%	7.178	0.277
	GDP	0.507*			
Enter	Intercept	–15,486.8*	97.9%	4.931	0.415
	Industrial production	376.638*			
Stepwise	Intercept	–14,583.5*	96.9%	6.648	0.395
	GDP	364.4*	99.3%	3528	1.552
Enter	Intercept	687,063.9*			
	Inflation	–1.721			
	GDP	0.518*			
	Industrial production	209.525*			
	DM/€	–2,021.72			
	$/€	6,360.486*			
	¥/€	3.774			
	Amount of pensioners	0.399*			
	Average age	–27,805.1*			

Notes: *Significant at 5% level. When industrial production is controlled, correlation between GDP and exports is 0.081. When GDP is controlled, correlation between industrial production and exports is 0.710.

Finnish transition imports regression model

Method	*Parameters*	*Coefficients*	*Coefficient of determination*	*Condition index*	*Durbin-Watson*
Enter	Intercept	712.290*	90.8%	4.052	1.231
	GDP	0.092*			
Stepwise	Intercept	901.605*	96.4%	20.543	1.944
	GDP	0.205*			
	Average price of oil	–8.250*			
Enter	Intercept	599.504	100%	283	3.479
	Average price of oil	–8.914			
	Gas exports	–211.727			
	Average price of gas	34.975			
	Russian trade balance	18.764			
	Ruble/€	2.219			
	GDP	0.186			

Note: *Significant at 5% level

Russian GDP regression models

Method	*Parameters*	*Coefficients*	*Coefficient of determination*	*Condition index*	*Durbin-Watson*
Enter	Intercept	–1,787.437	97%	2.926	0.425
	Oil exports	238.006*			
Enter	Intercept	–4,345.589	89.1%	4.385	0.911
	Gas exports	752.762*			
Stepwise	Intercept	–1,787.437	97%	2.926	0.425
	Oil exports	238.006*			
Enter	Intercept	4,147.231	97.5%	21.868	0.893
	Oil exports	–258.392			
	Gas exports	314.348*			

Note: *Significant at 5% level

Publication II

Lättilä, L. (2011)

Modelling Seaports with Agent-Based Modelling and System Dynamics

International Journal of Logistics Systems and Management, 10(1), pp. 90 -109

Modelling seaports with Agent-Based Modelling and System Dynamics

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Abstract: Seaports are an important part of logistical systems and require adequate capacity to serve its customers. In this paper two simulation models are built with different simulation approaches, one with System Dynamics (SD) and another one with Agent-Based Modelling. Both of the simulation models study how well a seaport is able to cope with its demand. This research shows the advantages and caveats with both of the methodologies in analysing the development of seaports. Queuing Theory was required in the SD model while Agent-Based Modelling was found to be a more suitable approach for studying complex service systems like seaports.

Keywords: system dynamics; ABMS; agent-based modelling and simulations; seaports; logistics systems.

Reference to this paper should be made as follows: Lättilä, L. (2011) 'Modelling seaports with Agent-Based Modelling and System Dynamics', *Int. J. Logistics Systems and Management*, Vol. 10, No. 1, pp.90–109.

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1 Introduction

Seaports play a vital role in global supply chains (Panayides, 2006; Panayides and Song, 2008). Many nations depend heavily on trade, and seaborne transportation accounts for over 40% of all exports (World Trade Organization, 2009). On a global scale the amount of trade through the sea is enormous, and over 500,000,000 containers were handled (the figure also contains trans-shipments) in the whole world during the year 2008 (Fossey, 2009). As the world becomes even more connected through globalisation, this trend will most likely continue to grow (IMF, 2007). However, during the financial crisis of 2009 the Baltic Dry Index (the index tracks the worldwide international shipping prices of dry bulk cargoes) decreased by 90% (World Trade Organization, 2009). This indicates a major decrease in demand and it will also impact different seaports.

As seaports usually require significant investment from the private or public sector, estimating their development plays an important part in national well-being. According to Theys et al. (2010) estimation of congestion is an important aspect when terminals are awarded to operators and simulation is a good way to conduct this estimation. Congestion and efficiency play a part in port competitiveness (Yeo et al., 2008; Tongzon and Heng, 2005; Min and Park, 2008; de Sinay and Fernandes, 2010; Wu and Goh, 2010), which has an indirect impact on other industries dependent on seaport transportation as well (Na and Shinozuka, 2009).

Most simulation studies analysing seaports are constructed on a micro-level and this requires an extensive amount of time and data to develop the model. Also, these types of simulations are overly complicated to analyse larger systems. As seaports are a part of larger supply chains (Panayides and Song, 2008; de Langen and Visser, 2005; Tongzon et al., 2009), these types of micro-level simulations might be too complicated to implement in larger models. As Sterman (2000) points out, a broad model boundary is more important than a high amount of detail.

In order to analyse larger logistical systems by using simulations, more elegant solutions than micro-level seaport simulation models are required. Thus, the objective of this study is to understand how individual seaports can be simulated without using a micro-level simulation model. The research question can be expressed as:

How can a seaport be simulated with reasonable accuracy using System Dynamics or Agent-Based Modelling?

This can further be expanded to include following two sub-questions:

What are the advantages and disadvantages of System Dynamics and Agent-Based Modelling in simulating seaports?

Is it possible to create a simulation model which will calculate the average queues and waiting times at the individual seaports?

System Dynamics (SD) and Agent-Based Modelling and Simulations (ABMS) were selected as possible methods as they have different kind of approaches to studying complex systems (Phelan, 1999). As seaports handle different kinds of cargo (dry bulk, liquid bulk, and general goods cargo), this paper will only concentrate on one of the cargo types. Different cargoes require different kinds of equipment at the seaport, so it is not reasonable to simulate all of the different kinds of cargoes in the same way. Also, demand is imposed on the seaport from an external source and it is not estimated in this paper.

This paper is structured as follows: In Section 2 some general information about seaports is presented. Section 3 presents SD simulation background and earlier research findings, while Section 4 concentrates on ABMS. These sections show some general information about the simulation approaches but they no dot include any information about the actual simulation work. Section 5 explains the chosen methodology in this paper, while Section 6 contains the actual simulation models. In this section the basic assumptions behind both simulation models are presented. Section 7 shows the results obtained from both of the simulation models and discusses the differences between the approaches. The final Section 8 concludes this paper and offers avenues for further studies.

2 Seaports

Seaports are a major component in global supply chains (Panayides, 2006; Panayides and Song, 2008; Dias et al., 2010). Even though seaports should be supply chain oriented, ports tend not to be integrated with the whole chain (Tongzon et al., 2009). As seaports are nodes within larger networks, their functioning will impact the whole system. Many different definitions for seaports have been presented earlier (Winkelmans, 2002; Bichou and Gray, 2005). In this paper seaports are seen to be a part of larger logistical system and work as nodes in these systems. Only the physical cargo flow is considered in this paper excluding all information sharing or monetary flows.

According to Tongzon and Heng (2005) there are eight key determinants in port competitiveness. These are: port operation efficiency level, port cargo handling charges, reliability, port selection preference of carriers and shippers, depth of channel, adaptability to changing market environment, landside accessibility and product differentiation. Yeo et al. (2008) conducted a survey and generated seven factors explaining port competitiveness: port service, hinterland condition, availability, convenience, logistics cost, regional centre, and connectivity. There is a lot of overlap between these two sets of criteria. The efficiency of a seaport is among the most important aspects when port competitiveness is estimated.

Many times seaports are analysed using mathematical models (recent examples include Boontaveeyuwat and Hanaoka, 2010; Fan et al., 2010; Giallombardo et al., 2010; Bierwirth and Meisel, 2010, among others). However, simulations might be able to incorporate some small details which have a big impact on the results (Ujvari and Hilmola, 2006). Simulations have been earlier used to study seaport systems. Ho and Ho (2006) used simulation to analyse the impact of different types of demand growth rates on the development of the whole seaport. The main output of the model was financial measures (internal rate of return and net present value) and the model consisted of equations calculating the required amount of equipment in the seaport. Discrete-event simulation seems to be among the most widely used methods to analyse seaports. Terminal operations (Petering, 2009; Parola and Sciomachen, 2009; Na and Shinozuka, 2009) seems to be the most widely simulated area, but security checks (Longo, 2010) and seaport networks (Caris et al., 2011) have been analysed as well. All of these models have been constructed using a very high level of detail.

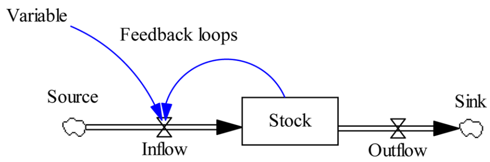
ABMS and SD have been used as well to analyse seaports. Terminal operations (Henesey, 2006; Vidal and Huynh, 2010) and security checks (Govindan et al., 2006) have been analysed using ABMS, while SD has been as well used to analyse terminal operations (Munitic et al., 2003). However, these simulation models have been constructed using a very high level of detail as well. This tends to narrow the applicability of these models as most of the development time is spent on adding detail to the model instead of expanding the model boundary.

3 System Dynamics

SD was developed by Jay Forrester in the late 1950s. The first published work was 'Industrial Dynamics' (Forrester, 1958) and the simulation model consisted of a supply chain. SD is part of a larger school of thought, systems thinking, which studies dynamic complexity through systems. Dynamic complexity is seen to arise from the non-linear and multi-loop feedbacks, while in detailed complexity the complexity derives from a wide array of possibilities (Maani and Maharaj, 2004).

SD uses only a couple of different kinds of elements to construct complex models. Nowadays almost all SD programs use a graphical interface where the model can be build by connecting different elements and writing the actual equations inside the individual elements. The used elements are shown in Figure 1.

Figure 1 The basic elements in a System Dynamic model (see online version for colours)



Among the most important elements in a SD model are the stock and flows. The stocks are accumulations, which are defined by the in- and out-flows of the model. Mathematically speaking, the equations are simply integrals. Stocks play an important part as the model reaches equilibrium as the stocks regulate the feedbacks in the system. For instance, in the example in Figure 1, the stock impacts the values of the in- and outflows so the system reaches equilibrium in time. As the model needs to have fixed boundaries, sinks and sources are used to represent stocks with an infinite capacity. Final parts in SD are variables/parameters and feedbacks. Variables simply store information and/or conduct different calculations during the simulation. The feedbacks represent either a positive or negative feedback, e.g., it will either have a positive correlation between the elements or a negative one (Sterman, 2000).

SD has been used in a wide area of applications. During the last few years the System Dynamics Society's annual conference has had many special tracks, including economic dynamics, environmental challenges, health care policy, corporate strategy, public safety, decision making etc. This list only includes a small portion of the tracks so the method can be used in many different problem areas. Logistics and supply chain management have been studied extensively with SD starting with the early Industrial Dynamics (Forrester, 1958) models. According to Angerhofer and Angelides (2000), there are five research areas in supply chain management which are studied using SD: inventory management, demand amplification, supply chain re-engineering, supply chain design, and international supply chain management. As long as it is possible to work on an aggregated level, SD should be a good way to simulate systems. SD has also been used earlier in studying seaports. Munitic et al. (2003) created a SD model, where they studied the material flows in a whole port cargo system. The model was constructed on a micro-level and it contained individual fork-lift trucks, wagons, wharfs, etc. Sanders et al. (2007), on the other hand, studied the investment dynamics in larger port systems including hinterland capacity. The model also contained the competition between the different seaports. Lättilä (2009) constructed a macro-level SD model where the focus was on the development of demand in different seaports. The simulation model did not include competition between the different seaports and the demand was imposed on individual seaports using the historical values. Even thought the amount of publications regarding system dynamic simulations of seaports are low, there should be no reasons why SD could not be a valid method in studying the development of seaports.

4 Agent-Based Modelling and Simulations

ABMS is a relatively new paradigm in modelling. However, the roots go back to the late 1940s in the original Von Neumann machines and it was later on developed into cellular automata (Macal and North, 2005). In ABMS individual agents make their own decisions and complexity emerges from the interaction between different agents (Bonabeau, 2002). The agents might only posses a couple of different rules, but it is not possible to know what the final interaction inside the whole system will be. Thus, only a couple of different rules can induce extremely complex behaviour (Reynolds (1987) has shown how it is possible to simulate a flock of birds using only three different rules: separation, alignment, and cohesion).

As agents are used in many different fields, many different ways to classify agents have been presented (Tweedale et al., 2007). Wooldridge and Jennings (1995) have classified agents from a computer science perspective. In their typology, agents should posses the following characteristics: autonomy, social ability, reactivity, and pro-activeness. Macal and North (2006), on the other hand, have used a practical modelling perspective and in their opinion agents should contain the following characteristics: identifiable and self-contained, situated, goal-directed, autonomous and self-directed, and flexible. According to Nwana (1996) the most important categories are: mobility, reasoning model, ideal and primary attributes, role, and hybrids of the previous ones. He studied agents from a software perspective. Shehory (1998) and Hayes-Roth (1995) have also proposed a classification for agents. Schieritz and Milling (2003) conclude that there are no clear agreements on the subject.

ABMS has been used in many different fields of science. These include economics, infrastructure, business and organisation dynamics, biology, military, crowds etc. As ABMS is still a relatively new field of modelling, there has not been that much of work on seaports. Henesey (2006) studied how to simulate a container terminal system with a multi agent system. Container terminal systems are a major part of seaports and as such the work can be seen to partially simulate a seaport. Govindan et al. (2006) used a geographic information system in conjunction with ABMS principles and studied how to model the security of a seaport. Vidal and Huynh (2010) developed a simulation model for a seaport container terminal. The model contains cranes and trucks and the studies the impact of different heuristics in the waiting time of the trucks. All of these models contain a relative high amount of detail.

5 Methodology

According to Vafidis (2007), studies can be classified using two dimensions. The first one explains whether the study is quantitative or qualitative, while the second dimension comes from the earlier work of Arbnor and Bjerke (1997). According to Arbnor and

Bjerke (1997), three different approaches can be defined: analytical, systems, and actors. The analytical approach is purely objective and rational, while in the actors approach the study is more subjective.

This study is quantitative by nature as the simulation models are based on mathematical calculations. Even though some parts of the simulation models are totally objective, the construction process depends on the understanding of the whole system. Also, parts of the system cannot be analysed independently. Thus, the work can be seen to be partially systems-based and partially analytical.

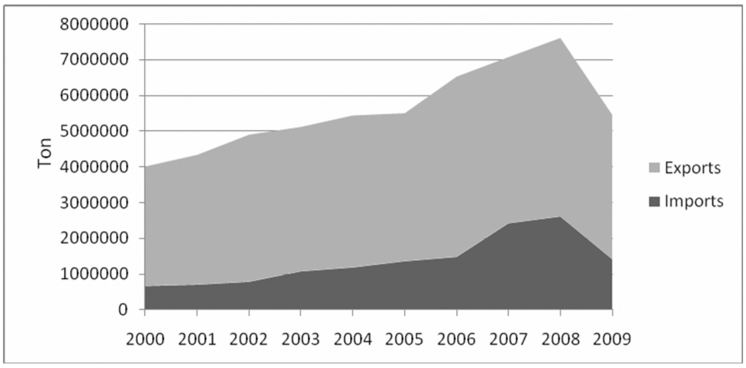
The purpose of this study is to explore how seaports can be simulated accurately enough without incorporating too much detail in the simulation model. This study uses two approaches to construct separate simulation model and compares the results between these models. The desired output of this study is a comparison between these two alternative simulation methods.

This study is part of a larger study where the cargo flows in the Gulf of Finland in emergency situations are studied (STOCA-project, funded by European Union Interreg regional development programme). Part of this study is also built upon an earlier study, where a simulation model was used to create a forecast for Finnish seaports. Most of the data used in this study have been gathered from public sources. There was no need to gather first hand data as many data sources for Finnish seaports already exist.

6 Simulating a Finnish seaport

In this section it is first shown how to simulate a seaport using SD (SD model is constructed with Vensim by Ventana Systems) and after that using ABMS (ABMS model is constructed with Anylogic by XJ Technologies). The seaport simulated is Kotka, one of the largest seaports in Finland. Kotka has been chosen due to its large size and importance in container traffic in Finland. As this study is focused only on general goods cargo, the simulation models will only contain this module. Also, all general goods cargo traffic will be treated as containers, as containerisation will most likely increase heavily in the future. Figure 2 shows the imports and exports of Kotka regarding general goods cargo.

Figure 2 Kotka general goods cargo demand development, data from Finnish Port Association, www.finnports.com



As it is possible to notice from Figure 2, the throughput of Kotka seaport has developed in a very dynamic fashion during recent years. The global recession, which began in 2008, will impact the demand of Kotka seaport in the near future (uncertainty and lower volumes), but in the used simulation models the demand is assumed to develop steadily as the recession will most likely be relatively short compared to the whole simulation period (30 years). The demand is generated in an external module, which is not shown in this paper. More information about the used demand can be found in Lättilä (2009).

6.1 A System Dynamic model of Kotka seaport

The SD model used is part of a larger simulation model of Finnish seaports. In this paper only the structure of the seaport is presented and demand is imposed on the seaport. In this simplified example it is assumed that the capability of the seaport does not impact the demand of the seaport, e.g., there is no competition between the seaports. If more seaports were simulated simultaneously, it would be possible study more competitive behaviour and some of the demand would be shifted to a different seaport. However, this would require other mechanics as well (Sanders et al., 2007 used hinterland capacity and investment dynamics to study competition between seaports) and is beyond this paper's focus. However, as port competitiveness depends on the serviceability of the seaport, the queuing in the seaport would impact the competitive behaviour.

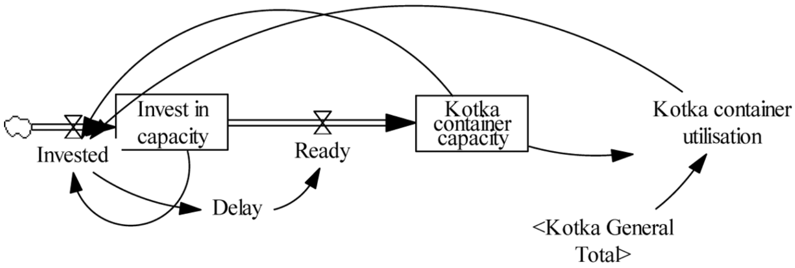
As the focus of this paper is on the capability of the seaport, the most important characteristics are the demand and capacity of the seaport. As was stated earlier, the demand is imposed on the seaport from an external source. The generated demand comes from an earlier work of Lättilä (2009), where it was found that the demand of Finnish seaports can be explained using industrial production of Finland, and Russian oil exports as explanatory variables (the latter for transit transports, since Finland is an important transit country for the Russian consumer sector). The reader can find out more about the used demand in Lättilä (2009).

The second important characteristics, capacity, has been estimated by gathering data from Port@Net. Port@Net is a Finnish database which contains data from all of the Finnish seaports. All of the ships which go through a Finnish seaport must document some essential information on the database. This information includes the amount of cargo, type of cargo, arrival and departure time, berth used etc.

As the database contains the arrival and departure times, it is possible to calculate how long a ship stays in the seaport by subtracting the arrival time from the departure time. By adding together all of the times from all of the ships at the appropriate berths, it is possible to calculate the utilisation of the seaport regarding that product category. The data from the database can be exported or copied to a spreadsheet where the actual calculations are straightforward. In the case of Kotka, the average utilisation in 2007 was about 37% (calculated using data from four different months: February, May, August, and December). The database has separated the berths and the area handling containers is called Mussalo. As the imposed demand is at maximum about 10,000 thousand tons for the seaport, the current capacity can be calculated by dividing the demand with utilisation. In this case, the current capacity is about 27,000 thousand tons per year. However, seaports in Finland do not work 24 hours a day. Finnish seaports tend to work two shifts per day, five days a week, and one shift on Saturday. This equals 11 shifts out of the possible 21 shifts, so the effective capacity is about 53% of the possible. The initial capacity used in the simulation model is 14,157 thousand tons per year.

In order to make a useable simulation model, the seaport needs to invest in new capacity in order to cope with the increased demand. It would be possible to simplify the model and assume the seaports' capacity to increase at the same rate as their demand increases. However, in reality the investments take a long time (might even take years), so in this simulation model the investments also come with a delay. As soon as the utilisation is higher than a threshold value, the seaport will invest in additional capacity, which will be added to the capacity after one year. The structure in the simulation model is presented in Figure 3.

Figure 3 The investments in the simulation model



The actual equation in the 'Invested' variable is

$$\text{Invested} = \text{Maximum}((\text{Kotka container utilisation} - 0.65) \\ \times \text{Kotka containercapacity} \times 1.1 - \text{Invest in capacity}, 0).$$

In this example the choice for maximum utilisation is 65%. If the utilisation is higher, the seaport is going to invest in new capacity. The seaport assumes an increase of 10% in their final demand (calculated from the current capacity) during the next year and takes into account the current investments (which are currently being constructed, but not yet available) as well in their investments decisions by subtracting this amount from the amount of capacity investments. The equation also contains a maximum function, which takes the higher of two values (in this case the other value is always zero) as the seaport does not want to make disinvestment/scrapping of capacity.

As SD works on aggregated level (all of the ships are treated in one equation), it is not easy to incorporate information about individual cases. In this simulation model it is not possible to simulate each individual sea vessel and calculate its time on queue. However, in this case it is assumed that the seaport is an M/M/1-system, and using the equations from queuing theory it is possible to calculate both the size of the queue and average waiting times (Tersine, 1985). A queuing model of M/M/1 is chosen as the seaport is seen to be one large system which serves the ships. Queuing theory is a well known modelling method which uses statistical methods to calculate how a service system works when new tasks arrive to be served using a known distribution.

When the arrival and service rates are known, it is possible to calculate the performance indicators for an M/M/1-system using the following equations:

$$L = \lambda \times W_q = \frac{\lambda^2}{\mu \times (\mu - \lambda)}$$

where L_q = Average length of queue

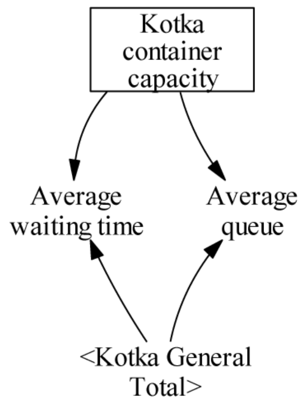
λ = Arrival rate of jobs (in this case, arrival rate of sea vessels)

W_q = Average waiting time in the queue

μ = Service rate of the server (in this case, capacity of the whole system).

As the arrival rate (λ) is "Kotka General Total", and service rate (μ) "Kotka container capacity" are known, it is possible to calculate the queuing performance indicators. In order to make the indicators more meaningful, the length of the queue needs to be divided with "5 tons/ship". Otherwise the queue would be as tons in the queue, not ships. This part of the model is presented in Figure 4.

Figure 4 The queuing theory parts of the simulation model

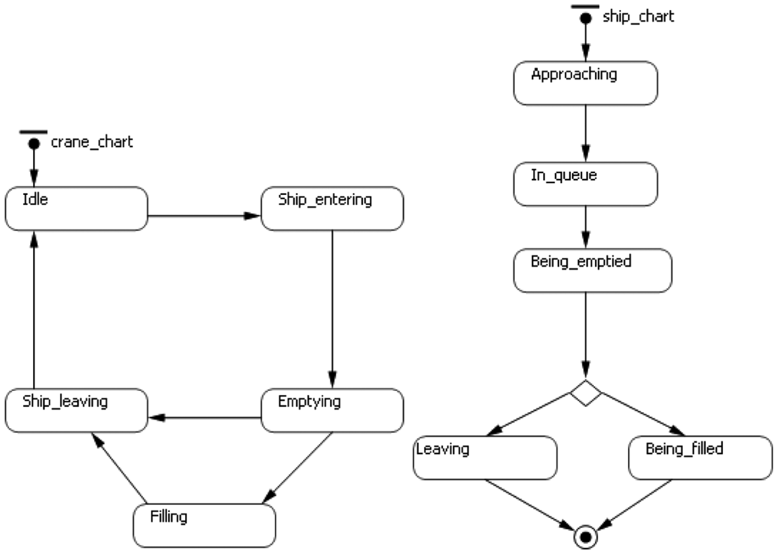


Overall, the SD model requires only a small amount of elements. The whole seaport only contains 10 elements + feedbacks between different parts of the system. The aggregated approach of SD does not fit well the study of queues and waiting times, so other methods need to be used as well.

6.2 An Agent-Based Model of Kotka seaport

As the basic unit in ABMS is an agent, it offers more degrees of freedom regarding the actual simulation model. In this paper we will consider two kinds of agents: sea vessels and cranes. Each vessel will arrive at the seaport and go into a queue in order to be processed. If there is a free crane, the ship will move there to be processed. The ships might be either loaded (25% of the cases), unloaded (25% of the cases), or both (50% of the cases). The amount to be loaded or un-loaded is uniformly distributed between 2222 tons and 4444 tons. On average, a ship will contain 5 thousand tons of cargo to be loaded and/or un-loaded. When the vessel has been processed, they will leave the crane and head for their next location. Figure 5 shows the state charts for the sea vessels and cranes.

Figure 5 State charts for the sea vessels and cranes



The seaport contains eight agents (cranes) with loading/unloading capacities of 387 tons per hour (Mussalo container terminal contains eight cranes), which is derived from the previously calculated capacity.

$$\frac{14157 \text{ thousand tons}}{\frac{11 \text{ shifts}}{\text{week}} \times \frac{8 \text{ hours}}{\text{shift}} \times 52 \text{ weeks}} = 3094 \frac{\text{tons}}{\text{hour}}$$

$$\frac{\frac{3094 \text{ tons}}{\text{hour}}}{8 \text{ cranes}} = \frac{387 \frac{\text{tons}}{\text{hour}}}{\text{crane}}.$$

When the cranes are loading or un-loading the ships, randomness has been included by allowing the loading speed to vary uniformly between –50% to +50% of the current capacity. A ship arrives, on average, every 2.23 h and the time between each arrival is uniformly distributed between –50% to +50% of the mean value.

$$\frac{10000 \frac{\text{thousand tons}}{\text{year}}}{5 \frac{\text{thousand tons}}{\text{ship}}} = 2000 \frac{\text{ships}}{\text{year}}$$

$$11 \frac{\text{shifts}}{\text{week}} \times 8 \frac{\text{hours}}{\text{shift}} \times 52 \frac{\text{weeks}}{\text{shift}} = 4576 \frac{\text{hours}}{\text{year}}$$

$$\frac{4576 \frac{\text{hours}}{\text{year}}}{2000 \frac{\text{ships}}{\text{year}}} = 2.23 \frac{\text{hours}}{\text{ship}}.$$

As the demand will double over 24 years, the average interval will decrease all of the time. After 109,824 h the demand is double, which was also the case in the SD model.

The Agent-Based Model does not require queuing theory to calculate the length of the queue and the waiting time as each agent can calculate this by themselves. The values are gathered by the seaport, so it can decide how much and when to increase the capacity of the cranes. The investment decision in the Agent-Based Model is similar to the one in the SD model. The seaport uses a moving average from the utilisation of the cranes and invests when the utilisation rate is higher than 65%. The utilisation is checked every three months (1056 h) and the invested amount is the same as in the SD-model. The new capacity will be divided between the cranes evenly.

The main variables of the models were tested with the help of unit testing. The mean size of the ship, amount of ships, and crane capacity were logged during the simulation and the mean values calculated. The results were in line with the expected values during the simulation. Also, the mean utilisation is close to the desired level of 65%, which confirms that the capacity investments work in the simulation model.

Overall, the Agent-Based Model is more complex to build than the SD model. The SD model contained only 11 elements over all, while the agents need a lot of different kinds of interactions and states to represent the seaport adequately.

7 Results from the simulation model and discussion

7.1 Results from the SD model

The simulation models contain a lot of interesting information regarding the performance of the seaport. The results from the SD model are presented first. The capacity at Kotka seaport increases from the current value of about 14 million tons to 20–25 million tons. The utilisation of the seaport varies a lot: It can be as low as 40% or as high as almost 100%. It should be noted, that the desired maximum utilisation level will most likely impact the overall utilisation a lot. The results are shown in Figures 6 and 7.

Figure 6 Kotka container capacity in the SD model

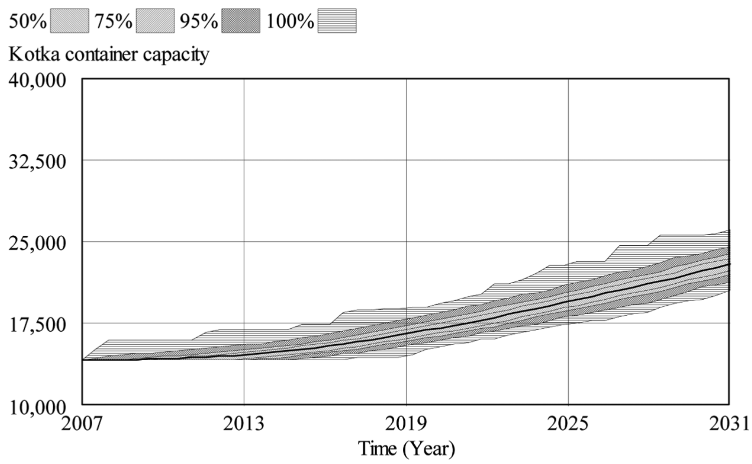
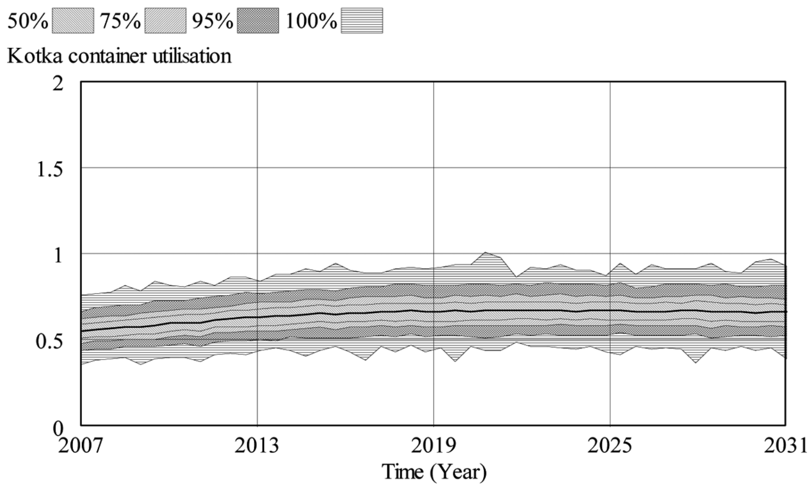


Figure 7 Kotka container utilisation in the SD model



Figures 8 and 9 show the size of queue and average waiting time at the seaport. The average queue at the seaport is relatively low. In most cases there is only one ship and in over 95% cases the queue is less than 2 ships. On rare occasions the average queue will be higher. The same is true for waiting times as well. In most cases the average waiting time is less than 4 h, but on rare occasions in might rise to higher values. Again, it should be noted that the desired maximum utilisation also impacts these values very heavily.

As is possible to notice from Figures 8 and 9, in some rare occasions (in this case one simulation run), the queue and average waiting time in the seaport are negative. This is due to the assumptions behind an M/M/1 system: the amount of arrivals cannot exceed the service rate. As a lot of stochasticity exists in the demand, the model can give irrational results.

Figure 8 Average queue at Kotka seaport in the SD model

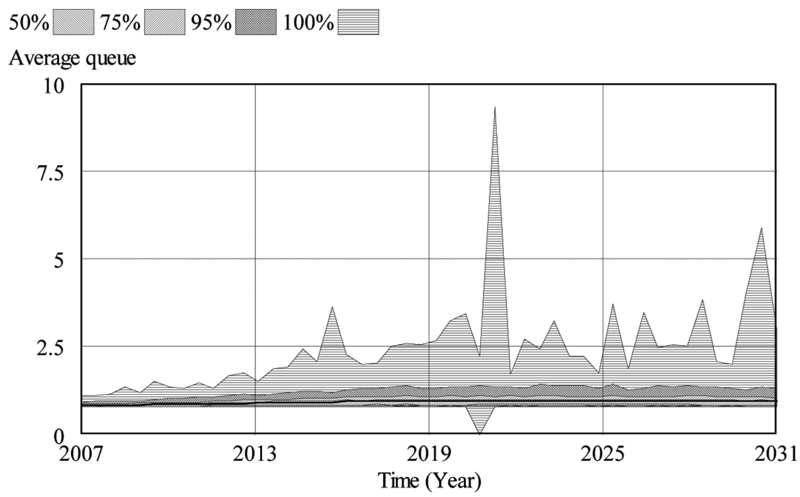
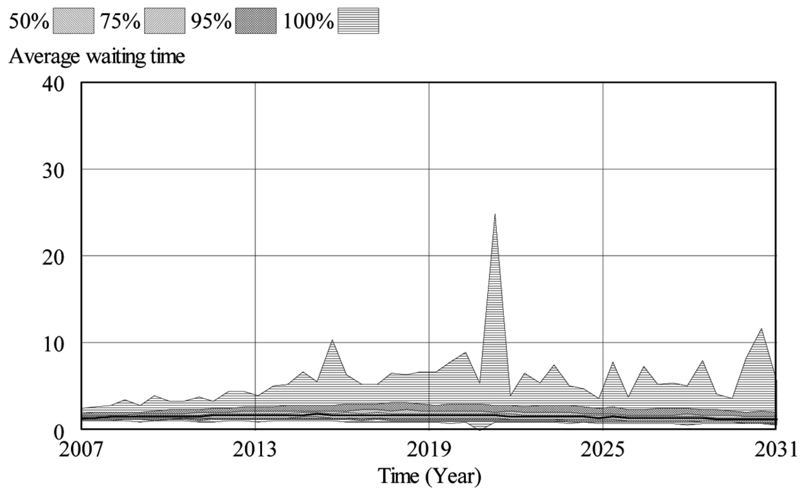


Figure 9 Average waiting time at Kotka seaport in the SD model



The SD model gives good insights about the behaviour of the Kotka seaport. The simulation model could be used to estimate a desired maximum utilisation, after which the seaport would invest to additional capacity in order to cope with the demand. Waiting time can be used as a good indicator for the desired service level. The values are yearly averages, so a high value would indicate extremely long queues from time to time and even with low values there might occasionally be long queues.

7.2 *Results from the ABMS model*

In this section the results for the Agent-Based Model are presented. First, the results for the utilisation and capacity are shown in Figures 10 and 11, while the queue and waiting times are shown in Figures 12 and 13.

Figure 10 Container capacity of Kotka in ABMS

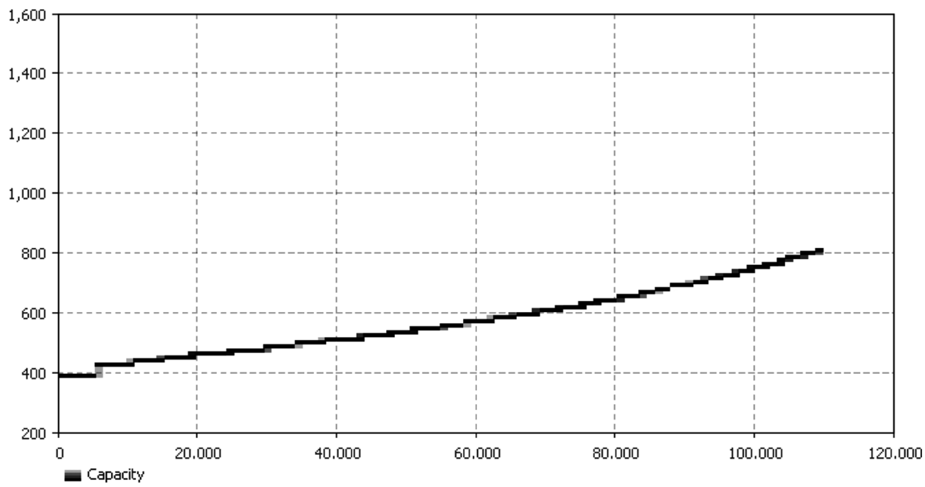


Figure 11 Utilisation of Kotka seaport in ABMS

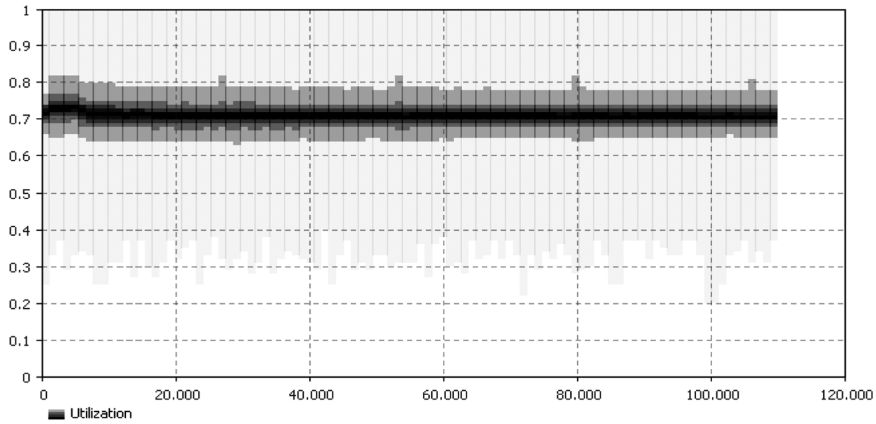


Figure 12 Average queue at Kotka seaport in ABMS

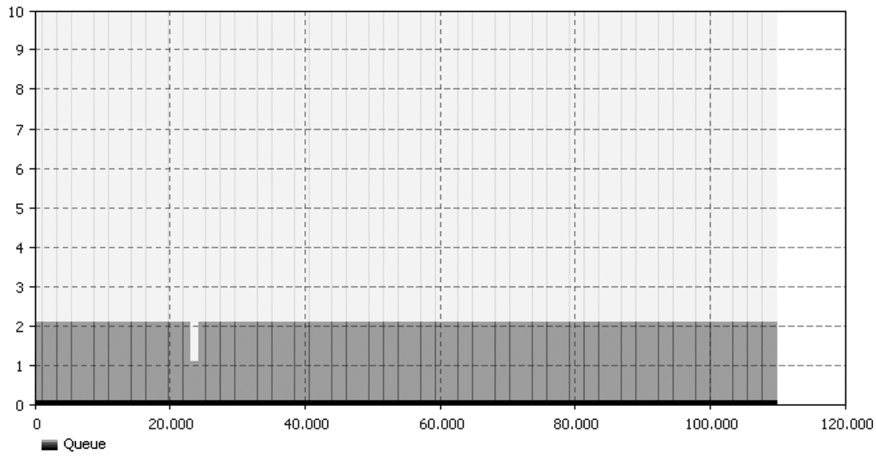
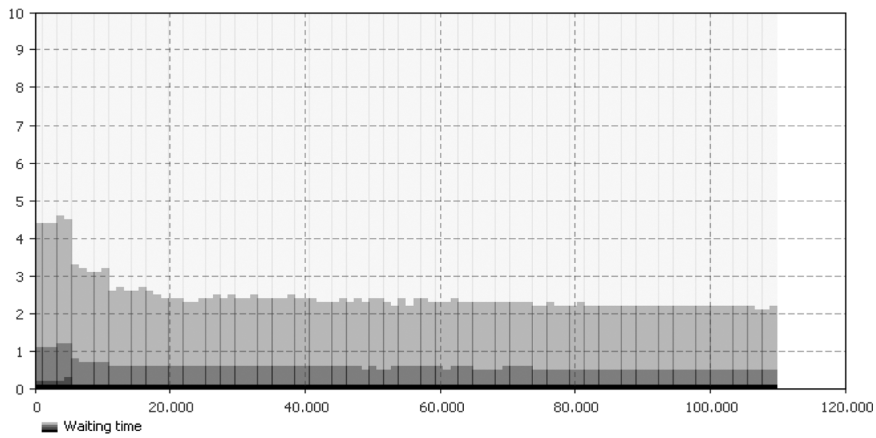


Figure 13 Average waiting time at Kotka seaport in ABMS



As is possible to notice from the figures, the capacity of the system is a lot higher than in the SD model. The mean capacity of a crane is about 800 tons per hour at the end of the simulation period, which is equal to about 3.7 million tons per year. With eight cranes this equals an overall capacity of 29.6 million tons per year, while in the SD model the capacities were 25 million tons per year in the high demand scenarios. The capacity utilisation is a little bit less than 70%, which is in the same range as in the SD model.

The queue in the Agent-Based Model is clearly smaller than in the SD model, being below one in most of the simulation runs (90% of the cases). In 95% of the cases the queue is below two ships. The waiting time is also very low being less than 0.5 h in 87% of the cases. The desired maximum utilisation level will most likely impact very heavily all of these key outputs of the model.

7.3 Differences between the simulation models

The results clearly differ between the simulation models. The Agent-Based Model invests a lot more in new capacity, even though the demand is equally large in both simulation models. One reason might be that the additional randomness in the Agent-Based Model or the M/M/1 is not a good system to study a whole seaport.

An SD model about a seaport can be built relatively easy. Only the total demand imposed on individual seaports needs to be generated, but it can be done using time-series analysis or other methods, which, in this case, was done by Lättilä (2009) in an earlier study. The use of queuing theory is based on strong assumptions as it is based on certain statistical distributions. If queuing theory would not have been used, it would have been very difficult to calculate the average waiting times and average length of queue. However, an M/M/1 system might not be the best one to represent a whole seaport. An M/M/8 system would be one possibility, but it might still be too simplistic to represent a seaport as the service time will most likely not follow an exponential distribution. An M/G/8-system might be a better one but that kind of a system requires approximations to come up with the performance indicators. This will decrease the confidence on the results.

The Agent-Based Model requires a lot more elements and different kinds of events to create a proper simulation model. Again, the demand is imposed on the individual seaports and needs to be simulated separately. The Agent-Based Model can be a lot more versatile than the SD model but there is one major drawback: the simulation model requires a lot more time to run. A single run requires about six seconds on a modern laptop, while the SD model can be run over 1500 times in the same time. The simulation time can be dropped significantly by decreasing the used time-steps in the model but this might bias the results.

7.4 Managerial implications

As this study has shown, constructing a SD model is faster and more simplified than constructing an ABMS model. As long as the rest of the model can be constructed using aggregated stocks, SD should be used. However, the queuing system should be more complex than a simple M/M/1 system as it was noticed to be too simple to adequately reflect the operation of a seaport. Using SD in conjunction with queuing theory allows studying seaports in a broader context than by using either one of the methods alone.

A queuing system could as well represent how well the seaport functions, but an SD model can be expanded to analyse broader systems.

As ABMS has a higher degree of freedom, it can be used to study more complex seaport systems. However, the largest drawbacks are longer development and run times. As SD works with differential equations, they are usually relatively straightforward to construct and it is possible to do collaborative construction, where both the modeller and subject-matter expert are present. ABMS models tend to require a lot more time to construct and collaborative modelling might not be possible (North and Macal, 2007). In this case a 1000 run Monte Carlo–simulation required 50 min to run; so even testing slightly different scenarios might require different appointments between the experts. It is possible to speed up the simulation by using a smaller time-step, but this might impose a bias on the results.

One important question is also the buy-in achievable using different methods. A queuing system based SD model might be more difficult to 'accept' as it is based on mathematical equations and approximations while an ABMS model shows the operations from the perspective of an individual actor. However, due to the lack of collaborative simulation with ABMS it is required to make many iterations between the subject-matter expert and the modeller before the model is ready.

8 Conclusions

The purpose of this paper was to show how to simulate a seaport using both SD and ABMS. ABMS is a much more versatile approach to simulate seaports and the simulation model does not need to be based on assumptions about different distributions in the simulation model. SD, on the other hand, needs to be used in conjunction with some other methods as well in order to study the service levels of the seaports (in this study it was combined with queuing theory). This would indicate that ABMS is a very suitable method for simulating seaports. The only drawback in using ABMS is a big increase in the actual simulation time. This is not a major issue, when running one simulation run, but running thousands of runs (such as Monte Carlo-simulation and/or sensitivity analyses) requires a large amount of time. This also makes the potential parameterisation of the simulation model difficult.

ABMS is a strong candidate for the further studies of cargo flows in logistical networks. It can easily incorporate different kinds of seaports in different areas. As the purpose in the larger project is to study emergency situations, ABMS is able to study more complex events (Schieritz and Grössler, 2003) while SD might have difficulties in some situations. It should be noted, though, that SD is still able to study many different kinds of situations but it is not as versatile as ABMS.

As there have been very few studies using ABMS in simulating seaports, it is difficult to compare the created model with them. The few models which have been published tend to be constructed using a very high level of detail. However, it seems that ABMS is very well suited to studying seaports using a more high level approach. There have been some earlier works regarding SD simulations about seaports and this simulation model was relatively simple compared to the others (such as Munitic et al., 2003). As such, it is a lot easier to simulate different seaports with the solution proposed in this paper.

Further studies include the expansion of the current model to emergency situations. In the SD model this can be done by increasing the load on some of the seaports, which are trying to help the malfunctioning seaport. However, this might be difficult if queuing theory is included, as it requires the utilisation rate to remain under 100% (Tersine, 1985). The ABMS model does not have similar assumptions, but it needs to be made sure that the investments are not made according to the emergency situation. Hinterland logistics should also be incorporated in the model to further advance the understanding about the importance of seaports across the entire supply chain network. One important aspect which should also be studied is the achievable benefits by creating some sort of hybrid-simulation model. There seems to be a lot of potential when these methods are combined (Lättilä et al., 2010). It might be possible to create more realistic logistical systems by using the best of both worlds.

Acknowledgements

The author would like to thank the reviewers for their comments and constructive criticism on developing the paper to its current form. This research has been funded by the European Union's European Regional Development Fund and Central Baltic Interreg IV A Programme 2007–2013.

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Publication III

Hilletofth, P., Lättilä, L., Ujvari, S. and Hilmola, O-P. (2010)

Agent-based decision support for maintenance service provider

International Journal of Services Sciences, 3(2/3), pp. 295 – 314

Agent-based decision support for maintenance service provider

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Abstract: Operations performed by a maintenance service provider (MSP) can include the entire maintenance function or select activities; these need to be well-balanced in terms of utilisation rate of own resources, maintenance cost incurred and the uptime of the customers' production systems. MSPs face challenges due to the task of planning several non-associated plants and with a frequent lack of reliable information. In this research work, an agent-based decision support system of service-related maintenance has been developed. Research shows that this approach can improve the understanding of the problem domain and also generate a basis for decision-making and structural changes.

Keywords: service operations; agent-based modelling and simulation; ABMS; decision support.

Reference to this paper should be made as follows: Hilletofth, P., Ujvari, S., Lättilä, L. and Hilmola, O-P. (2010) 'Agent-based decision support for maintenance service provider', *Int. J. Services Sciences*, Vol. 3, Nos. 2/3, pp.194–215.

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1 Introduction

To stay competitive in today's markets, companies have started to specialise on their core business and outsource the rest to service specialists (Sahay and Mohan, 2006). The increased outsourcing of non-core activities has created an emerging business opportunity attracting several new actors, companies, to enter the market and fill the demand for new services (Hertz and Alfredsson, 2003), e.g., in production support and the maintenance sector. Outsourcing of maintenance involves the use of external companies – referred to as maintenance service provider (MSP) – to perform maintenance operations, which have traditionally been performed within the company. The operations performed by MSPs can encompass the entire maintenance function or select activities. These provided services can either be corrective, preventive or conditional (Waeyenbergh and Pintelon, 2002; Garg and Deshmukh, 2006) and have to be provided faster, cheaper and more efficient than ever before. The main resource of a MSP is skilled personnel, e.g., technicians and engineers.

MSPs are subject to a rapidly changing business environment, strongly influenced by the Forrester effect of non-stock production (Akkermans and Vos, 2003) and research has shown that information is vital in avoiding up and down swings in resource needs. Additionally, operations need to be well-balanced in terms of utilisation rate of personnel (hours billed divided by hours worked) versus service rate towards customers. Another important topic is to keep a balance between maintenance cost and the uptime of the customers' production systems. The issue of maintenance planning in a service-based organisation is more complex than traditional internal maintenance. MSPs often serve multiple customers with different preferences and type of businesses. For instance, the size and branch may differ a lot among customers and they can require anything from long-term contracts of preventive maintenance to very rapid corrective maintenance assistance. Another important issue is varying geographical locations since the customer base can be widespread with long distances to cover for the MSP, especially if a centralised service structure is used. A final important issue is access to information and the quality of the information; depending on the type of relationship the MSP has with its customers, the access to information differs. Additionally, the information quality provided internally and by customers can differ a lot. In this research, we investigate how advanced decision support can improve the planning situation.

One line of research on how to improve decision-making is to generate business intelligence by fusing large amounts of data from various sources [information fusion (IF)]. The purpose of IF is typically to extract relevant information from several sources with known certainty to make better decisions than if fusion was not used. It can be defined as 'the study of efficient methods for automatically or semi-automatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision-making' (Boström et al., 2007). One method to realise IF in complex industrial environments, which normally is not highlighted as an IF method, is agent-based modelling and simulation (ABMS).

ABMS represents a new paradigm in modelling and simulation, especially suited for complex and dynamic systems distributed in time and space (Lim and Zhang, 2003). It implies that the real system of interest is modelled as a set of interacting agents in a defined environment and implemented in simulation software, resulting in an agent-based simulation model. It is related to IF in the way that information from different sources are collected and fused in a synergistic manner into a situation image that provides effective support for human decision-making. ABMS is expected to have comprehensive effects on the way that businesses use computers to support decision-making. For instance, it provides a pragmatic approach for the evaluation of management alternatives (Swaminathan et al., 1998). It is also considered important for developing industrial applications in complex environments (Davidsson and Wernstedt, 2002; Fox et al., 2000; Karageorgos et al., 2003). Empirical studies have shown that managers aided by agent-based simulations can benefit in several ways (Nilsson and Darley, 2006).

The purpose of this research work is to investigate if agent-based simulation models can increase the understanding of the problem domain and form a basis for better decision-making (i.e., constitute a decision support system). With the aim of improving the performance in an MSP environment, an agent-based simulation model of service-related maintenance has been developed. The simulation model is inspired by an actual case company, e.g., some stochasticity estimates are gained from the case company, but additional data has also been used. The access to information has been relatively good since some of the authors have been involved in a research project at the case company during years 2006–2009. Several data collection techniques have been used, such as in-depth interviews, observations, data retrieving from databases and internal documents. In the simulation model, the service order fulfilment process is managed by a set of agents that are responsible for one or more activity. It comprise a complex service network (more than 25 customer factories), which is modelled using one common type of industrial machine (CNC) to be served. The maintenance service provided was categorised as either corrective or planned maintenance; the expertise resource needed was categorised into two classes, mechanical and electrical.

This research approach is interesting since most of the previous studies are only theoretical and seldom practically-oriented. Based on literature reviews, Davidsson et al. (2005) and Cantamessa (1997) conclude that very few field experiments and developed systems have been reported in the academic literature. Davidsson et al. (2005) reviewed the maturity of agent approaches presented in the literature and used the following four main levels:

1 conceptual proposal

2 simulation experiment

3 field experiment

4 deployed system.

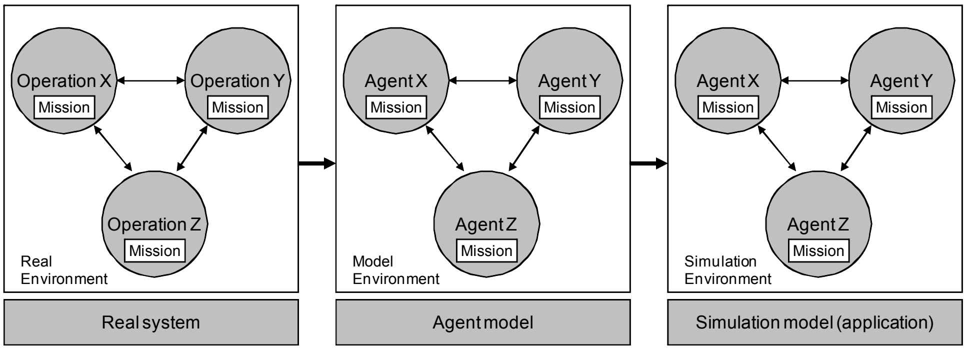
In their sample of 56 journal articles published between 1992 and 2005, only one level four and three level three research works were identified. A more recent literature review confirms that this situation still exists (Hilletofth et al., 2009); only one manuscript from 33 journal articles published during 2000–2008 included empirically verified results based on the implementation of agent-based models. This literature review also revealed that only a few research works were based on real life observations or systems. Simulations also offer additional flexibility compared to other mathematical models, according to Law and Kelton (2000), simulations should be used in situations where it is not possible to construct an analytical solution. Transportation issues are generally seen as a good problem domain for simulations (Saranen, 2009) and as such maintenance service logistics present a good candidate for simulations. A mathematical model will be constructed as well to compare the findings of the simulation model to an analytical model.

The remaining of this paper is structured as follows: in Section 2, the concept of agent-based decision support is discussed through existing literature. Thereafter, in Section 3, the research environment of the case company is presented. In Section 4, the simulation model is discussed, while some initial simulation results are presented in Section 5. Thereafter, in Section 6, managerial implications of the research are discussed. Finally, in Section 7, the research is concluded and further research avenues are proposed.

2 Agent-based decision support

ABMS implies that the real observed system of interest is modelled as a set of interacting agents in a defined environment (i.e., as an agent system) and implemented in simulation software, resulting in an agent-based simulation model (Figure 1). An agent system consists of a couple of individual agents with specified relationships to one another within a certain environment. The agents are presumed to be acting in what they perceive as their own interests, such as economic benefit (i.e., they have individual missions) and their knowledge regarding the entire system (i.e., other agents and environment) is limited (Macal and North, 2006). Still, the most important feature in an agent system is the agents' ability to collaborate, coordinate and interact with each other as well as with the environment to achieve common goals. By sharing information, knowledge and tasks among the agents in the system, collective intelligence may emerge that cannot be derived from the internal mechanism of an individual agent. Furthermore, the ability to coordinate makes it possible for agents to coordinate their actions among themselves, i.e., taking the effect of another agent's actions into account when making a decision about what to do. The term multi-agent system (MAS) is commonly used for agent systems including several interacting and collaborating agents.

Figure 1 The process of ABMS



The topic of the most important characteristics of an agent has been address in the literature; still, there is no agreement on the definition of an agent. First of all, the topic has been addressed from a computer science perspective, where four general characteristics have been discussed (Wooldridge and Jennings, 1995):

1 *autonomy:* implies that agents are autonomous in the sense that they operate by themselves without any direct human intervention and they have some kind of control over their internal state and behaviour in an environment

2 *social ability:* implies that agents have the capability of interacting with other agents and with its environment

3 *reactivity:* implies that agents have the capability to perceive their environment and respond to the changes of the environment

4 *proactiveness:* implies that agents are capable of pursuing their own goals by controlling their future in a proactive manner.

The topic has also been addressed from a more practical modelling approach where five characteristics have been discussed (Macal and North, 2006):

1 *Identifiable and self-contained:* implies that agents are discrete individuals with a set of characteristics and rules governing their behaviours and decision-making capability. The discreteness requirement implies that an agent has a boundary and one can easily determine whether something is part of an agent, is not part of an agent or is a shared characteristic.

2 *Situated:* implies that agents live in an environment in which they interact with other agents. Agents have protocols for interaction with other agents, such as for communication and the capability to respond to the environment. Agents have the ability to recognise and distinguish the traits of other agents.

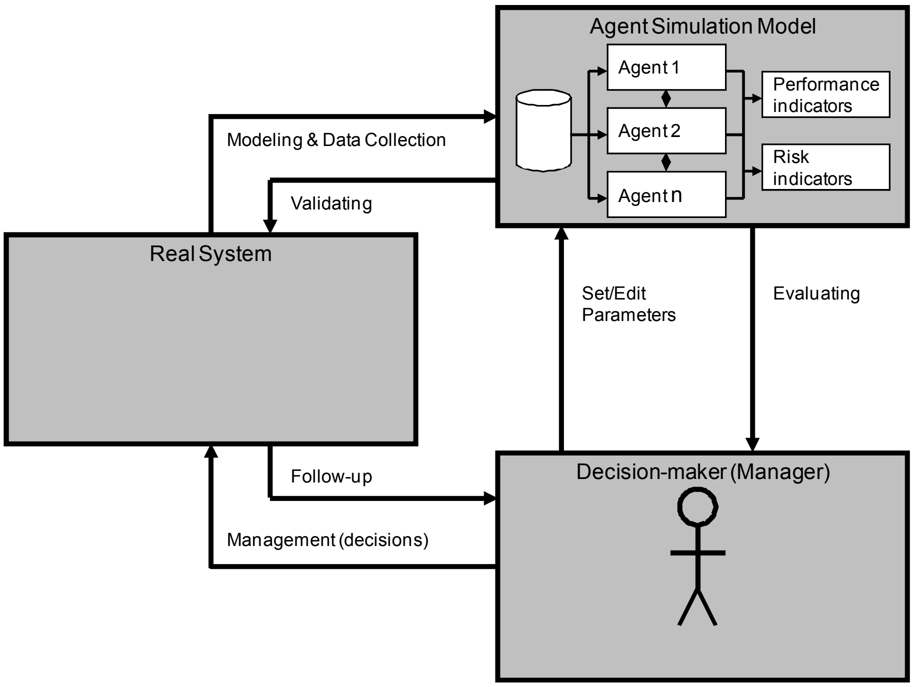
3 *Goal-directed:* implies that agents have goals to achieve with respect to their behaviours. This allows an agent to compare the outcome of its behaviour relative to its goals.

4 *Autonomous and self-directed:* implies that agents can function independently in their environment and in dealing with other agents, at least over a limited range of situations that are of interest.

5 *Flexibility:* implies that agents have the ability to learn and adapt their behaviours based on experience. This requires some form of memory. An agent may have rules that modify its rules of behaviour.

Agent-based simulation can be used to simulate the actions and interactions of individual agents in an agent system to evaluate the agents' effects on the system as a whole as well as to evaluate the system in general. This implies that an agent-based simulation model can be used as a decision support system (Figure 2). The simulation model consists of the interacting agents and some performance and risk indicators. The utilised data in the simulation model can be collected from databases, observations, interviews or documents in the real system. Decision-makers can set parameters in the simulation model, run the simulation and evaluate the results. Based on the retrieved information/knowledge, they can make decisions regarding how to handle the real system. They could also continually alter different parameters and repeat the simulation to evaluate different management alternatives. This implies that an agent-based decision support system fuses information from different sources in a synergistic manner into a situation image that provides effective support for human decision-making. Therefore, it could be regarded as an IF method.

Figure 2 Agent-based decision support system



Nilsson and Darley (2006) conclude in their empirical study that decision-makers aided by agent-based simulations can benefit in several ways. Firstly, they acquire an increased understanding of the impact of unscheduled factors such as breakdowns, accidents and changes of demands. Such factors are often found in reality, but usually reduced or even ignored, when transferred to most traditional models. This implies that the optimised solutions from these traditional models mislead decision-makers into believing in future scenarios, which do not reflect reality. Secondly, agent-based simulations can guide decision-makers' instinct, since interactive agents generate an emergent pattern, which can be explained and understood; bringing benefits for the improvement of decision-making in companies. Thirdly, agent-based simulations can help decision-makers to find, where the highest leverage is to be gained among improvement alternatives. This is based on the fact that ABMS allows models to encompass several business functions and how they affect each other. Finally, there are sometimes even opportunities to improve predictability based on the scenarios generated.

3 Research environment of the case company

In this research work, an agent-based simulation model for service-related maintenance has been developed. It is inspired by an actual case company, but additional data has also been used. The case company tries to manage all customer orders and inquires through a service central which primarily works with orders and inquires concerning operative maintenance. These types of orders are a large share of the total amount of orders. However, the service central also answers questions concerning product and service assortment and guide customer in the organisation. Only maintenance coordinators are connected to the service central: which implies that customer asking for other services is further guided into the organisation. Customer orders and inquires concerning other services than operative maintenance go through sales department, which handles customer contacts and communicates with different coordinators in the organisation. The maintenance coordinators are responsible for the weekly maintenance planning as well as for the day-to-day planning. This means that they determine which technical personnel should be assigned to which tasks. Currently, the organisation is divided into two divisions, mechanical and electrical maintenance. The technicians are responsible for conducting the tasks and also report what has been solved. Currently, the reported task information mostly concerns information for invoicing.

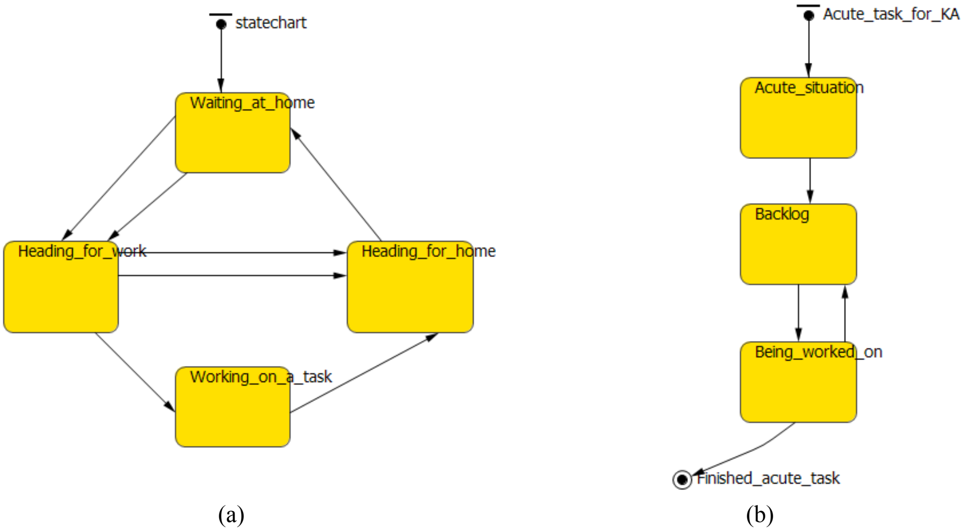
The case company has identified the service fulfilment process and its management to be one of the most important improvement areas. It has been recognised that there is a need to change the service organisation. The company wants to manage all orders and inquires, irrespective of type, through a sales and service central to make the operations more efficient (optimise resource utilisation) and more effective (enhance turnover and profits). Essentially, the focus is on enhancing the planning of maintenance services, which in a recently completed customer questionnaire has been ranked as one of the case company's most important improvement areas. The company is, however, not clear on how the sales and service central should be structured and managed. One discussed solution is to enlarge the current service central responsibilities to create a centralised order entrance, handling the entire product and service assortment. Another discussed solution is to have today's decentralised structure supported with a software application supporting the coordinators when they handle order entrance and customer service (virtual service organisation). An advantage with the decentralised structure is that experts interview the customers and a disadvantage is that it makes resource planning and follow-up more difficult, also disrupting operations. The decentralised structure is also beneficial, if tactical knowledge can be transformed into explicit knowledge. Irrespective of the alternatives, the sales and service central should store, collect and fuse information to provide appropriate decision support. Information can be gathered from customers (customer information, service needs, location of target/problem, information about target/problem), simulations (simulate 'what-if' scenarios), databases (customer information concerning system, equipment and what have been done previously) and staff (staff, skills, utilisation, distance to perform tasks) to support decisions concerning needed maintenance services.

4 Modelling an MSP

The simulation model is inspired by an actual case company, e.g., some stochasticity estimates are gained from service times, travel times, demand types and operating structure of the case company. However, additional data has been added to allow the simulation model to be developed. Empirical data was collected during a three year period (2006–2008) from various sources including databases, interviews, observations and internal documents. The sources contain information such as: operation structure, customer locations, service times, travel times, demand types and type of maintenance tasks. In this chapter, we will present both a mathematical and a simulation model, the simulation model is presented first as it explains the type of service provided. The simulation model was built using AnyLogic as it is one of the leading softwares for agent-based simulation in the industry. Other programmes or pure coding would work as well, but AnyLogic provides a reasonable level of detail and off-the-shelf functionality.

The model contains two types of agents: engineers and tasks. Each task requires a finite time to be completed and the individual engineers work on these tasks. Both types of agents send messages to each other to inform about changes in their states. There are two types of engineers: mechanical and electrical engineers; in this model, each task requires only one type of engineer to work on them, e.g., an electrical engineer cannot work on a task that requires the services of a mechanical engineer. Also, the engineers have further been divided to engineers working on either corrective tasks or planned tasks. Thus, there are four different types of engineers in the model and their numbers can be altered. Each engineer has four different states: waiting at home, heading for a task, working on a task and heading home. The engineers start at their home location and wait for a task to arrive; when it does they will change their state to 'heading for a task'. As soon as the engineer reaches its target, it will change its state to 'working on a task'. At the same time, the engineer will send a message to the task to inform that it is being worked on. The engineer will work on the task until it receives a message from the task. When the message arrives, the state changes to 'heading for home' and it will further change to 'waiting at home' as soon as the engineer arrives at home. These states are presented in Figure 3.

Figure 3 State charts for (a) engineer agent and (b) task agent (see online version for colours)



There are two types of tasks: corrective and planned. The locations of the tasks have been predefined and there are 28 different customer locations where they can occur. The corrective tasks occur all of a sudden while the planned tasks are planned well-ahead of their occurrence. The generation of both corrective and planned tasks is extracted from real task data for reality. In the model, the task lengths and frequency of occurrence are however estimations. Table 1 provides information on how corrective tasks are generated in the model. A new corrective task is generated between 4 to 12 hours, uniformly distributed. The corrective task generated will only contain one subtask, e.g., require only one visit from an engineer (or engineers). The duration of the visit is normally distributed with a mean value of eight hours and a standard deviation of 5.2 hours. 75% of the corrective tasks require a mechanical engineer.

Table 1 Variables in the simulation model

Variable	*Initial values*
Number of acute electrical engineers	2
Number of acute mechanical engineers	2
Number of planned electrical engineers	1
Number of planned mechanical engineers	2
Time between acute tasks	4–12 hours, uniformly distributed
Time between planned tasks	10–30 hours, uniformly distributed
Length of planned tasks	Mean: 10 hours, standard deviation 5 hours
Length of acute tasks	Mean: 8 hours, standard deviation 5.2 hours
Chance of ordering the wrong engineer	10%

It can also occur that the customer gives misleading information about the required task and the wrong type of engineer is sent to the task at first. As soon as the ‘wrong’ engineer arrives at the location, he immediately notices that he is not capable of completing the task. The engineer will then head home and the task is then given to the right type of engineers. When the first engineer arrives (right type or wrong type), the waiting time will be reported. Figure 4 shows an example of the states in a corrective task.

The tasks (both corrective and planned) have only three states. The first one, 'corrective situation', only initiates the agent. Immediately after this, the state changes to 'backlog' which is used to calculate the time waited for service. As soon as the first engineer arrives, the state is changed to 'being worked on'.

Corrective tasks can be allocated to the engineers in two ways; as soon as a new corrective task is generated, each of the right type of engineers will respond whether they are working on a task or not. If there are no available engineers, the task will go to a queue to wait for an engineer to become free. If the amount of free engineers is higher than the amount of corrective tasks to be worked on (in queue plus new tasks), more than one engineer will be assigned for the task. However, when this happens, each task waiting for work will always have at least one engineer assigned to it. The engineers will also look for a job as soon as they arrive back, if they do not have an assigned task. The heuristics are the same, e.g., there might be more than one engineer to be sent to a task. Each planned task is generated every 10 to 30 hours, uniformly distributed. Unlike the corrective tasks, planned tasks can have anything between one to three subtasks and the length for each subtask comes from a normal distribution with a mean value of ten and a standard deviation of five. There will always be at least one task, but there is a 50% chance to have a second subtask. If there is a second subtask, a third one will also have a 50% chance of occurring. A planned task will also have a randomised preferred starting date. In planned tasks, each engineer has a schedule for two weeks. When a new planned task is generated, the total length of the task is used to fit the task to a free time slot. The time slots will be checked one at a time for each engineer so the actual starting date will not be minimised. If a planned task cannot be fitted to any of the engineers, the planned will be tried to be fitted at a later time (each hour in the model). If there is more than one unscheduled planned task, the shorter one will 'steal' a time slot for the longer one. This is because there will be a free slot earlier for a smaller task. This does not necessarily reflect reality, but it is one solution to the scheduling problem. Overall, there are many different variables which can be altered to study the behaviour of the model. These are summarised in Table 1.

Four of the variables represent how many engineers there are in the model. The other variables are stochastic or have impact on a stochastic variable. Overall, the simulation model has much randomness and each simulation run differs to some extent from the previous ones. Thus, the model should be used in combination with Monte Carlo analysis to improve result accuracy and by using a variety of different seed values.

The statistics recorded in the simulation model are presented in Table 2. These indicators provide a situation image of the system's overall performance (performance indicators), these indicators can also highlight risks in the system, e.g., if the values are higher/lower than expected or preferred (risk indicators).

Most of the statistics can be calculated with the help of the states of the agents, the time spent waiting, moving and working on a task, can directly be calculated with the amount of agents in each hour at each state. Also, the amount of hours waiting for service can be calculated with the amount of corrective tasks in the 'backlog' state and amount of tasks at each location with the amount of tasks in the 'corrective situation' state. The last one, amount of kilometres driven, is calculated with the help of transitions in the engineer agents.

Table 2 Statistics gathered from the simulation model

Statistics
Amount of hours spent waiting at home
Amount of hours spent moving
Amount of hours spent working on a task
Amount of corrective tasks at each customer location
Amount of hours waiting for service at each customer location
Amount of kilometres driven

It is also possible to study MSPs using mathematical models. As the decision-makers are mostly interested about the performance of the system in a steady-state, queuing theory is a widely used approach which can also be used to study MSPs. As there are different types of actors in the system, there must be more than one type of queuing system. It might be possible to construct one queuing system with flexible resources, but in this case, it was not possible as the different types of engineers cannot work on the ‘opposite’ type of tasks.

The queuing system for one type of a corrective task (mechanical or electrical) consists of one queue (incoming service requests) and *n* number of engineers. The incoming requests can be assumed to be a Poisson process. The service tasks, however, do not follow a Poisson process. A Poisson process assumes an exponential service time, but in the case of service providers, this is unrealistic. The maintenance service personnel need to travel to the destination before they can start to work on the task. Also, they need to return to their home depot before departing to the next task. As the distributions for individual service operations will differ heavily, it is not possible to assign a certain distribution which can be used in each case. An Erlang distribution might work in some situations, but it is not possible to provide a generic model for MSPs.

The arrival rate of incoming calls for a corrective task needs to be adjusted due to the wrong type of engineers ordered from the customers; this can be done by shortening the arrival rate. In this case, there are eleven service requests instead of ten, as 10% of the service requests require a wrong type of engineer. This will also decrease the mean service time as the requested engineer cannot work on the task. The queuing systems mean service time should decrease by the length of the corrective task (in this case, 2.8 hours) multiplied with the amount of wrong type of engineers (10% in this case).

Time spent in the queue only represents how long time there were no engineers available, not how long the customer has to wait for the service. To calculate the mean waiting time at an individual location, the average travel time to the destination needs to be added to the length of the queue. Other performance indicators can also be calculated from the system, time waiting can be directly calculated from the utilisation of the system. If the travelling times to individual locations are assumed to be fixed, the moving time (and kilometres driven) can be calculated from the amount of service requests handled. The working hours can then also be calculated.

The planned tasks have a very similar queuing system; however, as the tasks are planned, there will always be the right kind of engineer working on the task. As such, there is no need to modify the arrival time, but the service time might contain more than one trip to the customer, this need to be taken into account when calculating the performance values. All of the required calculations are presented in Table 3.

The calculations require an estimate for the waiting time in individual queues. As the system is a type of M/G/m, no exact solutions exist. However, approximations for the waiting time in queue are available (Bolch et al., 1998). We are using the approximation of Martin (1972) to calculate the mean waiting time. The approximation is:

$$W \approx \frac{P_m / \mu}{1-\rho} \times \frac{(1+c_B^2)}{2m}$$

where

P_m = waiting probability

$\underline{\mu}$ = average service time

c_B^2 = coefficient of variation for service

m = amount of engineers

$$P_m \approx \begin{cases} \frac{\rho^m + \rho}{2}, \rho > 0.7 \\ \rho^{\frac{m+1}{2}}, \rho < 0.7 \end{cases}.$$

Table 3 Required calculations in simulation model

Description	*Formula*
Arrival rate for corrective tasks	$\lambda_{t,t} = \lambda_{t,i} + WE\% \times \lambda_{o,i}$
Service time for corrective tasks	$\mu_{t,t} = \frac{1}{(1/\mu_{t,i} + T_\mu \times 2) \times N_t / N_T + T_\mu \times 2 \times N_t / N_T}$
Average waiting time at individual locations for corrective tasks	$LW_{t,l} = W_{q,t} + T_l$
Engineer average waiting time, %	$EW_t = 1 - \rho_t$
Corrective engineer average moving time, %	$MT_t = N_t \times 2 \times T_\mu / T$
Corrective engineer average working time, %	$WT_t = (\rho_t \times T - N_t \times 2 \times T_\mu) / T$
Planned engineer average moving time, %	$MT_t = N_t \times 2 \times V_\mu \times T_\mu / T$
Planned engineer average working time, %	$WT_t = (\rho_t \times T - N_t \times 2 \times V_\mu \times T_\mu) / T$

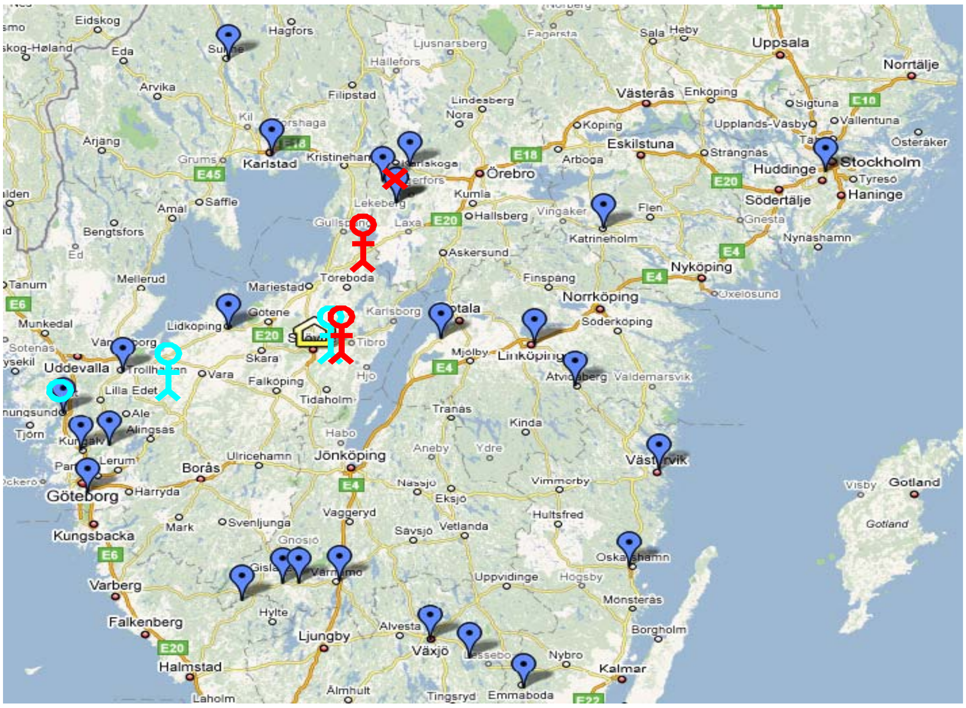
Notes: $\lambda_{t,i}$ = initial arrival rate for task type t
$\lambda_{o,i}$ = initial arrival rate for task type o
$W_{q,t}$ = waiting time in queue
T_l = mean travel time to location l
$WE\%$ = the chance of requesting a wrong type of engineer
ρ_t = average utilisation
$W_{t,l}$ = total waiting time at location l
N_t = total amount of tasks for engineer type t
T = total time
V_μ = average amount of tasks in a planned task.

The actual calculations are presented in the Appendix, while the results are summarised in the next chapter.

5 Results from the model

The simulation model has a graphical view (Figure 4): the red stick-figures are electrical engineers, while the mechanical ones are cyan. The crosses are corrective tasks, while the circles are planned tasks.

Figure 4 The main view of the simulation model (see online version for colours)



As the model contains many stochastic variables, a Monte Carlo analysis should be used to estimate the results of the model. In the Monte Carlo analysis, the same statistics were gathered as in Table 2. The amount of hours waiting for service was divided with the amount of tasks at individual locations and this statistics indicates the average waiting time for each task. Figure 5(a) shows an example of one of these statistics and most of the statistics is presented in Table 4. On average, the engineers have to wait for work 52% of their time. It should be noted though that the time engineers spend waiting is not translatable to idle time; in reality, this time is spent on other tasks at the MSP, but potentially with a lower billable hourly rate. Only 26% of their total working time is used on the actual value adding time of servicing at customer locations, while 22% is spent of moving between locations. As the engineers have to spend much time travelling between locations, the amount of kilometres driven has a strong impact on the profitability of individual customers. Figure 5(b) shows the average amount of kilometres driven. The mean value is 37,781 kilometres and the standard deviation is 1,979 kilometres.

Figure 5 Statistics in the Monte Carlo analysis (see online version for colours)

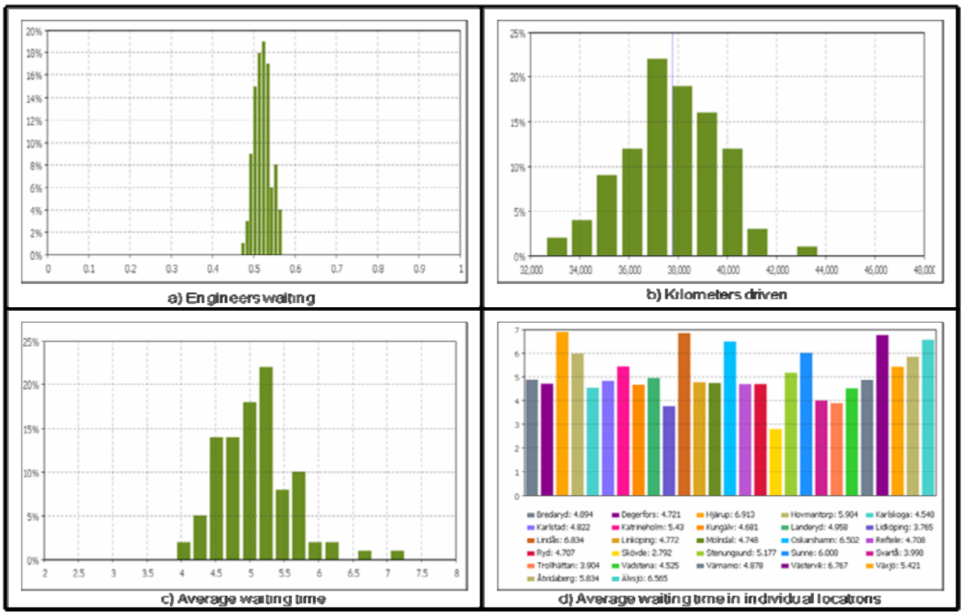


Table 4 The results for the most important variables

Variable	*Mean*	*Standard deviation*
Engineers waiting	52.2%	2
Engineers moving	21.6%	1.1
Engineers working	26.2%	1.4
Total kilometres driven	37,781 km	1,979
Acute waiting time	5.14 hours	0.68

The final statistics of average waiting time, overall and at each individual location in terms of mean value depends on many different things. Each individual task's waiting time does not depend solely on the location, but also from the availability of the engineers. This, on the other hand, is impacted by the location of the previous tasks and their length. Also, if the wrong engineer is sent to a corrective task, it uses much time of the engineers. These waiting times are presented in Figures 5(c) and 5(d).

As can be noted from Figure 5(d), the average waiting time on individual locations differ much. It should be noted that even in the city, where the MSP is located, the average waiting time is three hours, despite the fact that the engineers spend 50% of their time waiting for external tasks. This can be expected, when the rate of corrective tasks is relatively high with respect to planned tasks making effective planning difficult. Figure 5(d) can also be used to estimate the availability promised to customers.

The results from the mathematical model are relatively close (calculations are presented in the Appendix). The average waiting time for a customer is 8.63 hours and the engineers are idle 58.1% of the time. The results for working (21.7%) and moving times (18.5%) are also similar. Otherwise, the results are relatively close, but the waiting time for a specific customer differs heavily between the simulation model and the mathematical model. This is most likely due to the fact that the mathematical model is only based on an approximation which is used for general distributions. This might overestimate the length of the queue. However, as Nilsson and Darley (2006) point out, models do not need to be exactly precise, but reasonably accurate in order to find out how the system reacts to changes. The mathematical model can also be used to test what happens when the amount of engineers is increased or decreased or if the company is able to improve their processes and decrease the mean to repair.

6 Discussion

Simulation results, although, concerning only one machine type customers, increased the interest for sophisticated decision-making systems within the case company. Also, structural issues have been under discussion lately, in order to develop optimal service structures with respect to customer service levels and profitability. Some other competitors in this industry have more service points in one geographical territory (e.g., Sweden), and until today, the case company has been operating with a centralised structure. Although this strategy has previously been advantageous, increasing amounts of new customers in different locations have resulted in some minor decentralisation of operations already. After the analysis of the simulation model, different options on decentralising structures have been mapped and discussed. It seems to be the case that in future simulation scenarios, structural changes are going to be completed for the built model, including several decentralised service points. Advantages of agent-based models are that decentralisation could be completed with several structural operation variants, e.g., the level and type of task (e.g., planned or corrective) and engineering expertise required (e.g., electrical or mechanical). It could be the case that certain types of tasks should be decentralised, but not all the operations. This is clearly the advantage of sophisticated simulation modelling, since this can be evaluated for a certain demand pattern, over time and for different sets of customers, the present set being the most interesting. We argue that, e.g., for the response time of individual customers and the possible reconfiguration possibilities, the agent-based simulation provides much better results than the queuing model and there is thus a value in the additional effort.

Another discussed topic from the simulation results was the response time to customer orders, from receiving a corrective order till someone is at the customer site and the amount of travelled distances during month. The response time is critical for this type of operations with varying demands from customers in this regard, but it has also a direct and strong reverse effect on utilisation of personnel. The travelled distance and the response time will evidently be strongly influenced by the choice of centralised or decentralised structure, presumably being in favour to a decentralised one. This is a strong motivation for continued simulation studies since there are quite many possible mixes between centralised and decentralised structures. An evident aspect of the management of this type of operations is that planned maintenance is much more straightforward to manage than corrective maintenance. This implies that the ratio of corrective one-stop shoppers versus long-term planned maintenance customers is a critical issue. So, the ideal situation is a high rate of long-term customers using a high degree of planned maintenance, which leads to a beneficial situation for both provider and customer with high service-level and high utilisation rate.

In this paper, both a simulation model and a queuing system were constructed. The results were generally close, but there was a big difference in the customer waiting time. This is most likely due to the fact that an approximation was used in the queuing system as there are no exact results for general distributions. The simulation model can easily incorporate different distributions, but a Monte Carlo analysis needs to be conducted each time. The simulation model has a clear advantage with its graphical interface. Buy-in can be achieved much easier as the employees can see the simulation running which is not the case for the mathematical model. Also, it is easy to explain the structure of the simulation model as individual components (personnel and tasks) which have been constructed separately. This will also help to achieve validation for the simulation model as the stakeholders can approve whether the structure of the model and the results for individual components (in this case engineers) are logical.

The largest drawback of a simulation model is a longer time to build the model. A simple simulation model takes much more time to build than a mathematical model, but as soon as the simulation model becomes more complex, it is not possible to construct an analytical model. The simulation model can easily be expanded to study more complex behaviours. Currently, in the simulation model (as well in the mathematical model), the planned tasks only require one engineer while it is not uncommon to send more than one engineer to conduct a task. While this might be possible to do with a queuing system, it would be relatively easy to incorporate it to the simulation model by only changing the used heuristics which assigns the planned tasks for the engineers.

In decision-making, the presented model only gives an estimate of the current situation. The decision-makers can expand the model and conduct 'what-if' scenarios using the simulation model. One important decision is the location of the depots for the engineers. It would be relatively simple to expand the simulation model and use multiple locations to study the impact on the whole system. Currently, the company only works from one central location, but they are interested in dividing the engineers to multiple locations. The engineers can easily be positioned in the simulation model to different locations and a simple heuristics can be used to assign the tasks (e.g., engineers only go to closest locations). This way, it would be possible to see how much the amount of kilometre driven changes and how long customers have to wait in individual locations. It would even be possible to try different heuristics with the simulation model to see which kind of assignments work the best.

7 Conclusions

To realise efficient and effective maintenance management, decision-makers continuously need correct and updated information. The possibility to predict the outcome of their decisions is beneficial, also regarding the effect these decisions will have on the operations. In this research, an agent-based decision support system of service-related maintenance has been developed. This means that the real system of interest is modelled and implemented using ABMS. The resulting simulation model (application) enables the decision-maker to iteratively set parameters, run simulations and evaluate the results. Based on the retrieved information/knowledge, the decision-maker can make decisions on how to manage the real system. This type of decision support system fuses information from different sources in a synergistic manner into a situation image that provides effective support for human decision-making.

Some conclusions can be made about the problem domain based on this work. These conclusions should be considered in light of the validation of the model; since some data is not available for the real system estimations have been made. However, these have been evaluated by application domain experts and the behaviour of the model does not show any unrealistic properties. Still, the performance results presented here are not necessarily representative over time for the MSP; with improved input data, this could improve significantly. The simulation research findings reveal that response lead time in corrective maintenance differs greatly based on two factors, namely the amount of needed resources and the travel time. Demand itself is relatively easy to manage since typically only one maintenance resource visit is required when service is actually needed. However, in planned maintenance demand, management has a more significant role, since more than one visit on site is typically needed and the predictability of the number of visits as well as maintenance hours is larger. As the maintenance operator uses a centralised service structure (all resources in one location), a considerable amount of time and accumulated costs are tied in travelling to the customer sites. Our simulation experiment shows that management of travel times and costs should receive attention and also that the centralised service strategy should be evaluated. A closer study and monitoring of performance and costs can in the future motivate a more decentralised structure.

Additionally, an evident problem in successful operation of MSP and in many service organisations are based on billing customers for time, therefore, it is critical to have an appropriate level of utilisation rate of own resources in relation to customer service. These parameters are described as a percentage of billed hours in relation to total hours and the waiting time spent by customers with regard to rapid, non-planned tasks. Examples of businesses are maintenance providers (corrective tasks), fire fighting, ambulance operations, taxi and other difficult to plan operations. These businesses or systems are characterised by mutually excluding a high level of billing rate *and* service rate – someone will have to wait, the question is: is it the provider or the customer? By increasing the planability of maintenance tasks and increasing the number of long-term customers, this excluding characteristic can be resolved reducing waiting time for both customer and provider. MSPs are at advantage, when their operations can be planned with a higher degree of certainty and to the opposite, when planability is low. With a customer base with a high degree of long-term key-account customers, this becomes evident, rather than many one-stop-shoppers most commonly requiring corrective problem solving. The increased predictability of incoming tasks could be achieved by:

1 an increase of accessible information and increased data capture

2 change of ratio to favour long-term customers, rather than one-stop-shoppers

3 increased data gathering for all types of customers, specifically longer term, to enable prediction of maintenance demand.

Based on these results, it can be argued that this agent-based decision support system has improved the understanding of the problem domain (i.e., maintenance planning) and also generated a basis for decision-making. These results should be generic for other types of service organisations since the problem of achieving a high customer service rate and a high utilisation rate is inherently difficult in low a priori demand information contexts (e.g., some instances of taxi operations, ambulance etc.). The results of using this type of simulation approach are twofold:

1 it is possible to, once the simulation is validated, test the outcome of different settings to find a balance between, e.g., customer service rate and utilisation rate, the result of new locations on the ratio travel time and work time at customers

2 estimate and motivate the actual value of increased data gathering and information generating in most parts of the work process, e.g., service reports, customer production data, etc.

Avenues for further research can be twofold:

1 the application usage in company management is the most critical (how and where this simulation is useful)

2 how this simulation model could be connected to other decision support systems (e.g., customer relationship management programmes or databases).

Most often simulation is used in producing more efficient operations and cost leadership, but with agent simulation, we have identified that this new methodology also enables usage for increasing sales and attracting more customers.

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Appendix

The arrival rates for the corrective tasks can be calculated from the mean arrival rate of eight hours, 75% of the tasks belonging to mechanical engineers. In 10% of the cases, the customers order the wrong type of engineers. The arrival rates for the corrective tasks are:

$$\lambda_{CM,t} = \lambda_{CM,i} + \lambda_{CE,i} \times WE\% = \frac{1}{8} \times 0.75 + \frac{1}{8} \times 0.25 \times 0.1 = 0.09688$$

$$\lambda_{CE,t} = \lambda_{CE,i} + \lambda_{CM,i} \times WE\% = \frac{1}{8} \times 0.25 + \frac{1}{8} \times 0.75 \times 0.1 = 0.04063$$

For the planned tasks, arrival rates can be calculated from the mean arrival rate of 20 hours. The arrival rates for the planned tasks are:

$$\lambda_{PM,t} = \frac{1}{20} \times 0.75 = 0.0375$$

$$\lambda_{PE,t} = \frac{1}{20} \times 0.25 = 0.0125$$

In the queuing system, the service rate also includes the traveling time to the actual customer locations. The mean travel time 2.88 hours needs to be multiplied by two as the engineer returns back to the depot. Also, as 10% of the orders are wrong orders which do not require any actual work at the customer location. For the mechanical engineers during 8,000 hours, there would be overall 775 tasks (75% × 1,000 + 10% × 25% × 1,000) from which 25 are 'wrong calls' and the rest requiring actual work (for the electrical engineers, there are overall 325 tasks with 300 requiring work). The actual service time for the corrective task is 8.68 hours (even though the original time was eight hours with a standard deviation of 5.2 hours, it is not possible to have negative service times; as such, the mean service time is 8.68 hours) and for the planned tasks 10.3 hours. The service rates for the corrective engineers are:

$$\mu_{CM,t} = 1 / \left[\left(\frac{1}{\mu_{CM,i}} + 2 \times T_\mu \right) \times \frac{N_{CM,right}}{N_{overall}} + 2 \times T_\mu \times \frac{N_{CM,wrong}}{N_{overall}} \right] =$$

$$1 / \left[(8.68 + 2 \times 2.88) \times \frac{750}{775} + 2 \times 2.88 \times \frac{25}{775} \right] = 0.07062$$

$$\mu_{CE,t} = 1 / \left[\left(\frac{1}{\mu_{CE,i}} + 2 \times T_\mu \right) \times \frac{N_{CE,right}}{N_{overall}} + 2 \times T_\mu \times \frac{N_{CE,wrong}}{N_{overall}} \right] =$$

$$1 / \left[(8.68 + 2 \times 2.88) \times \frac{300}{325} + 2 \times 2.88 \times \frac{25}{325} \right] = 0.08041$$

The planned engineers might do more visits to the customer site which needs to be taken into account when calculating the service rate. The chance of a second trip was 50% and the chance for a third trip was 50% for the cases where a second trip was needed. The mean amount of visits to a customer is 1.75 (1 + 0.5 + 0.5 × 0.5). The service rates can now be calculated. The service rate is the same for both of the mechanical and electrical engineers. The service rates are:

$$\mu_{PM,t} = \mu_{PE,t} = 1 / \left(\frac{1}{\mu_{PM,i}} + 2 \times T_\mu \times V_\mu \right) = 1 / (10.3 + 2 \times 2.88 \times 1.75) = 0.03558$$

With the help of the arrival and service rates, it is possible to calculate the utilisation rates for the engineer. The utilisations are:

$$\rho_{CM} = \frac{\lambda_{CM,t}}{\mu_{CM,t} \times m_{CM}} = \frac{0.09688}{0.07062 \times 2} = 68.6\%$$

$$\rho_{CE} = \frac{\lambda_{CE,t}}{\mu_{CE,t} \times m_{CE}} = \frac{0.04063}{0.08041 \times 2} = 25.3\%$$

$$\rho_{PM} = \frac{\lambda_{PM,t}}{\mu_{PM,t} \times m_{PM}} = \frac{0.0375}{0.03558 \times 2} = 52.7\%$$

$$\rho_{PE} = \frac{\lambda_{EM,t}}{\mu_{EM,t} \times m_{EM}} = \frac{0.0125}{0.03558 \times 1} = 35.1\%$$

$$\rho_{mean} = \frac{\sum \rho_t \times m_t}{\sum m_t} = \frac{0.686\times 2 + 0.253\times 2 + 0.527\times 2 + 0.351\times 1}{2+2+2+1} = 41.9\%$$

The time spent on movement between the home depot and customer sites is calculated from the expected amount of tasks and the mean travel time between the home depot and customer sites. The movement times are:

$$MT_{CM} = N_t \times 2\times T_\mu \,/\, T = 775\times 2\times 2.88 / 16{,}000 = 27.9\%$$

$$MT_{CE} = N_t \times 2\times T_\mu \,/\, T = 325\times 2\times 2.88 / 16{,}000 = 11.7\%$$

$$MT_{PM} = N_t \times 2\times V_\mu \times T_\mu \,/\, T = 300\times 2\times 1.75\times 2.88 / 16{,}000 = 18.9\%$$

$$MT_{PE} = N_t \times 2\times V_\mu \times T_\mu \,/\, T = 100\times 2\times 1.75\times 2.88 / 8{,}000 = 12.6\%$$

$$MT_{mean} = \frac{\sum MT_t \times m_t}{\sum m_t} = \frac{0.279\times 2 + 0.117\times 2 + 0.189\times 2 + 0.126\times 1}{2+2+2+1} = 18.5\%$$

Time spent on actual value adding work will be calculated by subtracting the movement time from the total time being utilised. As some types of engineers have more than one engineer in the group, the total time needs to include all of their time. The amount of visits is again calculated from the time period of 8,000 hours. The amounts of time used on working are:

$$WT_{CM} = (50.7\%\times 16{,}000 - 775\times 2\times 2.88) / 16{,}000 = 22.8\%$$

$$WT_{CE} = (20.8\%\times 16{,}000 - 325\times 2\times 2.88) / 16{,}000 = 9.1\%$$

$$WT_{PM} = \left(\rho_{PM} \times T - N_{PM} \times 2\times V_\mu \times T_\mu\right) / T =$$
$$(52.7\%\times 16{,}000 - 300\times 2\times 1.75\times 2.88) / 16{,}000 = 32.8\%$$

$$WT_{PE} = \left(\rho_{PE} \times T - N_{PE} \times 2\times V_\mu \times T_\mu\right) / T =$$
$$(35.1\%\times 8{,}000 - 100\times 2\times 1.75\times 2.88) / 8{,}000 = 22.5\%$$

$$WT_{mean} = \frac{\sum WT_t \times m_t}{\sum m_t} = \frac{0.228\times 2 + 0.091\times 2 + 0.328\times 2 + 0.225\times 1}{2+2+2+1} = 21.7\%$$

In order to calculate the customer waiting times, it is necessary to know how long the individual customer orders wait in the queue. The coefficient of variation for the total service time is used in the calculations and for the planned tasks the value is 0.32. There is no need to calculate the length of the queue for the planned tasks as the service is totally flexible and it does not make a difference for the customer. The waiting times for the corrective tasks are:

$$P_m \approx \begin{cases} \dfrac{\rho^m + \rho}{2}, \rho > 0.7 \\ \rho^{\frac{m+1}{2}}, \rho < 0.7 \end{cases} \qquad \begin{aligned} P_{m,CM} &\approx 0.686^{\frac{2+1}{2}} = 0.568 \\ P_{m,CE} &\approx 0.253^{\frac{2+1}{2}} = 0.127 \\ P_{m,PM} &\approx 0.527^{\frac{2+1}{2}} = 0.383 \\ P_{m,PE} &\approx 0.351^{\frac{1+1}{2}} = 0.351 \end{aligned}$$

$$W_{CM} \approx \frac{P_{m,CM} / \mu_{CM,t}}{1-\rho_{CM}} \times \frac{\left(1+c_{B,CM}^2\right)}{2m_{CM}} = \frac{0.568 / 0.07952}{1-0.686} \times \frac{\left(1+0.41^2\right)}{2\times 2} = 7.46$$

$$W_{CE} \approx \frac{P_{m,CE} / \mu_{CE,t}}{1-\rho_{CE}} \times \frac{\left(1+c_{B,CE}^2\right)}{2m_{CE}} = \frac{0.127 / 0.08041}{1-0.253} \times \frac{\left(1+0.41^2\right)}{2\times 2} = 3.50$$

$$W_{mean} \approx W_{CM} \times \frac{N_{CM}}{N_{all}} + W_{CE} \times \frac{N_{CE}}{N_{all}} = 7.46 \times 75\% + 3.5 \times 25\% = 5.75$$

For the individual locations, it is still necessary to include the travel time to the location. The mean total waiting time for the customers is:

$$LW_{mean} = W_{mean} + T_\mu = 5.75 + 2.88 = 8.63$$

Publication IV

Lättilä, L., Saranen, J. and Hilmola, O-P.

Decision Support System for AS/RS Investments: Real Benefits Out of Monte Carlo Simulation

Submitted to review: *International Journal of Manufacturing Technology and Management*

Decision Support System for AS/RS Investments: Real Benefits Out of Monte Carlo Simulation

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Abstract

Warehousing plays an important role in the efficiency of today's international supply chains. Optimal configuration of warehouse activities depends on several design criteria. Basic alterative system designs are based either on manual labour or automated systems. While manual systems typically require smaller investments, automated systems in turn enable increased efficiency in space utilisation, advanced flexibility, as well as reduction in spoilage and administration cost. In this research we combine static spreadsheet modelling with Monte Carlo simulation to estimate the payback time of two suggested Automatic Storage and Retrieval System (AS/RS) investments as well as for identifying the main factors affecting their economic feasibility. By offering a rapid tool for evaluating the potential of an AS/RS, detailed time consuming analyses need to be performed only for the most potential configurations.

Keywords: Investment analysis, AS/RS, warehousing, simulation, decision support systems

1. Introduction

Warehousing and transportation can be regarded as one of the most important functions of today's international supply chains (Tuzkaya and Önüt, 2009). While the total employment in transportation and logistics sector in the USA rose by 20 percent during the period between 1998 and 2005, the respective increase in warehousing and storage was 380 percent (Bowen, 2008). Automated Storages and Retrieval Systems (AS/RS) enable advanced flexibility, increased efficiency in space utilization, as well as reduction in spoilage and administration cost (Roodbergen and Vis, 2009). According to Kulwiec and Forger (1998) in 1997 the sales of materials handling systems was nearly 7.2 billion USD (about 9.5 billion in current USD when inflation has been taken into account). In 2008 (Rogers 2009) the sales exceeded 15.3 billion USD.

The prime reasons for choosing an AS/RS system are to accommodate growth, reduce operating costs, and improve customer service (Baker and Halim 2007). However, need for detailed planning arises as AS/RS incur large investments (Roodbergen and Vis, 2009). According to Gu et al. (2010) design of warehouses consists of five different areas. These are: overall structure, department layout, operation strategy selection, equipment selection, and sizing and dimensioning. All of these fields are also interconnected and modifying one has an impact on the others. Most of the recent research has been on the categories of department layout and sizing and dimensioning. Gu et al. continues (2010) by stating that there is a gap between the research community and practice. Cross fertilization between these groups would enhance the quality of research. Due to the interconnectness, high costs, and lack of communication between practitioners and academia, it is not yet known what the practitioners see to be of high importance during investment decisions.

Simulation offers a tool for evaluating dynamic systems (Chatfield et al., 2005). They are frequently used to analyze warehousing systems. Roodbergen and Vis (2009) found seven papers where simulations where used to analyze AS/RS systems. Simulations require extensive building time as well as special training (Banks et al., 2005; Chung, 2004; Ljung and Glad, 1994). According to Baker and Canessa (2009) simulations are not used in the early phase of warehouse design projects. Spreadsheets are frequently used in this phase.

The objective is to study is to find out how decision-making can be improved when warehousing designs are compared. The research question is *"What are financially the key variables to be considered in the early phase of an AS/RS investment project"*. In this research an easy-to-use evaluation tool for decision making is presented. The tool is used to calculate investment payback time. The proposed tool can be used in the early phase of investment decisions so time consuming analyses can be avoided. The tool also allows investigating the financially most important variables in the decisions.

This research work is structured as follows: Section 2 reviews literature from warehousing and AS/RS, as well as from spreadsheet based simulations. Section 3 introduces the two case studies. Section 4 discusses the research findings, while Section 5 presents the conclusions and future research avenues.

2. Related Literature

Warehousing and AS/RS

The increasingly complex supply chain networks induced by globalization (Poon et al., 2009) have lead to an expansion in transportation and logistics activities, especially in warehousing and storage. While the total employment in transportation and logistics sector in the USA rose by 20 percent during the period between 1998 and 2005, the respective increase in warehousing and storage was 380 percent (Bowen, 2008). The global revenue of the main automation suppliers has risen by 60 percent during the period between 1997 and 2008 (Kulwiec and Forger (1998); Rogers 2009). According to Parikh and Meller (2009) warehouse activities include the receipt of items and customer orders, storing items, order picking, shipping, customer service and reclamation, and control. Based on earlier studies Baker and Canessa (2009) state that warehousing investment and operating costs account for

22 to 24 percent of total logistics cost in the USA and Europe. Order picking constitutes 55-65 per cent of the total operating costs for a typical warehouse (Coyle et al., 1996; De Koster et al., 2007).

Gunasekaran et al. (1999) have proposed a conceptual model for improving the efficiency of warehouse operations. However, the models used in practice differ in number of steps, in their sequence, as well as tools applied (Baker and Canessa, 2009). Optimal configuration of warehouse activities depends on several design criteria (see e.g. Petersen et al., 2005). Basic alternative system designs are based either on manual labor or automated systems. Automated systems enable increased efficiency in space utilization, advanced flexibility, as well as reduction in spoilage and administration cost (Roodbergen and Vis 2009). Manual systems tend to require smaller initial investments.

According to Material Handling Industry of America (2011): *"An Automated Storage and Retrieval System (AS/RS) is a combination of equipment and controls that handle, store and retrieve materials as needed with precision, accuracy and speed under a defined degree of automation. Systems vary from relatively simple, manually controlled order-picking machines operating in small storage structures to extremely large, computer-controlled storage/retrieval systems totally integrated into a manufacturing and distribution process"*. Roodbergen and Vis (2009) have summarized different classification methods for AS/RS. They can differ in the used cranes, handling of goods and used racks. In addition to the classification, the system design will also heavily impact the final system. These decisions include (Roodbergen and Vis, 2009) the system configuration, storage assignment, batching, sequencing, and dwell-points.

According to Baker and Halim (2007) there are many reasons why an automated system is chosen over a conventional system. The prime reasons are to accommodate growth, reduce operating costs and improving customer service. Other benefits include reduced staffing level, consolidated inventories, and improved accuracy. Possibility to grow (increased amount of pallet positions) and reduce costs (decrease in personnel costs) can be more easily estimated than other benefits. There has been a lot of work regarding consolidated inventories and some work on the impact of inaccurate data on supply chain performance (Sari, 2008). The performance of the final warehouse will depend on many issues and they are presented in Figure 1.

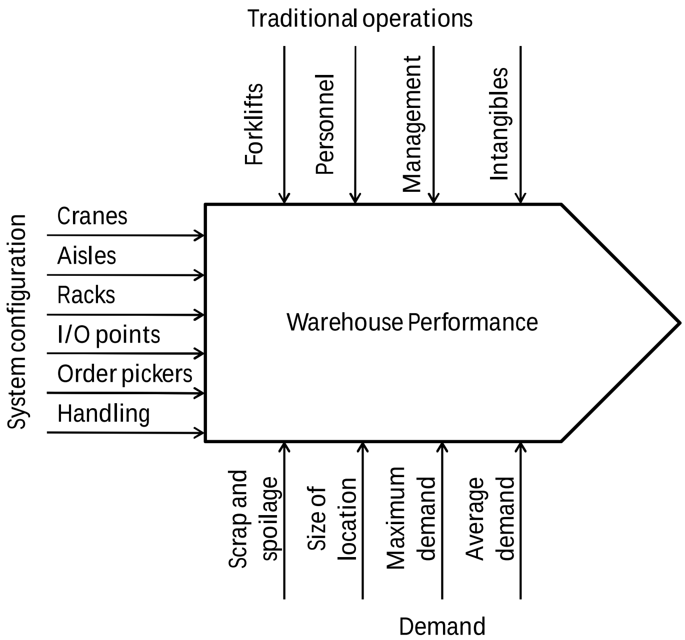

Figure 1: Variables impacting warehouse performance

All of the various criteria are interconnected. The system configuration and size of location define the amount of pallet positions. The average and maximum inflow and outflow rates impact the amount of I/O points and the amount of cranes / forklifts. Traditional operations tend to high a higher rate of spoilage and scrap due to mishandling. Finally, many intangible benefits can be achieved with an AS/RS compared to a manual system. All of these issues should be taken into account when making the decisions whether to invest into automation or not.

Simulations

According to Banks et al. (2005) the purpose of simulations is to imitate a real system. There are many different kinds of simulations available. These include physical simulations (e.g. car in an air tunnel), interactive simulations (physically evacuating a building), and computer simulations etc. Naylor et al. (1966) define simulation as the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain, and predict the behavior of the real system.

Simulation analysis is a descriptive modeling technique. It does not provide explicit problem formulation and solution steps like linear programming.

According to Jahangirian et al. (2010) the most widely used approaches in manufacturing and business are discrete-event simulation, system dynamics, agent-based modeling and hybrid modeling. The fifth most widely used approach is Monte Carlo. In this approach a model contains stochastic variables (follows a predefined random distribution) and thousands of runs are done using different values for the stochastic variables. Monte Carlo can be combined with different simulation approaches. (Taha 2007)

According to Seila (2005), spreadsheet simulations contain three types of cells: input cells, intermediate computation cells, and output cells. In the input cells the users gives the specific parameters for the simulation model. They can be either inputted by the user or they can be sampled values from known distributions. The intermediate computation cells use the input values and they define the transformations into outputs. The final output cells provide the actual simulation results. According to Seila (2005) there are two situations where spreadsheet simulations are used: when the model contains stochastic (random) elements or one wants to conduct proper sensitivity analyses.

Simulations have been used with AS/RS to improve decision-making. In a recent literature review on AS/RS, Roodbergen and Vis (2009) found seven papers using simulation as a methodology to analyze these systems. Discrete-event simulation (Ekren et al. 2010; Lee et al. 1996; Lerher et al. 2010; Meinert et al. 1999; Portč et al. 2004; Sari et al. 2005) and Petri-Nets (Cheng and He, 2010; Lee et al. 2006) are widely used approaches to analyze AS/RS. The problem with Petri-Nets and Discrete-event simulation is the relatively long construction time. They are not suited in the early phase of warehouse design projects.

Research has been conducted also using analytical methods. Nonlinear integer programming has been applied to implement class based storage (Muppani and Adil, 2008a; Muppani and Adil, 2008b; Yu and de Koster, 2009). However, there have been few studies using spreadsheet simulations (Wilson and Laney, 2003). Nevertheless, current simulation models have emphasized the actual performance of the AS/RS, not the high level configuration estimates.

3. Case Study: Estimating Benefits of an AR/RS Investment Configuration with Decision Support System

Research Methodology

In the two case studies presented in the following, two spreadsheet based decision support systems were constructed. As it was noticed in Figure 1, many issues impact warehouse performance. The managers considering potential designs have limited knowledge on AS/RS systems. Spreadsheet was chosen as the modeling approach due to its easy use. Eventually the decision support system can be distributed to managers considering an AS/RS investment. If the investment is feasible, more thorough analyses are conducted with the system supplier. The supplier also uses discrete-event simulation in later phases but they are too cumbersome in the early phase of warehouse design projects.

The AS/RS decision support system is presented in Figure 2. They only require a limited number of inputs which the managers are aware of. With the input information the system estimates the physical structure of the AS/RS system. This can then be converted to financial estimates about the differences between a manual and an automated system. The automated loading solution decision support system has a similar approach but it will only concentrate on the loading operations.

Our research team was integrated with the case organization for this task, and one researcher participated in meetings during nine month period, which took place during year 2009. Some critical parts of decision support system development were also in our responsibility (like Monte Carlo simulation capability, and use in feasible places). From the case company side participation included managing director, and two management level persons. In the following developed industrial cases were taken from company’s existing sales cases, and application areas are in turn reflecting in detailed level the reality of AS/RS investment calculations. Case company is currently enjoying from high demand for their systems, and sales growth estimates for following years are more than hundred percent per annum.

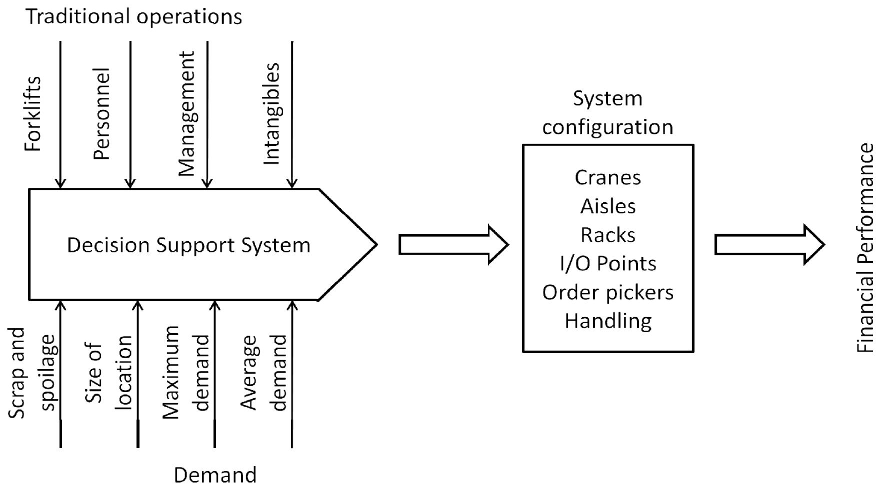

Figure 2: Decision Support System

The AS/RS enhances space utilization by increasing the number of pallet positions. It is also possible to increase input/output capacity within the system. The system offers integrated value added functions such as buffer inventory, order sorting, picking, staging and shipment consolidation. It also enables optimization of storage and handling processes. The supplier provides solutions also for automated load forming and loading of transportation vehicles. The system requires no modifications for transportation vehicles or the cargo space. It enables minimizing turnaround time and improves cargo space utilization.

The models were validated by comparing the system configuration inside the decision support system against delivered systems. The models were reasonably accurate as the delivered systems are always case dependent. The system supplier (case company) considers currently offering the tool directly for its potential customers on the web. This increases the trustworthiness of the empirical part concerning structure and chosen parameters. Some of the parameters were estimated based on previous deliveries and the rest by contacting current customers.

Decision Support System for Automated Loading System

The first model consists of three sheets: (1) Instructions, (2) Information, and (3) Results. The instructions sheet simply states the general information about the simulation model. The information sheet is used to gather inputs used to make the financial estimates. The final sheet, results, gives the actual financial savings achievable by using the automated system. Main inputs of the model can be divided to three categories: operational information, transportation information, and investment requirements. All of the inputs are presented in Figure 3.

Operational		
Labour costs	4000	€ / month
Working days	22	/ month
Effective working hours	7	hours / day
Worker / loading crew	3	workers
Forklifts / loading crew	2	fork lifts
Forklift monthly investment costs	1500	€ / month
Forklift operating cost / container	3	€ / container
Containers handled by one crew in an hour	3	containers / crew
Time to load a container	20	minutes
Less days of illnesses due to safer handling of goods	2	/ year
Transportation		
Transport cost per DC	2000	€
Transport cost per OC	4000	€
Percentage of OC containers	10,00	%
Are your containers constrained by volume or by weigth?	Weigth	
By volume we mean timber, plastic tubes, etc.		
By weight we mean steel, marble, etc.		
Transportation idling costs	80	€ / hour
Value of goods in container	20000	€
Damaged goods during loading	0,05	%
Investment requirements		
Investment time to amortization	60	months
Desired discount rate	10,00	%

Figure 3: Input window of the automated loading system spreadsheet model.

The results of the model are also divided to three categories: operational, transportation, and additional savings. The automated loading system can load 6 containers per hour with one forklift and two workers, which allows comparing the results with a traditional system. Transportation savings occur due to less use of open top containers. As the loading system pushes the material into the container, there is no need to use a crane and load the material from above. The additional savings include a shorter turnaround time (a truck needs to wait only for 5 minutes instead of 20 minutes), better space utilization (which requires less containers to transport the same amount of goods), less damages during loading and less days of illness. The spreadsheet model's results are presented and compared against the amount of containers to be loaded per hour.

For the company there are two ways to use the simulation spreadsheet model. It can either use it internally to organize marketing efforts as new knowledge can be gained using simulations, or they can use it in their own selling process as the customers might not have exact information on all of the inputs. Nevertheless, both are done in a similar fashion by allowing some variable to vary according to certain distributions.

As a default setting the simulation model contains a base scenario. This scenario is used in our decision support system too. In the base scenario the customer uses three workers and two forklifts to load a container. The material is long and heavy (steel rods), which means that it is difficult to load using forklifts and includes a lot of safety issues. Sometimes the material is also loaded to an open top container which is even more hazardous. Some variables can be assumed to be well known, which does not require the use of stochastic variables. The rest require some sort of confidence limits. Using a spreadsheet simulation software (@Risk from Palisade), some values are allowed to vary. The fixed values are presented in Figure 1, while the stochastic variables are given in Table 1.

Table 1: Distributions used in the automated loading solution simulation model.

Variable	Distribution
Less days of illness, days / month	Lognormal, $\mu = 2$, $\delta = 2$, Shift of 18 → Mean 20
Transport cost per DC, €	Normal, $\mu = 2000$, $\delta = 200$
Transport cost per OC, €	Normal, $\mu = 4000$, $\delta = 400$
Percentage of OC containers	Triangular, min = 5%, mode = 10%, max = 20%
Transportation idling cost, € / hour	Normal, $\mu = 80$, $\delta = 8$
Value of goods in container, €	Normal, $\mu = 20000$, $\delta = 2000$
Damaged goods during loading, % of all goods handled	Triangular, min = 0,005%, mode = 0,01%, max = 0,02%

The values of the parameters and distributions are based on expert opinions. The automated loading solution has been provided to many customers. The highest benefits have been reached with customer handling bulky goods, which are difficult to load. The system has been used in these types of locations and the values can be seen to belong to a typical case company. As most of the uncertainty is associated with the demand for the service and the amount of accidents, these parameters have been chosen to include stochasticity.

The results from the model are presented in Figure 4 and 5. Figure 4 shows the monthly savings by using the automated system compared to a traditional loading operation. There is a large amount of variation in the results. The savings range from 15,000 Euros to 105,000 Euros, mean value being 45,000 Euros. As it is possible to notice from the figure, the 90% confidence limit for monthly savings is between 27.6 thousand Euros and 68.9 thousand Euros. More information can be achieved by studying the regression coefficients of the independent variables (presented in Figure 5).

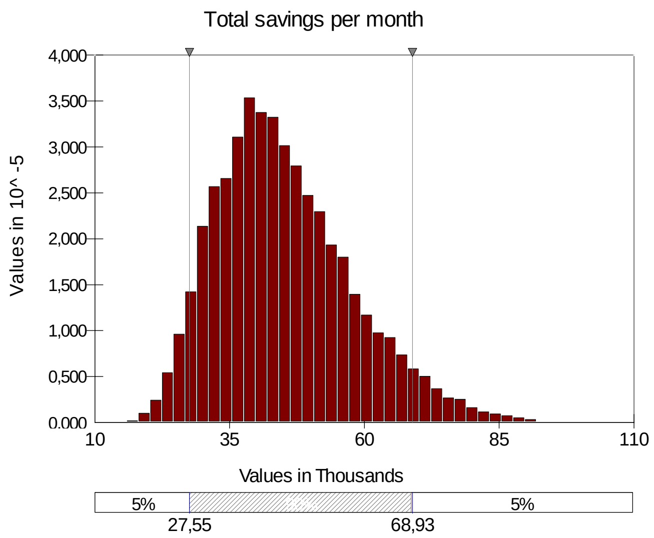

Figure 4: Monthly savings in the automated loading solution model

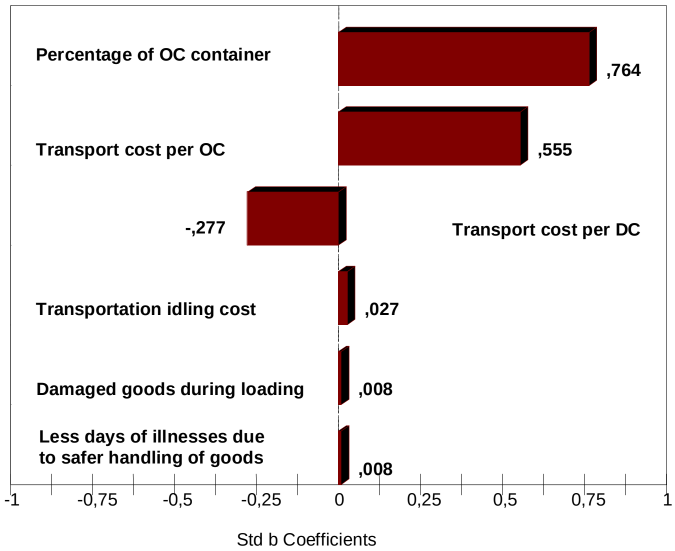

Figure 5: Regression coefficients in the automated loading solution.

The regression coefficients in Figure 5 represent the sensitivity of the input values on the final output. The closer the value is to one or minus one, the higher the connection between the variables. Clearly the benefits are most heavily dependent on the container type used. The ability to shift totally from open top containers to normal containers would drastically decrease the cost of transportation. Also, the cost of transportation for different types of containers will also impact the potential savings. If the transportation cost of open-top containers increases, the automated loading solution becomes more beneficiary, while the opposite is true for normal containers. Other variables have very little effect in this scenario.

When a manager considers implementing an automated loading solution, they should look careful into the amount of open-top containers which they are currently transporting. Managers cannot have an impact on the transport cost of different types of containers, but the higher the difference, the more can be achieved by using an automated loading solution.

Decision Support System for AS/RS

Like the automated loading spreadsheet model, the AS/RS model contains three sheets (similarly with previous one): (1) Instructions, (2) Information, and (3) Results. Again, the instruction sheet simply contains basic information about the spreadsheet program, while the information sheet is used to gather inputs for the model. The results sheet contains the actual output of the model.

The information is gathered under three categories: system data, operational costs and costs of ownership, and investment requirements. The system data contains basic information about the warehouse: size of the building, throughput rates and pallet sizes. Operational costs and costs of ownership contain basic operational costs like workers, wages, costs associated with forklifts, inventory costs, and facility costs. The last category is reserved for basic information about investments; cost of forklift trucks, facility investments, discount rate and other investments.

The spreadsheet contains many intermediate calculations, which use the system data to make an estimate of the potential automated system. The estimate includes actual physical information about the conveyors, lifts and amount of pallet positions. The system also estimates whether it is possible to have automated load forming where the automated loading system is integrated into the AS/RS. The average user does not need these values and they are not shown. The purpose of the simulation model is to provide an initial estimate for the cost of the system. However, the intermediate calculations have worked as a validation tool to see that the spreadsheet gives accurate results.

In the results sheet the final outputs are presented. In this sheet three different scenarios are presented. In the first one the financial results for a conventional system is presented. The second one contains the AS/RS while the third one also includes the automated load forming. The scenarios' results are divided to three categories: investments, operative costs, and additional benefits. The investments include the actual systems, possible facility and project management costs. The operative costs include everything which is needed to run the system (workers, forklifts, electricity, facility maintenance etc.). As an automated warehouse is able to save a lot of space and/or provide additional capacity for the warehouse, these needs to be taken into account in additional benefits. Also, as it was noticed in the literature review, there are many benefits available when an automated warehouse is used and it is difficult to convert the benefits into monetary values.

As the AS/RS spreadsheet contains a lot more variables, selected individual values are presented in Table 2, while the used distributions are presented in Table 3. Overall in the simulation model we are comparing a new automated facility to a new conventional facility. The physical warehouse is available, but the throughput is not known with certainty. Both the in- and outbound values are allowed to vary in the simulation model. The wages of the personnel are known, but the amount of personnel, as well as the amount of forklifts, is dependent on the simulated throughput. As price of electricity is expected to grow in the future, general facility costs are allowed to vary along with the price of electricity. Average price per pallet also contains uncertainty, as well as the amount of inventory costs in a traditional system. Annual cost savings are presented in Figure 6.

Table 2: Used values in the AS/RS decision support system.

Variable	Value
Length of warehouse, meters	120
Width of warehouse, meters	50
Heigth of warehouse, meters	9
Distance between docking platform and warehouse outbound, meters	16
Size of pallet	Euro Pallet,
Pallet overhang, %	10
Desired amount of pallets	10000
Shifts / day	2
Working hours / shift	7
Weeks / year	50
Amount of pallets handled by forklift	1
Forklift capacity, pallets per hour	40
Fork lift driver wage / € driver per month	4400
Supervisor wages, € / year	50 000
Fork lift truck investment costs, € / truck	25 000
Facility investment, €	8000000
Required rate of return, %	10

Table 3: Used statistical distributions in the AS/RS simulation.

Variable	Value
Inbound and Outbound maximum throughput	Normal, μ = 200, δ = 20
Inventory Costs, % total throughput	Triangular, min = 0%, mode = 0,05%, max = 0,25%
Average Price per pallet, € / pallet	Normal, μ = 1000, δ = 100
Facility general costs, € / m^2 per year	Triangular, min = 30, mode = 40, max = 60
Price of electricity, € / kW	Triangular, min = 0.08, mode = 0.1, max = 0.3
Other benefits, € / year	Normal, μ = 200000, δ = 20000

Like in the automated loading system, there are large differences in the yearly savings. The maximum value is nearly double compared to the minimum value and the values are in millions. The decision-makers should gather more information to make sound decisions. Conducting a sensitivity analysis on the independent variables will yield additional insights to the results (presented in Figure 7).

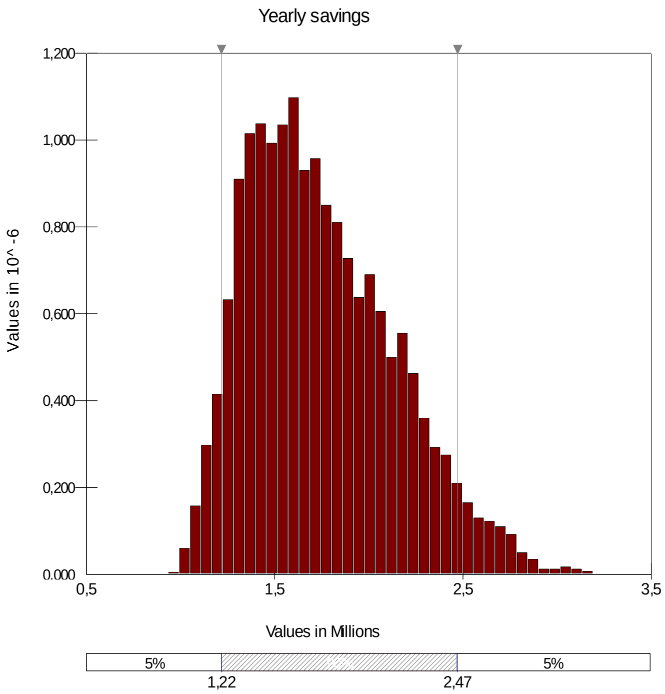

Figure 6: Annual savings of the AS/RS investment.

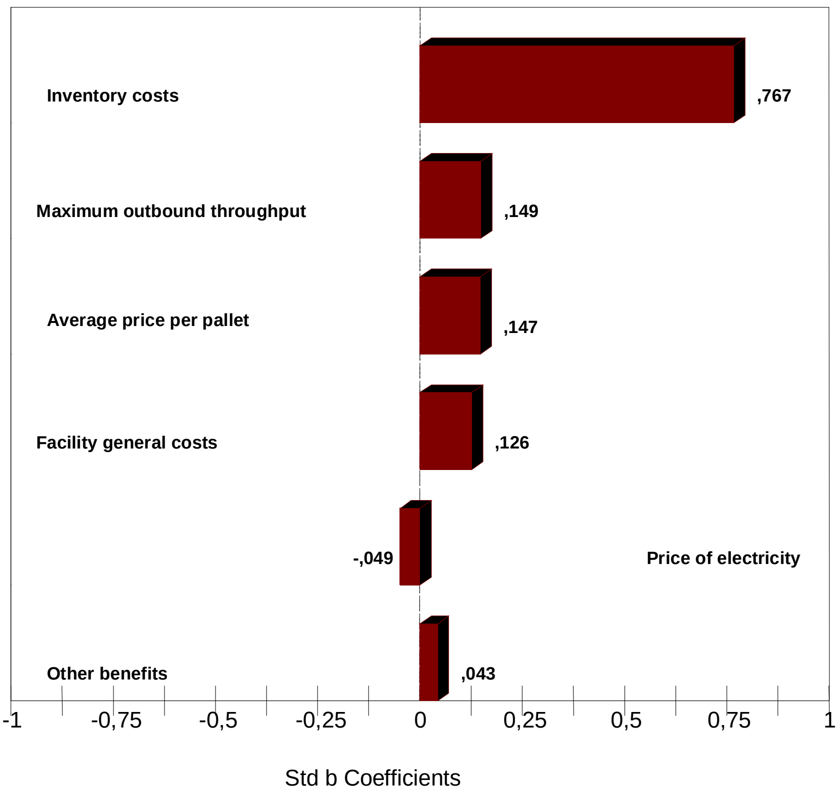

Figure 7: Regression coefficients in the AS/RS investment.

The sensitivity analysis shows, that the actual throughput values are not that critical for the cost savings compared to inventory costs. The price per pallet and inventory costs impact very heavily the results, as the AS/RS is able to keep the goods in good condition. Also, the costs associated to the facility and system impact the results but in different ways. If the price of electricity increases and facility costs increase due to this, the automated storage is a lot smaller than a conventional system, which minimizes these costs. On the other hand, the automated system requires electricity to function which will increase the system's costs.

The sensitivity analysis only studies

4. Discussion

The objective of our study was to improve decision-making for managers, when evaluating different warehousing designs. The constructed decision support system based on spreadsheets and Monte Carlo simulation offers additional insights to the AS/RS incorporating uncertainty into decision-making. In the two cases studied factors having the largest effect on the success of the investment could be identified. In case of automated loading system it was the container type used, while in the AS/RS case inventory cost was most crucial.

The automated loading system can be combined with other AS/RS as well, which makes the spreadsheet model a good marketing tool (as two cases are basically integrated together). Simulation of using Monte Carlo feature, gives a confidence interval for the financial benefits, which allows the potential customers to incorporate uncertainty in their decision-making. Also, the simulation model gives information on the sensitivity of the independent variables. The actual AS/RS model can be used in a similar fashion and simulation offers the exactly same benefits. This is unique part of our proposed construction – earlier simulation models have concerned the details of an AS/RS, and performance improvement, as they are already operational (e.g. Muppani and Adil, 2008a; Muppani and Adil, 2008b; Yu and de Koster, 2009; Ekren et al., 2010). Our proposed construct is developed in the phase earlier to this, when comparisons are being made to ordinary non-automated systems, and decision being made for operations of medium and long term. Based on Baker and Canessa (2009) research work, spreadsheet based decision support systems are very common on warehousing system design and equipment capacity management – giving further justification for our proposed system into the phase, where decisions are made from the overall configuration and level of automation in these.

According to the simulations, it is clear that an automated loading system can offer large financial benefits to companies, which need to load heavy and bulky cargo with cranes. Open top containers can be substituted with hard top containers and this allows to cut the transportation costs. The transportation costs had clearly the highest impact in the simulation model and the other variables impact was relatively small. It should be noted that other variables will become more important in different scenarios.

We also see that the area of automation in warehouses, and in material handling in particular, is likely to grow in the future as higher productivity, and increasingly more centralized warehouses and manufacturing units demand 24/7 operations. Service industry in general holds great importance in advanced economies (e.g. in USA warehousing was highest grown employment sector of transports in years 1998-2005; more see Bowen, 2008), and is in the spotlight to be more efficient. Currently outsourcing of different logistics functions is popular, but after outsourcing wave we expect automation investments to gain more ground as margins tighten and further efficiency improvements are needed.

5. Conclusions

Warehousing plays an important role in the efficiency of today's international supply chains, and they have grown in numbers (e.g. employment, number of units) in advanced economies considerably (Ducruet and Lee, 2007; Bowen, 2008). Optimal configuration of warehouse activities depends on several design criteria (Gu et al. 2010). The conceptual model presented in Figure 1 was seen to represent the most important variables according to the AS/RS supplier. The variables were used as input values or within the decision support systems. The research question, *"What are financially the key variables to be considered in the early phase of an AS/RS investment project?"* was analyzed with these systems. Previous studies have not discussed about the financial implications of investments or identified the most important categories. Reduced amount of personnel and smaller inventory costs due to less mishandling of goods were the most important categories. Amount of personnel is usually well known but total scrap and spoilage costs might not be even though they have a high impact on the final results. Facility total maintenance costs will also decrease despite of having a large machinery to be maintained. Space utilization was greatly improved with the help of the AS/RS. A lot more pallet positions can be included in the same amount of space. These findings are in line with previous studies (Roodbergen and Vis 2009) but the relative importance was analyzed in this study. Also, this study was done in close cooperation with an AS/RS supplier which provides more practical relevance to the academia which has been previously lacking (Gu et al. 2010). Automated loading solutions were also studied in this paper. They can be combined with an AS/RS to minimize mishandling of cargo and decrease costs related to personnel.

This research points out two managerial implications. Firstly, warehouse managers with a high amount of scrap due to mishandling should consider shifting to an AS/RS. It clearly has the highest impact in the provided AS/RS. Using these types of decision support systems managers can test various AS/RS configurations without heavy investments in time. This allows managers to concentrate more on their actual work, managing the warehouse. Secondly, companies handling heavy and bulky cargo should look into automated loading solutions. The automated loading solution can load the goods into hard top containers with safer operations. This decreases the likelihood of accidents and cut the transportation costs. The efficiency improvements are also available at the receiving end as well. It is possible to pull out the cargo from the container in a fast and safe way.

This research is limited by analyzing only one type of AS/RS. Each AS/RS supplier has their own types of warehouses with different configurations. Similar studies should be conducted on different types of warehouses to see whether the largest financial benefits come from the lowered amount of scrap due to mishandling. Also, two scenarios were used as the default scenarios within the models. Different variables might become more important in different scenarios. For instance, with the automated loading solution, the turnaround time and smaller amount of scrap become important with lighter goods.

This research provides many avenues for further research. The model could also be expanded to include other design parameters. These could include the size of buffer locations, storage assignment methods, batching rules, sequencing and dwell-points (Roodbergen and Vis, 2009). Similar approach should be used with other AS/RS suppliers as well to find out whether the scrap is the most important category. The area of intangibles requires still more research. It is possible to claim many different advantages but they are difficult to quantify in monetary terms. Also, currently the model uses an external program (@Risk) to create the Monte Carlo analysis. By developing a standalone application, it would be possible to use the software on any computer with spreadsheet software.

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Publication V

Lättilä, L., Hilletofth, P. and Lin, B. (2011)

Hybrid simulation models: When, Why, How?

Expert Systems with Applications, 37(12), pp. 7469 - 7975.

Expert Systems with Applications 37 (2010) 7969–7975

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Hybrid simulation models – When, Why, How?

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ARTICLE INFO

Keywords:
System Dynamics
Agent-Based Modeling and Simulation
Hybrid simulation models
Artificial intelligence
Expert Systems

ABSTRACT

Agent-Based Modeling and Simulation (ABMS) and System Dynamics (SD) are two popular simulation paradigms. Despite their common goal, these simulation methods are rarely combined and there has been a very low amount of joint research in these fields. However, it seems to be advantageous to combine them to create more accurate hybrid models. In this research, the possible ways to combine these methods are studied. The authors have found five different situations where it will be useful to combine these methods. All of them have already been used in earlier studies, so modelers should use them as possible interfaces to combine the methodologies. By using hybrid simulation models it is possible to create more accurate and reliable Expert Systems (ES).

1. Introduction

Agent-Based Modeling and Simulations (ABMS) and System Dynamics (SD) are among the most important simulation methods available. In ABMS, the complexity of the system emerges from the interactions between different agents (Phelan, 1999) whereas in SD the complex multi-loop feedbacks create the complexity (Sterman, 2000). However, both of these methods are used to study the leverage points of complex systems (Phelan, 1999). Despite their common goal, there has been little discussion between these two schools (Borshchev & Filippov, 2004; Phelan, 1999; Scholl, 2001a). However, some studies have started to appear in international scientific journals (Hines & House, 2001; Rahmandad & Sterman, 2008), which would indicate that there is an increasing interest in the integration of these methods. In supply chain management, many hybrid simulation models have been presented (Akkermans, 2001; Kim & Juhn, 1997; Schieritz & Grössler, 2003; Sevkli, Koh, Zaim, Demirbag, & Tatoglu, 2008). Some (Scholl & Phelan, 2004) have even proposed designs which can be used to create new knowledge by combining these two simulation methods. In a recent study, Osgood (2007) stress that currently good toolsets exists, which can be used to create these hybrid models: this would indicate that integration is possible using only one toolset.

The purpose of this paper is to find out what the current state of discussion about integrated simulation models is, and the research questions are as follows: (i) When is it appropriate to use hybrid simulation models? (ii) Why is it appropriate to use hybrid simulation models? and (iii) How can hybrid simulation models be developed? The primary research strategy is a literature review focusing on finding out the possible interfaces where the combination of these two methodologies is possible. The literature has been gathered from several databases (EBSCO-Host, Emerald, Elsevier, ABI-Inform, Springer-link, ACM Portal), and the time-frame for this review spans from 1997 to 2008. This study will briefly comment on the comparison of different simulation models (which simulate the same system with different methods) while the main focus is on the hybrid simulation models.

The remainder of this paper is structured as follows: Section 2 gives a short overview about ABMS and SD. This section does not give any actual information about how to model with these methods but it gives information about their general properties and use in Expert Systems (ES). Section 3 is a literature review about the possible combinations (or comparisons) of these two methods and presents how the current hybrid simulation models have been build. This section also shows the main differences between these two methodologies and the most beneficial situations to combine the simulation approaches. Section 4 represents the effect of hybrid simulation models from an ES perspective whereas the final Section 5 includes the discussion about the literature review findings and concludes the paper among consideration of further research.

2. Agent-based modeling and System Dynamics

AMBS is a relatively new method suited for complex and dynamic systems distributed in time and space (Jennings, Sycara, & Wooldridge, 1998; Lim & Zhang, 2003). It is expected to have comprehensive effects on the way that businesses use computers to

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doi:10.1016/j.eswa.2010.04.039

support decision-making, e.g. it provides a pragmatic approach for the evaluation of management alternatives (Swaminathan, Smith, & Sadeh, 1998). Moreover, it is considered important for developing industrial applications in complex environments (Davidsson & Wernstedt, 2002; Fox, Barbuceanu, & Teigen, 2000; Karageorgos, Mehandjiev, Weichhart, & Hammerle, 2003). The complexity of the system emerges from the interaction between different agents, not from the structure of the whole system (Scholl, 2001a).

There is a growing interest in using ABMS in several business-related areas, such as manufacturing, maintenance and supply chain management (Hilletofth, 2009; Hilletofth, Aslam, & Hilmola, 2010). A couple of reasons for the increased utilization have been discussed in the literature (Macal & North, 2006): (i) the observed systems are becoming more complex in terms of their interdependencies, which implies that traditional approaches no longer are as applicable as they once were; (ii) some systems have been too complex to model earlier, but are now possible to model through agent principles; (iii) data are becoming organized into databases at finer levels of granularity supporting micro simulations; and (iv) computational power is advancing rapidly. However, it is important to note that the field is still in its infancy and most of the work done is on a conceptual level (Hilletofth et al., 2010).

ABMS means that the real system of interest is modeled as a set of interacting agents in a defined environment (i.e. as an agent system) and implemented in simulation software. An agent system consists of a couple of individual agents with specified relationships to one another within a certain environment. The agents are presumed to be acting in what they perceive as their own interests, such as economic benefit (i.e. they have individual missions), and their knowledge regarding the entire system (i.e. other agents and environment) is limited (Macal & North, 2006). Still, the most important feature in an agent system is the agents' ability to collaborate, coordinate, and interact with each other as well as with the environment to achieve common goals. By sharing information, knowledge, and tasks among the agents in the system, collective intelligence may emerge that cannot be derived from the internal mechanism of an individual agent. Furthermore, the ability to coordinate makes it possible for agents to coordinate their actions among themselves, i.e. taking the effect of another agent's actions into account when making a decision about what to do.

The topic of the most important characteristics of an agent has been addressed in the literature; still there is no agreement on the definition of an agent. First, the topic has been addressed from a computer science perspective where four general characteristics have been discussed (Wooldridge & Jennings, 1995):

1. **Autonomy** implies that agents are autonomous in the sense that they operate by themselves without any direct human intervention and they have some kind of control over their internal state and behavior in an environment.
2. **Social ability** implies that agents have the capability of interacting with other agents and with its environment.
3. **Reactivity** implies that agents have the capability to perceive their environment and in respond react for the changes of the environment.
4. **Pro-activeness** implies that agents are capable of pursuing their own goals by controlling their future in a proactive manner.

The topic has also been addressed from a more practical modeling approach where five characteristics have been discussed (Macal & North, 2006):

1. **Identifiable and self-contained** implies that agents are discrete individuals with a set of characteristics and rules governing their behaviors and decision-making capability. The discreteness requirement implies that an agent has a boundary and one can easily determine whether something is part of an agent, is not part of an agent, or is a shared characteristic.
2. **Situated** implies that agents live in an environment with which they interact along with other agents. Agents have protocols for interaction with other agents, such as for communication, and the capability to respond to the environment. Agents have the ability to recognize and distinguish the traits of other agents.
3. **Goal-directed** implies that agents have goals to achieve with respect to their behaviors. This allows an agent to compare the outcome of its behavior relative to its goals.
4. **Autonomous and self-directed** implies that agents can function independently in its environment and in its dealings with other agents, at least over a limited range of situations that are of interest.
5. **Flexibility** implies that agents have the ability to learn and adapt its behaviors based on experience. This requires some form of memory. An agent may have rules that modify its rules of behavior.

An example of other highlighted characteristics is "local view" which implies that no agent has a full global view of the system, or the system is too complex for an agent to make practical use of such knowledge, and "decentralization" which implies that there is no one controlling agent, otherwise a monolithic system (Borshchev & Filippov, 2004). These are only some of the characteristics which have been proposed for agent-based systems and there are many others. As agents can be used in a wide area of applications, it is difficult to create one "right" set of classification (Tweedale et al., 2007).

Nilsson and Darley (2006) conclude in their empirical study that decision-makers aided by ABMS can benefit in several ways. First, they acquire an increased understanding of the impact of unscheduled factors such as breakdowns, accidents, and changes of demands. Such factors are often found in reality, but usually reduced or even ignored, when transferred to most traditional models. This implies that the optimized solutions from these traditional models mislead decision-makers into believing in future scenarios, which do not reflect reality. Secondly, ABMS can guide decision-makers' instinct, since interactive agents generate an emergent pattern, which can be explained and understood; bringing benefits for the improvement of decision-making in companies. Thirdly, ABMS can help decision-makers to find where the highest leverage is to be gained among improvement alternatives. This is based on the fact that ABMS allows models to encompass several business functions and how they affect each other. Finally, there are sometimes even opportunities to improve predictability based on the scenarios generated. These advantages are also valid in ES; using ABMS it is possible to create more realistic logic in the ES and it might be possible to combine the emergent behavior in the explanation logic. Also, the ES should be able to make better decisions as it can easily capture knowledge from many different sources and give recommendations which take into account the whole of the organization. ABMS has been widely used in ES. Application areas include electronic commerce (Chen et al., 2008; Lee, 2004), supply chain management (Kwon, Im, & Lee, 2007), banking (Yoon, Broome, Singh, & Guimaraes, 2005), and steel production (Zarandi & Ahmadpour, 2009). For further information regarding this modeling and simulation approach, the authors suggest the works of Borshchev and Filippov (2004) and Macal and North (2006).

SD is a more established method, originally introduced by Jay Forrester in the late 1950s (Forrester, 1958), and concentrates on dynamic complexity. It has been used in a wide area of fields; the original work by Forrester was interested in the demand amplification effect (also known as the bullwhip or Forrester effect) in

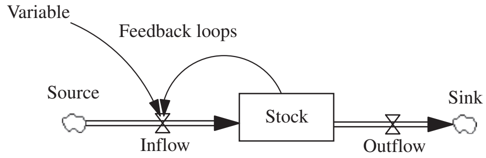

Fig. 1. A simple system dynamic model. Adapted from Sterman (2000).

supply chains (Forrester, 1958), but later Forrester expanded his methodology to urban and world development (Forrester, 1991). During the last five decades SD also has been applied to other areas, such as economics, ecology, innovation diffusions, work force management, software development, competition, markets. This list is by no mean exclusive; it merely shows how it can be applied in many different fields. However, there has not been that much of use of SD in ES; only a few applications have been published. Yim, Kim, Kim, and Kwahk (2004) studied sales and marketing with a knowledge-based system. Kljajic, Bernik, and Skraba (2000) created a simulation model which studied the financial implications of different scenarios and it was connected to an ES. On the other hand, Ghazanfari, Alizadeh, and Mostafa (2002) used an ES to solve SD models.

SD means that the real system of interest is modeled using seven basic elements: (i) source; (ii) inflow/outflow; (iii) stock; (iv) sink; (v) variables; and (vi) feedback-loops (Fig. 1). By combining these elements it is possible to simulate more complex elements such as delays. Elements have their own kind of mathematical formulas underneath them, and the purpose of the simulations is to find out how the whole system reaches equilibrium. It is different from detailed complexity, where the complexity arises from the wide array of possibilities, while in dynamic complexity the non-linear and multi-loop feedbacks create the complexity. Thus, the structure of the system drives the complexity (Maani & Maharaj, 2004; Sterman, 2000). Stock and flows are among the most important things in a SD model (Sterman, 2000). The stocks are simply integral equations and work as accumulations in the simulation model. These accumulations drive the model towards the equilibrium as they stabilize the whole system. However, the accumulations tend to homogenize everything and the modeler needs to have an aggregated view about the system (Forrester, 1961). For further information regarding this simulation approach, the authors suggest the work of Sterman (2000). The fundamentals of SD are widely accepted in the community and there are almost no disagreements about the concepts (Schieritz & Milling, 2003).

3. Hybrid simulation models

Both of the above-presented simulation methods are used to study the leverage points of complex systems. In ABMS the complexity of the system emerges from the interactions between different agents (Phelan, 1999) while in SD the complex multi-loop feedbacks create the complexity (Sterman, 2000). Despite their common goal, there has been little discussion between these two schools (Borshchev & Filippov, 2004). However, some studies have started to appear in the academic literature.

The first publications proposing a combination between ABMS and SD appeared in the late 1990s (Kim & Juhn, 1997; Parunak, Savit, & Riolo, 1998; Phelan, 1999). At the beginning of the next decade, two other publications appeared (Akkermans, 2001; Pourdehnad, Maani, & Sedehi, 2002) and all of these five publications have played an important part in the development of this field. Sterman and Wittenberg (1999) and Hines and House (2001) both created hybrid simulation models but they did not participate in the discussion about the use of hybrid models. Fig. 2 illustrates the citation tree of the most important works. The names of the publications can be found in Table 1. Some publications have been combined together as their citations do not differ that much between the publications.

Kim and Juhn (1997) presented a hybrid model which was constructed with the principles of SD by using array variables to represent the individual agents. Parunak et al. (1998) demonstrated how to simulate a supply chain separately using ABMS and a SD model. Phelan (1999, 2001), on the other hand, did not have a simulation model but he compared the different schools of thought (Complexity Sciences and Systems Theory). According to Phelan (1999) three differences between the methodologies exist: agenda, techniques, and epistemology (Table 2). Phelan (1999) argued that the agenda in complexity sciences (ABMS) will move more from exploratory to confirmatory studies and there are no real reasons to rule out the other simulation method when studying a system. Phelan (1999) continues by claiming that the complexity school seems to be changing towards a more constructivist stance. In con-

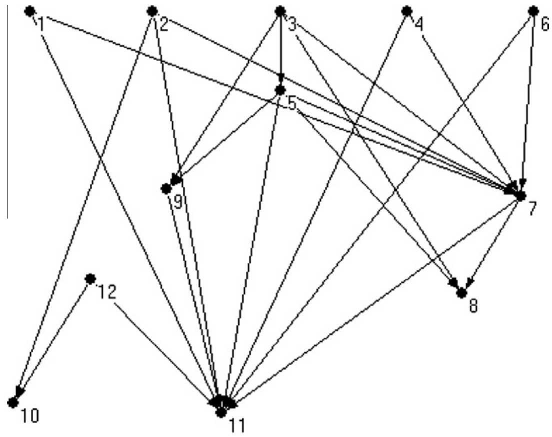

Fig. 2. Citation tree of the most important publications.

Table 1
Authors for the citation tree.

Citation	Reference
1	Kim and Juhn (1997)
2	Parunak et al. (1998)
3	Phelan (1999, 2001)
4	Akkermans (2001)
5	Scholl (2001a, b)
6	Pourdehnad et al. (2002)
7	Schieritz and Grössler (2003), Schieritz and Milling (2003), Grössler et al. (2003)
8	Scholl and Phelan (2004)
9	Wakeland et al. (2004)
10	Osgood (2007)
11	Martinez-Moyano et al. (2007)
12	Rahmandad and Sterman (2004)

Table 2
The differences between complexity sciences (ABMS) and systems theory (SD). Adapted from Phelan (2001).

Parameter	System Dynamics	Agent-based modeling
Agenda	Confirmatory	Exploratory
Techniques	Circular flows	Agent-based models
Epistemology	Post-positivist	Positivist

clusion, Phelan (1999) seems to argue that these two schools of thoughts will get closer together. However, according to Scholl (2001a) these schools are already relatively close to each other but he concurs with the notion that there should be a more thorough cross-study between these methodologies.

In addition to simulation models, both Kim and Juhn (1997) and Parunak et al. (1998) compared the main features of these simulation methods together. This work has been advanced by other authors also. Pourdehnad et al. (2002) compared the methods from a pedagogical point of view and found six different categories between the methods. Scholl (2001a) also studied the differences between the schools, and he (Scholl 2001b) later compared the differences between actual simulation models which studied the same behavior with different methods. There are also many other who have discussed the differences between the methodologies, and most of the differences are summarized in Table 3.

There were some disagreements between some of the features. Kim and Juhn (1997) argued that SD had integrated environments while ABMS works mostly on low-level languages. Parunak et al. (1998) support this claim. However, since year 1997 there has been an increase in the supply of simulation tools. Osgood (2007) studied current toolsets for SD and compared the traditional toolsets with ABMS toolsets. Osgood (2007) stresses that some toolsets, especially AnyLogic™, work very well with both methodologies. Anylogic™ is a multi-paradigm simulation tool which is able to use object-oriented language to simulate both SD and ABMS models (Borshchev & Filippov, 2004). Thus, the differences between the modeling tools, at least in some toolsets, have diminished and there exists integrated environments for ABMS also.

Pourdehnad et al. (2002) argues that the main modeling focus for ABMS is in human/social processes. Kim and Juhn (1997) also comment on the modeling focuses and claim that the main application area for ABMS is in cyber space (artificial world) while SD concentrates on human space (natural world). This might have been the case in the early years of ABMS but as Scholl (2001b) points out, there are many similar research subjects in both fields of study. Supply chain management was the first subject in SD (Forrester, 1958) but ABMS has also started to study the complex behavior of supply chains (Akkermans, 2001; Schieritz & Grössler, 2003; Scholl, 2001b).

Overall it can be said that the differences between these two simulation methods have been clearly defined. Even though the methodologies differ by many aspects, they still have a common goal: the purpose of both methodologies is to find the leverage points of a system (Phelan, 1999). As both of the schools have their own separate history, there has been practically almost no discussion between the communities (Borshchev & Filippov, 2004; Phelan, 1999; Scholl, 2001a). Parunak et al. (1998) pointed out that there are two possible ways to combine ABMS and SD models: Either an agent can be part of a larger system dynamic model or an agent can be modeled using the equations of System Dynamics. Scholl and Phelan (2004) have even proposed a design which can be used to combine these methodologies. It is not mandatory to combine these methods to conduct cross-study as even studying the same problem with different methods can give fruitful insights (Scholl, 2001a). Scholl (2001a) also points out to Miller's active nonlinear tests (ANTs) (Miller, 1998), which are a special combination of ABMS and SD. Here, a SD model is being studied with the help of agents in order to find out the most sensitive variables in the model.

Some areas have already been studied separately in both methodologies, and they have indicated interesting results. Scholl (2001b) presented a literature review about the bullwhip effect and showed which explanations differed between the different modeling methods and which were similar. Rahmandad and Sterman (2008) also present a literature review about differential equation (SD) models and ABMS concentrating mainly on "networking" issues (AIDS spreading through needle sharing, innovation diffusion, etc.). In addition to diffusion and supply chain management, ABMS and SD models have been compared in areas such as biology (Wakeland, Macovsky, Gallaher, & Aktipis, 2004) and ecology (Norling, 2006).

There have been a relatively small number of hybrid simulation models. Schieritz and Grössler (2003) created a model where indi-

Table 3
The differences between System Dynamics and agent-based modeling.

Component	System Dynamics	Agent-Based Modeling and Simulation	Author
Level of analysis	Aggregates/quantities (homogeneity)	Individual agents (heterogeneity)	Kim and Juhn (1997) Parunak et al. (1998) Martinez-Moyano et al. (2007)
Unit of analysis	Structure of the system	Rules of agents	Pourdehnad et al. (2002) Parunak et al. (1998)
Crucial mechanism	Feedbacks between different parts of the system	Emergent behavior due to interaction	Kim and Juhn (1997) Phelan (1999) Pourdehnad et al. (2002) Parunak et al. (1998) Martinez-Moyano et al. (2007)
Building blocks	Equations, feedback-loops, stock and flow diagrams	Individual agents and their decisions (logic)	Parunak et al. (1998) Pourdehnad et al. (2002) Phelan (2001) Martinez-Moyano et al. (2007)
System structure	Fixed	Flexible	Kim and Juhn (1997) Schieritz and Grössler (2003) Pourdehnad et al. (2002)
Application	Problem-solving	Exploring	Pourdehnad et al. (2002) Phelan(1999)
Origin of dynamics	Levels	Events	Schieritz and Milling (2003) Parunak et al. (1998)
Handling of time	Continuous	Discrete or continuous	Borshchev and Filippov (2004) Osgood (2007)

vidual companies were modeled using SD but they communicated using a separate program. Kim and Juhn (1997) created a SD model with the help of arrays. Akkermans (2001) also used SD to model the logic of individual agents but he does not specify how the agents interact with each other. A similar approach was used by Sterman and Wittenberg (1999) as well. BenDor, Scheffran, and Hannon (2009) also created a simulation model using only SD with many agents and studied fishery management. However, the model only contained four agents so it should be questioned whether it can be easily scaled. Martinez-Moyano, Sallach, Bragen, & Thimmapuram (2007) created a simulation model with separate SD and ABMS modules for financing and used a middleware to connect these separate models together. Using these as examples it is clear that with the current toolsets it is possible to create complex hybrid models. However, it is important to know the limitations of both methods in order to know when and why to combine these methodologies. Table 3 gives a good starting point for potential interfaces.

According to Rahmandad and Sterman (2008) the results for agent-based and differential equation models differ when compartments contain small populations. In their work they study the SEIR model (a well-known model used to study how diseases spread) in different network environments and as expected, the network typology and individual heterogeneity impact the results. If there are big differences between the members in different groups, it might be useful to use an agent-based method. However, Rahmandad and Sterman (2008) continue by stating that access to data might make the use of ABMS impossible. Similar claims have been made by Borshchev and Filippov (2004), but in their opinion ABMS is easier to construct as one only needs to understand the behavior of individual agents, not the feedback structures of the whole system. As different data might be available from different parts of the system, it would be possible to use the appropriate method depending on the data available.

As the structure of the system tends to be fixed in SD, it is impossible to use it to study systems which tend to evolve through time. Supply networks are a good example as the supply chain evolves as companies create new partnerships. This requires an agent-based approach and it has been done many times earlier (Akkermans, 2001; Schieritz & Grössler, 2003; Surana, Kumara, Greaves, & Raghavan, 2005).

As SD models are continuous by nature, SD models have difficulties in coping with discrete events. As an example, a SD model might not be able to model a conveyor belt in a manufacturing unit (Parunak et al., 1998) or mimic certain type of actions (Schieritz & Grössler, 2003). These tasks can be simulated easily using the principles of ABMS. Also, sometimes it is useful to have equations in individual agents to control their policies so SD principles are helpful in these situations (Parunak et al., 1998).

The use of ABMS comes at a price, as the simulation model usually contains stochastic elements and each individual agent requires own computations, the time to run the simulation increases considerably. Sensitivity analyses are much more difficult to conduct as they require a huge amount of time (Rahmandad & Sterman, 2008). There is a big risk of modeling just for the sake of modeling (Osgood, 2007; Rahmandad & Sterman, 2008) and having two sets of tools increases this risk for a novice modeler. Thus, proper training is required in both of the methodologies.

Overall, there are some very clear differences between the simulation methodologies of ABMS and SD. Both methodologies have their own strengths and weaknesses and they can be used to complement each other (Scholl, 2001a). According to the literature there seems to be some specific situations where either one of the modeling methods has difficulties coping with. Using hybrid simulation models it is possible to avoid these pitfalls and create more realistic simulation models. These situations are summarized in Table 4.

Table 4
The problematic situations in both of the simulation methods.

Situation	Modeling method preferred
Actors not homogenous	Agent-based modeling
Data not available	Agent-based modeling or System Dynamics
Flexible structure	Agent-based modeling
Complex events present	Agent-based modeling
Following a policy	System Dynamics

It seems that SD has difficulties in many situations and ABMS might help to cope with these problems. The authors are not implying that SD is a poorer simulation method than ABMS. Most likely the field of SD is more mature than ABMS, which is still in its infancy (Hilletofth et al., 2010). As the knowledge about ABMS accumulates, the possible pitfalls will emerge.

Two of the problematic situations concern the basic assumptions behind SD. Working mainly on aggregate variables makes the use of System Dynamics difficult in heterogeneous environments. Also, the structure is relatively rigid in SD models compared to ABMS. Data availability does not concern either one of the simulation methods in itself but it depends on the phenomena to be simulated. The last two depend more on the actual simulation languages. It might be possible to simulate complex discrete events with SD but it might be easier to approach them with ABMS, or it is possible to simulate a policy using ABMS but SD works particularly well with policies so it should be used then. These methods have already been used in the hybrid simulation models so they have been proven to work in practice. The problematic situations can be avoided by integrating these two methods together. Table 4 also answers the first two research hypotheses: (i) "When is it appropriate to use hybrid simulation models?" and (ii) "Why is it appropriate to use hybrid simulation models?" The hybrid simulation models are needed in the problematic situations in order to be able to create more realistic models.

There are many possible ways to create hybrid simulation models. It would be possible to only use a low-level programming language to create the whole simulation model. However, this requires relative heavy investments in time and skills as there would not be any specialized program in automating the work. Many current models were constructed by only using a SD program (e.g. Akkermans, 2001; BenDor et al., 2009). This usually requires the use of arrays to be able to cope with added complexity. Some models (such as Martinez-Moyano et al., 2007 and Schieritz & Grössler, 2003) used another programs in conjunction with a SD program. This can be done by either using some middleware or creating a separate code using a low-level programming language. Currently, there also exists commercial software, which is able to do both SD and ABMS. Osgood (2007) recognized Anylogic™ as one particularly well-suited program. One final way to construct the hybrid simulation models is to create an own platform for the work. However, this is similar to the use of a low-level programming language as the whole software needs to be programmed first. These are summarized in Table 5.

For the last research hypotheses: (iii) "How can hybrid simulation models be developed?" there is not a one clear answer as there are many possibilities to create the hybrid models. Each method has its own advantages and disadvantages. The choice of the methods also depends on the skills of the individuals constructing the simulation model. An expert SD modeler might be able to construct good hybrid models with using arrays while an expert programmer might prefer to use a low-level programming language.

Table 5
Different methods to create hybrid simulation models.

Method	Advantages	Disadvantages
Low-level programming language	Totally flexible	Time-consuming Requires good expertise in programming
System Dynamics program	Relatively easy to use	Structure of the model usually fixed
	Includes all the necessary pieces for a SD model	Might not be able to incorporate complex events
System Dynamics program with middleware	Includes all the necessary pieces for a SD model	Might require some own programming
	Flexibility regarding agent model	Synchronization might be an issue
Hybrid simulation model toolset	Includes the basic elements of both SD and ABM Easy to integrate	Few exists
Construct simulation software	Flexible	Time-consuming Requires good expertise in programming

4. Research implications for Expert Systems

ABMS and SD have been used in conjunction with ES. As both the simulation methods have their own weaknesses, the available intelligence for ES has been limited. As the overall amount of hybrid simulation models is still a very small one, it would be reasonable to assume that currently there exist very few (if any) ES with true hybrid simulation models. However, the potential benefits of using hybrid simulation models in ES are clear.

As the amount of ES with SD models is scarce, it is assumed that the hybrid simulation models will be heavily based on ABMS. If the experts are not able to express their opinions regarding individual agents but are more aware of the "global" consequences, then SD might help the expert to create a more advanced ES. Also, it might be extremely difficult to translate a mental model to simple logic as there are many different factors impacting the actual decisions. SD might be helpful in these situations as it is especially well suited in studying how policies develop. Data availability will also impact the chosen modeling method.

In SD-based Expert Systems it is possible to include additional diversity in the potential actors. The ES can gather information from databases and assign proper elements to different actors, or the expert building the system can assign more diverse elements in the system. Also, the ES does not have to function using a fixed structure as a hybrid simulation model can have a flexible structure. As SD models are not capable of simulating complex events, the ES can incorporate them as well in the decision-making. One especially well suited approach for ES is the use of agents in parameterization. As Miller (1998) has shown, it is possible to enhance the validity of SD models by finding out the most sensitive variables in the model using agents. The ES could ask the user for more information regarding the most sensitive parts or the systems validity could be enhanced during the construction process.

The research questions are equally valid with ES as well. Only the last research question "How can hybrid simulation models be developed?" requires some expansion. As the goal of the whole construction process is to build an ES, not to build a simulation model, the choice of simulation method should represent this. If a hybrid model is build by using a SD program, it still needs to be integrated to another system. This needs some sort of middleware so the same middleware could easily connect the SD model with an ABMS model. Using a low-level programming language gives the highest flexibility as it is totally customizable but it requires a lot of programming skills and time. Again the choice depends partially on the skills of the ES constructor as well.

5. Conclusions

SD and ABMS both have their own schools of thought and there has not been a wide spread discussion between them. In this paper the relevant literature concerning the cross-study of these methods was studied, and there is a relatively large agreement about the differences between these two methodologies. Nevertheless, both methodologies have the same objective (find the leverage points of a system) and opportunities for cross-studies between the methodologies exist.

There are two different ways how to combine these methods. At one end of the continuum, an ABSM is constructed using SD methodology in individual agents while at the other end ABMS principles are used as part of a larger SD model. It is also possible to construct models with both methodologies on one problem and compare the results with each other. Different modeling methods might give different reasons for the complex behavior. In addition to these, it is possible to use ABMS to conduct sensitivity analyses in SD models. These methods will improve the quality of the ES and give better results for the users.

The differences between the methodologies allow studying the potential interfaces where these two methodologies can be combined. In this paper five situations were recognized as possible points for the use of hybrid simulation models. Using both the methods will improve the quality of the model and give more insights. Some studies have already been done using these interfaces but there is no reason why the amount of these combinations would not increase in the future. The only clear hindrances with combining these methods are the increase in computational time and the risk of simulating without a reason. This risk can be minimized by offering adequate training for the modeler or ES constructors.

There is a clear need for further research regarding the actual simulation models. More simulation models need to be done where these two methodologies have been combined. This kind of research should not only include some general information about the model and its results; there is also a need to know the pitfalls during the simulation processes. This information is valuable to modelers and it would improve the quality of integrated models. The proposed five interfaces should also be tested in practical simulation work to see whether they help to create hybrid models. As there is still a small amount of hybrid models, it is expected to see the amount of actual simulation models first to increase before the amount ES with hybrid models increases. However, the advantages of hybrid simulation models are clear and they will increase the value of the ES. Hybrid ES should be tested against conventional ES to see whether the use of hybrid simulation model improves the accuracy of the ES.

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Publication VI

Lättilä, L. and Saranen, J. (2011)

Multimodal transportation risk in the Gulf of Finland region

World Review of Intermodal Transportation Research, 3(4), pp.376 – 394

Multimodal transportation risk in Gulf of Finland Region

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Abstract: Globalisation has resulted in larger volumes of foreign trade, especially in maritime transportation. No studies exist on how the maritime volumes could be handled, if the operational environment changes unexpectedly. The objective of this paper is to identify possible risks in transportation routes that use seaports in the Gulf of Finland and to evaluate the functionality of the transportation system under selected risk scenarios. Four system dynamics simulation experiments reveal that the impact of a spillage depends on concentration of resources and cargo types carried and highlight the importance of international cooperation.

Keywords: supply chain management; intermodal transportation; seaports; efficiency; containerisation; system dynamics; simulation.

Reference to this paper should be made as follows: Lättilä, L. and Saranen, J. (2011) 'Multimodal transportation risk in Gulf of Finland Region', *World Review of Intermodal Transportation Research*, Vol. 3, No. 4, pp.376–394.

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1 Introduction

Globalisation has resulted in large volumes of foreign trade, especially in maritime transportation. For example, trade using containers has increased to 142.9 million TEU per year (Drewry Shipping Consultants, 2009). Sea is the main mode of transportation also in the Gulf of Finland region, e.g., from the Finnish foreign trade flows; in 2009, more than 77% of imported cargo (in tonnes) and 88% of exported cargo travelled through seaports (National Board of Customs, 2010). The economic well being of a small country is typically dependent on international trade. For instance, in Finland, the amount of exports and imports are 45.5% and 40.8%, respectively, from Gross Domestic Product (Statistics Finland, 2010). Although the economic crisis at the end of 2008 has decreased international trade dramatically in medium term, the growth is expected to continue in 2010, as the world becomes even more connected through globalisation (United Nations, 2009).

While oceanic maritime transportation infrastructure promotes large-scale units in containers and port infrastructure (currently, MSC Daniela has the largest container carrying capacity with 13,800 TEU), justly limits of narrow and low water boat routes, the ports of the Baltic region are served by smaller feeder containerships (200–1000 TEU) and ro-ro ropax ships from the big European oceanic ports. The harbours on both sides of the Gulf of Finland are well connected; in addition to other European ports, each of the Estonian harbours is connected directly at least to two Finnish ports (Fossey, 2009). Along with own import and export, the ports of Gulf of Finland handle a great deal of Russian transit. In transit, Finnish ports have mainly concentrated on container and consumer commodities import to Russia, whereas Estonian ports carry a great share of the oil export from Russia (Hilmola et al., 2007; Terk et al., 2007). The Finnish route constituted about one-third of transit value of Russian import in 2008 (Märkälä and Jumpponen, 2009). Russia has also own ports on the shores of the Baltic sea, in the St. Petersburg region and Kaliningrad. In Russia, e.g., in Ust-Luga, additional port facilities are under construction, which will probably have a major structural impact on transit routes in the Baltic Sea Region. In 2004, the Russian Government announced its transportation strategy, according to which Russia aims at gaining self sufficiency in logistics by building up its own seaports and other logistics infrastructure (World Bank, 2011).

Although sea is the main mode of transportation in the region, there is no study on how the maritime volumes could be handled, if the operational environment changes unexpectedly. Our specific research questions are

- What kind of risks are related to transportation routes that use seaports in the Gulf of Finland
- If realised, how do selected risks affect the functionality of the transportation system.

This research report is structured as follows: In Section 2, a literature review of factors affecting the efficiency and risk related to port operations is presented. Based on the literature review, the functionality of a maritime transportation system is affected by the information exchange between the parties involved in the system. Special risks identified for international ports included foreign containers and recreational vessels. Section 3 presents System Dynamics (SD) simulation, the quantitative modelling method used. Section 4 starts the empirical part of the paper by presenting case study analyses of selected seaports, railway yards and stakeholders in the logistic chain in the Gulf of Finland Region. In line with the findings of the literature study, different stakeholders in the supply chain face different risks. However, a spillage is a common perceived source of risk in intermodal transportation in Gulf of Finland. The simulation studies are presented in Section 5. The results show that the effects of an oil spillage preventing container handling in one harbour depend on the location of substituting equipment. In case of spillage on rails, the impact of a disruption depends on the cargo carried. In Section 6, we discuss the limitations of our research. Section 7 concludes the paper by providing further research avenues.

2 Literature review

Before 9/11, research on the functionality of intermodal supply chains has typically concentrated on exploring ways to efficiently manage and ensure adequate capacity to accommodate forecasted growth in trade flows. Fung (1998) estimated optimal schedule for container terminal construction in port of Hong Kong and defined the optimal value of the related terminal handling charge. In some research works, the insufficient capacity of the transportation system has even been treated as a factor influencing commodity prices between regions (Terahara, 1999). Research has also been conducted to fine tune operational strategies to increase throughput, such as in scheduling and allocating containers in intermodal train operations (Newmann, 1998) and scheduling of trucks in intermodal hubs (Duan, 2006). More recently, even studies concentrating on supply chain risk have been conducted. Vandiver (2006) has identified US critical infrastructure and its dependence on selected imported commodities. The most critical commodities for the infrastructure have been found to be computers, telecommunication equipment and pharmaceutical preparations. Direnzo (2007) has estimated the maritime risk related to different US regions based on the trade and passenger flows in different areas. International containers and recreational vessels were identified as being the largest contributors to risk. Table 1 presents the risk aspect of the studies reviewed.

Table 1 Summary of the identified risks from the reviewed studies

Source	*Risk*	*Description*	*Duration*	*Environment*
Duan (2006)	Collaboration	Lack of collaboration can increase the effect of disturbances	Hours, days	Hub cities, USA
Terahara (1999)	Bottleneck resources, institutional settings, market dynamics	Emphasises investing on bottleneck resources in the transportation network and promotes market mechanism as a tool to achieve this	Weeks, months	Coal transportation in China
Direnzo (2007)	Physical resources	In the US number of foreign containers and recreational vessels contribute to maritime risk	Hours, days, weeks	In hub cities in USA
Vandiver (2006)	Labour, weather	Interruptions are typically caused by labour or weather	Days, weeks	In the port of Houston, USA
Fung (1998)	Scheduling	Concentrates on scheduling investments to ensure suitable capacity	Weeks, months	In the port of Hong Kong

According to Table 1, it can be stated that the single major source of risk in intermodal transportation infrastructure is related to the efficiency of timing of decisions and their implementation in relation to critical investments of physical resources. Sources of risks can be related to resources of the system, i.e., labour or information systems, or types of customers served by the system, such as foreign containers and recreational vessels or external factors like weather. As such, no ultimate set of risk sources can be identified. The probability of a risk being realised depends e.g., on the above-mentioned factors. It also seems that the duration of the consequences of identified risks is in most cases less than a month.

According to de Langen (2004) also the governance of a seaport has an important impact on its performance. In less developed countries, the primary measure to be taken when improving the functionality of transportation is to provide political stability (Razzague, 1997). The risk related to ship transportation in North Sea has been modelled and evaluated based on historical causes of serious marine accidents by Fowler and Sorgård (2000). Yip (2008) has recently studied maritime accidents within Hong Kong seaport. According to his research, the port of registration and vessel type have an impact on risk. Trucco et al. (2008) have included human and organisational factors in risk analysis of maritime transportation. In rail traffic, human error has been identified as a substantial source of risk (Hassan et al., 2009).

3 SD simulation

Naylor et al. (1966) define simulation as the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain and predict the behaviour of the real system. Simulation analysis is a descriptive modelling technique. It does not provide explicit problem formulation and solution steps like linear programming.

Borshcev and Filippov (2004) distinguish between discrete-event system simulation, agent-based simulation and SD modelling. In agent-based modelling, individual actors' behaviour is modelled; the dynamics of the system is derived from the interaction between the actors. Furthermore, in discrete-event simulation, discrete units flow inside the system, while resources offer services to the units.

Syatem Dynamics (SD) was developed by Forrester in the late 1950s. The first published work was 'Industrial Dynamics' (Forrester, 1958) and the simulation model consisted of a supply chain. SD is part of a larger school of thought, systems thinking that studies dynamic complexity, which is seen to arise from the non-linear and multi-loop feedbacks (Maani and Maharaj, 2004).

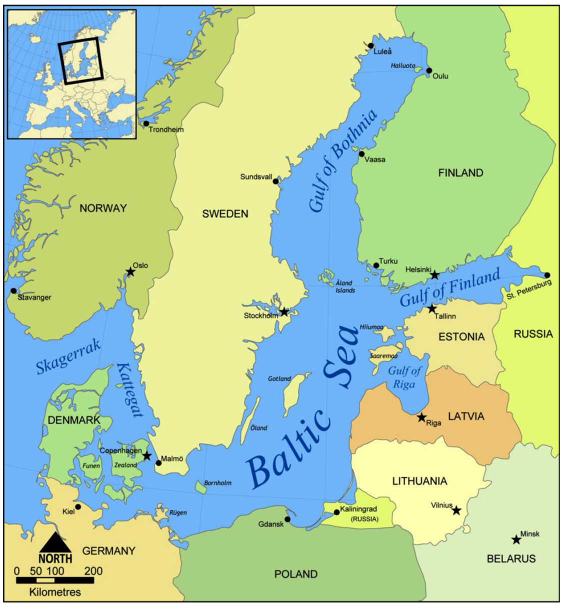
Syatem Dynamics (SD) has been used in a wide area of applications. These include ecology, economics, supply chain management, urban development and even world development. In maritime context, Engelen et al. (2006) have used SD for a strategic and tactical decision-making model for ship owners in the dry bulk sector. Earlier, SD was used in studying seaports. Munitic et al. (2003) created an SD model, where they studied the material flows in a whole port cargo system. The model was constructed on a micro-level and it contained individual fork-lift trucks, wagons, wharfs, etc. Sanders et al. (2007) studied the investment dynamics in larger port systems including hinterland capacity. The model also contained the competition between the different seaports. Lättilä (2009) constructed a macro-level SD model where the focus was on the development of demand in different seaports. The simulation model did not include competition between the different seaports, and the demand was imposed on individual seaports using the historical values.

4 Research methodology

This research was conducted during a project called Study of cargo flows in the Gulf of Finland in emergency situations. The project contained many partners both from Estonia and Finland and the purpose was to improve preparation for potential emergency situations. One work package was responsible for interviewing local logistical operators to find out what are the main risks in maritime supply chains and then devising simulation models to analyse these disruptions. The interviews were conducted between June 2009 and April 2010. Several simulation models were then constructed based on the interviews. Data for the models wee collected from public sources or by communicating with the responsible authorities.

Gulf of Finland is located in Northern Europe between Finland, Estonia and Russia. The region is presented in Figure 1. The region contains many seaports but most of them are of small size compared to Europe's or Asia's main ports. The largest ports in the region are Primorsk and Port of Saint Petersburg, which are located in Russia. The first one handles nearly 80 million tonnes of oil products each year while the latter handles more than 50 million tonnes of various cargos (Kämärä, 2010). Seaports of Vysotsk (Russia), Ust-Luga (Russia), Sköldvik (Finland), Helsinki (Finland), Kotka and Hamina (Finland), and Port of Tallinn (Estonia) each handle approximately 10 million tonnes of cargo annually. A large amount of the traffic is liquid bulk vessels, which export oil from Russia to the rest of the world. Smaller vessels connect the region's seaports to the main ports of Europe and through these ports to the rest of the world.

Figure 1 Baltic Sea Region (Map from Wikimedia Commons) (see online version for colours)



A relatively large amount of the traffic in Finnish and Estonian seaports is transit traffic to Russia. Russia mainly exports oil and chemical products and other raw materials through Finnish and Estonian seaports.

Especially, the port of Muuga (part of port of Tallinn) handles a great amount of oil (more than 20 million tonnes each year), which is transported to the seaport with a railway connection. The eastbound transit consists mainly containers and cars (Posti et al., 2009).

5 Case studies in Gulf of Finland region

Table 2 provides a summary of the main risks in the case studies. Both in case of ports and railway yards, risks are of similar type, but their specific nature depends on each contextual settings. In line with the findings of literature review, there is no ultimate set of sources of risks, and in most cases, a timeframe of hours and days, rather than weeks or months, is involved.

According to Table 2, different ports and railway yards have differing risk profiles depending on the infrastructure and cargo handled. Sources of risk include energy supply, information systems, weather conditions and labour. In addition to these, the form of collaborating firms affects system performance. As multinational firms can change their transportation flows in case of disruptions, local operators might be forced to close down their businesses. Generally, the ports that have specialised to ro-ro and ropax are more flexible compared to the ports that handle containers or liquid bulk. In handling containers or liquid bulk, special loading and unloading devices such as derricks, long leg spiders, pipe and pump systems, indicators of spillage and monitoring cameras are needed. Meanwhile, ro-ro and ropax transportation need only quays and road connection from harbour. However, a spillage is a common perceived source of risk.

Table 2 Summary of the identified risks from the case studies

Case	*Risk*	*Description*	*Duration*
Port of Hamina	Electric power and gas, spillage	Port uses gas and does not have own power plant, spillage in harbour	Hours, days, weeks
Port of Helsinki	Tunnel closure	Port is accessed through tunnels, weather/ice conditions	Hours, days
Port of Kotka	Information system, accident, spillage	Port lies in large area, port handle a lot of transit goods	Hours, days, weeks
Port of Naantali	Accident, spillage	Port lies in compact small area	Hours, days, weeks
Port of Lappeenranta	Saimaa canal closure	Port is accessed through Saimaa Canal and canal closure stops ship traffic	Hours, days, weeks
Port of Kokkola	Accident, derrick capacity	Accident in the narrow boat lines or in the harbour	Hours, days, weeks
Port of Raahe	Accident	Accident in the narrow long boat line	Hours, days, weeks

Table 2 Summary of the identified risks from the case studies (continued)

Case	*Risk*	*Description*	*Duration*
Ports of Tallinn: Old harbour	Accident spillage, accident	Accident in harbour	Hours, days
		Spillage of tank wagons in harbour	Days, weeks
Muuga	Accident	Accident in harbour	Hours, days, weeks
Paldiski			
Port of Sillamäe	Spillage, accident	Spillage or accident in harbour	Hours, days, weeks
Kouvola railway yard	Spillage	Handles a great deal of Russian liquid and chemical tankers	Hours, days
Tampere railway yard	Derailment	Derailment in building new trains in railway yard	Hours, days, weeks
Finnish Road Administration	Information systems	Centralised Traffic Management Centre	Hours, days, weeks
Stella Corona	Accident	All warehouses located in Kotka	Hours, days, weeks
Kuehne + Nagel	Information systems	Global operator is dependent on information systems functionality	Hours, days, weeks

6 Simulation studies

As spillage was identified as a source of risk in several cases; the four simulation studies will explore the effects of spillages in different locations the Gulf of Finland Region. Figure 2 presents the location of the spillages. The seaports were chosen as they are major seaports in both of the countries, while Tapa and Kouvola were chosen as they work as important hubs in the railways connecting different seaports to Russia.

Figure 2 Location of the spillages in the four simulation studies

Source: Adapted from Hilmola et al. (2007)

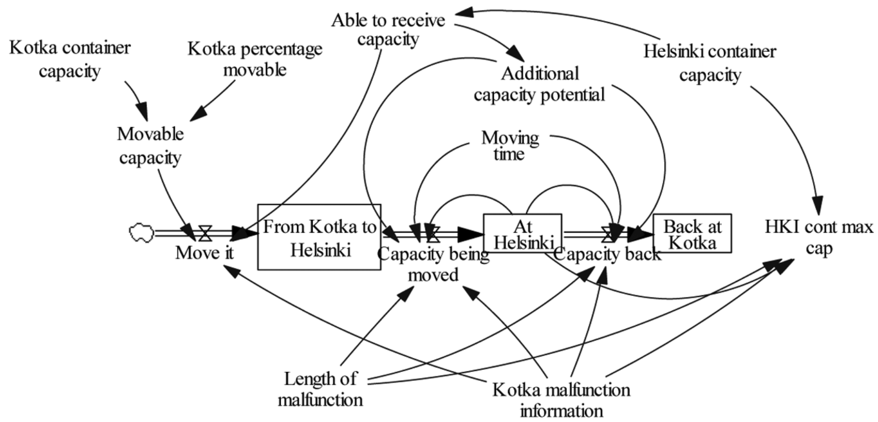
6.1 First scenario: oil spillage at sea near of Kotka

In this scenario, Hamina and Kotka seaport are going to be closed due to an oil spillage in the Gulf of Finland. The container traffic from Kotka is transferred to Helsinki seaport and we analyse what happens with different amounts of hinterland capacity. Hamina's demand is assumed to be transferred to another seaport, so it is not included in the simulation model.

6.1.1 Simulation model

In the simulation model, both of the seaports have daily demand and capacity. As soon as the Kotka seaport malfunctions, the seaports start shifting some of the capacity from Kotka (for instance mobile cranes) to Helsinki. There is also a limit to the amount of additional capacity which Helsinki can absorb. The shifting operation requires 15 working days. Also the storage capacity of the harbour is fixed. In the simulation model the containers stay in the seaport for two days on average. There are two constraining factors in the maximum handling capacity of the seaport: hinterland capacity and the capacity of the cargo handling equipment. The shifting operation is presented in Figure 3.

Figure 3 Capacity shifting



Kotka and Helsinki container capacity is an exogenous variable, which represents how much capacity currently exists in both of the seaports. A fraction of the capacity (Kotka percentage movable) of Kotka seaport can be transferred to Helsinki, while there is also a limited amount capacity, which Helsinki seaport can receive. The duration of the malfunction and information about its initial occurrence impact the speed at which capacity is moved from Kotka to Helsinki and later on back to Kotka. Helsinki's current capacity and the moved capacity from Kotka then provide the current maximum handling capacity of Helsinki seaport. This handling capacity is connected with the storage capacity of Helsinki. This is presented in Figure 4.

The seaports absolute maximum capacity is constrained by the amount of free storage space and the handling capacity at the berths. As soon as the amount of free storage space runs out, the whole seaport system's maximum capacity is constrained by the size of the outbound logistics flows. The maximum capacity of the seaport system is then used to estimate how large amount of the whole demand cannot be handled by the system. This is presented in Figure 5.

Figure 4 Storage usage

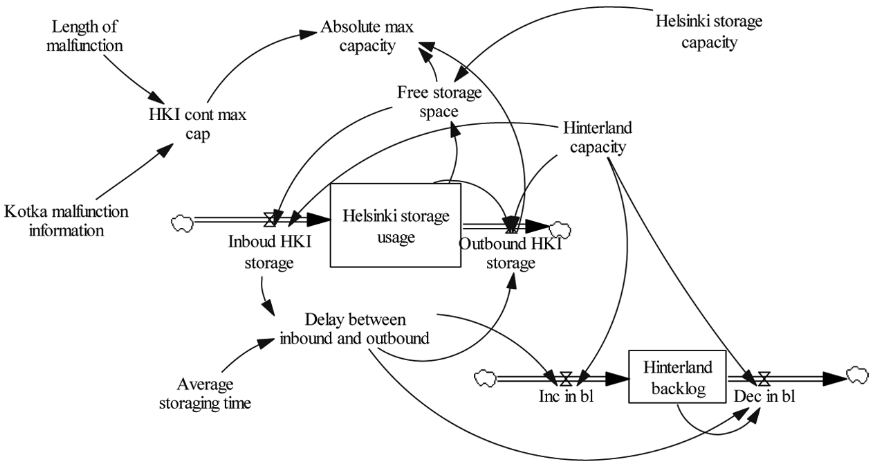
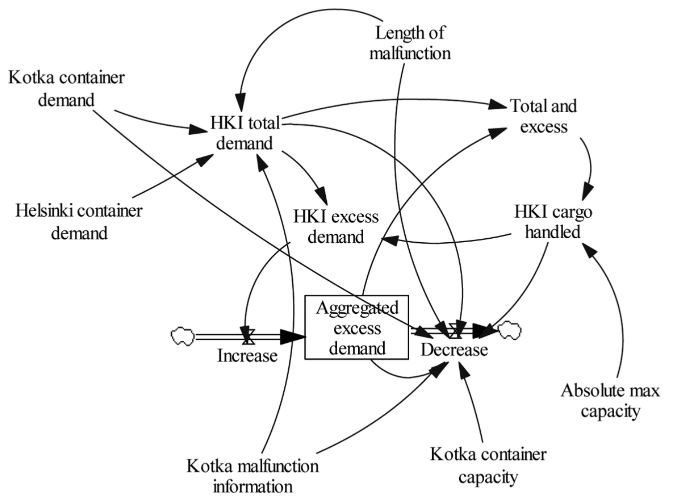


Figure 5 Excess demand



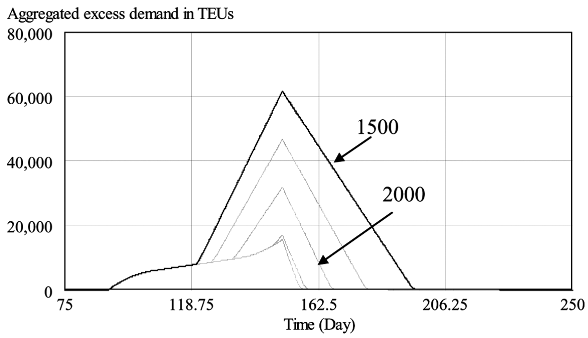
The model compares the capacity of the seaport to the current amount of demand. The demand is calculated by the total demand of both Kotka and Helsinki seaport, as well as amount of excess demand. The difference between the capacity and demand is the excess amount of demand, which does not get handled during the normal working hours and queues start to build up at the sea. As soon as Kotka is able to handle goods again, it will take part of the excess demand and decrease the queue.

We run nine scenarios where hinterland capacity will differ between 1500 (a little bit over Helsinki seaports current demand) and 3500 containers (the demand of Kotka and Helsinki combined) per day. We will study the excess demand, which cannot be handled by the seaport as well as the amount of free storage space in different scenarios. The crisis with duration of 60 days will start on day 90.

6.1.2 Results

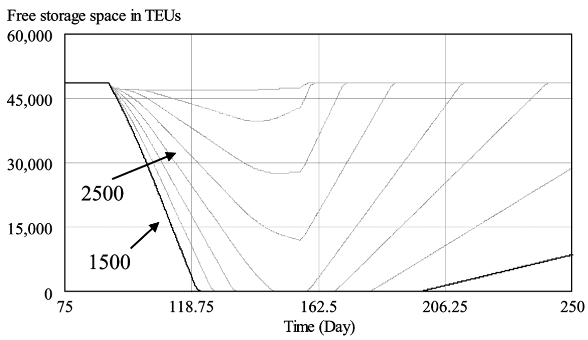
Aggregated excess demand in all scenarios is presented in Figure 6.

Figure 6 Aggregated excess demand (TEUs) in different scenarios. Each line represents one simulation run with a different amount of hinterland capacity in TEUs



As it is possible to notice from Figure 6, all scenarios have the same amount of excess demand for the first 30 days of the crisis. Approximately during day 120, the scenario with the lowest amount of hinterland capacity starts to differ from the rest of the scenarios. The scenarios with a hinterland capacity of at least 2500 TEU do not differ between each other. In these cases, the additional amount of hinterland capacity will not make a difference as free storage space does not run out during these simulation runs. Figure 7 shows the amount of free storage space in different scenarios.

Figure 7 Amount of free storage space (TEUs) in different scenarios. Each line represents one simulation run with a different amount of hinterland capacity in TEUs



The free storage space runs out in four scenarios. These scenarios have a hinterland capacity between 1500 to 2250 TEUs. As soon as there is an inadequate amount of storage space available, the amount of excess demand starts to increase significantly. In the scenario with a hinterland capacity of 1500, there is no more free storage space available during the 120th day. During this same day, the excess demands starts to increase sharply. When there is no more excess demand in the seaport (as soon as the crisis is over), the amount of free storage space starts to increase. Although the crisis ends at day 150, many of the scenarios are working on full storage capacity for a long time. Even at day 210, there is still a large amount of material in storage in three scenarios.

6.2 Second scenario: oil spillage in Muuga

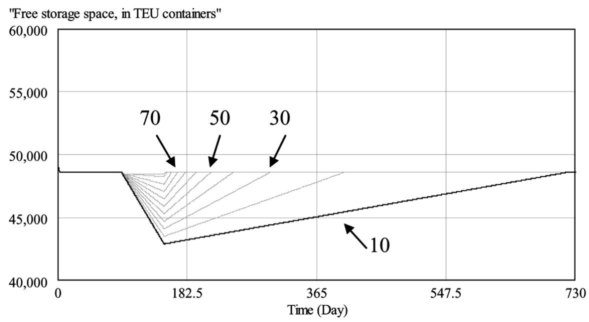
In this scenario, Muuga seaport, where Estonian container handling capacity is concentrated, is going to be closed due to an oil spillage in the port. In all, 20% of container volume is considered sufficient in respect of security of supply. This amount of 105 TEU per day is transported via Helsinki seaport. From Helsinki, containers will be transported back to Estonia through Paldiski on platforms with ro-ro ships. In all, 80% of the containers will remain in the seaports in Central Europe. We analyse the effect of having different amounts of platforms available for the sea transport between Helsinki and Paldiski.

In Helsinki, the handling capacity is annually 500,000 TEU. In 2009, it handled about 350,000 TEU (Port of Helsinki, 2010). Tallinn and Helsinki have at least two ro-ro connections daily (Port of Tallinn, 2010a). As Muuga is closed, the ferries from Helsinki visit Paldiski port. A standard platform is assumed to carry two TEUs. Empty platforms are transported back to Helsinki. The turnaround time for the platforms between Helsinki and Paldiski is assumed to be two days. Although the same platforms are not returned directly, the number of platforms dedicated to the transportation loop between Helsinki and Paldiski equals the number of daily containers. In different simulations, the number of dedicated platforms receives the values from 10 to 110 with an increment of 10. The duration of the malfunction is 60 days.

6.2.1 Results

During the malfunction Helsinki is able to take 105 containers of Muuga seaport without any problem as the initial utilisation of the handling capacity is only 70%. The effect on the amount of free storage in Helsinki is limited in all cases (Figure 8). As such, this does not impose a constraint for the Helsinki seaport system's handling capacity in any of the scenario runs.

Figure 8 Free storage space in Helsinki (TEUs). Each line represents a different scenario with a different amount of container platforms available each day



However, from an Estonian perspective, Figure 8 has more dramatic consequences. If the amount of platforms is not sufficient, receiving the containers will take months. As container handling capacity in Estonia is concentrated in the port of Muuga, the system is vulnerable to local disturbances.

6.3 Third scenario: wagon spillage in kouvola

In this scenario, a major node of the Finnish railway network, Kouvola, malfunctions due to methanol wagon spillage. As a result, no cargo or passengers can be transported between Kouvola and the Russian border. Many bulk materials are transported using railways, and it might be difficult to find specialised trucks for this kind of material in a short period of time.

6.3.1 Simulation model

In the simulation model, we study the impact on transit, as other freight flows might rerouted more easily. Transit through Kouvola includes traffic from Hanko, Helsinki, Kotka and Hamina harbours to the border crossing railway stations. As Hanko and Helsinki, and even Kotka and Hamina, use the same route to access Kouvola, these locations are aggregated into two respective pairs. There are delays connected to all of these routes. Moreover, each of the yards has a fixed capacity, which can be reserved for temporary holding area for wagons. In the simulation model, it is assumed that the export/import is lost and cannot be regained.

The amount of westbound transit has been about 4000 thousand tonnes per year (VR, 2010) This equals to about 830 tonnes per hours (300 days, 16 h days), while eastbound transit is about 920 tonnes per hour (4400 thousand tonnes overall). Rail handles almost all westbound transit, whereas the amount of eastbound transit handled by railways is only 10% (Posti et al., 2009). When the volumes of Kokkola harbour are removed, as it uses separate railways, the westbound flow per hour is 518 tonnes, while the respective eastbound flow is 83 tonnes. The size of individual rail yards and throughput capacity of the links is presented in Table 3.

Table 3 Capacity in different parts of the model

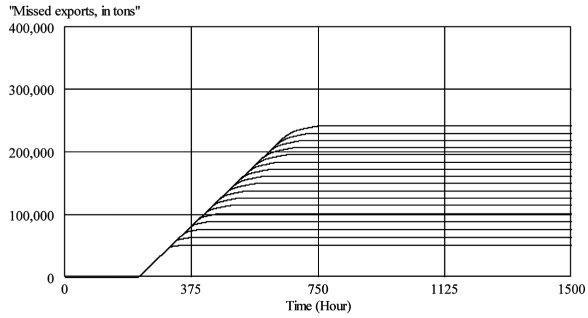
Node or link	*Capacity*
Russian border	12,000 tons
Kouvola	12,000 tons
Kotka and Hamina	6000 tons
Lahti (Helsinki and Hanko)	12,000 tons
Kouvola – Lahti	800 tons/hour
Kouvola – Kotka / Hamina	600 tons/hour
Kouvola – Russian border	900 tons/hour

The parameter values have been constructed in discussions with the Rail Department of the Finnish Transport Agency. Exact measures for the capacities are hard to acquire as the throughput capacity for a given link depends on the speed and distribution of speed of the different trains. Furthermore, as the length of a train is limited by network geometry, the storage capacity in tonnes depends on cargo type. In a crisis situation, the available capacity could be affected by prioritisation of the trains. In this study, such measures are not assumed to be taken.

6.3.2 Results

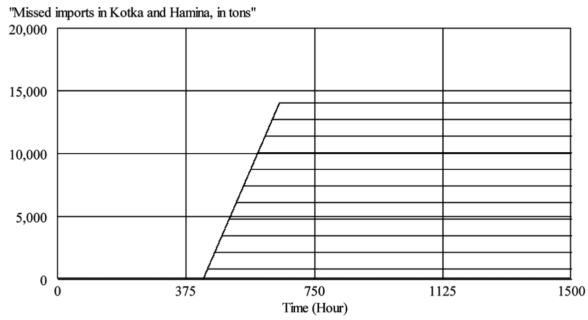
In this model, we analyse the impact of the length of the malfunction. It is going to vary between 112 and 448 h, which equals one to four weeks. We are mostly interested in the amount of transit volumes lost, but other results are presented as well. Figure 9 shows the amount of lost export transit.

Figure 9 Aggregated amount of missed export transit, tonnes. Each line represents a different simulation run with a different length of disruption



As it can be noticed from Figure 9, there are large differences between the scenarios. Nevertheless, even the first scenario contains lost revenue and the losses increase linearly. However, with the current parameters, there are no lost imports in Helsinki and Hanko in any of the scenarios, as the amount of imports is relatively small, 26% of the total. In Kotka and Hamina, the amount of lost imports increases linearly depending on the scenario. In six scenarios, there is adequate storage capacity, but in most situations, capacity is lacking (shown in Figure 10).

Figure 10 Aggregated amount of missed eastbound transit in Kotka and Hamina, tonnes. Each line represents a different simulation run with a different length of disruption



In overall, it can be stated that a malfunction in the hinterland capacity will have heavy financial implications for seaports. Especially, export transit would suffer as most of the transit is conducted using railways. It might be possible to conduct part of the transit using trucks, but this is not cost-efficient and would still have a financial impact on the seaports. In the simulation study, it was assumed that passenger trains are given priority over freight traffic. In a crisis situation, additional capacity for freight could be gained by discontinuing passenger traffic temporarily, e.g., one-third of the daily trains using the track linking Kouvola to the East are passenger trains. (Finnish Transport Agency, 2010). Additional transport capacity would speed up the recovery process once the crisis is over.

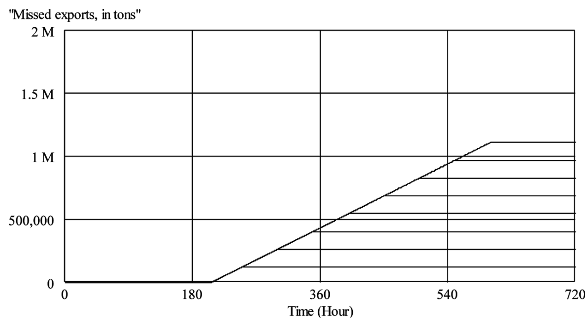
6.4 Fourth scenario: wagon spillage in Tapa

Estonian ports carry a large amount of Russian transit oil. The oil is transported to the ports by rail. In this scenario, the rail connection between Tapa and Vaivara is going to malfunction. During the malfunctioning, traffic from Tapa to Muuga and Paldiski and vice versa is going to be zero. When this happens, rail yards start to fill up in Vaivara and Sillamäe. However, oil export will continue as long as oil storages last in the ports of Muuga and Paldiski. In the ports of Muuga and Paldiski, the total storage capacity of oil is 1.7 million m^3 (0.7 million m^3 for light oil products and 1.0 million m^3 for heavy oil products). In addition, railway yards in the ports can stock up on oil about 190,000 tonnes. In 2009, annual oil shipment from Muuga and Paldiski were nearly 23 million tonnes, i.e., 100,000 tonnes per day. (Port of Tallinn, 2010b). Oil is transported to the ports by train. In case of disruption in oil delivery on rail, full oil tanks in the harbour would last 17 days and tanks that are 80% full have enough oil for 14 days. In addition, wagons on the railway yard could serve demand for two additional days, enabling normal level of oil exports during a disruption of a limited time. Because of the oil reserves in the tanks consequences of disruptions are experienced at a later time and have a shorter duration than the malfunction itself.

6.4.1 Results

The results from simulation study, with different durations for the disruption are presented in Figure 11. The structure of the model is similar to Scenario 3 above, but there exists only one way traffic as Russia does not conduct import transit through Estonia. We assume bad winter conditions and due to this Sillamäe is able to handle only half of the normal capacity. This is about 3000 m^3 of oil per hour. As it is possible to notice from Figure 9, there are large differences between the scenarios. Nevertheless, even the first scenario contains lost revenue and the losses increase linearly.

Figure 11 Missed export during malfunction in Muuga, tonnes. Each line represents a different simulation run with a different length of disruption



If the port of Sillamäe would operate normally, Sillamäe should be able to handle all of the oil. The biggest difference is in total capacity of oil tanks; Sillamäe has only approximately 292,000 m^3 of warehousing silos for oil. Furthermore, Sillamäe railway yard can stock oil around 13,000 tonnes. The maximum oil pumping capacity of the port of Sillamäe is 6000 m^3 per hour (about 100,000 tonnes during an 18 h working day). Therefore, the port of Sillamäe can substitute the port of Muuga if the stoppage will continue longer than 17 days momentarily, but longer stoppages will be hard to substitute with the limited oil tank storage and oil pumping with maximum capacity.

7 Discussion

In this research work SD simulation analyses were conducted to experiment the impact of selected risk scenarios on the functionality of the transportation routes in the Gulf of Finland Region. Simulation scenarios were constructed based on case study interviews.

Although common perceived risk of spillage identified by the case studies might be biased and thus not reflect the risks related to transportation objectively, using multiple case studies increases the reliability of the findings (Eisenhardt and Graebner, 2007; Yin, 1994).

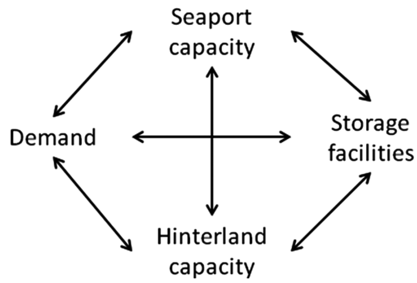
System Dynamics (SD) is a good tool to estimate how maritime supply chains work in crisis situations. It is possible to aggregate cargoes to just few categories (this case only analysed containers but it would be possible to include also liquid and dry bulk, as well roro-cargo) which makes it manageable with SD. The used model could as well be expanded to include a more detailed view about hinterland capacity, differentiate between different types of demand (imports, exports, and transit), and also include the impact of having a right amount of empty and full containers. However, in railway simulations, SD was more difficult implement. During the construction process, the model went into a 'grid-lock' as the railway yards filled up and there was no room to shift cargoes between different nodes. It is manageable to model railways but discrete-event or agent-based simulation could perhaps be a better way to model the system.

To logistics service providers, this research presents an overview about the potential risks, which exist in maritime supply chains. Sources of risk include energy supply, information systems, weather conditions and labour. The risk profile differs between actors as each location has their own peculiarities. To manage the risk identification and managing process, it is necessary to estimate hinterland capacity as well in maritime supply chains. Simulations can be used to estimate route feasibility in different situations.

From an academic perspective, this study promotes the usage of SD in analysing maritime transportation risks. According to the study, there is a constant interplay between demand, seaport capacity, hinterland capacity and storage facilities. This is presented in Figure 12. If even more of logistical operators shift towards lean operations where only a small amount of excess capacity exists, the systems will be highly sensitive to disruptions. Moreover, the chain is as strong as its weakest link, which makes sensitivity to disruptions even higher.

The proposed simulation approach can as well be used in other geographical areas as well. Currently, the most heavily operated seaports are in Asia where an interruption would have a large impact in global supply chains due to large size of exports from China.

Figure 12 Interplay between seaport demand and capacity



8 Conclusions

As in other corners of the world, globalisation has resulted in large volumes of foreign trade, especially in maritime transportation in the Baltic Sea Region. Although sea is the main mode of transportation in the region, there is no study on how the maritime volumes could be handled, if the operational environment changes unexpectedly. The aim of this paper was to identify risks related to transportation routes that use seaports in the Gulf of Finland and to evaluate how selected risks affect the functionality of the transportation system if realised.

Based on the case analyses different ports and railway yards have differing risk profiles depending on the infrastructure and cargo handled. Sources of risk include energy supply, information systems, weather conditions and labour. In addition to these, the form of collaborating firms affects system performance. As multinational firms can change their transportation flows in case of disruptions, local operators might be forced to close down their businesses. Generally, the ports that have specialised to ro-ro and ropax are more flexible compared to the ports that handle containers or liquid bulk. Spillage was perceived a common source of risk related to freight transportation in the Gulf of Finland region. This seems plausible as Finnish ports handled 37.4 million tonnes of dangerous goods in 2007, according to Ministry of Transport and Communications Finland (2009), petroleum and oil products counting for two thirds of the volume. The same year, transportation of dangerous goods on road and rail network totalled 9.5 and 5.6 million tonnes, respectively, flammable liquids being the largest transportation group.

According to the simulation studies, the effects of an oil spillage preventing container handling in one harbour depend on the location of substituting equipment. As the Estonian container handling capacity is concentrated in one harbour, necessary container flow could be rerouted through Finnish harbours and shipped to Estonia on platforms, the availability of which might limit the capacity of the alternative route. As there are several container handling harbours in Finland, closing one harbour will not cause a problem in the short run. However, when the container storage capacity of the alternative harbour is full, the hinterland capacity will be the bottleneck of the reroute. In case of spillage on rails, rerouting possibilities of freight are limited. Here, the impact of a disruption depends on the cargo type carried. Westbound transit through Finland and Estonia uses mainly rail. In transporting bulk, such as oil in Estonia, disruptions can be prepared for by inventories located in seaport. In other types of cargo, disruptions have immediate effects, which is the case in Finland.

One of the strengths of the simulation studies is that they provide a system wide perspective on the supply chain instead of concentrating on the functionality of one part of it. Based on the simulation experiments, a long time is required to return to normal situation in the supply chain after the local crisis, e.g., in the seaport, is over. The whole network is interdependent and the whole system reacts to a malfunction. Based on our findings, the functionality of seaports should not be analysed in isolation, but merely as a part of a wider transportation chain.

Although SD enabled system wide analysis of malfunctions, it requires a lot of feedback loops even to study basic flows between the nodes. In addition, the functions used to estimate the allocations to individual routes tend to be long as many parameters affect this decision.

Equipped with a more flexible and efficient simulation tool, such as discrete-event or agent-based simulation, a larger variety of scenarios could be analysed in practice. For example, feeder traffic in the Gulf of Finland is probably affected by new Russian ports, such as Ust Luga. Moreover, an extension to the geographical scope of the research to other countries located on the shores of the Baltic Sea could be performed, as several countries are networking when providing security of supply. Such models could also evaluate more sophisticated control mechanisms for managing alternative routes in crisis situations.

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