Vaasan yliopisto
UNIVERSITY OF VAASA

Panu Laasanen

Capacity assessment of Lasse's quay and the impact of the quay extensions on waiting time by using a digital twin : Case Vaasa Harbour

Master's thesis

School of Technology and Innovations
Master's thesis in Industrial Management
Master's programme in Industrial Management

Vaasa 2024

UNIVERSITY OF VAASA
School of Technology and Innovations
Author: Panu Laasanen
Title of the Thesis: Capacity assessment of Lasse's quay and the impact of the quay extensions on waiting time by using a digital twin : Case Vaasa Harbour
Degree: Master of Science in Economics and Business Administration
Programme: Industrial Management
Supervisor: Rayko Toshev
Year: 2024 **Pages:** 90

ABSTRACT:

Layout changes can be expensive. Especially changes in the layout of ports, such as the construction of new quays or the extension of quays, are often very expensive and the implementation of the construction work often takes a lot of time. For this reason, it is necessary to use the most appropriate means and tools to study the needs and possible effects of the extensions, so that the effects of the expensive construction works can be evaluated as comprehensively as possible. It is also often necessary to compare different extension options with each other to choose a solution where the ratio of costs and benefits is as efficient as possible.

Kvarken Ports Ltd, which operates the port of Vaasa, wanted to find out the impact of different expansion options on the port's capacity and waiting times, as well as the most suitable schedule for liner traffic and the best possible location of the ramp used by liner traffic in the port. The study examined three different expansion phases. Phase 1, where the length of Lasse's Quay was increased by 144 meters, Phase 2, where the ramp used by liner traffic is located at the southern end of Lasse's Quay, and Phase 2, where the liner traffic ramp is located in the new quay area.

Anylogic 8 software was used in the study, which is a versatile simulation software that can be used to implement various simulation models such as logistics, supply chain, and production facility simulations. Anylogic 8 was used to create Discrete-event simulation models of the Present state of the port, Phase 1, and two different versions of Phase 2. The operation of these models was tested by increasing Lasse's Quay traffic between 0-25% in six different simulation runs per scenario model. The schedules for the 5-year simulation tests were created using the 2021-2022 schedule data. Data on the utilization rate of Lasse's Quay and the waiting times of ships were collected from different scenarios.

Based on the results of the study, it can be concluded that the planned extensions will significantly reduce waiting times at Lasse's Quay in all traffic growth scenarios. The best location for the liner traffic ramp is in the new quay area, but also the location at Lasse's quay does not cause excessive congestion and is cheaper and faster to implement. The best arrival time for liner traffic is on Tuesday at 4 p.m. It is worth noting that with better planning and traffic optimization, the operation of Lasse's Quay could be made more efficient.

KEYWORDS: Digital twin, Simulation, Marine traffic, Layout, Capacity

VAASAN YLIOPISTO
Tekniikan ja innovaatiojohtamisen yksikkö

Tekijä:	Panu Laasanen
Tutkielman nimi:	Capacity assessment of Lasse’s quay and the impact of the quay extensions on waiting time by using a digital twin : Case Vaasa Harbour
Tutkinto:	Kauppatieteiden maisteri
Oppiaine:	Tuotantotalous
Työn ohjaaja:	Rayko Toshev
Valmistumisvuosi:	2024 **Sivumäärä:** 90

TIIVISTELMÄ:
Layout muutokset voivat olla kalliita. Erityisesti satamien layoutin muutokset, kuten uusien laiturien rakentaminen tai laiturien laajentaminen, ovat usein erittäin kalliita ja rakennustöiden toteuttaminen vie usein paljon aikaa. Tästä syystä laajennustarpeiden ja mahdollisten vaikutusten selvittämiseen on käytettävä tarkoituksenmukaisia metodeita ja työkaluja, jotta kalliiden rakennustöiden vaikutukset voidaan arvioida mahdollisimman kattavasti. Usein on myös tarpeen vertailla eri laajennusvaihtoehtoja keskenään, jotta voidaan valita ratkaisu, jossa kustannusten ja hyötyjen suhde on mahdollisimman tehokas.

Vaasan satamaa operoiva Kvarken Ports Oy halusi selvittää erilaisten laajennusvaihtoehtojen vaikutusta sataman kapasiteettiin ja odotusaikoihin, sopivimman aikataulun linjaliikenteelle, sekä linjaliikenteen käyttämän rampin parhaan mahdollisen sijoituspaikan satamassa. Tutkimuksessa tarkasteltiin kolmea eri laajennusvaihetta: Vaihe 1, jossa Lassen laiturin pituutta kasvatettiin 144 metriä; Vaihe 2, jossa linjaliikenteen käyttämä ramppi sijaitsee Lassen laiturin eteläpäässä; ja toinen vaihtoehto Vaiheesta 2, jossa linjaliikenteen käyttämä ramppi sijaitsee uudella laiturialueella.

Tutkimuksessa käytettiin työkaluna Anylogic 8 -ohjelmistoa, joka on monipuolinen simulointiohjelmisto, jonka avulla voidaan luoda ja toteuttaa erilaisia simulaatiomalleja, kuten logistiikka-, toimitusketju- ja tuotantolaitossimulaatioita. Anylogic 8:lla luotiin Diskreetti-tapahtumasimulaatiomallit sataman nykytilasta, vaiheesta 1 ja vaiheen 2 kahdesta eri vaihtoehdosta. Näiden mallien toimintaa testattiin lisäämällä Lassen laiturin liikennettä välillä 0–25 % kuudessa eri liikenteen kasvuskenaariossa. 5 vuoden simulaatiotestien aikataulut luotiin käyttämällä vuosien 2021–2022 aikataulutietoja. Eri skenaarioista kerättiin tietoja Lassen laiturin käyttöasteesta ja laivojen odotusajoista.

Tutkimuksen tulosten perusteella voidaan päätellä, että kaikki suunnitellut laajennukset vähentävät merkittävästi Lassen laiturin liikenteen odotusaikoja kaikissa liikenteen kasvuskenaarioissa. Linjaliikenteen käyttämän rampin paras mahdollinen sijainti on uudella laiturialueella, mutta myöskään sijainti Lassen laiturilla ei aiheuta liiallista ruuhkautumista ja on kustannuksiltaan halvempi, sekä nopeampi toteuttaa. Linjaliikenteen paras saapumisaika Lassen laituriin on tiistaina klo 16. On huomionarvoista, että paremmalla suunnittelulla ja liikenteen optimoinnilla Lassen laiturin toimintaa voitaisiin tehostaa.

AVAINSANAT: Digitaalinen kaksonen, Simulointi, Meriliikenne, Layout, Kapasiteetti

Contents

Figures

Tables

Abbreviations

3D	Three-dimensional
DES	Discrete-Event Simulations
GIS	Geographic Information System

Acknowledgment

I would like to thank my supervisor Dr. Rayko Toshev for the guidance and support I received during my thesis work. I would also like to thank the entire staff of Kvarken Ports Ltd, and especially development manager Tommi Tuominen for the topic of the thesis and the data that I used in my research. The cooperation was very smooth and pleasant throughout the work.

Thanks also to my family and friends for their support and encouragement during this research.

In Vaasa, April 2024

Panu Laasanen

1 Introduction

The cargo volumes of the port of Vaasa have increased in the last years. The total tonnage of 2022 was 39% higher than the equivalent of 2021. The number of vessel visits has also increased by 11% during the same period. The total tonnage of cargo in 2022 was 1,35 million. tons (Vasek 2023), which made it the 15th largest port in Finland in terms of tonnage (Suomen satamat ry. 2023). Especially the capacity of the cargo quay (Lasse's quay) is no longer sufficient to serve the growing number of ships. Lasse's Quay was very congested in the summer of 2022 (Vasek 2023). In particular, project ships carrying wind turbines congest Lasse's quay. These ships are about 150 meters long and can only fit one at a time at the Lasse’s quay. Especially in the summer of 2022, a situation was experienced where the waiting times at the end of the fairway increased to more than a week (Yle 2022). Phase 1 of the Lasse's Quay extension has already started. Phase 1 will increase the length of Lasse's Quay by 144 meters, which will increase capacity. However, there is pressure to continue the increase in capacity, as GigaVaasa, a concentration of the battery industry, is planned for the Vaasa area, which would increase the port's traffic explosively (Vasek 2023).

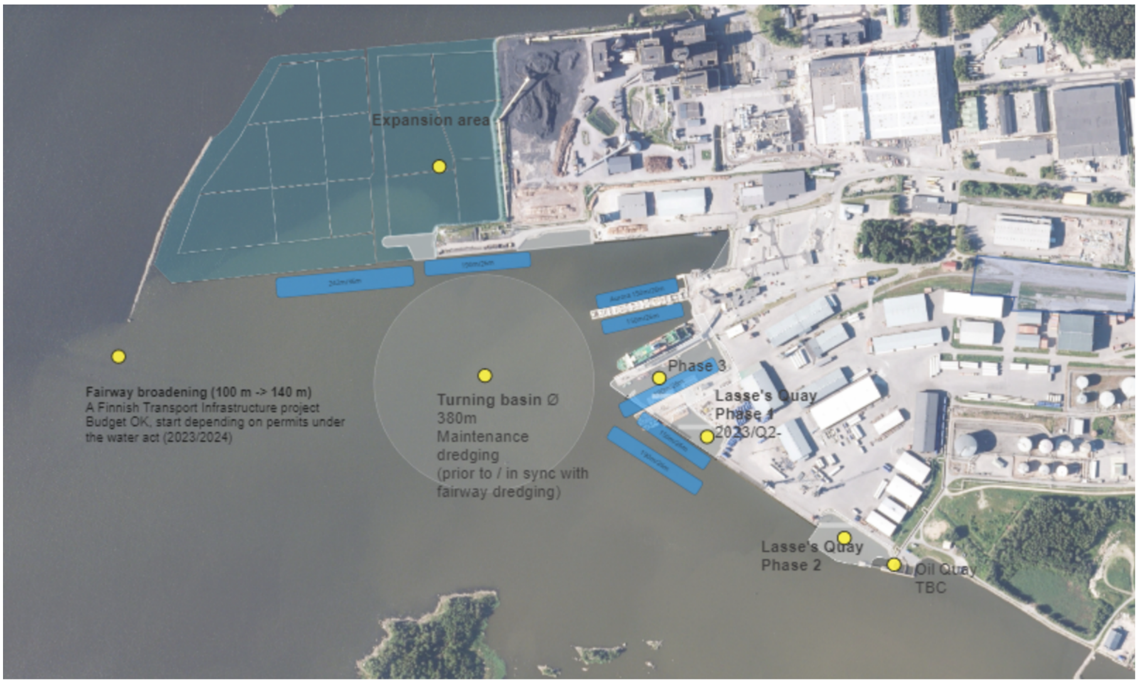

Figure 1 Vaasa harbor development plans

Figure 1 shows planned expansion projects in the port of Vaasa. Phase 1, which is already underway, will extend the length of Lasse's Quay by 144 meters. In Phase 2, a ramp will be added to the southern end of Lasse's Quay, which will be used for RoRo loading and unloading of the planned weekly liner service on a ConRo vessel. In Phase 3, Lasse's quay would be expanded even further. The new quay area has started to be built on the west side of the coal power plant.

1.1 Justification and Contributions

This research is carried out on behalf of Kvarken Ports Ltd, which operates the port of Vaasa. Due to the capacity problems mentioned above, the company needs data to help with decision-making, so that the decisions made are as rational and justified. The purpose of the study is to provide the company with data on the effect of different expansion options on the capacity of the quays and the waiting time of ships outside the fairway. The research is carried out by simulating the current environment and different expansion scenarios with Anylogic 8 simulation software, which is an excellent tool for simulating logistics and supply chains. With the help of simulation, it is possible to produce a large amount of data to support decision-making.

A simulation model was created for the research, which models the different scenarios of the system. The different levels and options of the extension serve as different scenarios. These scenarios were tested with different traffic volumes. Anylogic's GIS map was used to create the model, where the fairways and quays were placed.

1.2 Field of study

Computer simulations are a common means of studying various complex systems and analyzing their operation. Simulations are widely used in the field of industrial management. Typical simulation objects are, for example, production plants and storage systems. In addition to this, simulation models are often used to analyze and optimize the operation of supply chains and complex transport systems (airports, ports) (Altiok & Melamed 2007). Logistics and transport systems are related to supply chain management, which is also an essential part of industrial management (Waters 2009).

Simulations are an important part of computer science by providing tools, methods, and applications in many different areas. The operation of simulations is based on the cooperation of computer software and hardware, through complex algorithms and calculation models (Wee Chuan Lim 2012).

Discrete-event simulation is a simulation method where the system is modeled as a set of successive discrete events. Events follow one another, and the state of the system often changes because of these events. DES is a useful tool in many different fields, such as logistics, production, healthcare, transportation, and economics. It is used, among other things, for optimizing processes, supporting decision-making, risk analysis, and resource planning. DES can be used to simulate complex systems and evaluate the effects of different scenarios without the need for real experiments or tests (Altiok & Melamed 2007).

Industrial management focuses on the use of resources and the optimization of production in companies and organizations. It studies the power and efficiency of production processes and strives to find ways to achieve more products or services with fewer resources. Key concepts in industrial management include production costs, productivity, production optimization, work distribution, utilization of technology, quality control, and inventory management. Industrial management helps companies and organizations plan and manage their production efficiently and improve their competitiveness in the market (Thukaram 2009).

Layout planning refers to the process of defining the physical arrangement and placement of facilities such as factories, warehouses, offices, and ports. This aims to optimize the use of space efficiently and appropriately. Key elements in layout design are optimizing the use of space, smooth workflow and material flows, work safety and ergonomics, customer experience, flexibility and adaptability, and cost efficiency. Layout design is a key part of operational planning and management in many industries, and a well-designed layout can improve efficiency, safety, and user experience (Moran 2017; Pérez-Gosende 2021). Layout planning is one of the basic themes of industrial management (Rao 2009).

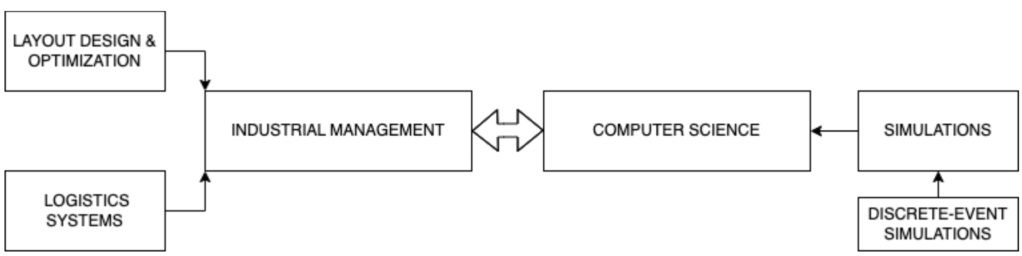

Figure 2 Field of Study

Figure 2 shows how the research combines logistics systems and layout design & optimization in the field of industrial management, and simulations in computer science, more precisely discrete-event simulations. The research deals with a complex transport system in the form of port and maritime transport, which belongs to logistics, but since it is about optimization, industrial management can be considered a discipline.

1.3 Research objectives and questions

The objective of the research is to create a digital twin that models the operation of the port of Vaasa in such a way that it can be used to simulate the effect of changes in traffic volume on the utilization rate of the quays and the congestion of the quays and fairways. The simulation model's ship and schedule information for the years 2024-2028 is created using the 2021-2022 schedule and ship-specific information. The objective of the simulation model is to analyze the operation of the port and the effect of the increase in traffic on it, as well as to obtain information to support decision-making. Based on the objectives of the research, three research questions were formed.

i. What is the utilization rate of Lasse’s quay in different layout models and the different growth scenarios of these models (No growth, + 5%, + 10%, + 15%, + 20%, and + 25%)?
ii. How do the expansion phases Phase 1 (extending Lasse's Quay by 144 meters) and Phase 2 (Adding a ramp to Lasse's Quay or the new area) affect the waiting time of vessels outside the fairway?
iii. What is the optimal schedule for the liner service?
iv. Where should the loading ramp used by liner traffic be located in the port?

1.4 Research process

The research was based on the Simulations of the Production Systems course I took in the spring of 2023, where I was introduced extensively to the use of different simulations and simulation software in the modeling of production systems. The course used the Visual Components 4.5 software, which was a very versatile software, and I found its use interesting. During the course, I had the idea that I would like to use simulation in my thesis. During the course, I heard about the possibility of doing a commissioned thesis for Kvarken Ports LTD, where the effect of port expansions on capacity would be studied. The company needed research-based information to support decision-making. There are many expensive development projects ahead, which had to be justified by scientific research. The topic seemed very interesting, which is why I chose it as the topic of my thesis. I received the necessary data and task assignment so that I could start creating the simulation model. I started modeling with Visual Components software, but I ran into several problems because Visual Components was not designed for simulations like that. I failed to create the logic of the quays with Visual Components so that the ship could only use a certain part of the quay. Also, the 3D modeling of the ships and their utilization in the simulation produced challenges and used so much computing power that the software often crashed. I started researching if there was a more useful way to create a logistics simulation. I quickly found the Anylogic software and learned how to use the program by making several different simulation models according to the instructions. I became convinced that Anylogic would be the right software to solve that problem. Basic information about the port and planned development projects, as well as schedule information for the years 2021-2022 by vessel and by quay, were provided as data for the study. After going through the materials, I created a simple simulation model using Anylogic software, which made it easy to present the operating principle of the model and the logic affecting its operation. In the first meeting with Kvarken Ports Ltd, we reviewed the objectives of the study and I presented them with a simple version of the model. In this way, it could be concluded that the objectives of the research were clear and that the model in question would be the right way to study the problem. We also agreed together which would be the most appropriate key performance indicators for the study. Quay utilization and average waiting times were found to be the values that provide the clearest answer to the study's problems. After that, I created a more complex model that better modeled the real situation. I simulated different scenarios and created a presentation based on their results. In the second meeting with Kvarken ports, in addition to the development manager and traffic manager, also the port master and construction manager were present. They were presented with a more complex version of the simulation model with different scenarios and the results of different simulation models. They were very satisfied with the model and the results and provided constructive feedback on the model and the presentation of the results. Based on this feedback, I made small corrections to both so that the model and presentation would meet the client's needs as well as possible. In the third meeting, we made sure that the results of the research were comparable with each other and that the presentation would be as clear as possible before it was presented to other stakeholders. Comparability was ensured by comparing the simulation values of the years 2021-2022 to the actual events of these years. In the fourth meeting, in addition to Kvarken Ports staff, representatives of the cargo handling company Bloomberg Stevedoring were also present. The operation of the simulation model and the results of the study were presented to them. The presentation sparked a lot of discussion, and all participants found the results of the research interesting and thought that they would help in making future decisions. There were different opinions only about the best arrival time for liner traffic. The research results were also found to be credible in that respect, but there was a difference of opinion on how the results should be treated.

1.5 Research onion

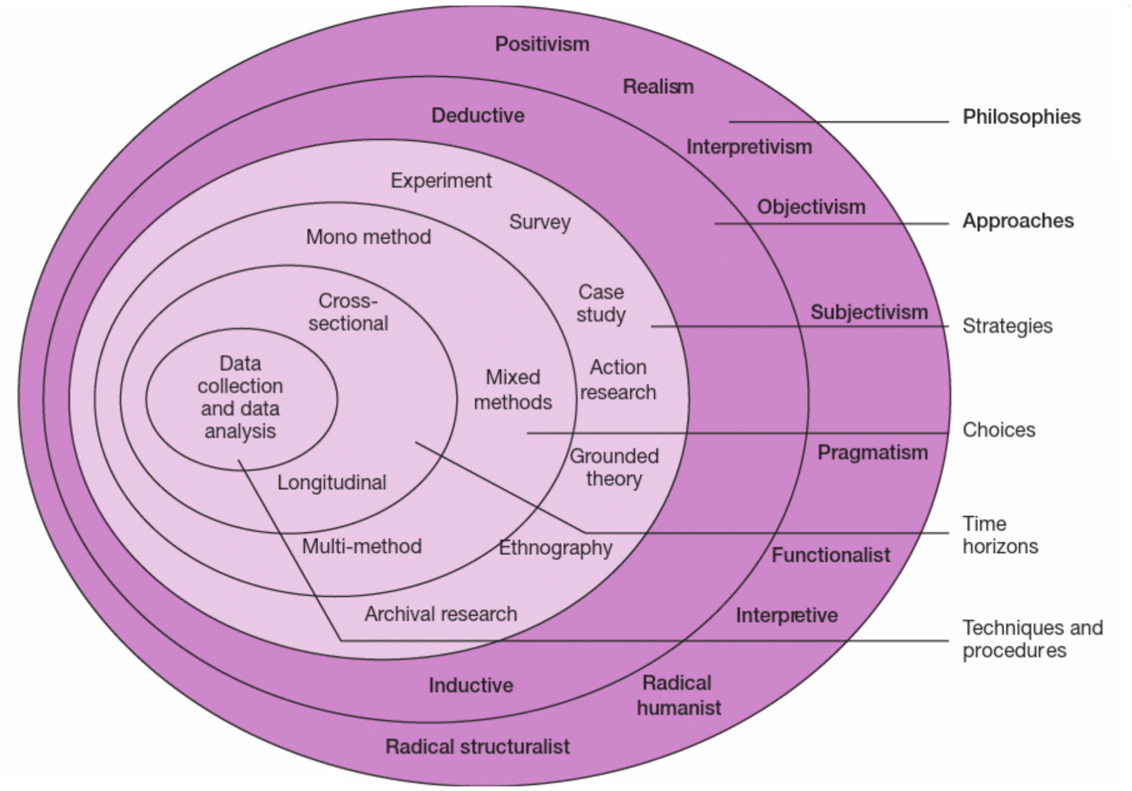

Figure 3 Research onion (Saunders et al 2006).

Figure 3 shows the research onion which helps to understand how different research philosophies, methods and approaches have been used in this research. The layers of the research onion are revealed to the reader from the outside inward in the following paragraphs.

1.6 Research Philosophy

Research philosophy deals with questions and principles related to conducting research. Research philosophy helps to understand how research is carried out, and what kind of methods and principles are involved. Research philosophy answers questions: What makes research reliable? and how can we ensure that fair and ethically acceptable? (Cooper & Schindler 2011).

Philosophies typical of business studies include positivism, realism, pragmatism, interpretivism, objectivism, and constructivism. **Pragmatism** is used as a research philosophy in this study. Pragmatism is a philosophical view that emphasizes the importance of experience and action in evaluating the accuracy of information and truth. According to pragmatism, ideas, and thoughts are useful if they work in practice and help achieve certain goals. Pragmatism focuses on what works best in each situation. The most important factor is the research question. The superiority of different methods is related to how they can produce answers to the research question in question. This means that the most appropriate methods must be used. Also mixed with different methods (Saunders et al 2007).

In this research, the pragmatism can be seen in the fact that the research utilized the best-suited simulation software for the study, which was Anylogic 8 PLE software. From a pragmatic point of view, the key points in simulations are their practicality and ability to produce useful information. Simulations can provide an opportunity to test different hypotheses, try different strategies, and evaluate different decisions without the need to conduct expensive and time-consuming field trials or real experiments. Simulation is a pragmatic choice because it offers a practical approach to studying complex phenomena that can produce useful information and lead to concrete actions and decisions (Saunders et al 2007; Borshchev & Grigoryev 2013).

1.7 Research approach

The research approach is how research is planned or carried out. It defines how research questions are examined, as well as how information is processed, collected, and analyzed. There is no order of preference for the approaches, but they serve different purposes. (Saunders et al 2007). Deductive reasoning, Inductive reasoning, and abductive reasoning are three different approaches (Walton 2014).

Deductive reasoning consists of true premises followed by a logical true conclusion. That is, if the general rule is true, the individual cases to which it applies are also true.

Deductive reasoning produces the most reliable generalizable conclusions. In deductive reasoning, the theoretical position must be decided before starting to collect information. Inductive reasoning forms a generalization or theory based on individual observations. The generalization is not necessarily true in all scenarios. Inductive reasoning is based on observations and probabilities. The theoretical position is developed after the data collection (Saunders et al 2007). Abductive reasoning is speculative reasoning. The best possible explanation is made based on certain observations or events (Walton 2014).

In this study, an **inductive approach** is used, as the data needed for the study has been obtained directly from the organization for which the study is being conducted. The data provided by the organization was the 2021-2022 schedule and ship information, as well as information on the harbor structures and fairway. The limitations of the study can also be seen from the data. The theory and the conclusions that follow from the research are obtained by entering the data into the simulation model.

1.8 Research strategy

Research strategies are choices within which the research is carried out. The choice of a research strategy is guided by research questions, research goals, time, and resources. Research strategies are experiment, survey, case study, action research, grounded theory, ethnography, and archival research. When choosing a strategy, the strategy must be appropriate and a suitable means of solving the research problem of the study (Saunders et al 2007).

Based on the title, this study is already a Case study, but the study also has many features that connect the study to experimental research. A case study is a strategic empirical study of a phenomenon in its context. A case study is a good research strategy if you want to get a broad and versatile understanding of the process in its context. A case study answers the questions of why, what, and how. A case study is used especially in exploratory and explanatory research (Saunders et al 2007). Experimental research is a classic research strategy originating from natural science research. Experimental research examines the causal connections between different events. What changes does a change in one variable cause in other variables? The magnitude and relative importance of the changes are also the subject of research. Experimental research often asks how and why questions. With the help of experimental research, comparisons can be made before and after a change. For example, simulation can be used to compare the effect of changes on a variable or the behavior of the entire simulation model (Saunders et al 2007).

This study investigates the impact of harbor quay extensions on capacity and waiting time by utilizing simulation models. Based on the experimental studies performed with the help of simulation, the research can be considered thoroughly experimental. On the other hand, the research examines the processes of the port of Vaasa in their context, which is why the research is a case study. Therefore, the research can be considered as an **experimental case study** in strategy.

1.9 Research choices

Research choices can be made using mono-methods, mixed methods, or multi-methods. The mono-method uses either quantitative or qualitative methods. Mixed methods, on the other hand, combine quantitative and qualitative research methods. Multi methods use qualitative and quantitative methods, but separately, and do not combine them (Saunders et al 2007).

Based on the research questions, data, and expected results, the research is quantitative mono-methods research. On the other hand, creating a 3D simulation model involves a lot of qualitative questions, and the simulation model can be considered qualitative.
This research is carried out with the help of discrete-event simulation, where events follow each other, and all entered values and the values produced by the simulation are numerical. Therefore, the study is a **quantitatively implemented mono-method study**.

1.10 Time horizons

There are two different time horizons used in research. Cross-sectional and longitudinal. A cross-sectional time horizon means that a certain phenomenon is studied at a certain point in time. For example, different scenarios and their effects are studied (Saunders et al 2007). A longitudinal time horizon is again a diary-like description of events in a certain period. A longitudinal time horizon studies the change and development of a phenomenon along a timeline (Ruspini 2002).

This research makes use of a simulation model to study the behavior of the system and its capacity within a certain period. In this study, the simulation runs are run between 1 January 2024 and 31 December 2028. Therefore, the study is **longitudinal.**

1.11 Research limitations

The research must be defined in terms of the scope with which it studies the phenomenon under research. Therefore, the limitations of the research must be clarified to know what the research has not considered when studying the issue or phenomenon (Saunders et al 2023). All studies have limitations, which is why it is so important to reveal these limitations so that it becomes clear in what research conditions the results have been reached (Zikmund 2023).

The study simulates the effect of the quays and fairways of the port of Vaasa on the capacity. Cargo handling capacity or pilot capacity are excluded from the study. The study therefore expects that cargo handling capacity and pilot capacity will be able to handle all traffic without delays.

At the request of Kvarken Ports Ltd, the study deals with the effect of different scenarios and their growth on the capacity and waiting times of Lasse's quay. The growth scenarios are no growth in traffic, 5% growth in traffic, 10% growth in traffic, 15% growth in traffic, 20% growth in traffic, and 25% growth in traffic. The study does not examine situations where the volume of traffic to Lasse's quay is reduced.

The simulation was initially intended to be implemented with Visual Components 4.5 software. However, the software in question is intended for modeling production lines and warehouses (Visual Components 2024). Because of this, it became clear that the software in question was not the best possible way to implement the simulation, because, for such an extensive logistics simulation, too many compromises would have had to be made to make the logic work in the Visual Components. In addition, the computing power of the available computers would not have been sufficient to run the entire simulation.

For Anylogic, the limitations are related to the fact that ships arriving at Lasse's quay were divided into classes according to their length. This was partly because the Anylogic 8 PLE in use limits the number of logic blocks in the simulation. On the other hand, even if the ships arriving at Lasse's quay could have been implemented without classes and using the 2021-2022 ship data as such, creating random schedules for ships would have been more impractical.

1.12 Structure of the study

Chapter 2 is a literature review where the reader is introduced to the basic definitions and concepts of simulation modeling, maritime transport, and layout design. In the basic definitions, the concepts of system, layout, layout optimization, and FIFO are made clear to the reader. In the Modeling & Simulation section, the reader is introduced to the concepts of 3D modeling, simulation, digital twin, and discrete-event simulation. In the maritime operations section, the reader is introduced to the concepts of maritime transport, marine terminal layout design, RoRo, liner traffic, ROPAX, and CONRO.

Chapter 3 is Methodology, which contains information about the methodology used for the research. The chapter reviews the quantitative methods used in the research, as well as the discrete-event simulations used in the research.

Chapter 4 discusses the verification and validation of the simulation model. The chapter discusses how it can be stated that the simulation model in question describes the operation of the real system sufficiently well.

Chapter 5 discusses the results of the study and the tools used to achieve them. In the results, the data collection and its analysis are first presented. After this, the Anylogic 8 PLE software used in creating the simulation is presented. After that, the parameters used in the simulation are presented in the form of schedule data and waiting time distributions. After that, four different simulation scenarios are presented, as well as their simulation results with six different growth scenarios, i.e., no growth in traffic, 5% growth in traffic, 10% growth in traffic, 15% growth in traffic, 20% growth in traffic and 25% growth in traffic.

Chapter 6 discusses the research summary, conclusions, presents managerial implications, and makes recommendations for future research. The chapter answers the research questions and thus provides clarity on the problem being investigated in the research.

2 Literature review

The literature review provides an overview of the literature and research on the topic. The literature review helps the reader understand what is already known about the topic (Onwuegbuzie 2016). The literature review also shows that the author of the study has mastered the previous research on the topic and the central theories of the field, as well as their application (Hart 2018).

2.1 Basic definitions

This section introduces basic definitions related to research, such as system, layout, layout optimization, and FIFO.

2.1.1 System

The world is full of different systems. Understanding these systems and their operation is very important for researchers who strive to understand how a certain phenomenon or entity works (Tripto et al 2016). According to Dori et al (2020), the system can often be defined in different ways. Different viewpoints often emphasize to different degrees whether systems occur concretely in the real world or whether they are mental constructions. Systems can also be divided into systems created by humans or systems naturally occurring in the universe. However, for the sake of expediency, this study will focus on man-made systems that are tangible in the real world. Law (2015) describes a system as a group of entities, for example, individuals or devices, that interact with each other to achieve some logical result. On the other hand, the definition of the concept of the system is affected by the form and purpose of the system in question.

Dori et al (2020) describe the features and criteria of the system as follows. A system is a holistic entity that has a specific task and goal that it strives for with its activities. the system must be able to perform the function or functions for which it is designed. The object of the operation is an object inside the system or outside the system. The functions of the system also have a certain hierarchy, according to which the processes in the system work. The system groups its activities into a unified whole. Systems consist of units between which a hierarchical or internal structure prevails (Haray & Batell 1981). The system has a relationship with its environment and the system implements the exchange of matter, energy, and information with its environment. Communication within and outside the system is also important for the existence of the system. The system must also be able to process feedback and optimize its operations based on feedback (Dori et al 2020).

A system can also be defined based on how the variables of that system change. In a discrete system, the variables change over time in a certain order immediately, while in a continuous system, the variables change smoothly all the time (Law et al. 1991).

2.1.2 Layout

The term Layout refers to the locations of physical parts of production facilities, logistics facilities, or service facilities, such as machines, equipment, storage areas, and passageways in the organization's premises (Haverila et al 2009). Layout means how the organization's premises and process points are laid out according to the plan. Layout planning is influenced by the organization and its operational goals, the available infrastructure, and the targeted number of processes in the network, workspace, or workstation in question (Kikolski & Chien-ho 2018).

Layout planning aims to influence the fact that the available infrastructure can be used as efficiently as possible so that processes can be carried out in them as efficiently as possible and in accordance with the purpose (Kikolski & Chien-ho 2018). In layout planning, the key is to place production factors in the organization's premises so that they support the organization's strategic goals as effectively as possible. Layout affects the efficiency of production systems (Pérez-Gosende 2021). According to Drira et al (2007), an effective layout enhances the company's processes and can, in the best case, reduce up to 50% of the organization's operating costs.

In planning, the aim is to create a layout that is appropriate, effective, and cost-effective. The aim is to utilize the ready infrastructure as efficiently as possible. The efficiency of the infrastructure is often related to how well different functions have been placed in the layout (Kikolski & Chien-ho 2018).

2.1.3 Layout optimization

Hosseini-Nasab et al (2018) describe layout optimization as decisions about placing the organization's functions on its premises. The goal of layout planning is to determine the most efficient layout solution, considering the limitations of the organization's premises, such as the size, shape, and grouping of the premises. Layout optimization focuses on the structure of the layout, its efficiency, and increasing speed. It is important to collect as much data as possible from the processes and analyze this data to find out the need for improving the layout. The optimization of the layout and the superiority of different options are decided by one or more criteria, with different weights. An optimal layout shortens the cycle time, lowers costs, and improves the use of resources (Kikolski & Chien-ho 2018).

The optimized layout guarantees a smooth and even flow of material, machines, and labor flow cost-effectively. Layout optimization aims to use the spaces as efficiently as possible. Because of this, layout optimization aims to achieve the most efficient workflow possible, so that facilities, machines, and employees can produce as much as possible (Abdel-Malek et al 2005).

Several different methods are used in layout optimization. For example, mathematical, systematic, and visual methods. In optimizing the layout, it is important to understand the dependencies between the various functions of the system in question, links, material flows, lot sizes, processing times, available workforce, resource limitations, and time limits. When performing optimization, all external and internal factors that affect the operation of the layout must be considered (Kikolski & Chien-ho 2018).

Designing an optimized layout begins with the compilation and analysis of parameters. After this, the optimization method/methods are selected. The created models are analyzed, and the obtained results are compared. Finally, the most optimal solution is selected. Simulation models are indeed very useful in optimization planning, as they do not interfere with the organization's daily operations (Kikolski & Chien-ho 2018).

2.1.4 FIFO

FIFO (First In, First Out) is a storage and inventory method in which the products or materials that are taken into the warehouse first are sold or used first. In other words, the oldest items that arrive in the warehouse are sold or used first, and the newer items after them (Alarmi & Syntetos 2018). In the FIFO method, the value of the inventory is calculated by assuming that the oldest items that entered the warehouse leave first, which also affects accounting and inventory valuation (Sembiring et al 2019).

FIFO queuing is a queuing method where the customer or task that arrived first in the queue is served first. This means that queued customers, tasks, or objects are processed or served in the order in which they arrive (Mustafa & Talab 2016).

The FIFO queuing principle is often used, for example, in customer service situations where people are waiting for their turn (Naufal et al 2023), or in computer systems, where processes are waiting for execution (Mustafa & Talab 2016). This method helps ensure equal treatment and reduces potential delays or unfairness between those in the queue (Naufal et al 2023; Mustafa & Talab 2016).

2.2 Modelling & Simulation

In this section, concepts related to modeling and simulation are presented as versatile as possible.

2.2.1 3D modeling

3D modeling refers to the creation of a digital 3D model of an object, system, scenario, or process. 3D modeling therefore means the three-dimensional reconstruction of objects and entities in the digital world. 3D modeling is applied in many ways. For example, in visualizations, navigation, and simulations. 3D models are present almost everywhere today (Remondino & El-Hakim 2006). In 3D modeling, it is necessary to consider the use of the model. 3D models are often used in computer-aided design and various simulations. Most products and systems use 3D modeling today. The requirements for the accuracy of the model and its technical characteristics depend greatly on their intended use (Mcdonald et al 2001).

The implementation of 3D modeling begins with the collection of data related to the object of modeling and ends with a virtual 3D model in computer software. Creating simple models looks easy, while complex models are challenging to create. (Remondino & El-Hakim 2006).

2.2.2 Simulation

Simulation refers to when a computer program imitates or simulates the premises, phenomena, and processes of a real system. Scientific assumptions are made about the operation of the system. Assumptions are made about the mathematical or logical relationships of the system. Based on these assumptions, a model is created, which is used to understand the operation of a system. If the relationships of the system are simple, it is possible to use mathematical means to get exact answers. This is called an analytical solution. However, many real-world systems are too complex for this (Law 2015).

Computer modeling became common after the Second World War when it started to be used to analyze different scenarios of different systems. It was used to evaluate the performance values of production, logistics, and storage systems in different scenarios, and it was used to make better decisions when the decisions could be justified with the data obtained with the help of the model. Different production and layout options were easier to compare with each other using computer simulation models (Altiok & Melamed 2007).

With the help of simulations, the functionality, efficiency, and usefulness of expensive investments can be determined without an expensive construction process. Simulations have several uses. For example, the design and analysis of production systems, design and operation of transport systems, analysis of supply chains, analysis of the structures, and design of service organizations. Simulations are indeed one of the most used operation research and management techniques (Law 2015; Helo et al 2019).

Simulating large and complex systems can be very challenging. Complex systems may have to be divided into smaller parts that are simulated. Dividing into smaller parts can leave out variables that are important for the whole, so dividing a complex whole into smaller simulations must be planned well. Modern simulation software and advanced hardware are capable of even wider and more comprehensive simulations (Law 2015).

The use of simulation makes sense, as simulation enables the study and experimentation of complex systems without expensive investments. With the help of simulation, changes planned for organizations can be planned in a virtual environment and the effects of the changes on the organization can be evaluated. The effects caused by changes in the simulation inputs can be evaluated in a variety of ways, with the help of 3D simulations, the operation of the system as a whole can be visually presented (Banks et al 2010).

It is also necessary to understand when the use of simulation does not make sense. Like when simulating problems that are too simple or that can be solved by common sense is not appropriate. It is also not reasonable to simulate problems that can be solved analytically. If doing direct tests and experiments is cheaper than simulation, then simulation is not a reasonable method. There must be reasonable expectations about the results of the simulation (Banks et al 2010).

2.2.3 Discrete-event simulations

Discrete-event simulations involve modeling the system as a series of discrete events or stages, where each event occurs at a specific time. These events can be described by their characteristics such as arrival time, duration, and resource requirements. The simulation proceeds by processing each event in sequential order, and the system state is updated based on the outcome of each event (Banks et al 2010). Choi and Kang (2013) define a discrete-event system as a system designed to handle certain types of objects with certain types of resources. Greasly and Edwards (2021) describe the simulation of discrete events as modeling a system with a time-evolving representation where the state changes instantaneously at different points. At these respective points in time, some discrete event occurs that results in a change in the state of the system. Examples of discrete-event simulations are queuing systems, warehouse systems, hospitals, assembly lines, restaurants, and traffic systems (Banks et al 2010; Choi et Kang 2013).

Discrete-event simulations often also include probability elements. In general, the input systems of various actors and events work on the principle of probability. It is therefore important to plan carefully how to model the probability factors of the simulation, such as arrival, waiting, and service times so that the simulation matches reality as closely as possible (Choi & Kang 2013).

2.2.4 Digital twin

A digital twin is very useful for connecting physical systems and digital spaces. The definition of a digital twin is a digital copy of a physical object or system. With the help of a digital twin, real physical systems can be designed, analyzed, optimized, predicted, and sorted. Different applications of augmented reality are also examples of the versatile application possibilities of the digital twin (Zan 2024). Digital twins represent real objects or entities in the digital world. A digital twin is a digital duplicate of a real-world device or system that aims to model real-world system functions, behaviors, and dependencies as realistically and consistently as possible (Schulse et al 2018). The digital twin must also consider the environment and interactions that affect the digital twin. The term is closely related to industry 4.0, as the digital twin enables a better understanding and reporting of the performance and behavior of devices and systems (Pang et al 2021). Some digital twins imitate their target's behavior more closely than others. It is therefore necessary to define the minimum level that is required of the model. So that its results can be considered valid (Batty 2018).

Digital twins can be used for many different purposes. For example, Siemens uses them to optimize and monitor products, production, and performance. (Pang et al 2021) Digital twins are often used inside the real system to manage intelligent systems and user interfaces, as well as training systems (Schulse et al 2018).

The simulation can be used to observe the operation of the digital twin and test how modifications affect the system. It is practical to compare the effects of the changes in a digital environment to get information about the real effects and performance of the changes for decision-making. It makes sense to evaluate the effects of changes on complex entities through a digital twin. On the other hand, complex systems require a large amount of data and detailed modeling of dependencies from the digital twin. Models can be developed from many sub-assemblies and combined at the system level. (Sculuse et al 2018). The massive amounts of data produced by digital twins create challenges for data processing (Pang et al 2021).

2.3 Maritime operations

In this section, the terminology and concepts related to maritime transport are introduced to make the study easier to understand.

2.3.1 Maritime transport

Maritime transport refers to the transfer of cargo and passengers between different ports on ships. Maritime transport has grown throughout history. (Tapaninen 2018) The growth of maritime traffic has always been directly or indirectly related to global revolutions and changes (Leggate et al 2004). Today's international supply chains require efficient maritime transport. Products are often not manufactured and used in the same country, whose transport by sea is necessary due to the large capacity of maritime transport. Maritime transport takes place largely between industrialized countries. 83% of Finland's foreign trade goes by sea (Tapaninen 2018). Maritime transport internationally transports 80% of all goods. For this reason, maritime transport and its uninterrupted operation is very important, and crises such as wars and other disruptions to maritime transport have a significant impact on the world economy and its growth (Węcel et al 2023).

Sea freight is divided into bulk cargo and unit cargo. Bulk cargo is not separated into packages or units. Bulk cargo is, for example, grain and oil. Bulk cargo usually fills the entire ship, and no other cargo is suitable for transport. Unit cargo transport means containers, trucks, and trailers. There can be several units on board. Different ships are used for different cargoes. Container ships and Ro-Ro ships are used for unit cargo transportation. Containers are loaded on board with a crane and wheeled cargo drives onto the ship via a ramp (Tapaninen 2018).

An important factor in the productivity of sea transport is the transport speed, as well as the minimization of the time spent in the port. The faster the port operations are handled, the faster the ship can start carrying new cargo and thus earn income. Efficient cargo handling equipment, standardized cargo (containers), loading and unloading speed of wheeled cargo, and port layout planning help minimize port time (Tapaninen 2018). Shipping company operators strive to improve their competitiveness by acquiring larger ships and preferring ports where the loading and unloading of cargo is handled most efficiently. This results in more efficient ports having a significant competitive advantage (Leggate et al 2004).

The pursuit of sustainability values is also important in modern sea traffic. Sustainability is pursued through more efficient ways of using energy, with less polluting fuels, and by making the operation of ships more efficient from a sustainability and environmental perspective. In particular, the operation of ships could be made more efficient from an environmental point of view by better planning the operation of ports and fairways. The cooperation of the entire industry is very essential so that better operating methods can be used as widely as possible (Orosa 2023; Trodden et al 2015). As other forms of transport gradually move to more sustainable solutions, the environmentally friendly development of maritime transport is slow. Maritime transport is the only form of transport whose greenhouse gas emissions have increased since 1990 in the EU. Considering the large amount of traffic, sea traffic must be made more environmentally friendly than it is today (Yliskylä-Peuralahti 2017). Maritime traffic is responsible for 25% of the EU region's greenhouse emissions, which is why reducing maritime traffic emissions would be very important in terms of climate goals (Krzykowska-Piotrowska et al 2020).

2.3.2 Marine terminal layout design

Maritime terminals are very important hubs for international supply chains. Therefore, it is important that they work efficiently and that their operation is as well optimized as possible. The layout optimization of maritime transport terminals includes, for example. quay layout and cargo handling areas layout (Wawrzyniak et al 2024). All types of ports need a layout design that supports their intended functions and makes the functions as appropriate and efficient as possible (Diab et al 2017). In small and medium-sized ports, the need for optimization is often very important, as their shorter piers and lack of space often require better planning (Grubisic et al 2020). Pier capacity and ship loading and unloading time are very important factors in optimizing port operations and therefore layout optimization must take these into account (Bierwirth & Meisel 2010). A well-planned layout increases the performance of port operations (Abu-Aisha et al 2021). The new layout plans must enable faster, cheaper, and more efficient handling of goods and passengers in the port area. Today, ports must handle even bigger ships, faster than before. This requires improving the layouts. Although technologies have developed, the basic harbor layout has not fundamentally changed over time (Gharehgozli et al 2020).

STEP		Decision level
1	Layout analysis & design	Longtime, strategy
2	Design optimization, optimizing configurations & operations	Medium term, tactical
3	Operations planning & control, studying impacts	Short term, operational

Table 1 a three-step framework for port layout design (Gharehgozli et al 2020).

Table 1 gives an overall picture of the phases of layout planning and the effects of these phases on the operation of the port. Port layout design is an important strategic decision that also affects other functions and decisions. In the medium term, it can be influenced by optimizing planning and optimizing operations. Several studies focus on optimizing existing layouts because planning and implementing new layouts is very expensive. Short-term actions are planning and control of operations, as well as impact assessment (Gharehgozli et al 2020).

According to Daib et al (2017), port layout planning is an optimization problem that is limited by constraints. These constraints are divided into environmental constraints, structural constraints, maneuvering constraints, and fluid-mechanical constraints. Environmental constraints are water quality, water height, water depth, ecology, ice, and noise. Structural constraints are economic constraints, such as costs, materials, and construction processes, as well as mechanical constraints. Maneuvering constraints are related to entrance, fairways, and maneuvering areas. Fluid-mechanical constraints are the effects of waves, erosion, and flooding. The effects of waves are considered very important when building on coasts. The layout design must consider what kind of ships are operated in the port now and in the future so that the design does not create restrictions for the operation of the port.

When planning the layout of ports, a wide variety of things must be considered, which is why mathematical, statistical and simulation models are used in decision-making. (Dalb et al 2017) Due to the complexity of the problems, most studies related to the topic use various simulations to help describe and solve the problems (Gharehgozli et al 2020).

In the future, in layout planning, we will think about sustainability in addition to costs and efficiency. Layout affects, for example, the generation of emissions and changes in the environment (Abu-Aisha et al 2021). When planning the port layout, sustainability aspects must also be considered, as an inefficient and poorly designed layout may produce clearly more CO2 emissions than a layout that takes environmental factors into account better. Energy can be consumed if a lot of extra movements must be made when loading ships, such as moving ships in the middle of loading (Budiyanto et al 2021). Climate change will also affect the water level and natural phenomena, which should be considered when planning the layouts (Dalb et al 2017).

2.3.3 RoRo

RoRo ships (Roll-On/Roll-Off) are ships whose cargo is vehicles equipped with rubber wheels, such as trucks. The operation of Ro-Ro vessels is very efficient in the port, as the wheeled vehicles drive themselves out through the ramp, and there is no need to load and unload the cargo with cranes, which is slow (Christiansen et al 2021). As a form of transport, RoRo-vessels speed up transportation significantly, because cargo travels from the point of departure to the destination on the same wheeled vehicle. (Christodoulou et al 2019).

2.3.4 Liner traffic

Liner traffic refers to the regular and frequent route traffic of transport vessels, such as container ships or other cargo ships, between certain ports. The business model of liner transport is based on pre-planned schedules and routes, and it is common, for example, in container transport and RoRo transport. With Liner Traffic, companies, and transport operators can offer reliable and regular transport services (Schlar 1988). Liner traffic is the most common mode of transport in the Baltic Sea, especially in Ro-Ro traffic (Tapaninen 2018).

Liner service is a service that transports large amounts of cargo on ships that follow regular fixed routes according to fixed schedules. Generally, liner traffic uses either RoRo ships or LoLo (Lift-on/Lift-Off) ships (Christiansen et al 2021). Liner traffic is divided into feeder routes and long-distance routes. Long-distance routes operate between large hub ports on different continents, while feeder routes transport cargo from smaller ports to these hubs (Meng & Wang 2015).

2.3.5 ROPAX

ROPAX is an acronym that stands for "Roll-On/Roll-Off Passenger" or "Roll-On/Roll-Off Passenger Ship". A ship designed to carry both passengers and roll-on roll-off (Ro-Ro) cargo. ROPAX ships are very flexible and practical. Thus, they are suitable for many routes (Endrina et al 2018). The routes operated by ROPAX vessels have been called motorways of the seas, as they connect passenger and freight traffic routes across the seas (Morales-Fusco et al 2018). ROPAX ships are often used as part of multimodal transports, where different transport methods such as land and sea transport are used, to make supply chains as efficient as possible (Marzano et al 2020).

2.3.6 CONRO

CONRO or Container & Roll-on Roll-off ships can transport both containers and traffic on wheels, making the ships efficient, as they can integrate different forms of cargo into one type of ship (Zhou et al 2023). With the help of CONRO vessels, the transport of different types of cargo can be combined on the same vessel, which makes it usable also between smaller ports (Daduna 2013).

3 Methodology

The purpose of the methodology chapter is to explain how the research was carried out. What research methods have been used to achieve the research results? The methodology acts as a kind of instruction book on how to repeat the same research so that the results are the same (Saunders et al 2007). The researcher must choose a research method. which is most appropriate for the study in question and follows the chosen method throughout the study (Bairagi & Munot 2019). The methodology is a key part of research planning and implementation because it helps the researcher to define goals, decide the methods and tools to use, and interpret the results (Quinlan 2011).

The simulation type is a discrete-event simulation, where the events of the system follow each other over time. Ships arrive and depart and their logical behavior patterns in the simulation follow each other over time (Banks et al 2010). DES creates a simulation model in which different events follow each other in time. DES models are controlled by the clock and chronological event lists, where events follow one another according to the logic of the simulation model (Altiok & Melamed 2007). In supply chains and logistics systems, events follow each other as described above, so DES is a useful tool for simulating the behavior of these systems (Goth 2010). In DES models, the simulation model has a state S, which is bound to a certain point in time. This state contains a data set that contains the values of the variables of the simulation model at that moment in time. Such information can be, for example, the number of simulation agents in the queue, the arrival and departure times, and the location in the model. In this way, the state of the system can be defined based on the values of these variables. State S therefore describes the state of the system at a certain point in time. Calculations can be made based on the values stored in the state's data set, which can be used to find out, for example, the utilization rate of one of the model's functions or the average waiting time in the queue (Altiok & Melamed 2007).

The trajectory of the state over time S(t) is implemented as a step function, the different steps of which cause discrete events that can change the state of the system at certain times. In DES models, events follow each other according to order, and the execution of events changes the state of the model. The state of the model only changes because of events (Altiok & Melamed 2007).

This study is implemented quantitatively as its primary and secondary data are numerical. The information obtained from the simulation is also numerical and the results are analyzed using numerical methods, such as calculating the average of the results and creating correlations based on the results (Saunders et al 2007). The information stored in the variables of the discrete-event simulation is also numerical, as they tell the departure and arrival times of different ship types to the waypoints of the simulation model. Based on these variables, with the help of the statistical and mathematical functions of the simulation model, it is possible to calculate the average waiting times and the utilization rates of different resources, which can be used to conclude the study.

In Anylogic, Little's law can be used to calculate the average waiting time, which can be used to determine the average waiting time of a queue. The equation in question describes the average time spent in the queue. The equation is of the form

$$W = \frac{N}{\lambda} \tag{1}$$

In the equation, W is the average waiting time, N is the average queue length, and λ is the average arrival speed of incoming units in the queue (Shaw 2016).

In this study, the averages were calculated in Excel using the mean, as it was much more appropriate.

$$Average\ Waiting\ Time\ = \frac{Sum\ of\ all\ waiting\ times}{Numbers\ of\ entities\ waiting} \qquad (2)$$

(Iversen & Gergen 1997)

The utilization rate studied in the simulation model was calculated using the utilization rate formula. This calculation was automatically calculated by the Anylogic 8 software using the "UtilizationStats" property of the ResourcePool block.

$$Utilization\ = \frac{Total\ busy\ time}{Total\ time} \qquad (3)$$

(Karjalainen 2012; Anylogic 2023)

4 Verification & Validation of the simulation model

Various simulation models are used to solve problems and help in decision-making. It is very important that the simulation models and their outputs are valid and that there are ways to verify their correctness (Sargent 2010). However, the model should not be evaluated separately, but always in relation to the real context (Foures & Nketsa 2016).

The following concepts are important for model verification and validation:

- **Model verification**: It ensures that the model and its implementation are correct, appropriate, and made with sufficient accuracy
- **Validation of the model**: The purpose is to ensure that the simulation model produces reliable results and that it represents the real system or phenomenon with sufficient accuracy.
- **Credibility of the model:** The simulation model develops the confidence in users that they need to use the model and that they trust the information produced by the model. (Sargent 2010).

According to Altiok and Melamek (2007), simulation creates a simplified representation of the system under study. However, it is important that all the most important variables are considered, and that the constraints are clearly expressed. The accuracy of the model must be at an acceptable level. It is often too expensive to determine whether a model is absolutely valid. Therefore, it is most important to ensure that the model is sufficiently accurate for the most important and sensitive variables. In this way, sufficient confidence can be achieved that the model is suitable for its intended use (Sargent 2010). Often the model must be simplified a bit. Simplification means that some of the scope or detail of the actual system is removed or presented more simply. In this case, it is important to consider that the simplification process does not reduce the sufficient accuracy level of the model (Stewart et al 2010). In the validation of the simulation model, it is important to check that the requirements of the real system set for the model are met (Foures & Nketsa 2016).

Two basic approaches are used to validate the model. Firstly, the users of the model are involved in determining the validity of the model with the development team. Users of the model have information about the functioning of the real system and what things the model should tell. Therefore, the participation of users in evaluating the validity of the model helps to produce usable simulation models. Another way is to use a third party to determine the validity of the model. This produces an independent validation of the model. Validations produced by a third party are very important in large simulation models. However, it must be ensured that the third party performing the validation controls the purpose of the simulation model at a sufficient level (Sargent 2010).

The following techniques are used in the validation of simulations:

- **Animation:** Make sure the model works as it should from a graphical perspective.
- **Event validity:** Events in the simulation model are compared to events in the real system to find out that the behavior is similar.
- **Extreme conditions test:** The simulation model and its results must be believable even in extreme cases and when different rare cases occur simultaneously.
- **Face validity:** Someone familiar with the real system finds out whether the model and its functions sufficiently correspond to the real system.
- **Validation of historical data:** The data accumulated from the operation of the system is compared with the data of the simulation model to verify that sufficient accuracy is met.
- **Historical methods:**
    - **Rationalism:** If the background assumptions are correct, logical conclusions can be used to develop the right kind of model
    - **Empiricism:** Every assumption and result should be empirically validated.
    - **Positive economics:** The model must be able to predict future events.
- **Internal validity:** Several stochastic models are run on the simulation model to determine the amount of variation in the model. Too much variation can make the model's results unreliable.

- **Multistage validation:** Combining three historical methods into a multistage validation process.
    1. Assumptions about the Model's theory, observations and general knowledge are developed
    2. Validation of assumptions through empirical testing
    3. Comparing input-output ratios with real system values
- **Sensitivity analysis:** Different parameters of the simulation model are changed and their effect on the model and its outputs is defined. Parameters whose influence causes significant changes to the model and its results should be implemented as accurately as possible.
- **Predictive validation:** The model is used to predict the behavior of the system. These predictions are compared with actual information about the system.
- **Traces:** The behavior of certain functions of the model is observed and compared with reality.

(Sargent 2010)

The simulation model of the port of Vaasa can be validated with several different techniques. The model works graphically as it should. The simulation model models the port of Vaasa, its quays, and fairways. Ships follow planned routes and quays. The events of the simulation model correspond to real events. The arrival and departure times of 2021 and 2022 were entered into the simulation model. The model worked as planned and the ship schedules were the same as in those years. The speeds on the fairway and the sailing time on the fairway also corresponded to the real world. The model was also validated by presenting its modeling, logic, and behavior to the port's staff. They validated the model and found it to match reality. The model was also internally valid as the results of the model with different schedule versions were believable, and there was not too much variance between tests if the annual volume of vessels remained the same.

5 Results

5.1 Data collection and data analysis

Data can be collected from primary or secondary sources. Primary data is data that is collected during the study. Secondary data is data that was originally collected during another study (Saunders et al 2007). In this study, **secondary data** is used, as the research data is the 2021-2022 traffic data obtained from the case organization, the sizes and restrictions of the fairway and quays, the priority of ships, information on the handling of ships in the port, and a literature review. The simulation produces **primary data** from different simulation model options, which can be analyzed with the help of Excel.

It is also important to make sure that the data is valid because the simulation works on the principle of garbage in, and garbage out. That means that, if the data entered the simulation is wrong, the results will also be wrong (Saunders et al 2007). Data validation is important so that the results of the study and the conclusions drawn from them are valid (Sapsford et al 2006).

In the data analysis, the schedule data was classified by ship and quay and entered into the simulation model, along with other data. In the simulation model, different layout solutions are analyzed in terms of capacity performance. Output data was analyzed with the help of Excel.

5.2 Anylogic 8 software

Anylogic is a multi-method simulation software created by The Anylogic Company. The software can be used to create three types of simulation modeling: system dynamics, discrete event, and agent-based modeling. Different simulation methods can also be combined into multi-method simulations (Grigoryev 2023; Anylogic 2024). The first

Anylogic version, Anylogic 4.0, was released in 2000. It was based on the Covers software previously created by the same company. The first version of Anylogic modeled discrete and continuous simulations (Anylogic 2024). Today, Anylogic can be used to create simulation models on a very large scale, such as consumer behavior models, infectious disease models, supply chain models, traffic models, pedestrian behavior models, and even war simulations (Grigoryev 2023). Anylogic software includes a versatile 3d object selection that covers factory environment, logistics, sea traffic, air traffic, rail traffic, road traffic, and pedestrians. With the help of these objects, it is possible to implement 3d modeling of the model. It is also possible to import your own CAD objects into the software if the ready-made models are not enough (Borshchev & Grigoryev 2013).

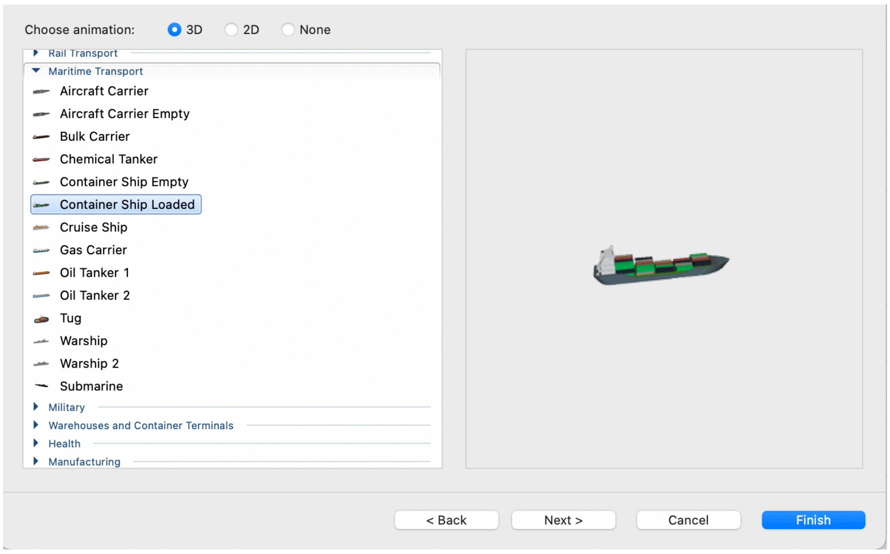

Figure 4 3D objects

Figure 4 above, is an example of the agent's animation from the object selection window, where you can see a large number of ready-made objects. 3D objects can be used both as agents and as static elements.

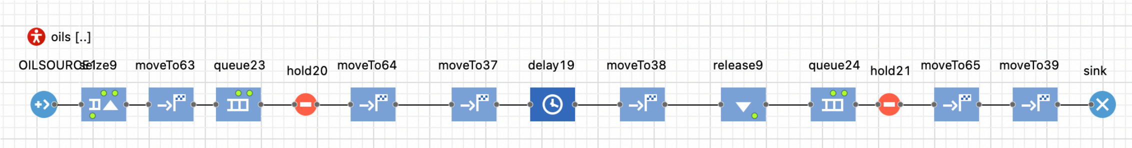

Figure 5 Process modeling example

The logic blocks of the Process Modeling Library are used to create the logic of the model. **Figure 5** shows the logic modeling the traffic of the oil quay. The source block at the beginning creates the ship according to a certain logic. The arrival of ships in the source block can be determined, for example, based on the annual total, an interval, or an Excel schedule. The Seize block reserves quay space and within the seize block the queuing of ships and queuing priorities are defined. MoveTo blocks define which route and at what speed the agents move between the defined waypoints. The delay block can be used to define the waiting time of ships at a certain location. In the example, it is the time spent by the agent at the quay. The release block releases the unit reserved in the seize block. The sink block removes the agent from the simulation. In the queue block, queuing can be implemented according to the defined conditions. The hold block stops the agent according to the specified conditions. In the logic shown in **Figure 5** hold and queue blocks are used to create a waiting mechanism for a section of the fairway where neither ship can’t meet or pass each other.

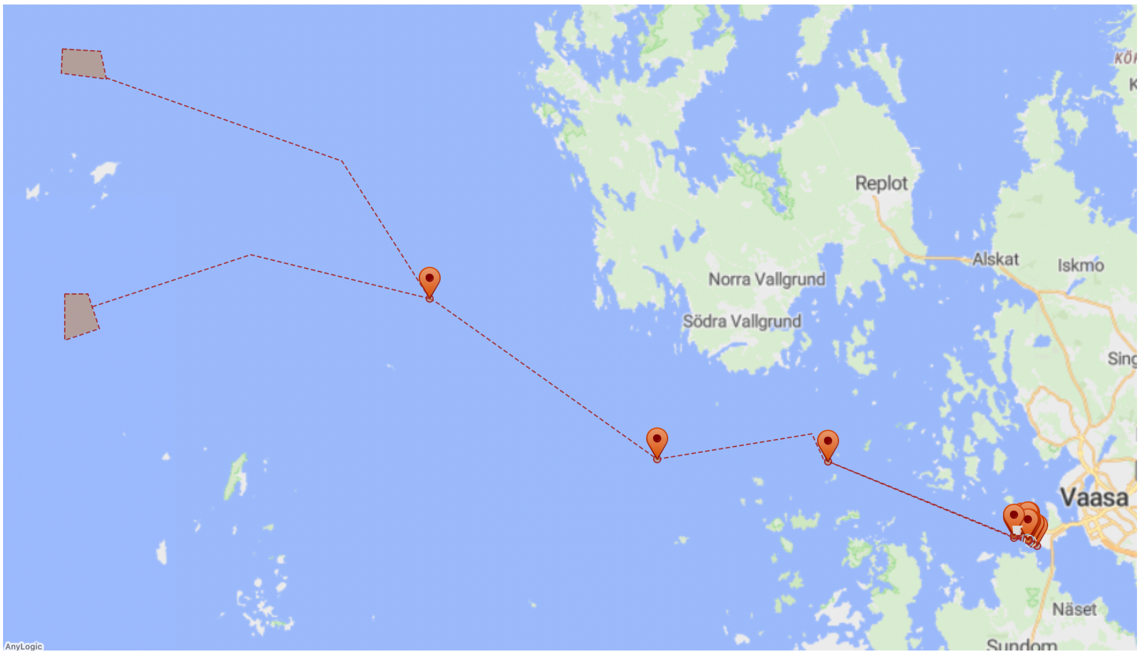

Figure 6 GIS map

In the Anylogic software, you can create the visual appearance of the model on top of the base image, or you can use the interactive GIS map provided by Anylogic. A GIS map is a map of the entire globe, and, for example, roads are already defined. **Figure 6** shows the area of the GIS map that was used to create this simulation model. Waypoints, routes, and areas can be created on the GIS map, which can be used in creating the logic of the model. For the blocks of the process modeling library, you can define in which location the logic of each block is implemented.

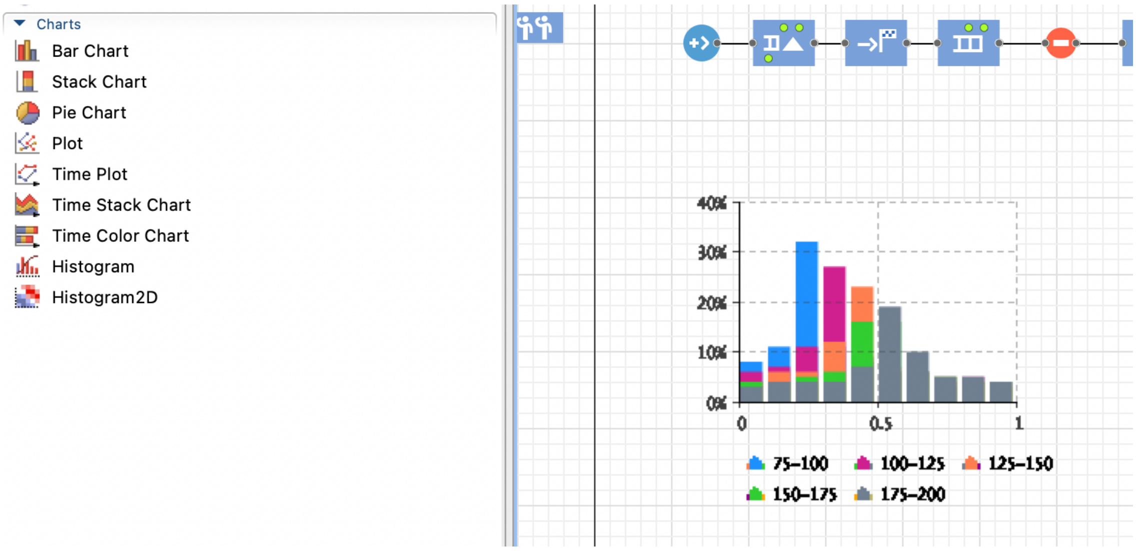

Figure 7 Statistics example

Anylogic also includes several different data collection and analysis tools. In **Figure 7**, on the left, there is a list of possible graphs that can be used to define how different data from the simulation is presented and collected. On the right, you can see a graph that accumulates data about agents by category. Statistical data can also be transferred directly to an Excel file, in which case they can be analyzed using Excel.

5.3 Model structure

The simulation model was created to model the port of Vaasa with its quays and fairways. An interactive GIS map was used as the basis for the modeling, on which quays and waypoints of the fairways were created with the help of GIS points. These points were connected using the GIS routes along which the ships move in the simulation. The waiting areas at the beginning of the fairway were created in GIS regions. The location of GIS points is based on their actual coordinates.

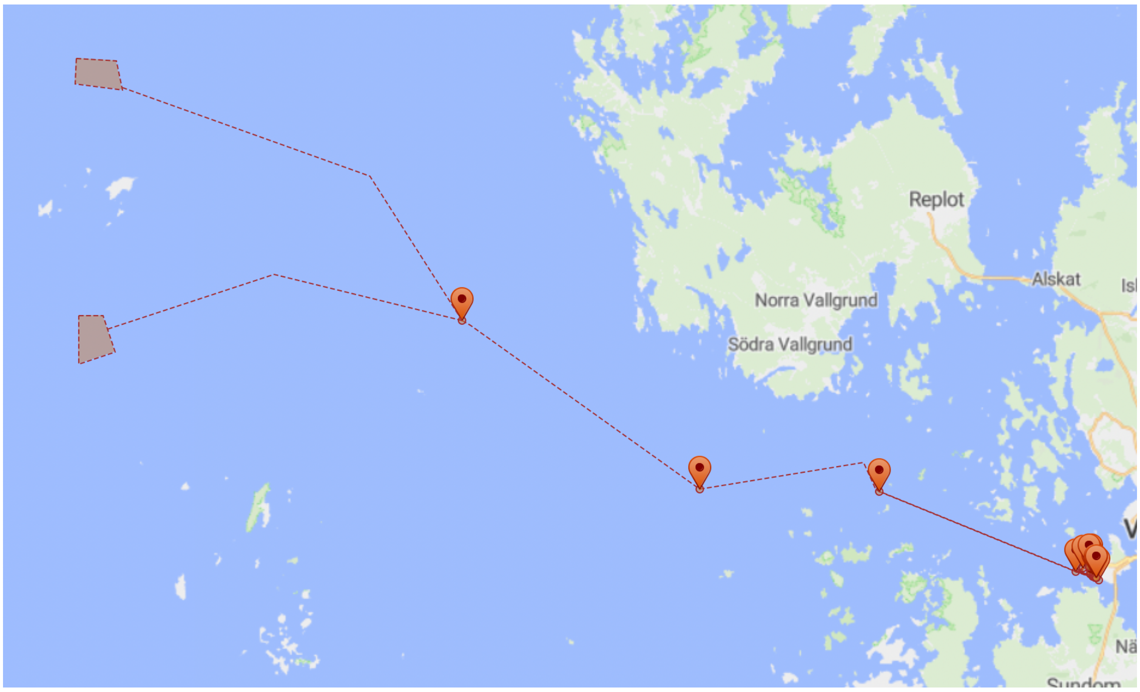

Figure 8 GIS map

Figure 8 shows the entrance fairway into the port of Vaasa. The fairways and waiting areas are marked with GIS routes and regions.

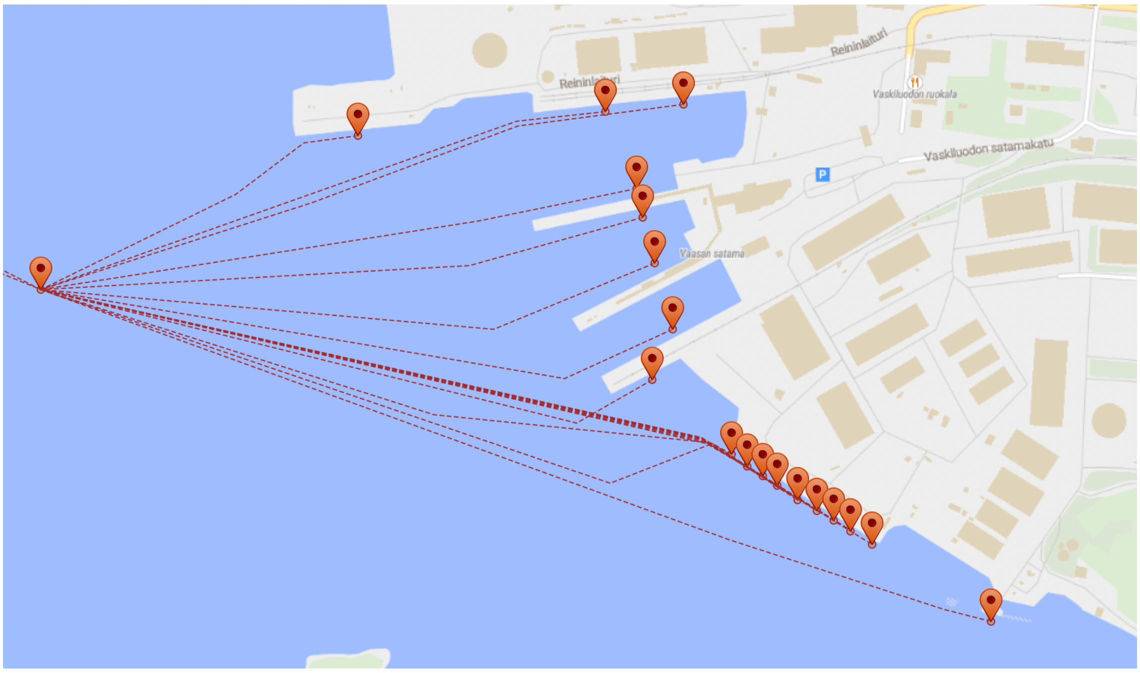

Figure 9 Present layout

Figure 9 shows a modeling of the layout of the port of Vaasa in the present scenario. The different GIS points present different quays. With the capacity of Lasse's Quay at the center of the study, it has been divided into 25-meter sections, allowing a certain section of the quay to be reserved according to the length of the ship.

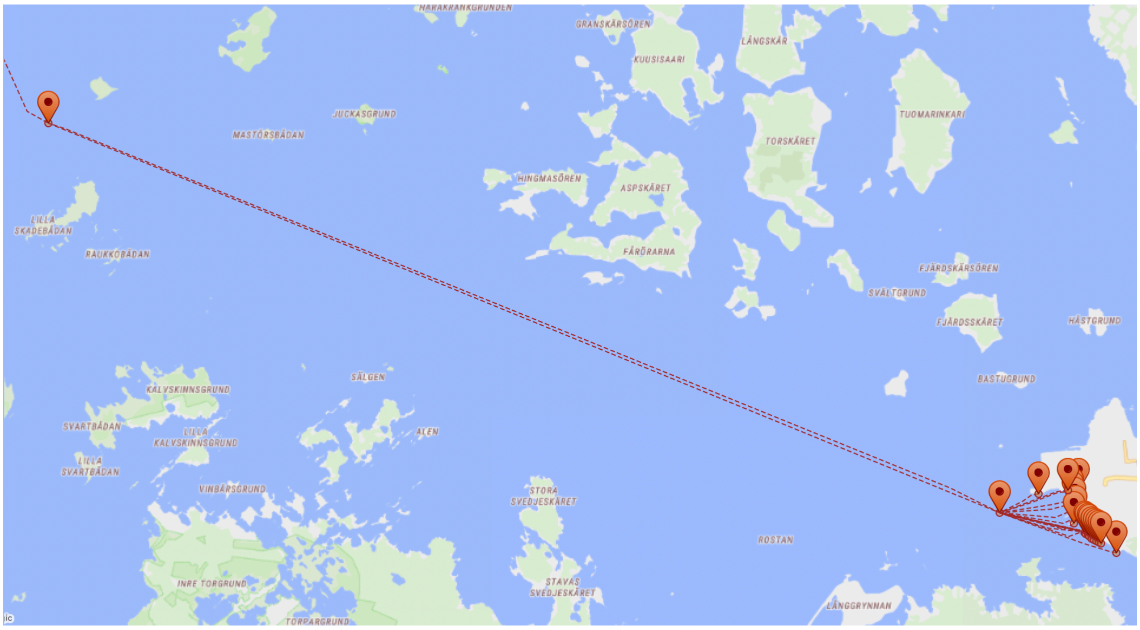

Figure 10 Last part of the entrance fairway

Figure 10 shows the last part of the entrance fairway. The fairway is so narrow that ships cannot meet or pass in it (Väylävirasto 2023). For this reason, a logic was created in the simulation model, where when the ship arrives, it is checked that there is no encounter on the fairway.

5.3.1 Ships

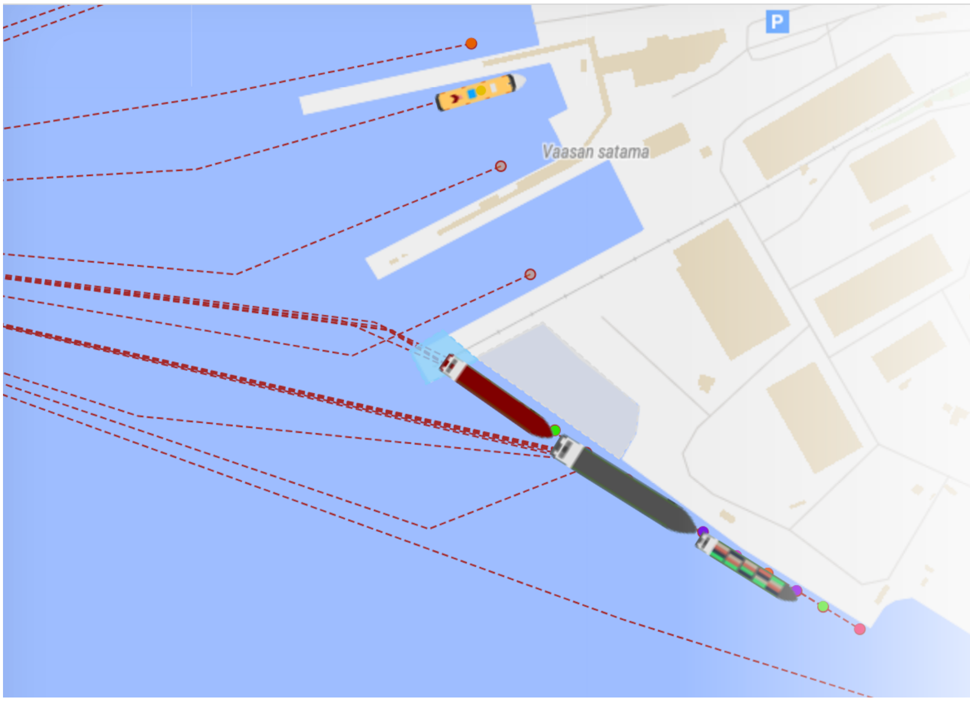

Figure 11 Ships in the harbour of Vaasa

Ready-made models offered by Anylogic were used as 3D models of the ship agents in the simulation. There were five different ship types: ROPAX, oil tanker, bulk carrier, container ship, and CONRO ship. In addition to this, the Container ships were of different lengths and colors so that the different variations would be better visible. **Figure 11** shows ships at the quays.

The simulation based on the GIS model has two visual weaknesses. The size of the ships on the screen remains the same, even if zoomed out. This is because GIS models in Anylogic are created for supply chain simulations that cover large geographic areas, which makes it important for agents to be visible on a map. Another weakness is that when the simulation is run at the highest possible speed, the alignment of the ships in the simulation is abnormal. At normal speed, there is no problem. However, neither of the mentioned problems affects the operation, logic, or results of the model, because the problems are only visual. Models were tested at different running speeds and the results were the same. Therefore, there is no need to pay more attention to them.

5.3.2 Logic

This section describes the logic and functions of the model. With the help of process modeling blocks, the agents of the model can be made to work in the desired way, which corresponds as closely as possible to the operation in the port of Vaasa and its fairways.

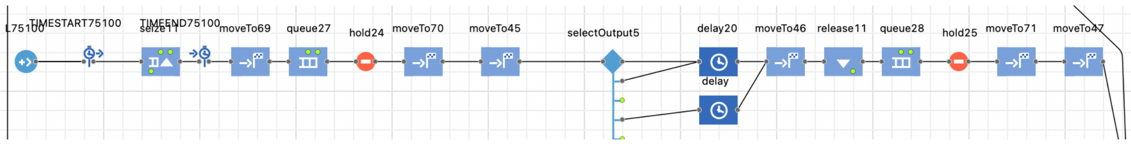

Figure 12 Logics of Containership length class 75–100

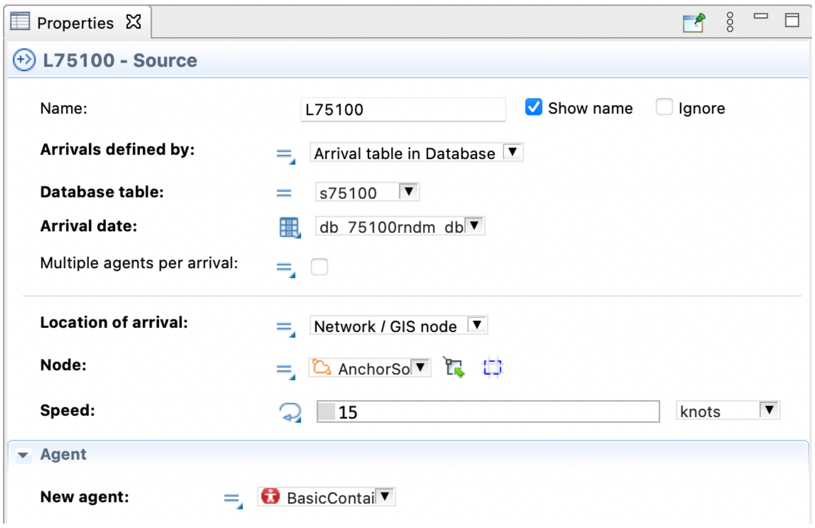

Figure 13 Source blocks parameters

In **Figure 12**, you can see the logic of the 75–100-meter cargo ships arriving at Lasse's quay in the model. First on the left is the Source block, named "L75100" for the length class. **Figure 13** shows the properties of the Source block. The creation of new agents is defined based on the arrival table "s75100". New agents arrive at the anchor location "AnchorSouth" and the speed in the block’s route is 15 knots. The agent type is "Basic-Container". Next, in **Figure 12** is the "Timestart" block, which together with the "TimeEnd" block defines the area where the time spent by the agent is stored in a statistic dataset. Between these blocks is the Seize block, which reserves resources from a certain resource pool for the agent. It is also possible to define queuing in the block if resources are not available. **Figure 14** describes the properties of the seize block. That agent reserves 4 resources from the resource pool "LASSEQuay". Queuing takes place at the location "AnchorSouth". In addition to this, the agent is assigned a priority of 0. The higher the number, the higher the priority, so in this model the priority of the ROPAX ship is 2 and the priority of the CONRO ship is 1. Resources are allocated based on priorities. If the priority is the same, the principle is FIFO.

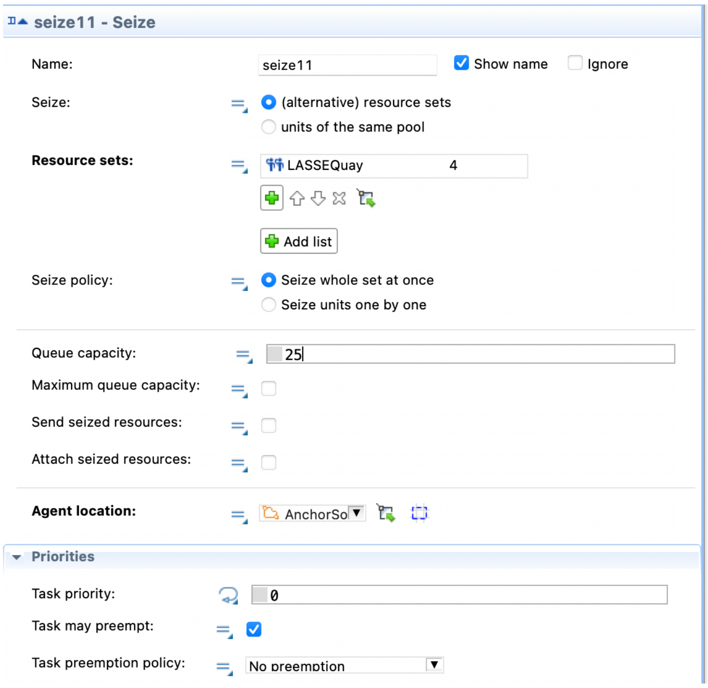

Figure 14 Seize block

Next in **Figure 12** is the "moveto" block, which defines the movement of the agent to a specified location in the simulation. The "moveto" block in question directs the agent to travel along the fairway to the GIS point, which is located at the west end of the last part of the entrance fairway shown in **Figure 10**. Next in **Figure 12** is the hold block. The hold block stops the agent if certain specifications are met. In this case, a parameter has been created, based on which it is determined whether there is oncoming traffic on the entrance fairway. If the fairway is free, the hold is released, and the agent moves according to the definitions of the "moveTo70" block to the GIS point located on the border of the port area. The next "moveTo45" block directs the ship to the resource specified in the seize block. Next in **Figure 12** is the "SelectOutput" block, where when different parameters are fulfilled, the agent moves to a different output. In this case, if the day of the week is Saturday or Sunday, the agent proceeds to block "delay20", which determines the waiting distribution at the quay when the agent arrives on the weekend. If the Arrival date is other than Saturday or Sunday, proceed to the "delay" block. After the end of the delay, the agent moves according to the "moveTo46" block to the GIS point at the border of the port area. The release block releases the resources reserved in the seize block. After this, the hold block checks whether there is oncoming traffic on the last part of the entrance fairway. If the fairway is free, the "moveTo71" block moves the agent to the west end of the part of the fairway. After this, the "moveTo47" block directs the agent to move to the end of the fairway, after which the agent exits the simulation via the sink block.

5.4 Parameters

5.4.1 Schedules

The schedule information for the years 2021-2022 obtained as secondary data was used as the basis of the schedule information. Based on that, the annual number of visits to different quays and ship sizes was determined. ROPAX vessel Aurora Botnia's future schedule data was used to create a ROPAX ship schedule for the RoRo1 quay. Based on this, schedules for the years 2024-2028 were created. The schedules were created with Excel's random function, where the first day of each year was set as the lower limit and the last day of the year as the upper limit. Values were created for these intervals with a function according to the desired annual number of ships. **Table 2** shows the number of vessels per year at Lasse's quay in different growth scenarios. If the annual traffic volume of the vessel class is not a whole number, the traffic is divided among the years so that the growth rate is as accurate as possible in the 5-year simulation.

SIZE	(No growth)	+ 5 %	+ 10 %	+ 15 %	+ 20 %	+ 25 %
75–100	73	76,6	80,3	83,95	87,6	91,25
100–125	12	12,6	13,2	13,8	14,4	15,00
125–150	29	30,45	31,9	33,35	34,8	36,25
150–175	14	14,7	15,4	16,1	16,8	17,50
175–200	2	2,1	2,2	2,3	2,4	2,50

Table 2 Vessel class visits to Lasse's quay in different volume scenarios.

At first, the annual number of ships was supposed to be determined using Anylogic's "Rate" function, but it was not a suitable method, because the number of ships varied a little between tests, which caused the results to be not comparable.

5.4.2 Delay distributions

Delay distributions were formed based on the schedule data for the years 2021-2022. The delay time of the ships in the port was examined by length category. It was noticed that in classes 75-100, 125-150, and 150-175 there was a significant difference in delay time, depending on whether the ship arrived on a weekday or a weekend. This is because it is more expensive to load and unload ships on the weekend, which is why ships arriving on the weekend often waited until Monday before loading and unloading started. Based on this, a different Delay distribution for weekdays and weekends was created for these three classes. Exceptional observations that were more than two standard deviations away from the mean were ignored. The minimum, maximum, and mode delay times of different classes are shown in **Table 3**.

MONDAY - FRIDAY			
	MIN	MODE	MAX
75–100	4	30	79
100–125	8	45	112
125–150	3	35	87
150–175	2	49	132
175–200	32	44	58

SATURDAY-SUNDAY			
	MIN	MODE	MAX
75–100	17	55	99
100–125	8	45	112
125–150	24	54	91
150–175	22	41	60,5
175–200	32	44	58

Table 3 Delay times at Lasse's quay

Delay times in the quay were generated using Anylogic's triangular probability distribution, which uses the maximum, minimum, and mode to create a triangular distribution.

Triangular distribution

$$f(x) = \begin{cases} \frac{2(x-min)}{(max-min)(mode-min)} & , min < x \leq mode \\ \frac{2(max-x)}{(max-min)(max-mode)} & , mode < x \leq max \end{cases} \tag{4}$$

(Anylogic 2023)

5.5 Scenarios

To answer the research questions of the study, four different simulation model scenarios were created. First, the current situation was modeled. After this, the extension Phase 1 was modeled, where the length of Lasse's Quay was increased by 144 meters. After that, two different versions of the expansion Phase 2 were modeled. The difference in the models of Phase 2 was that in the first version, the RoRo ramp for the liner traffic was placed in Lasse's quay, and in the second version the RoRo ramp was placed in the new quay area being built on the fill land. Phase 1 and Phase 2, when the ramp is at Lasse's quay, can be seen in **Figure 1.** Phase 2, when the ramp is in a new area, can be seen in **Figure 38**.

In all the different scenarios, the fairways and the logic of the ships are the same. The changes in the different models are represented by the capacity expansion of Lasse's

Quay, the placement of the RoRo ramp, and changes in the amount of traffic using Lasse's Quay.

5.5.1 Present tests

The main goal of the present scenario modeling was to obtain data with which different scenarios can be compared. Based on the 2021-2022 schedules, five-year schedules were created, where the number of visits to the quay was the same every year as in 2021-2022. After that, traffic growth was simulated in 5% increments between 5-25%. Based on the simulation runs, information was collected on the utilization rate of Lasse's Quay, waiting times outside the fairway, and the distribution of waiting times. The KPIs are the same for all tests.

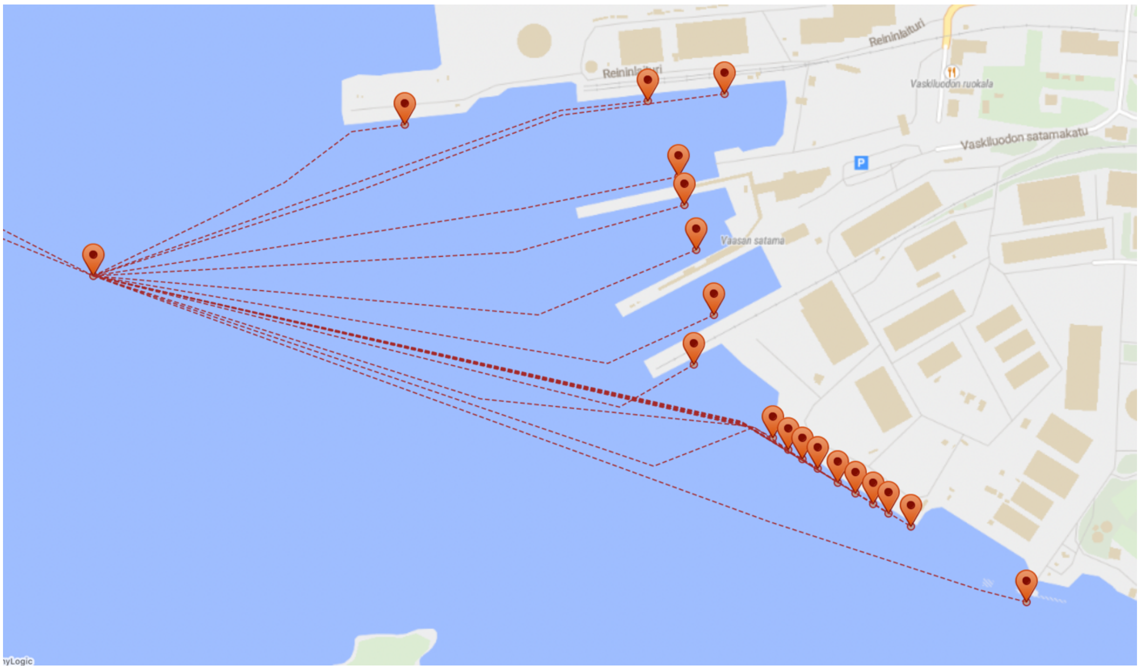

Figure 15 Present layout

Figure 15 shows that Lasse's Quay is divided into nine sections, each of which represents a 25-meter section of the quay.

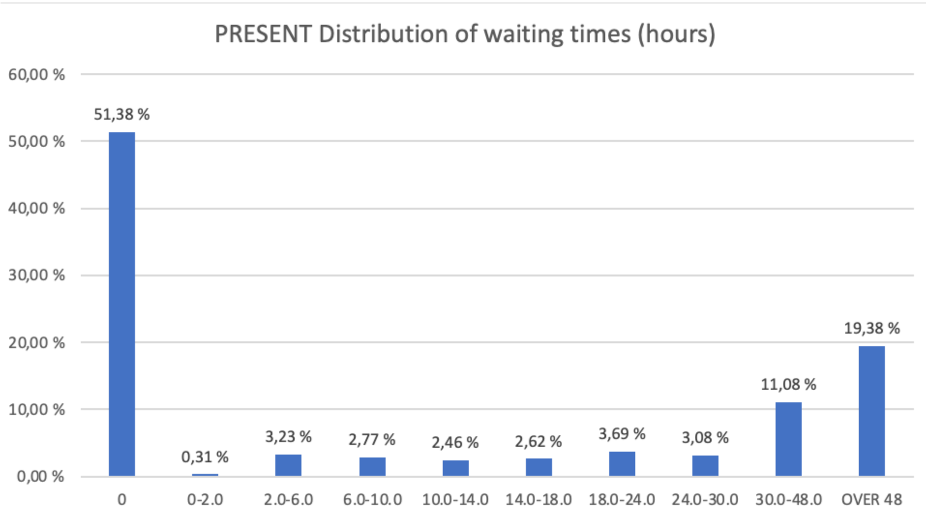

Figure 16 Present NG

Figure 16 describes the distribution of waiting times if the traffic does not increase from the current level. 51,38% of vessels entered the quay without waiting, while 48,62% had to wait outside the fairway. It is also noticeable that the waiting times often got long. 19,38% of ships had to wait more than 48 hours and 33,54% had to wait more than 24 hours. This can be seen as corresponding to what YLE wrote in its article in 2022 about the port's capacity problems. These long waiting times have led to the desire to expand the capacity. The average waiting time for ships was 23,48 hours. The utilization rate of the quay was 40%.

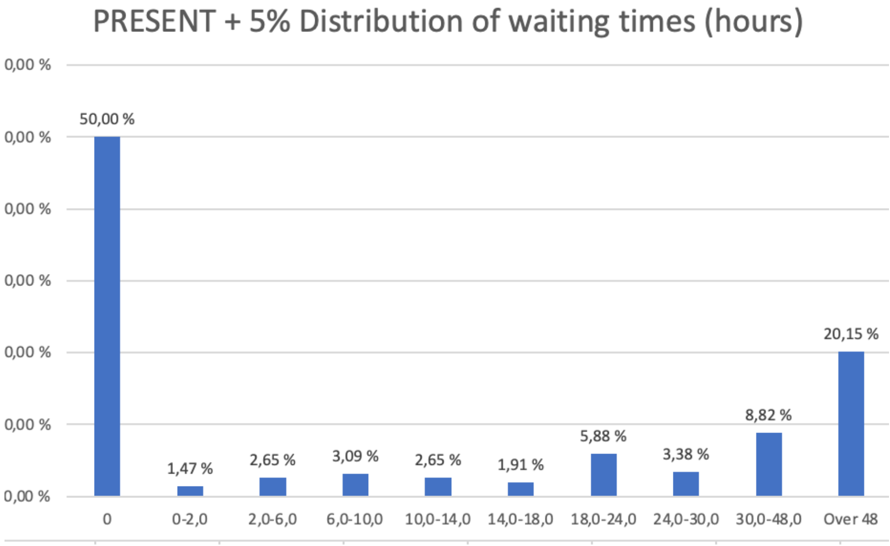

Figure 17 Present +5 %

Figure 17 shows the distribution of waiting times in a situation where traffic increases by 5% from the current level. 50% of the vessels had to wait outside of the fairway. The waiting times were very long in several cases. The average waiting time was 26,49 hours. The utilization rate of the quay was 41 %.

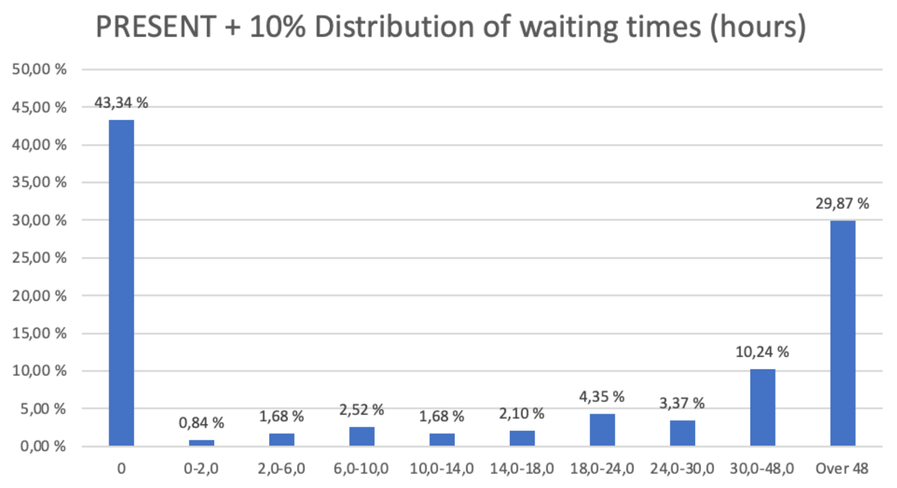

Figure 18 Present +10 %

Figure 18 shows the distribution of waiting times in a situation where traffic increases by 10% from the current level. 56,66% of the vessels had to wait outside the fairway. It is noteworthy that waiting times of more than 48 hours increased. The average waiting time is 37,08 hours. The utilization rate of the quay was 43 %.

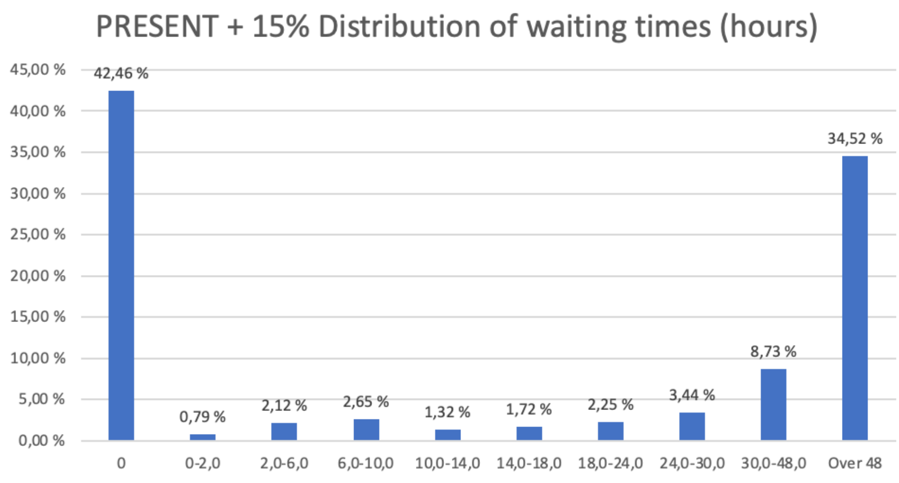

Figure 19 Present +15 %

Figure 19 shows the distribution of waiting times in a situation where traffic increases by 15% from the current level. 57,54% of vessels had to wait outside the fairway. Waiting times which are longer than 48 hours continued to grow. The average waiting time was 42,47 hours. The utilization rate of the quay was 45 %.

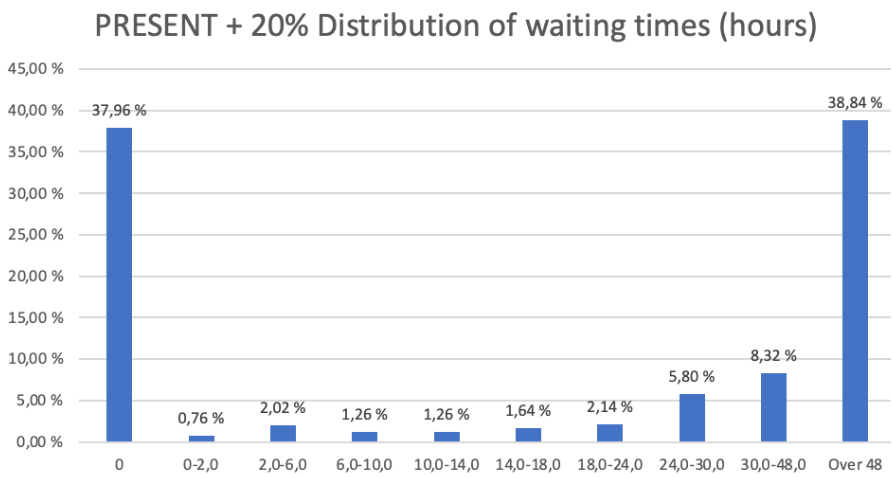

Figure 20 Present +20 %

Figure 20 shows the distribution of waiting times when traffic increases by 20%. 62,04% of vessels have to wait outside the fairway. Waiting times of more than 48 hours continue to grow. The average waiting time is 44,21 hours. The utilization rate of the quay was 47 %.

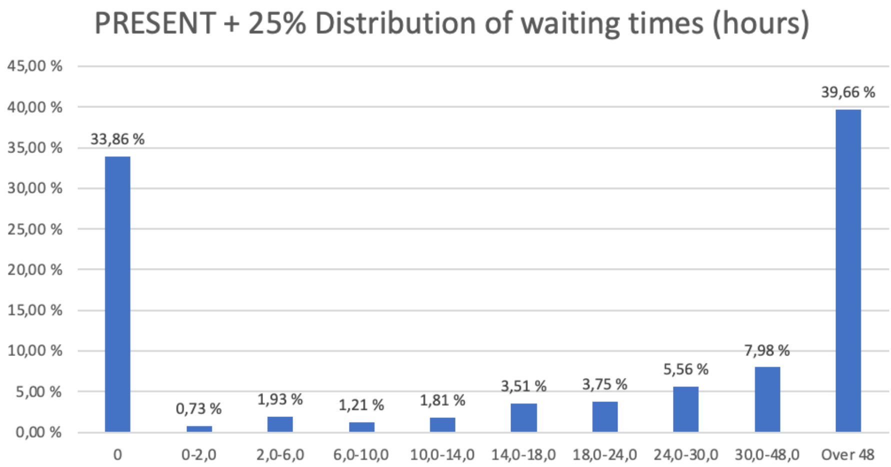

Figure 21 Present +25 %

Figure 21 shows a situation where traffic increases by 25%. 66.14% of vessels have to wait outside the fairway. The average waiting time is 49.7 hours. The utilization rate of the quay was 50 %. It can be said that Lasse's Quay is very congested.

5.5.2 Phase 1 tests

The effect of increasing the length of Phase 1 Lasse's Quay by 144 meters on capacity was tested with six different simulations. In the first simulation, traffic volumes remained the same as in 2021-2022. After that, traffic growth was simulated in 5% increments between 5-25%. The simulation runs were 5 years long and simulated the years 2024-2028. The KPIs are the same for all tests.

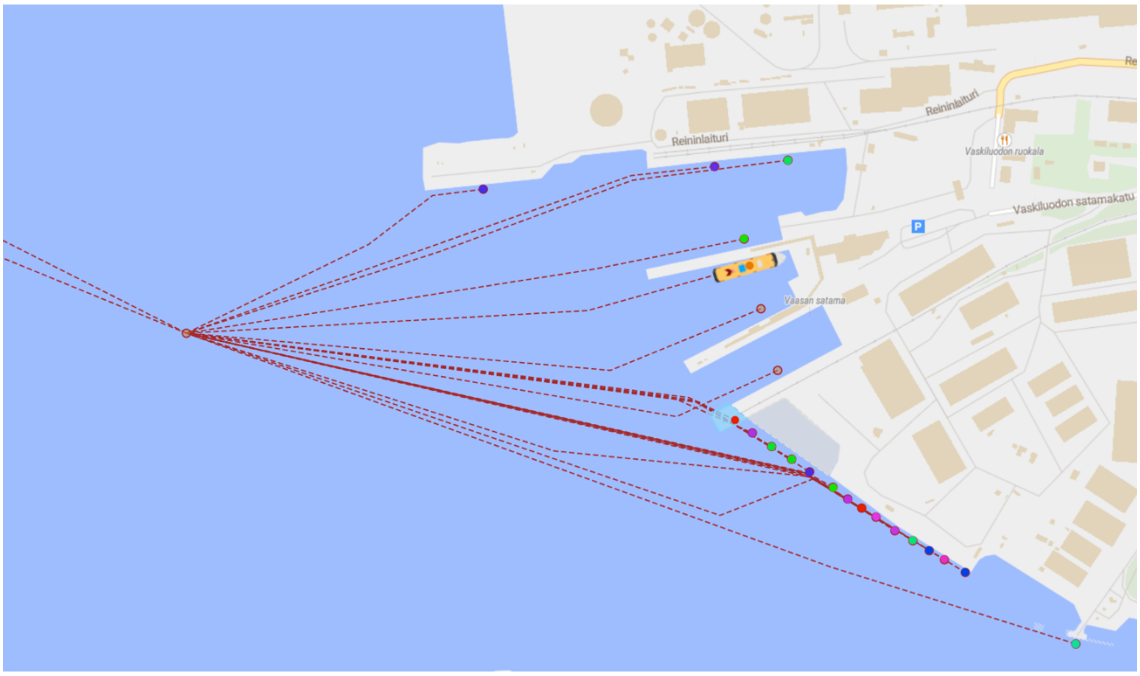

Figure 22 Phase 1 layout

Figure 22 shows the layout of Lasse's Quay in Phase 1. The capacity of the quay has increased and now it is divided into fourteen 25-meter sections in the simulation.

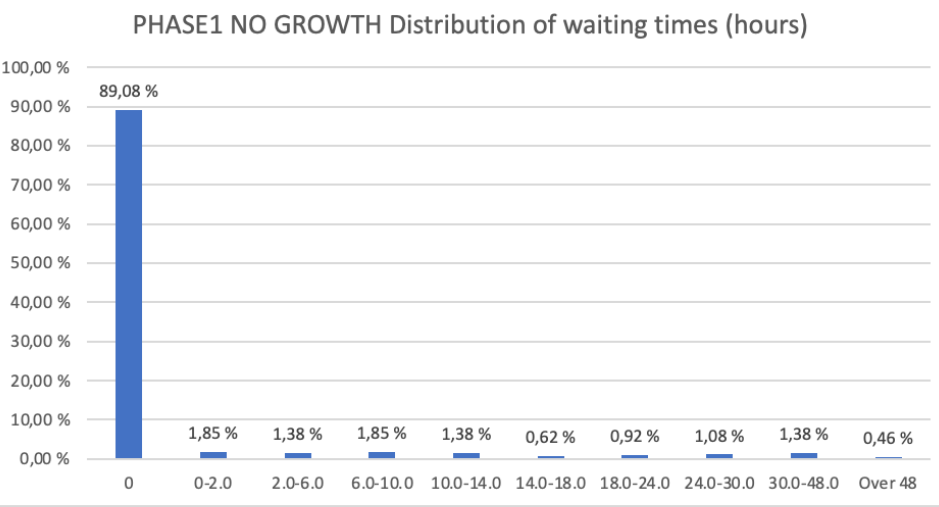

Figure 23 Phase1 NG

Figure 23 describes the distribution of waiting times if the traffic does not increase from the current level. 89,08% of ships got to the quay without waiting. 10,92% had to wait at the end of the fairway, but it is noticeable that the distribution of waiting times is moderate and most of the waiting times are short. The average waiting time is 1,73 hours, which is a huge decrease from the current situation. Quay's utilization rate was 25%.

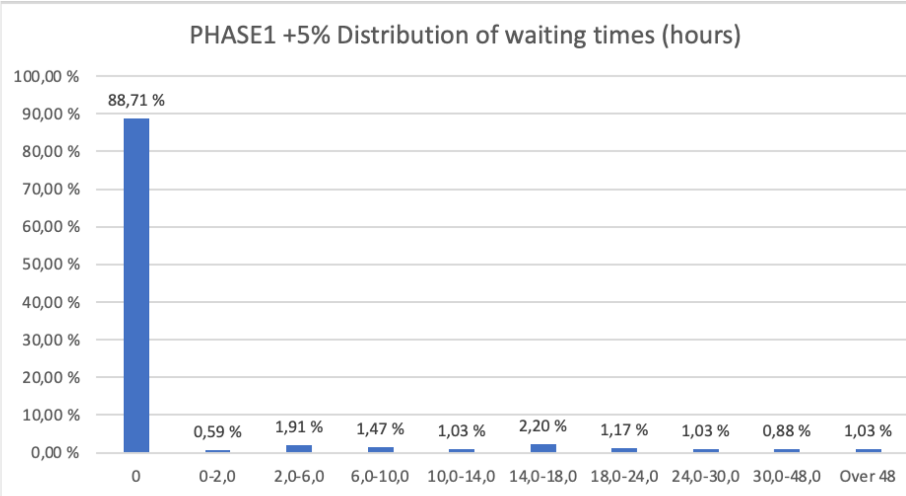

Figure 24 Phase +5 % growth

Figure 24 shows the distribution of waiting times if the traffic increases by 5% from the current level. 88,71% of ships do not have to wait at the end of the fairway. 11,29% had to wait. Again, it can be noticed that the waiting times are moderate. The average waiting time is 2,11 hours. The utilization rate of Lasse's Quay was 26%.

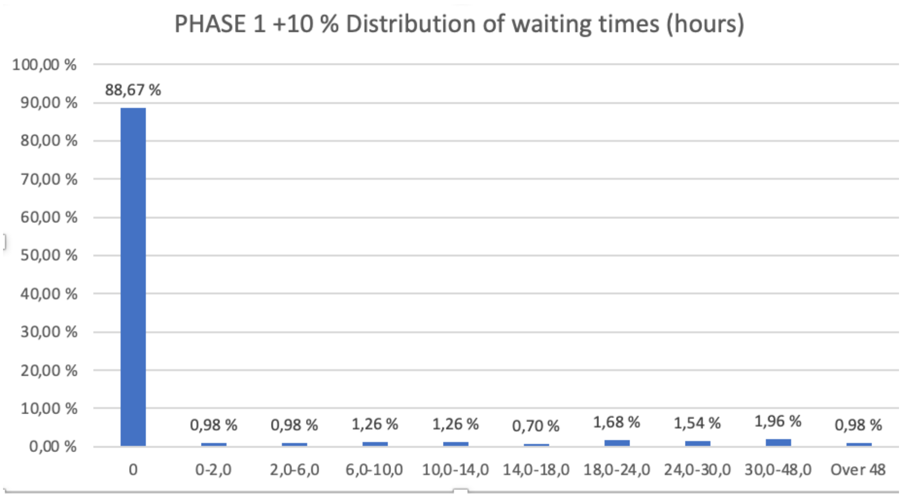

Figure 25 Phase 1 +10 % growth

Figure 25 shows the distribution of waiting times if the traffic increases by 10% from the current level. 88,67% of ships do not have to wait at the end of the fairway. 11,33% had to wait. Waiting times are again moderate, with a slight increase in higher classes. The average waiting time is 2,34 hours. The utilization rate of Lasse's Quay was 28%.

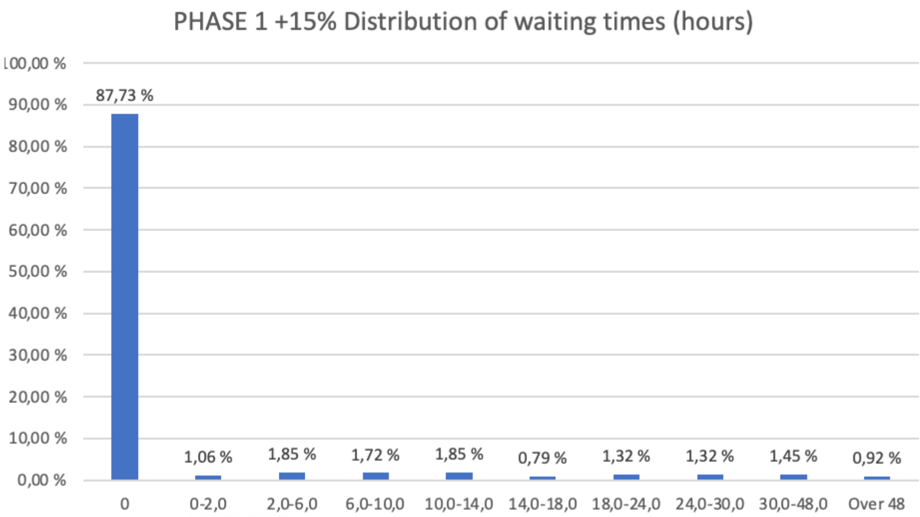

Figure 26 Phase 1 +15 % growth

Figure 26 shows the distribution of waiting times if traffic increases by 15% of the current level. 87,73% of ships do not have to wait at the end of the fairway. 12,27% had to wait. The waiting times are moderate. The average waiting time is 2,55 hours. The utilization rate of Lasse's Quay was 29%.

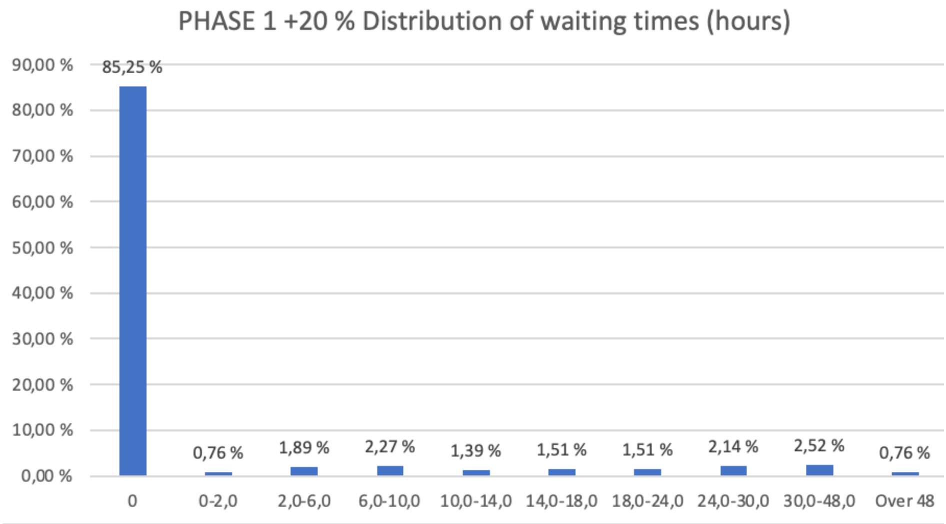

Figure 27 Phase 1 +20 % growth

Figure 27 shows the distribution of waiting times if traffic increases by 20% from the current level. 85,25% of ships do not have to wait at the end of the fairway. 14,75% had to wait. Waiting times are moderate, although there is a small increase in the larger classes. The average waiting time is 2,94 hours. The utilization rate of Lasse's Quay was 30%.

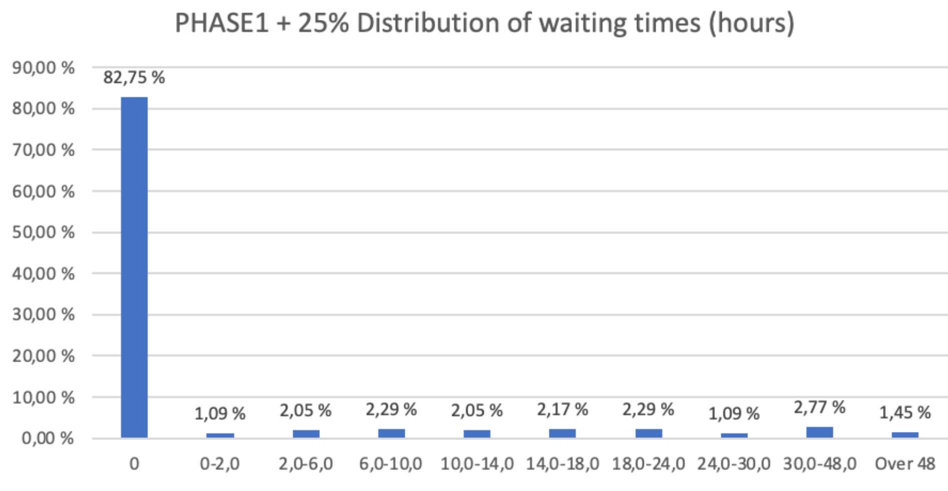

Figure 28 Phase 1 +25 % growth

Figure 28 shows the distribution of waiting times if traffic increases by 20% from the current level. 82,75% of ships do not have to wait at the end of the fairway. 17,25% had to wait. Waiting times are moderate, although there is a small increase in the larger classes. The average waiting time is 3,55 hours. The utilization rate of Lasse's Quay was 32%.

5.5.3 Liner schedule tests

The purpose of liner schedule tests is to find the best possible schedule for liner traffic. The simulation tests test the arrival of the liner at Lasse's quay on all weekdays 6, 8, 10, 12, 14, and 16 o'clock. The simulations were run with two different schedule data. In the simulations, the schedules of the years 2021-2022, as well as random schedules created using Excel, are used as the schedules of other ships. The most suitable timetable is the one which causes the least amount of waiting for Lasse's Quay traffic. Therefore, the average of the waiting times is a suitable measure to express the effects of different scheduling options. The liner's time at the quay is a random value between 4 and 8 hours.

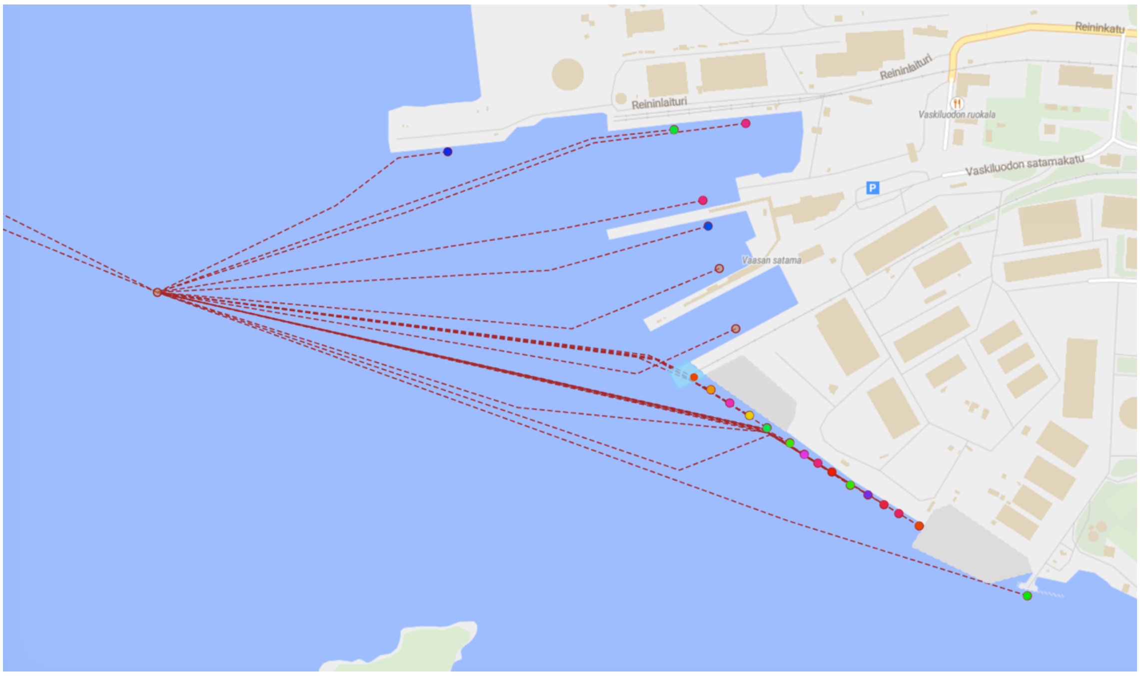

Figure 29 Phase 2 Ramp on Lasse's quay

Liner schedule tests are simulated in the layout shown in **Figure 29**, where in addition to the Phase 1 expansion, a ramp enabling Ro-Ro traffic has been built at the southern end of Lasse's Quay.

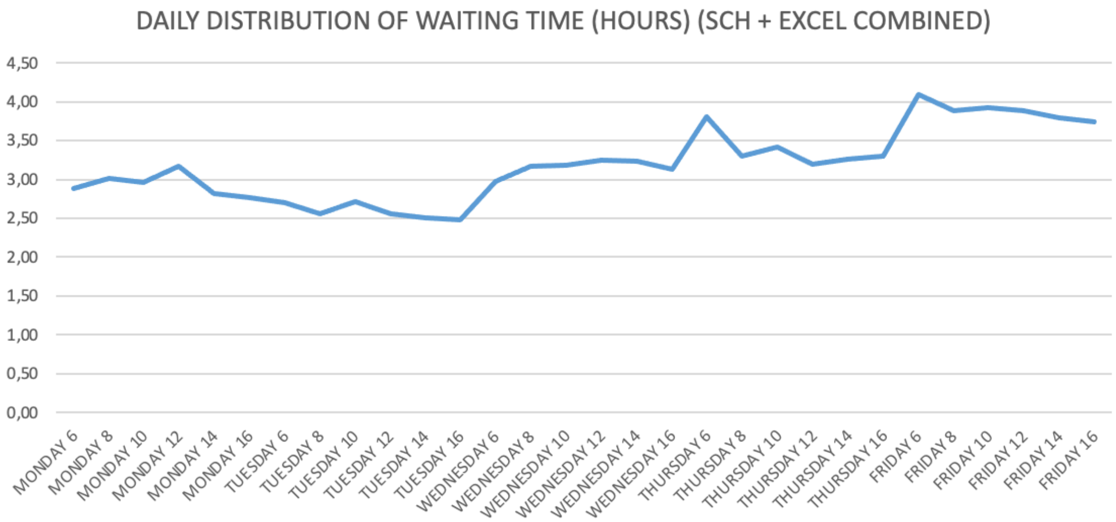

Figure 30 Daily distribution of waiting time per hour

Figure 30 shows the effect of liner arrival time on the average waiting time of Lasse's Quay traffic outside the fairway. The graph shows the combined results from both schedule tests. The shortest average waiting time (2,48 hours) is realized when the liner arrives at the quay at 4 pm on Tuesdays.

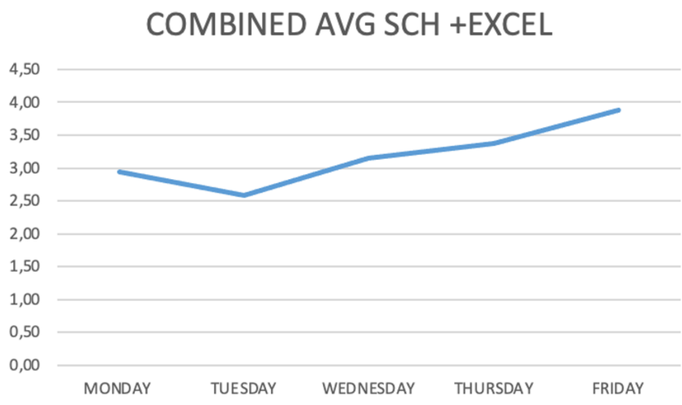

Figure 31 Daily distribution of waiting time

Figure 31 shows the daily average of the results of both tests. It can be noticed that Tuesday is also clearly the best day with an average of 2,58 hours. The second-best day is Monday, the other days are worse options in terms of waiting time.

5.5.4 Phase 2 ramp at Lasse's quay tests

Phase 2 tests where the ramp is placed at Lasse's quay were carried out in the layout shown in **Figure 29**. In simulation tests, the liner arrives at the quay on Tuesdays at 4 p.m., which was found to be the best arrival time. 6 different tests were run. In them, the growth of other traffic at Lasse's quay is 0, 5, 10, 15, 20, and 25 percent. The traffic of other quays remains the same. The KPIs are the same for all tests.

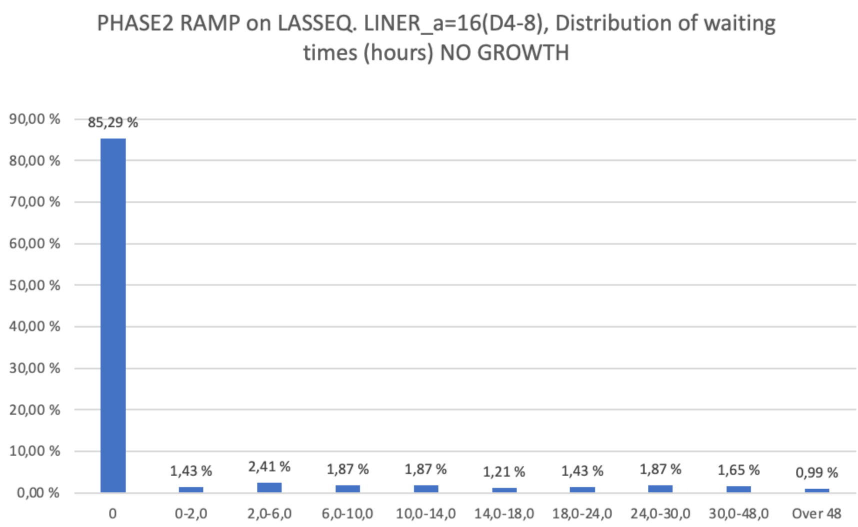

Figure 32 Phase 2 ramp on Lasse's quay NG

Figure 32 shows the distribution of waiting times in Phase 2, when the ramp is at Lasse's quay and traffic volumes at Lasse's quay have not increased. 14,71% of ships have to wait at the end of the fairway, but it should be noted that the percentages of higher waiting times remain reasonable. The average waiting time is 2,72 hours. The utilization rate of Lasse's quay was 27 %.

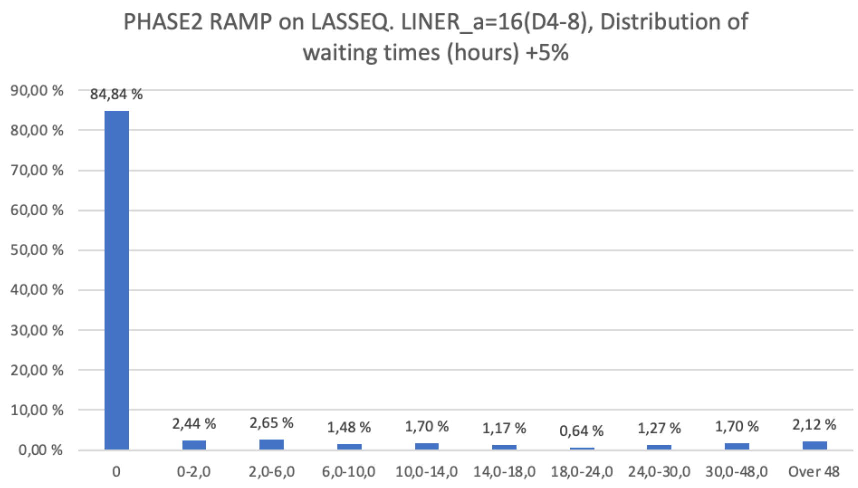

Figure 33 Phase 2 ramp on Lasse's quay +5 %

Figure 33 shows the distribution of waiting times in Phase 2 when the ramp is at Lasse's quay and other traffic to Lasse's quay has increased by 5%. 15,16% of vessels, have to wait outside the fairway. The average waiting time is 3,18 hours. The utilization rate of Lasse's quay was 29 %.

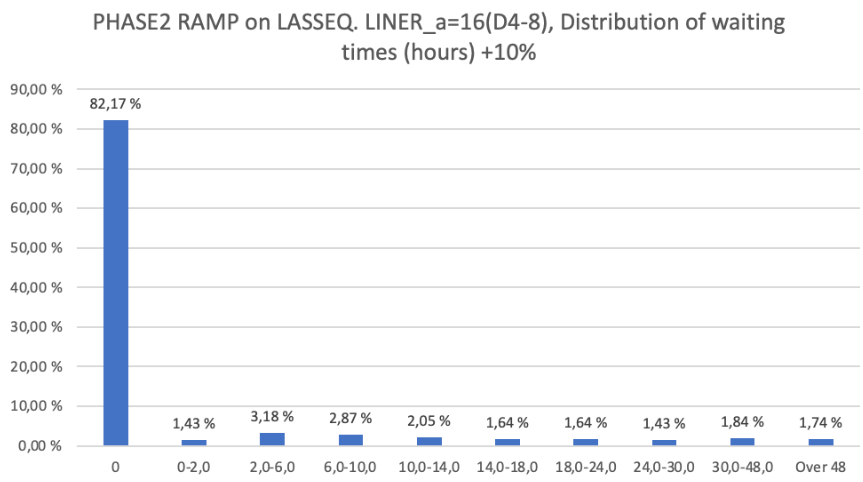

Figure 34 Phase 2 ramp on Lasse's quay +10 %

Figure 34 describes the distribution of waiting times in Phase 2, when the ramp is at Lasse's quay and other traffic has increased by 10%. 17,83% of vessels have to wait outside the fairway. The average waiting time is 3,31 hours. The utilization rate of Lasse's quay was 30 %.

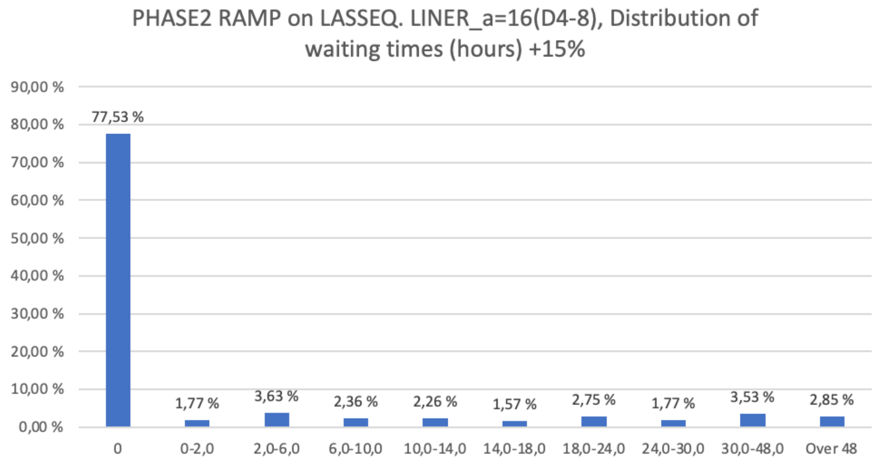

Figure 35 Phase 2 ramp on Lasse's quay +15 %

Figure 35 shows the distribution of waiting times in Phase 2, when the ramp is at Lasse's quay and other traffic on the quay increases by 15%. 22,47% of vessels have to wait outside the fairway. The average waiting time is 5,22 hours. The utilization rate of Lasse's quay was 32 %.

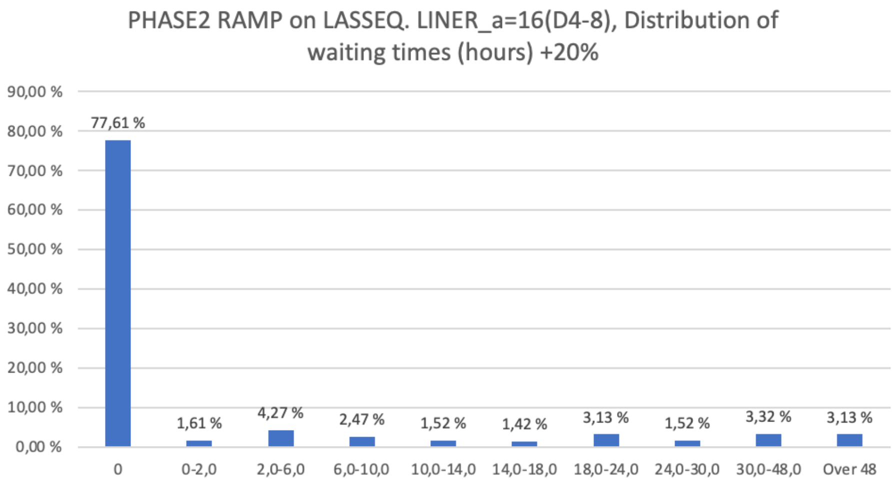

Figure 36 Phase 2 ramp on Lasse's quay +20 %

Figure 36 shows the distribution of waiting times in Phase 2 when the ramp is at Lasse's quay and other traffic increases by 20%. 22,39% of vessels have to wait outside the fair-way. The average waiting time is 5,26 hours. The utilization rate of Lasse's quay was 34 %.

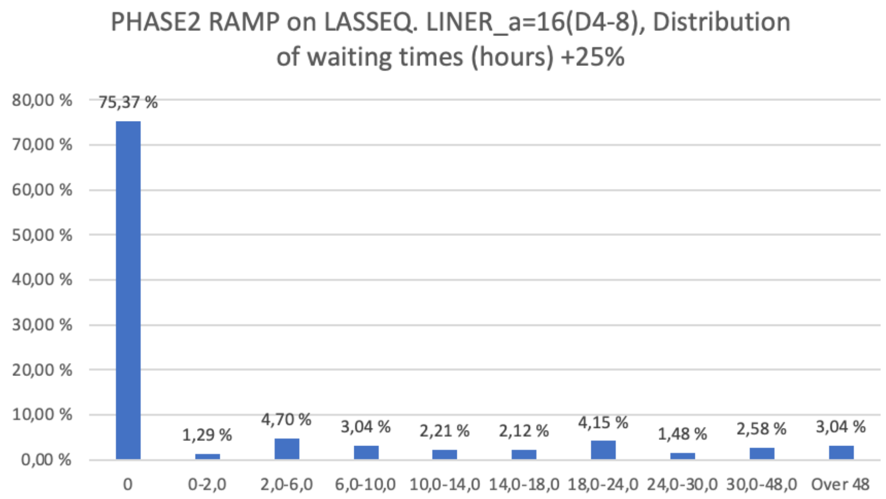

Figure 37 Phase 2 ramp on Lasse's quay +25 %

Figure 37 shows the distribution of waiting times in Phase 2, when the ramp is at Lasse's quay and other traffic increases by 25 %. 24,63% of vessels have to wait outside the fairway. The average waiting time is 5,57 hours. The utilization rate of Lasse’s quay was 35 %.

5.5.5 Phase 2 ramp on new quay tests

Kvarken Ports Ltd also wanted to study the option where the ramp is built on a new quay area in the northern part of the port. This scenario is called the Phase 2 ramp at the new Quay area.

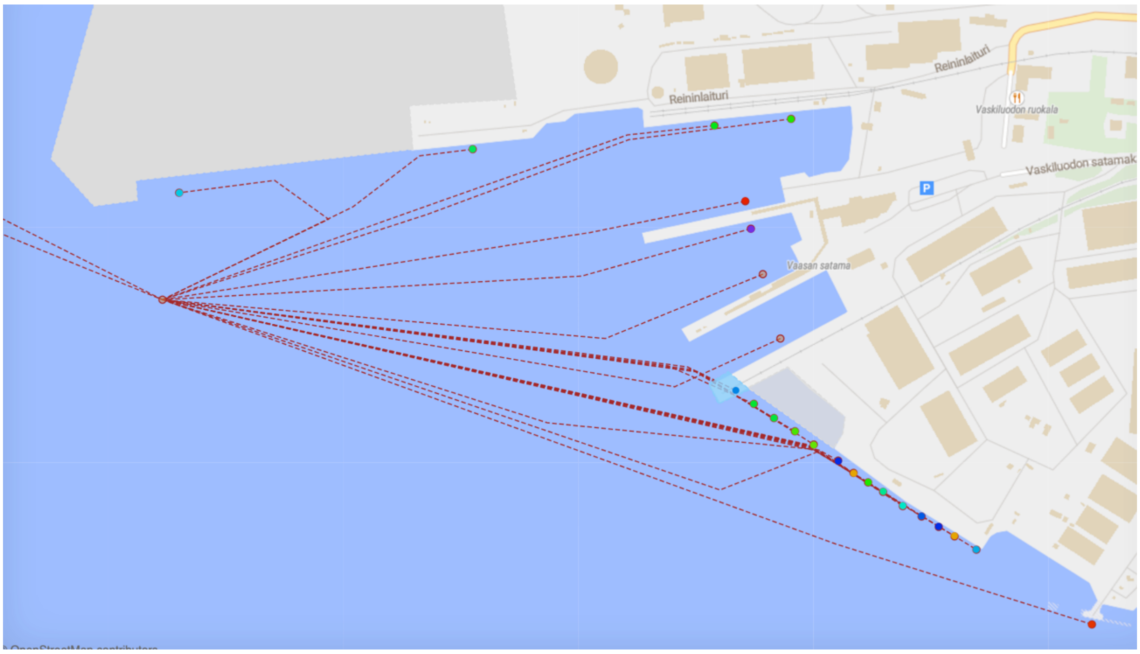

Figure 38 Phase 2 ramp at the new quay area

Figure 38 shows the scenario described above. In the simulation tests, the traffic to Lasse's quay is tested with 6 different tests, where the growth of other traffic is between 0-25%. The liner uses a new quay. The duration of the tests is 5 years. The KPIs are the same for all tests.

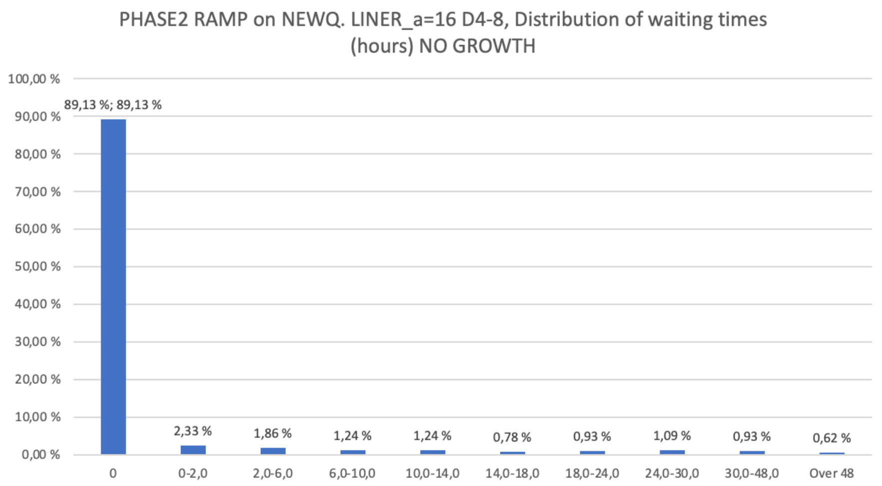

Figure 39 Phase 2 ramp at new quay NG

Figure 39 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes have not increased. 10,87% of vessels have to wait outside the fairway. The average waiting time is 1,8 hours. The utilization rate of Lasse's quay was 25 %.

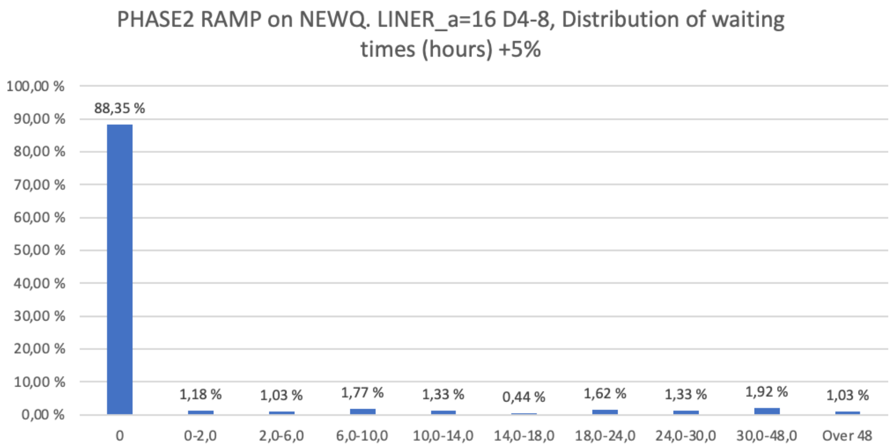

Figure 40 Phase 2 ramp at new quay +5 %

Figure 40 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes increased by 5 %. 11,65% of vessels have to wait outside the fairway. The average waiting time is 2,5 hours. The utilization rate of Lasse's quay was 26 %.

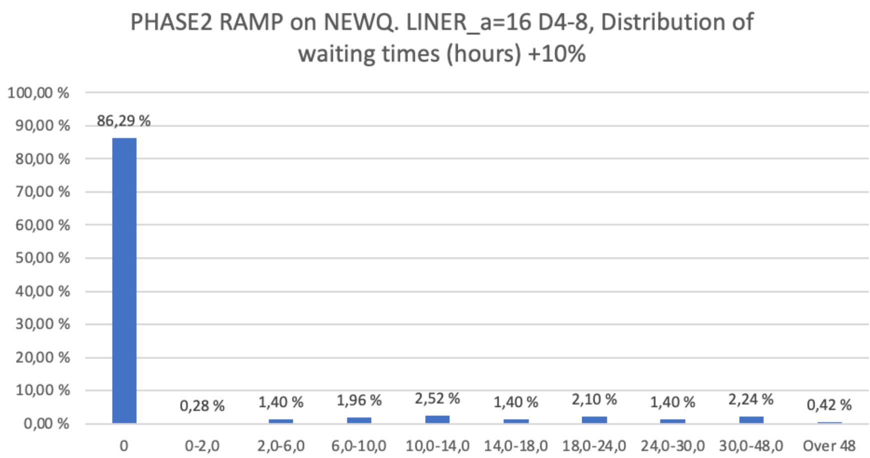

Figure 41 Phase 2 ramp at new quay +10 %

Figure 41 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes increased by 10 %. 13,71% of vessels have to wait outside the fairway. The average waiting time is 2,72 hours. The utilization rate of Lasse's quay was 28 %.

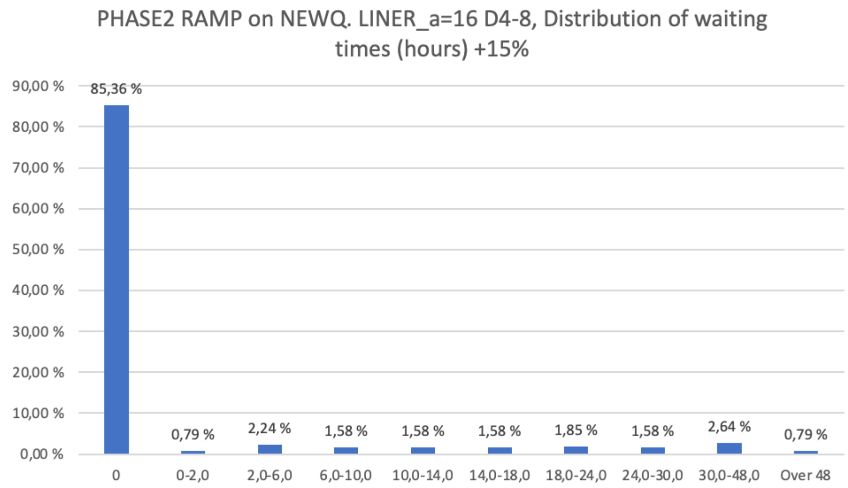

Figure 42 Phase 2 ramp at new quay +15%

Figure 42 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes increased by 15%. 14,64% of vessels have to wait outside the fairway. The average waiting time is 2,94 hours. The utilization rate of Lasse's quay was 30%.

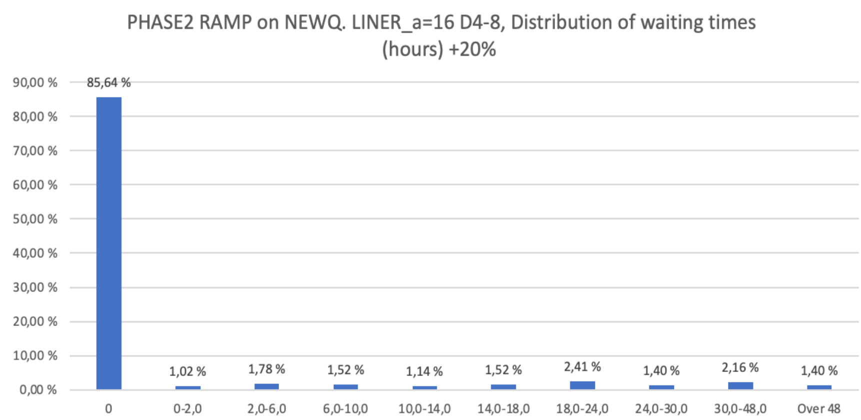

Figure 43 Phase 2 ramp at new quay +20%

Figure 43 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes increased by 20%. 14,36% of vessels have to wait outside the fairway. The average waiting time is 3,2 hours. The utilization rate of Lasse's quay was 31%.

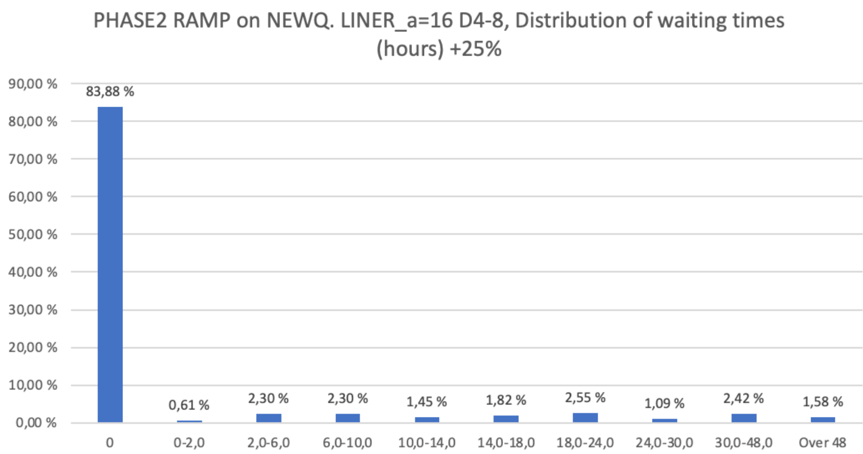

Figure 44 Phase 2 ramp at new quay +25%

Figure 44 shows the distribution of waiting times in Phase 2 when the ramp is placed at the new quay area and the traffic volumes increased by 25%. 16,12% of vessels have to wait outside the fairway. The average waiting time is 3,55 hours. The utilization rate of Lasse's quay was 32%.

6 Summary and Conclusions

In this chapter, the research results are interpreted, summarized, and the research questions are answered. A huge amount of data was collected from the simulation tests, which were analyzed in Excel and charts were created based on the data, which, by interpreting them, provided answers to the research questions.

The research questions were:

i. What is the utilization rate of Lasse's quay in different layout models and the different growth scenarios of these models (No growth, + 5%, + 10%, + 15%, + 20%, and + 25%)?
ii. How do the expansion phases Phase 1 (extending Lasse's Quay by 144 meters) and Phase 2 (Adding a ramp to Lasse's Quay or a new area) affect the waiting time of vessels outside the fairway?
iii. What is the optimal schedule for the liner service?
iv. Where should the loading ramp used by liner traffic be located in the port?

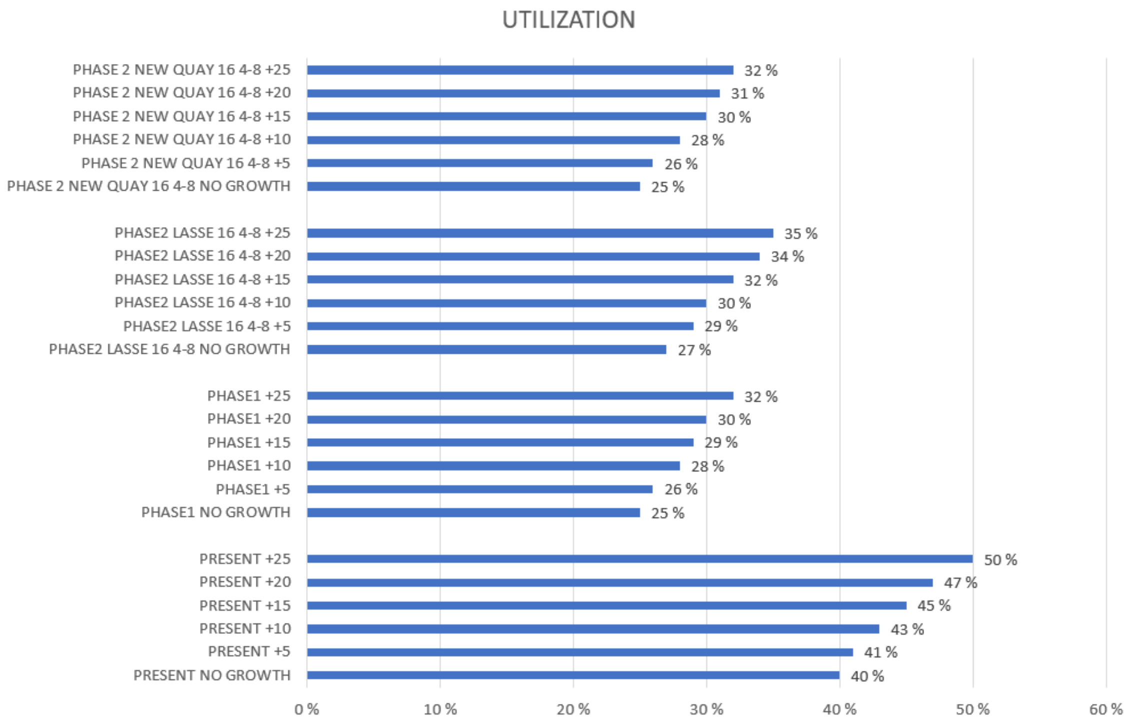

Figure 45 Utilization of the Lasse’s quay

Figure 45 describes the utilization rate of Lasse's Quay in different scenarios. It provides an answer to research question i. *What is the utilization rate of Lasse's Quay in different scenarios?* It is remarkable that even in the most congested scenario (Present +25%) the utilization rate does not rise above 50%. This is because only in rare situations the entire capacity of the quay can be utilized. For example, if in the current situation (length capacity 224m) there is a 150m long ship at the quay, 66% of the current capacity is used, but if the arriving ship is not less than 76 meters, the free capacity cannot be used. For this reason, the average and distribution of waiting times is a better indicator to indicate congestion at the quays. The increases in utilization rates correlate with the values seen in **Figure 46 and Figure 47.** However, it can be stated that with better planning and optimization of ship arrival times, the utilization rate of the quay could be increased and thus the use of the layout could be made more efficient. In any case, it can be stated that all extension options reduce the utilization rate of quay.

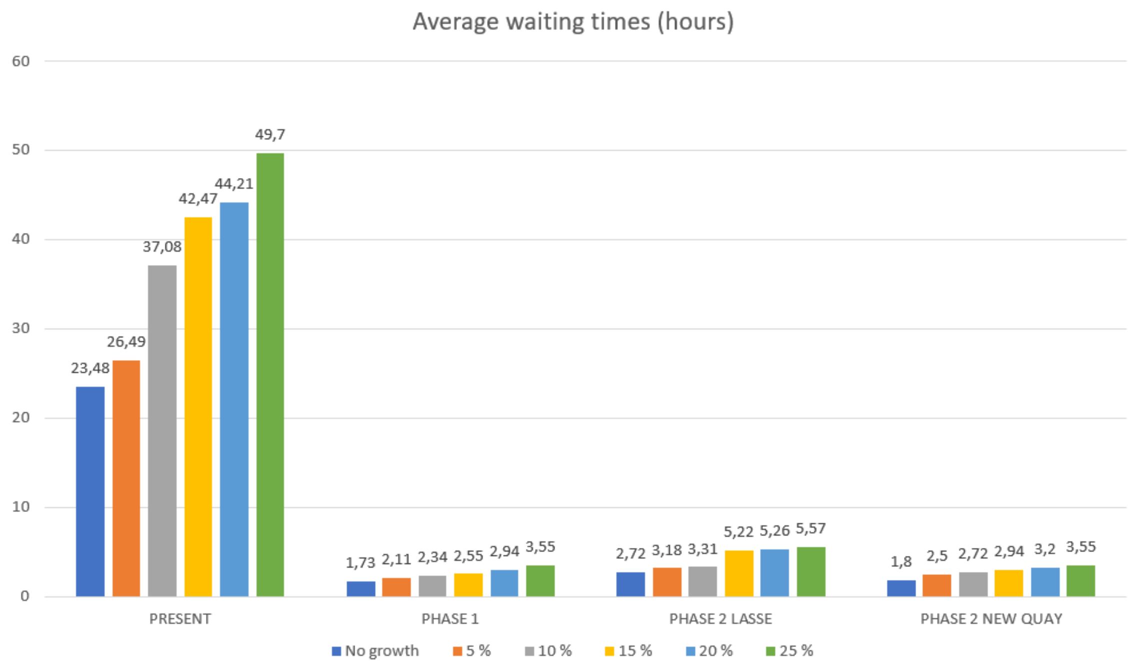

Figure 46 Summary of average waiting times

Figure 46 and **Figure 47** answer research question *ii. How do the expansion phases Phase 1 and Phase 2 affect the waiting time of vessels outside the fairway?* **Figure 46** shows the average waiting times of different layout models in different growth scenarios. It can be noticed that in the Present scenario and its growth scenarios, the waiting times in the current layout are very long. Especially if the traffic increases by 10% or more, the average waiting times become very long. The background of these is a phenomenon visible in the present tests (**Figure 16, Figure 17, Figure 18, Figure 19, Figure 20,** and **Figure 21)**, where quay congestion leads to a great percentage of long waiting times outside the fairway. It is noteworthy that already the Phase 1 144-meter extension reduces the average waiting times very much. The percentage decrease in waiting time is 92,64% when comparing the Present and Phase 1 scenarios without traffic growth. The percentage difference also remains relatively the same when comparing the Present and Phase 1 scenarios with a 25% increase in traffic (a decrease of 92,79%). In the Phase 1 scenarios, the average waiting times do not increase significantly in any growth scenarios, but the growth is steady. It can be said that the Phase 1 scenario can withstand traffic growth very well. The Phase 1 extension solves the current congestion problems very well.

Phase 2, where the ramp used by liner traffic is placed at Lasse's quay, also reduces waiting times considerably compared to the Present scenario. However, it should be noted that if the amount of traffic increases by 15% or more, the waiting times will increase more. However, it is noteworthy that even then the waiting times are only a fraction of the current situation. Phase 2, where the ramp used by liner traffic is placed at the new quay, will also shorten waiting times significantly compared to the present scenario. When the ramp is located in the new quay, the average waiting times are almost the same as in the Phase 1 scenario. It can be said that each expansion scenario produces clear improvements to the flow of traffic in the port and reduces waiting times to very short compared to the current situation.

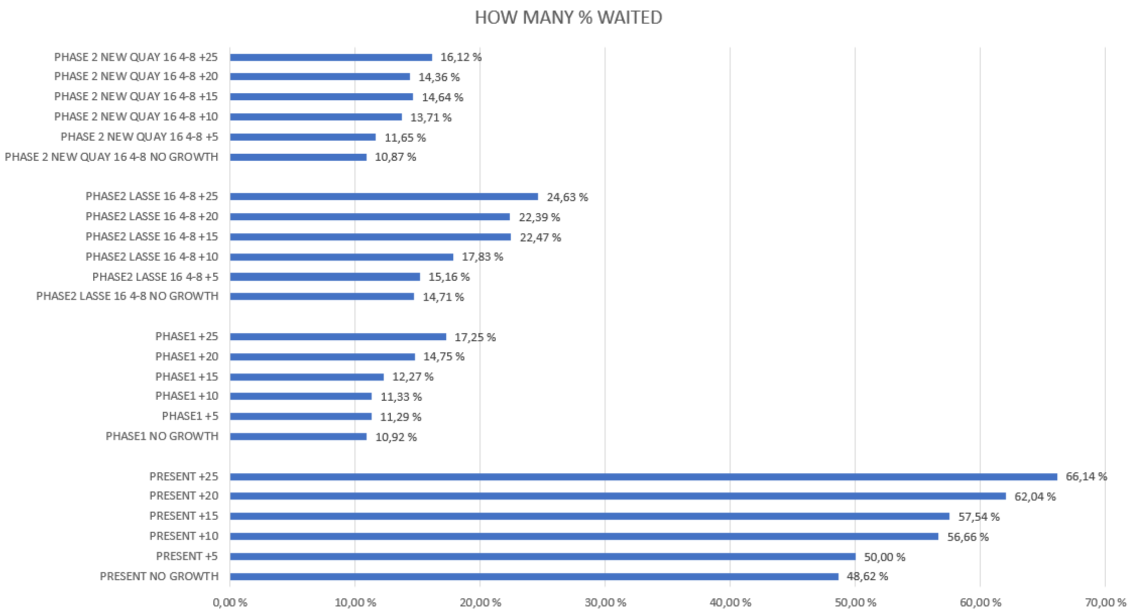

Figure 47 Summary of the percentage of vessels waiting outside the fairway in different scenarios.

Figure 47 shows a summary of the percentage of vessels that had to wait outside the fairway in different scenarios. Remarkably, **Figure 47** well supports the conclusions from **Figure 46**. The waiting times drop in all expansion scenarios compared to the Present scenario. Average waiting times largely correlate well with what percentage of ships had to wait. Only in the Phase 2 tests, it can be noticed that the percentage of vessels waiting decreases slightly when the traffic growth changes from 15% growth to 20% growth.

However, this is because the distributions of waiting times are different (See **Figure 35, Figure 36, Figure 42,** and **Figure 43)**. It should be noted that the average of the waiting times is greatly influenced by the length of the individual waiting times, the distribution of which can be seen in the Results section.

Figure 30 and **Figure 31** answer the research question *iii. What is the optimal schedule for the liner service?* Liner traffic causes the least amount of waiting for other traffic when it arrives at Lasse's quay on Tuesday at 4 p.m. Tuesday is also overall the best day, and there are no big differences in waiting times during Tuesday. **Figure 46** answers to research question iv. *Where should the loading ramp used by liner traffic be located in the port?* The most optimal location for the ramp is the new quay area, but it should be noted that it can also be located at Lasse's quay, without causing unreasonable waiting for other traffic. However, it should be noted that when the ramp is at Lasse’s quay if other traffic increases by more than 15%, the quay starts to become congested. Even then, the situation is far from the quay congestion of the current situation.

6.1 Managerial implications

The purpose of this study was to help Kvarken Ports Ltd in decision-making related to the layout solutions of the port of Vaasa. As Gharehgozli et al (2020) state, changes in the layout of ports are often expensive, which is why their effects must be evaluated as well as possible. For this reason, simulations were used to study various scenarios and their effects on increasing the amount of traffic as versatile as possible. The study’s results were also clear, so it is easy to make decisions based on them. It is worth noting that even relatively small differences in the average waiting times can generate large additional costs for ship operators because waiting is very expensive. It should also be noted that although the best location for the ramp in Phase 2 is in the new quay area, the construction of the new area is expensive and will take years. For this reason, it is also important to evaluate the cost-to-benefit ratios of different construction projects. As we noticed in **Figure 46**, the placement of the ramp has a relatively small effect on the average waiting time. It is therefore important to be able to assess the port's traffic development in the future so that when making investments, one does not fall into over-development, which leads to wasting resources, or underdevelopment, which leads to port congestion. Therefore, when deciding on the best option, a scientific assessment of the development of traffic volumes in the future must also be made. (O’Connor et al 2023)

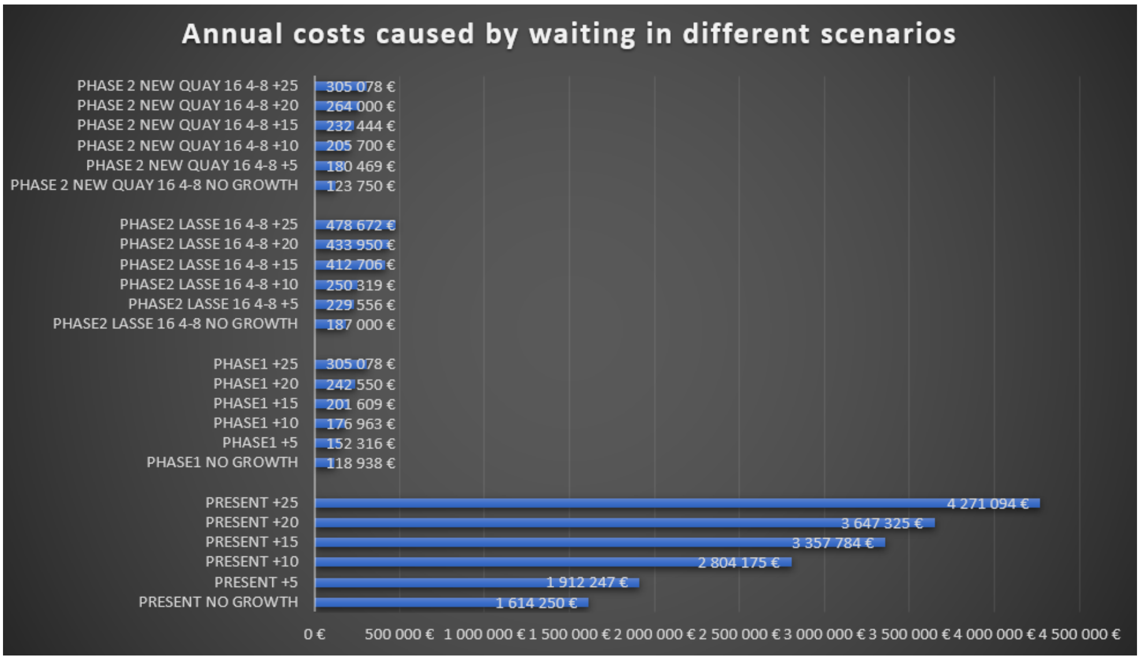

Figure 48 Estimated annual costs caused by waiting

Figure 48 describes the estimated annual costs caused by waiting in different scenarios. The daily charter price for an average ship visiting Lasse’s quay is assumed to be €12,500. This average cost was estimated in discussions with Kvarken Ports Ltd and Bloomberg Stevedoring. It can be noticed that in all development scenarios, the annual costs are significantly lower than in the current situation. These annual costs are very important from the port's point of view because if the ship operator constantly incurs high costs due to the ship having to wait for a quay, the ship operator will certainly start investigating alternative ports where to unload and load their cargo. When operators prefer other ports, the income of that port decreases. Therefore, the operation of the port must be as efficient as possible.

The utilization rate of the harbor could be improved with the help of a reservation system. The port of Gävle in Sweden uses the TimeSlot reservation system in one of its quays, which enables better planning and optimization of the use of the quay (Gavle Hamn 2023).

6.2 Further research

Ships currently arrive at the port of Vaasa for the most part on the First in first out (FIFO) principle, whereby the first ship to arrive is served first. This is a logical course of action where arrivals cannot be planned far into the future. However, it can be seen from **Figure 45** that Lasse's quay has a lot of unused capacity on an annual basis. This capacity could only be made available if the arrival of ships at the quay could be planned and optimized better according to their arrival time and ship sizes. Gävle timeslot system (Gävle hamn 2023) would certainly be an option. No research has yet been published on the functionality of the slot reservation system in question. For this reason, I recommend that the slot reservation system in question and its operation should be studied. It would be interesting to find out if the port of Vaasa could benefit from a similar system to use the capacity more efficiently. O'Connor et al (2023) also mention gaps in research in the research world that investigate the more efficient and optimal use of port resources. Therefore, it would be important to study how the processes of the port of Vaasa could be optimized in the current operating environment. On the other hand, maritime transport is such a complex entity that the possibilities for an individual port to influence are not endless. Optimizing the use of piers would also require that ship traffic should be better organized worldwide so that the arrivals and departures of ships of different sizes in a single port could be effectively optimized (Yu et al 2022). Martin-Iradi et al (2022) present an interesting idea of an international system that would optimize ship transit speeds between different ports, considering the ports' limitations, so that the arrival of ships of different sizes at the port could be optimized. A system like this could certainly help improve the utilization rate of ports, but it would require international cooperation in the matter. However, creating such a system is very challenging, as the operation of ships is affected worldwide by numerous factors, such as ports, fairways, weather, other ships, cargo handling capacity and other forms of transport (Yazar et al 2022).

References

Abdel-Malek, K., Mi, Z., Yang, J., & Nebel, K. (2005). Optimization-based layout design. *Applied bionics and biomechanics*, *2*(3-4), 187-196.

Abu-Aisha, T., Ouhimmou, M., & Paquet, M. (2021). A simulation approach towards a sustainable and efficient container terminal layout design. *Journal of international maritime safety, environmental affairs, and shipping, 5*(4), 147-160. https://doi.org/10.1080/25725084.2021.1982636

Aitor Goti (2010). *Discrete Event Simulations*. Sciyo.

Alamri, A. A., & Syntetos, A. A. (2018). Beyond LIFO and FIFO: Exploring an Allocation-In-Fraction-Out (AIFO) policy in a two-warehouse inventory model. *International journal of production economics, 206*, 33-45. https://doi.org/10.1016/j.ijpe.2018.09.025

Altiok, T., & Melamed, B. (2007). *Simulation Modeling and Analysis with ARENA*. https://doi.org/10.1016/B978-012370523-5/50000-6

Anthony J. Onwuegbuzie, R. F. (2016). *Seven Steps to a Comprehensive Literature Review*. SAGE Publications.

AnyLogic. (2024.). Triangular Distribution. Retrieved March 11, 2024, from https://anylogic.help/advanced/functions/triangular.html

Anylogic (2024). *Anylogic timeline*. Retrieved February 21, 2024, from https://www.anylogic.com/features/timeline/#anylogic-4-0

Anylogic Help. (2023) Retrieved March 22, 2024, from https://anylogic.help/library-reference-guides/process-modeling-library/resourcepool.html

Bairagi, V., & Munot, M. V. (2019). *Research Methodology*. Chapman & Hall/CRC.

Banks, J., Carson II, J. S., Nelson, B. L., & Nicol, D. M. (2010). *Discrete-event system simulation* (Fifth edition. International edition.). Pearson Education.

Batty, M. (2018). Digital twins. *Environment and planning. B, Urban analytics and city science, 45*(5), 817-820. https://doi.org/10.1177/2399808318796416

Bierwirth, C., & Meisel, F. (2010). A survey of berth allocation and quay crane scheduling problems in container terminals. *European journal of operational research, 202*(3), 615-627. https://doi.org/10.1016/j.ejor.2009.05.031

Borshchev, A., Grigoryev, I. (2013) *The Big Book of Simulation Modelling*. Anylogic, America https://www.anylogic.com/resources/books/big-book-of-simulation-modeling/

Budiyanto, M. A., Huzaifi, M. H., Sirait, S. J., & Prayoga, P. H. N. (2021). Evaluation of CO2 emissions and energy use with different container terminal layouts. *Scientific reports, 11*(1), 5476. https://doi.org/10.1038/s41598-021-84958-4

Christiansen, M., Hellsten, E., Pisinger, D., Sacramento, D., & Vilhelmsen, C. (2021). *Liner Shipping Network Design*.

Christodoulou, A., Raza, Z., & Woxenius, J. (2019). The integration of RoRo shipping in sustainable intermodal transport chains: The case of a North European RoRo service. *Sustainability (Basel, Switzerland), 11*(8), 2422. https://doi.org/10.3390/su11082422

Choi, B. K., & Kang, D. (2013). *Modeling and simulation of discrete event systems*. John Wiley & Sons, Incorporated.

Cooper, D. R., & Schindler, P. S. (2011). *Business research methods* (11. ed.). McGraw-Hill Irwin.

Daduna, J. (2013). Short sea shipping and river-sea shipping in the multi-modal transport of containers. *International journal of industrial engineering, 20*(1-2), 225-240.

Diab, H., Younes, R., & Lafon, P. (2017). Survey of research on the optimal design of sea harbours. *International journal of naval architecture and ocean engineering, 9*(4), 460-472. https://doi.org/10.1016/j.ijnaoe.2016.12.004

Dori, D., Sillitto, H., Griego, R. M., McKinney, D., Arnold, E. P., Godfrey, P., . . . Krob, D. (2020). System Definition, System Worldviews, and Systemness Characteristics. *IEEE systems journal, 14*(2), 1538-1548. https://doi.org/10.1109/JSYST.2019.2904116

Drira, A., Pierreval, H., & Hajri-Gabouj, S. (2007). Facility layout problems: A survey. *Annual reviews in control, 31*(2), 255–267. https://doi.org/10.1016/j.arcontrol.2007.04.001

Endrina, N., Rasero, J. C., & Konovessis, D. (2018). Risk analysis for RoPax vessels: A case of study for the Strait of Gibraltar. *Ocean engineering, 151*, 141-151. https://doi.org/10.1016/j.oceaneng.2018.01.038

Flor, N. (2011). Technology Corner: Virtual Crime Scene Reconstruction: The Basics of 3D Modeling. *The journal of digital forensics, security and law, 6*(4), 67-74. https://doi.org/10.15394/jdfsl.2011.1108

Foures, D., Albert, V., & Nketsa, A. (2016). A new specification-based qualitative metric for simulation model validity. *Simulation modelling practice and theory, 66*, 1-15. https://doi.org/10.1016/j.simpat.2016.03.002

Gavle Hamn (2023). Retrieved March 7, 2024, from https://gavlehamn.se/wp-content/uploads/2022/12/Time-slot-Gavle-page-1-3-221221.pdf

Gharehgozli, A., Zaerpour, N., & de Koster, R. (2020). Container terminal layout design: Transition and future. *Maritime economics & logistics, 22*(4), 610-639. https://doi.org/10.1057/s41278-019-00131-9

Greasley, A., & Edwards, J. S. (2021). Enhancing discrete-event simulation with big data analytics: A review. *The Journal of the Operational Research Society, 72*(2), 247-267. https://doi.org/10.1080/01605682.2019.1678406

Grigoryev, I. (2023) *Anylogic in three days*. Anylogic

Grubisic, N., Krljan, T., & Maglic, L. (2020). The Optimization Process for Seaside Operations at Medium-Sized Container Terminals with a Multi-Quay Layout. *Journal of marine science and engineering, 8*(11), 891. https://doi.org/10.3390/jmse8110891

Harary, F., & Batell, M. F. (1981). What is a system? *Social networks, 3*(1), 29-40. https://doi.org/10.1016/0378-8733(81)90003-4

Hart, C. (2018). *Doing a Literature Review: Releasing the Research Imagination*. SAGE Publications.

Helo, P., Tuomi, V., Kantola, J., Sivula, A., yliopisto, V., Vaasa, U. o., . . . Innovations, S. o. T. a. (2019). *Quick guide for Industrial Management thesis works*. Vaasan yliopisto.

Hosseini-Nasab, H., Fereidouni, S., Fatemi Ghomi, S. M. T., & Fakhrzad, M. B. (2018). Classification of facility layout problems: A review study. *International journal of advanced manufacturing technology, 94*(1-4), 957-977. https://doi.org/10.1007/s00170-017-0895-8

Iversen & Gergen, M. (1997). *Statistics*. Springer New York.

Karjalainen, L. (2012). *Liiketalouden matematiikka* (2., uud. p.). Pii-kirjat.

Kikolski, M., & Ko, C. (2018). Facility layout design - Review of current research directions. *Engineering management in production and services, 10*(3), 70-79. https://doi.org/10.2478/emj-2018-0018

Krzykowska-Piotrowska, K., Piotrowski, M., Organiściak-Krzykowska, A., & Kwiatkowska, E. (2022). Maritime or Rail: Which of These Will Save the Planet? EU Macro-Regional Strategies and Reality. *Sustainability (Basel, Switzerland), 14*(6), 3555. https://doi.org/10.3390/su14063555

Law, A. M. (2015). *Simulation modeling and analysis* (Fifth edition. International student edition. International edition.). McGraw-Hill Education.

Law, A.M. & D.W. Kelton (1991). *Simulation Modeling and Analysis.* 2nd ed. McGraw-Hill International Editions. Industrial Engineering series.

Leggate, H. M., Leggate, H., McConville, J., McConville, J., Morvillo, A., Alfonso Morvillo, & James McConville. (2004). *International Maritime Transport: Perspectives*. Routledge.

Martin-Iradi, B., Pacino, D., & Ropke, S. (2022). The Multiport Berth Allocation Problem with Speed Optimization: Exact Methods and a Cooperative Game Analysis. *Transportation science, 56*(4), 972-999. https://doi.org/10.1287/trsc.2021.1112

Marzano, V., Tocchi, D., Fiori, C., Tinessa, F., Simonelli, F., & Cascetta, E. (2020). Ro-Ro/Ro-Pax maritime transport in Italy: A policy-oriented market analysis. *Case studies on transport policy, 8*(4), 1201-1211. https://doi.org/10.1016/j.cstp.2020.08.001

McDonald, J. A., Ryall, C. J. & Wimpenny, D. I. (200)1. Rapid Prototyping Casebook. Professional Engineering Publishing Limited. The Cromwell Press.

Meng, Q., & Wang, S. (2011). Optimal operating strategy for a long-haul liner service route. *European journal of operational research, 215*(1), 105-114. https://doi.org/10.1016/j.ejor.2011.05.057

Morales-Fusco, P., Grau, M., & Saurí, S. (2018). Effects of RoPax shipping line strategies on freight price and transporter’s choice. Policy implications for promoting MoS. *Transport policy, 67*, 67-76. https://doi.org/10.1016/j.tranpol.2017.03.021

Moran, S. (2017). *Process plant layout*. Butterworth-Heinemann.

Mustafa, M. E., & Talab, S. A. (2016). The effect of queuing mechanisms first in first out (FIFO), priority queuing (PQ) and weighted fair queuing (WFQ) on network's routers and applications.

Naufal, M., Marjito, M., & Komarudin, K. (2023). Implementation Of a Web-Based Queuing System in Hospital Polyclinic Services Using the FIFO Method: Case Study of Karangpawitan Community Health Center. *Informatics Management, Engineering and Information System Journal*, *1*(2), 112-118.

O'Connor, E., Evers, N., & Vega, A. (2023). Port capacity planning – A strategic management perspective. *Marine policy, 150*, 105537. https://doi.org/10.1016/j.marpol.2023.105537

Orosa, J. A. (2023). *Sustainability in Maritime Transport: Advances, Solutions and Pending Tasks*. MDPI - Multidisciplinary Digital Publishing Institute.

Pang, T. Y., Pelaez Restrepo, J. D., Cheng, C., Yasin, A., Lim, H., & Miletic, M. (2021). Developing a Digital Twin and Digital Thread Framework for an 'Industry 4.0' Shipyard. *Applied sciences, 11*(3), 1097. https://doi.org/10.3390/app11031097

Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. *International journal of production research, 59*(12), 3777-3816. https://doi.org/10.1080/00207543.2021.1897176

Quinlan, C. (2011). *Business research methods*. South-Western Cengage Learning.

Rao, M. T. (2009). *Industrial Management*. Himalaya Publishing House.

Remondino, F., & El-Hakim, S. (2006). Image-based 3D Modelling: A Review. *Photogrammetric record, 21*(115), 269-291. https://doi.org/10.1111/j.1477-9730.2006.00383.x

Ruspini, E. (2002). *An Introduction to Longitudinal Research*. Routledge.

Sapsford, R. J., Jupp, V., & Sapsford, R. (2006). *Data Collection and Analysis (Second Edition)*. SAGE Publications Ltd.

Sargent, R. G. (2010). *Verification and validation of simulation models*. https://doi.org/10.1109/WSC.2010.5679166

Saunders. (2023). *Research methods for business students*. Pearson Education.

Saunders, M., Lewis, P., & Thornhill, A. (2007) *Research methods for business students*. Pearson Education UK.

Schluse, M., Priggemeyer, M., Atorf, L., & Rossmann, J. (2018). Experimentable Digital Twins—Streamlining Simulation-Based Systems Engineering for Industry 4.0. *IEEE transactions on industrial informatics, 14*(4), 1722-1731. https://doi.org/10.1109/TII.2018.2804917

Sclar, M. (1988) L. GLOBAL LINER TRAFFIC--A CURRENT AND FUTURE ANALYSIS OF ROUTES, COMMODITIES AND CARGO FLOWS. In *Ro-Ro'88BML Business Meetings Ltd.*.

Sembiring, A. C., Tampubolon, J., Sitanggang, D., & Turnip, M. (2019). Improvement of inventory system using first in first out (FIFO) method. In *Journal of Physics: Conference Series* (Vol. 1361, No. 1, p. 012070). IOP Publishing.

Shaw, K. A. (2016). *Operations methods: Managing waiting line applications*.

Suomen Satamayhdistys Ry. *Yearly statistics 2023.* Retrieved February 14, 2024, from https://www.satamaliitto.fi/fin/tilastot/kuukausitilastot/?stats=monthly&T=0&year=2023&month=1&changes=rolling

Stewart Robinson, Brooks, R., Kotiadis, K., Robinson, S., & Van Der Zee, D. (2010). *Conceptual Modeling for Discrete-Event Simulation*. CRC Press.

Tapaninen, U. k. (2018). *Logistiikka ja liikennejärjestelmät*. Otatieto.

Tripto, J., Ben-Zvi Assaraf, O., Snapir, Z., & Amit, M. (2016). The 'What is a system' reflection interview as a knowledge integration activity for high school students' understanding of complex systems in human biology. *International journal of science education, 38*(4), 564-595. https://doi.org/10.1080/09500693.2016.1150620

Trodden, D., Murphy, A., Pazouki, K., & Sargeant, J. (2015). Fuel usage data analysis for efficient shipping operations. *Ocean engineering, 110*, 75–84. https://doi.org/10.1016/j.oceaneng.2015.09.028

Uusi-Rauva, E., Kouri, I., Miettinen, A., Haverila, M., & Haverila, M. J. (2009). *Teollisuustalous* (6. p.). Infacs.

Vasek. *Liikenne kasvoi voimakkaasti Vaasan satamassa*. Retrieved February 14, 2024, from https://www.vasek.fi/vaasanseudun-kehitys-oy-vasek/viestinta/uutiset/liikenne-kasvoi-voimakkaasti-vaasan-satamassa

Visual Components. (2024) Retrieved March 21, 2024, from https://www.visualcomponents.com/about-us/

Väylävirasto (2023). *Vaasan väylä*. Väylä.fi. Retrieved February 21, 2024, from https://vayla.fi/documents/25230764/35410858/Vaasa+9+m1.pdf/37d74600-137c-43dc-8ad7-1daba56ceaa4/Vaasa+9+m1.pdf?t=1591778013847

Walton, D., & Project Muse. (2014). *Abductive Reasoning*. The University of Alabama Press.

Waters, D. (2009). *Supply chain management: An introduction to logistics* (2nd ed.). Palgrave Macmillan.

Wawrzyniak, J., Drozdowski, M., Sanlaville, É., Pigné, Y., & Guinand, F. (2024). Quay partitioning problem. *International transactions in operational research, 31*(3), 1554-1584. https://doi.org/10.1111/itor.13389

Węcel, K., Stróżyna, M., Szmydt, M., & Abramowicz, W. (2024). The Impact of Crises on Maritime Traffic: A Case Study of the COVID-19 Pandemic and the War in Ukraine. *Networks and spatial economics, 24*(1), 199-230. https://doi.org/10.1007/s11067-023-09612-0

Wee Chuan Lim, E. (2012) *Discrete Event Simulations*. IntechOpen.

Yan Zhang. (2024). *Digital Twin: Architectures, Networks, and Applications*. Springer Nature.

Yazar Okur, İ. G., & Tuna, O. (2022). Schedule Reliability in Liner Shipping: A Study on Global Shipping Lines. *Pomorstvo, 36*(2), 389-400. https://doi.org/10.31217/p.36.2.22

Yle Uutiset. *Vaasan sataman laituri on liian lyhyt – alukset odottavat ankkuroituna Merenkurkussa*. Retrieved February 14, 2024, from https://yle.fi/a/3-12547054

Yliskylä-Peuralahti, J. (2017). Ecological modernization and the multi-scaled governance of sustainability in maritime transport. *Geografiska annaler. Series B, Human geography, 99*(1), 42-58. https://doi.org/10.1080/04353684.2016.1277077

Yu, J., Tang, G., & Song, X. (2022). Collaboration of vessel speed optimization with berth allocation and quay crane assignment considering vessel service differentiation. *Transportation research. Part E, Logistics and transportation review, 160*, 102651. https://doi.org/10.1016/j.tre.2022.102651

Zhou, J., Fagerholt, K., Liu, Y., & Zhao, Y. (2023). Profitability prospects for container roll-on/roll-off shipping on the Northern Sea Route (NSR). *Maritime economics & logistics*. https://doi.org/10.1057/s41278-023-00266-w

Zikmund, W. G. (2003). *Business research methods* (7th ed.). Thomson.