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A simulation Analysis of the Container Handling Process at Husøy Port

The Effect of a New Container Terminal

Per Einar Husby and Emilie Klausen

Supervisor: Mario Guajardo

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Abstract

In this thesis we have been using simulation as a method to analyse the structural changes at Karmsund Container Terminal. By measuring the different steps in the container handling process, we were able to evaluate how the structural changes affected the latter process. Structural changes can in this thesis be defined as the construction of a new container terminal, including relocation of the various facilities and expanding the quayside.

The simulation also made it possible to do a sensitivity analysis on the ship activity at the terminal. In this way we could evaluate how the structural changes affected the container terminals ability to handle an increased number of ship arrivals, as well as a growth in the container throughput at the terminal.

First we will be introducing relevant theory for this research. Parts of previous literature were used in the development of the simulation model. The rest is presented as a basis for the overall evaluation of the result.

Our primary data were collected through interviews and observation when visiting the container terminal. This information has been crucial for the development of the simulation model, making sure we captured a realistic picture of the situation.

The secondary data were collected through historical statistics acquired from Karmsund Port Authorities database. Data concerning the terminal activities for the last 9 months were collected and processed using different goodness of fit tests. The distributions developed made it possible to utilize the full extent of the simulation program by capturing the stochastic dynamic aspects of the port activities.

The results of the simulation told us that the structural changes potentially could affect the overall cargo handling process in a positive way. Leading to increased efficiency and an overall more stable operation. We also found the new terminal better suited to handle the expected traffic growth to the container terminal.

Preface

This thesis is submitted as the independent work of the master program at the Norwegian School of Economics.

The work started in early June 2015, when we approached Karmsund Port Authorities, requesting a cooperation toward our master thesis. Through a good dialogue with the Harbourmaster Leiv Sverre Leknes, we were granted the opportunity conduct research regarding the maritime operations at the container harbour. A topic we both found very rewarding. The cooperation with the Karmsund Port Authorities have been crucial for us writing this thesis. We therefore wish to thank Harbourmaster Leiv Sverre Leknes for providing us with this opportunity. Several interviews were conducted with the different stakeholder at the port. While the port authorities granted us access to their very extensive database.

Collecting the required data for the thesis proved to be a major and very time consuming part of the work. We wish to thank our supervisor Mario Guajardo for great assistance regarding both the collection and processing of the data. He was always available and his feedback made the entire process much more manageable.

We also want to thank Ingolf Ståhl for taking the time out of his schedule to meet with us after holding a guest lecture at NHH. His inputs regarding the GPSS program was of great value to us. He also provided us with the full version of GPSS, which proved crucial in order to run the simulation as intended.

We found working on this subject very rewarding. Much of the knowledge acquired over the years studying at both NHH and Molde University College became relevant while working on the thesis. The entire process was very informative and we feel we have benefited greatly from the experience.

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Glossary

Stevedore company	The operators responsible for the loading and unloading of ships
Reachstacker	Trucks handling intermodal cargo containers in small terminals or medium-sized ports
Roro container	Roll on / Roll off containers
Lolo container	Lift on / lift off containers. Requires cranes to be discharged/loaded on/off vessels.
TEU	Twenty-foot equivalent unit
IAT	Inter arrival times
GOF	Goodness of fit
ST	Service Time
KCT 1	Karmøy container terminal 1
KCT 2	Karmøy container terminal 2
EXP	Export berth
Empty container depot-agreement	Agreement between the oversea shipping lines and the stevedore company considering container storage

1. Introduction

Today, large parts of the freight traffic in Norway is transported on the road network. It is a stated objective of the Norwegian authorities, to facilitate a shift in preferred mode of transportation. Sea transport can offer safe and efficient transport of large volumes of freight, and with clear environmental benefits. (Regjeringen, 2013)

In order to achieve this shift, the harbours must provide the shipping lines with efficient solutions and accessible capacity at all hours of the day. The port of Husøy have the last year experienced a rapid growth in the container traffic. Thus as a response to the market development they have decided to develop a new container terminal.

We are interested in evaluating the new terminal's ability to handle the container throughput. By performing a simulation analysis we attempt to get a more detailed insight in the dynamic of the container handling processes, and how it is affected by the structural changes

1.1 Karmsund Port Authorities

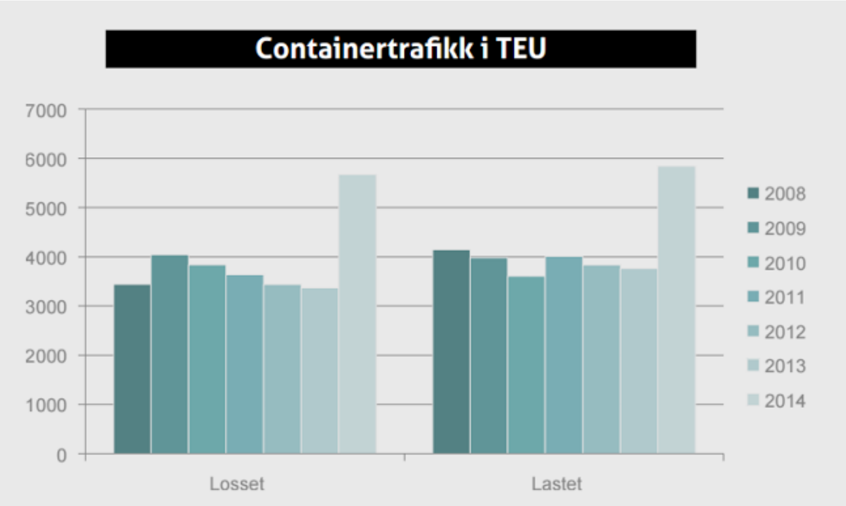
Karmsund Port Authorities is a part of an inter-municipal organization between 6 municipalities in the west coast of Norway. Their headquarter are located in Haugesund, close to a majority of the shipping related activities. In most of the shipping related activities around Haugesund and Karmøy the port authorities operates as a landlord. They makes sure the port operations are done according to laws and regulations. Their goal is always to be “*adapted to meet effective competitive sea transport of passengers and goods and to provide safe seafaring within its own sea area*” (http://karmsundhavn.no/en/about-karmsund-havnevesen)

Image 1 (Copy Right Karmsund Port Authorities)

One of the board's major priority regarding development is the expansion of Karmsund Sea-traffic Harbour - Husøy (Image 1). The Port Director, Tore Gautesen, is an ambitious and energetic leader who believe that due to major available areas, well established infrastructure and an already existing logistic center, Husøy Port is an ideal location for a maritime logistic hub. The planned development of highway E134, whose endpoint at the port, is also an argument for further investments at the port (Aftenbladet, 2015)

“*Our ambition is to become the most important maritime logistic hub on the west coast of Norway*” (http://karmsundhavn.no/en/about-karmsund-havnevesen/)

1.1.1 Future Projects



Graph 1 - Annual Report 2014

Graph 1 is an excerpt from Karmsund Harbour Annual Report 2014 and are only written in norwegian. On the left the graph shows the annual amount of discharged TEUs (equal 20 foot containers) and in the right graph we see annual amount of loaded TEUS.

The next step in the development of Husøy Port is building a new container terminal; Karmsund Container Terminal 2, and further on defined as KCT 2. As we can see from the annual numbers in image 2, the container activity increased rapidly last year (2014) and they expect this trend to continue (Leknes, 2015).

In image 1 on the previous page we can see an illustration of the new terminal. The expansion will hopefully contribute in the work of getting Husøy Port one step closer to its ambition. With help from the Harbourmaster, Leiv Sverre Leknes, we have been able to take a closer look at the development of the project and how it affects some of the processes at the terminal.

1.2 Objectives of the Research

1.2.1 General Topic

The port authority's intention behind the planned construction of KCT2, is to have access capacity facing the marked development. The structural changes at the port, enables them to give the different terminals more segmented and specialized roles. This raises several interesting questions regarding which positive effects that could be obtainable by such a development. In this thesis we wish to closer examine the effects on one aspect of the terminal operations and thereby:

Evaluate what effect structural changes at a container terminal could have on the dynamics of the container handling process.

Port authorities have to face increasing competition among ports, which require a higher efficiency in container operations both along the quayside and within the yard. The desired output of the shipping companies is usually to minimize the ship's turnaround time, which is one of the main indicators of the terminal performance. To measure the overall performance of a container terminal, it's important to identify and employ performance indicators. Clearly defined key performance indicators allows the port authorities to decision support systems that optimize their objectives (Vacca, Bierlaire, & Salani, 2007).

Vacca, Bierlaire and Salani, divided the KPIs evaluating port performance into two main categories. Service oriented and productivity oriented. The service oriented category addresses measurement considering the service level provided to the clients using the port. These indicators take into account the port competitiveness, and include berth service time, i.e. vessel turnaround time in hours, vessels berthed on time, etc. The productivity oriented class measure the volume handled by the port in relation to their available resources. Common indicators are crane utilization (TEUs per year, per crane), berth utilization (vessels per year, per berth) and gate throughput (containers per hour). (Vacca, Bierlaire, & Salani, 2007)

1.2.2 The Objectives

In order to closer evaluate what effect of the structural changes could have on the various parts of the container handling process, we divided the measurement in more detailed units. This enables us to evaluate the different aspects of the container handling process both separately as well as an overall process.

When evaluating the new terminals operational performance, regarding the discharging and loading operation, both service and productivity oriented measurements were included in the analysis. We developed the following objectives for the simulation, providing us with an opportunity to evaluate the planned move on the basis of several key performance indicators.

Objective 1: Measure the ship's crane utilization

As the port of Husøy don’t have any mobile harbour cranes, it’s the ship's own cranes that perform the discharging and loading sequence. The productivity measurement will therefore be the ship's crane utilization. Defined as the amount of the total berthing time the ships crane is operational. This is a sensitive procedure regarding the overall time the ship have to spend at the berth, and thus important for the shipping lines in order to keep their schedule.

We will perform a simulation with the objective of measuring the ship's crane utilization at both the current situation and the planned development at KCT 2. The measurements will tell us whether the development of KCT 2 can increase the utilization of the ship's cranes, and whether the ships crane can be seen as a bottleneck at some of the berths.

Objective 2: Measure the efficiency of the reachstackers

The average time spent by the reachstackers on each container will be regarded as an operational measurement. This includes placing the containers at the depot and delivering the containers portside for loading. We simulate the operational performance both on the current situation and at the new terminal KCT 2. Giving us the opportunity identify a potential increase in efficiency at the new terminal.

Objective 3: Measure the ship's overall berth time

As mentioned in objective 1, the overall berth time of the vessels is a very important factor for the shipping lines. It is therefore considered to be one of the most important service measurements for the port. We will measure the average berth time needed to finish the discharging and loading operation, including the time they potential must wait for a berthing space. Although some of the previous objectives measures different aspect of the discharging and loading process, it’s important to clearly measure the overall time spent by the ships at berth. The purpose is to make an assessment of the potential decrease in berth time, which the move to KCT 2 might accomplish.

Objective 4a: Measure the rate of congestion at the berths

In addition to the overall berth time, avoiding congestion at the berthing facilities upon arrival will be an important factor for the shipping lines. Potentially waiting for an available berth spot could have a very negative effect on the shipping lines schedule. The service measurement will be the number of vessel having to wait for a berth spot upon their arrival. The simulation also provides us with an opportunity to measure the time ships spend waiting for an available berth slot.

At the moment congestion at the berthing facilities are an increasing issue according to the port authorities (Leknes, 2015). With the planned relocation of the container terminal to KCT 2 the number of berth spots, designated for ships carrying containers, will be decreased from 3 to 2. The result of the simulation will give us an indicator whether the planned facility at KCT 2 will be able to avoid congestion with the current arrival rate of ships. A similar analyses will be performed on the current situation to verify the statement from the port authorities regarding congestion level at berth.

Objective 4b: Measure the effect of increased traffic

Objective 4b will also focus on the congestions, but now in regards to a change in the traffic to Husøy. There will be performed a sensitivity analysis which gradually increase the number of containers discharged and loaded at the different terminals. At the same time the inter arrival time of the ships will be decreased in order to simulate an increased arrival rate.

The performance indicators stated in the objectives will be used as a foundation when evaluating the planned relocation to the new terminal. We will analyse the effect the various structural changes could have on the overall container handling operation at the port.

1.3 The Container Terminal

1.3.1 The Operators

The containers at the container terminal are being handled by two different stevedores companies. Through several interviews and guided tours with representatives from the different stevedore companies, we were able to collect data about the terminal operations. Here we present the basic information about the two companies. We will also describe the organization and layout of the terminal that has been used as a foundation to form the simulation.

KTM shipping

KTM shipping are located at the west side of the terminal. They are agents for the shipping line ECL and Scan Shipping. All containers loaded and discharged at the Export berth (west side) are handled by KTM. They also manage their own container depot in connection with the Export berth. (Gaupås, 2015)

Sea Cargo Haugesund

The second stevedore company is Sea Cargo. The company is the freight forwarder part of Sea Cargo Group. In addition to its own shipping line, Sea Cargo Haugesund are also agents for NCL, Maersk and Nor Lines. Their location is on the east side of the terminal area, which is called the main Karmsund Container Terminal - KCT 1. Sea Cargo are also managing their own containers depot on this terminal. (Hauge, 2015)

1.3.2 The Current Terminal - Todays Situation

Image 2 - KCT 1-And Export

At image 2 we can see an overview over the container terminal, as it is today. In the simulation this will be presented as what we call the current terminal. Each facility are stated with a letter and will be explained in this chapter. By using Fonnakart ([www.fonnakart.no)](www.fonnakart.no) we have measured the distances between the various facilities, and used this to calculate different time aspects in the simulation. Each letter represent the following facility:

A - The berth spot for the Export terminal, operated by KTM as the stevedore company. This quayside is 80 meters long. Since the ships that are arriving here are around 100 meter, the Export terminal can only handle one ship at a time.

B - Regular container depot for KTM and the Export terminal. Here they stack both empty and full containers. Empty reefer containers are also stacked here.

C - Reefer container depot for KTM. This is where Karmsund Port Authority have installed electrical outlet for the reefer containers handled by KTM.

A, B and C are the facilities located at the Export terminal, and are all a part of KTM’s operation. KTM are also operating one reachstacker that they are in possession of 24/7. (Gaupås, 2015)

D - This is berth spot A at KCT 1, and will further on be defined as KCT 1-A. This is also where the roro ramp are located, so roro ships are also berthing here.

E - This is berth spot B at KCT 1, and will further on be defined as KCT 1-B. The total quayside at KCT 1-Are 270 meter. There are therefore not any exact line to distinguish between A and B, but we know that this quayside fits two ships at the same time.

F - Regular container depot for Sea Cargo and the overall KCT 1 terminal. This depot is for both empty and full containers. Empty reefer containers are also stacked at this location

G - Reefer container depot for Sea Cargo. All reefer containers that are full and discharged from KCT 1-A and KCT 1-B will be stored at this location due to the electrical outlets.

D, E, F and G are the facilities located to serve Sea Cargo. Due to different empty depot agreements we also take into consideration that the stevedores companies needs to occasionally collect empty containers from the other company's depot. Sea

Cargo are operating one reachstacker to handle all containers at KCT 1. (Hauge, 2015)

1.3.3 The New Terminal - The Planned Development

Image 3 – KCT 2

At Image 3 we can see on the right side of the map how they are planning on expanding the port. This will be done by filling out an area that today only contains reefs in the sea. The expansion will give the terminal a better possibility to segment the various cargo types into designated areas. According to the Harbourmaster the new area will be dedicated to handle, stack and deliver containerized cargo. Each letter in the figure represent the following (Leknes, 2015):

1 and 2 - These two berth spots will still be representing KCT 1-A and B, as described in Image 2. But in the new situation this quayside will only berth ships that are handling roro cargo and pallets. All bulk cargo will also have its own terminal, but this is not included in this map.

3 - Berth spot B at KCT 2, and further on defined as KCT 2-B. At this moment there is still not decided whether this berth spot will be on the east or west side of the expanded area. The location of this berth will however not have a great impact on the distances between the various facilities.

4 - Berth spot A at KCT 2, and further on defined as KCT 2-A. Together with KCT 2-B this berth spot will only be available for container ships.

5 - Empty container depot for KCT 2. In the new terminal we assume that every empty container depot-agreement includes a privilege to locate the containers at this area.

6 - Regular container depot for KCT 2

7 - Reefer container depot KCT 2. All the electrical outlets from KTM and Sea Cargo are now installed at this location.

Travel time between the various locations presented on the map can be seen in appendix 7. This have been developed in cooperation with the stevedore company, using the distance discovered in Fonnakart (Fonnakart.no). The table has been used in development of the simulation.

2. Litterature Review

This chapter reviews relevant literature and theory to the research topic. It aims to address previous research and theoretical concepts that has been taken into consideration. The presented theory has contributed to the simulation development, but also to evaluate the results. In the coming section it will also be explained how this is relevant to our research, but the detailed description is to be found at its relevant chapter.

2.1 Port Competitiveness

Notteboom and Yap stated that the competitive position of a container port is determined by its competitive offer its stakeholders such as shippers, shipping lines and the general geographical region it operates in. The connection to other ports and its ability to connect to different supply network might also be seen as an important aspect of the port competitiveness. (Notteboom & Yap, 2012)

It is evident that the competitive strength of a port doesn’t only depend on its own infrastructure and organization. The geographical region and the decision process of port players are also factors that could influence the port's competitiveness. In order to evaluate the factors influencing a port's competitiveness, it’s necessary to gain insight into the various functions of the port, as well as a general understanding of which qualities that are considered important by the various port players.
(Meersman et al. 2010)

Various research have been made in regards to the different factors affecting a port competitiveness. From the research of Winkelmans and Notteboom (2007) we can extract the following factors that could contribute in the evaluation of the planned expansion at Husøy. Evaluating what effects the port's proximity to major centers of production, consumption and major trade lanes could have on its competitiveness. Taken into consideration the port ability to connect to different supply chain networks. The port's ability to forecast and anticipate market development, in order to meet traffic trends and provide a stable and reliable capacity. This could also affect the overall port cost through higher efficiency. (Winkelmans, Notteboom, 2007)

The influence of container ports on the demand for containerized transport by sea is exerted mainly through improvements to productivity. Improvements made in regards to the efficiency of the container handling process, while ensuring that the port capacity is developed in order to meet the anticipated demand is of high importance. The port also need to provide its clients with excellent maritime and hinterland access. (Notteboom, Yap, 2012)

2.2 Container Yard Operations.

In the terminal operations, the container yard is the center of the operations. Most parts of the operations either originates from, or are destined to the various depots in the container yard. The container stacking in the depots will therefore influence the other parts of the operation at the container terminal. (Chen.T, 1999)

The stacking operation inside the container yards at a port could have an impact on the entire loading/discharge operation performed at the terminal. The time spent by the stevedore companies on the yard operation, will to some extent influence the total time spent by the ship at berth. Literature considering movements inside the container yards, could give us an idea about how the yard operations affect the entire loading/discharge operation. Chen, Lin & Juang classified the major unproductive moves in the loading and discharge operations as shifting and housekeeping moves. Their study identifies the factors causing these unproductive moves, and the impact they had on the transfer operation. Storage density and the number of containers loaded/discharged was found to be the major factors causing unproductive moves. (Chen.T Lin.K & Juang.Y, 2000)

The number of housekeeping moves performed when discharging was found to be 21% of the total number of containers discharged, and for the outbound containers, the number of shift moves was 17%. The authors stated that this information could be used by terminal operators to estimate the amount of work to be undertaken in terminal operations. (Chen.T, Lin.K & Juang.Y, 2000). This findings will be taken into consideration when developing the simulation model, in order to simplify the yard operation.

2.3 Theory of Constraints

According to Bassan (2007) several factors could limit the productivity at a container terminal. In this thesis we wish to identify the various physical limitations that might present itself during the container handling process. In order to investigate which part of the process is causing limitations at the different terminals, the theory of constraints will be used as a foundation for our evaluation.

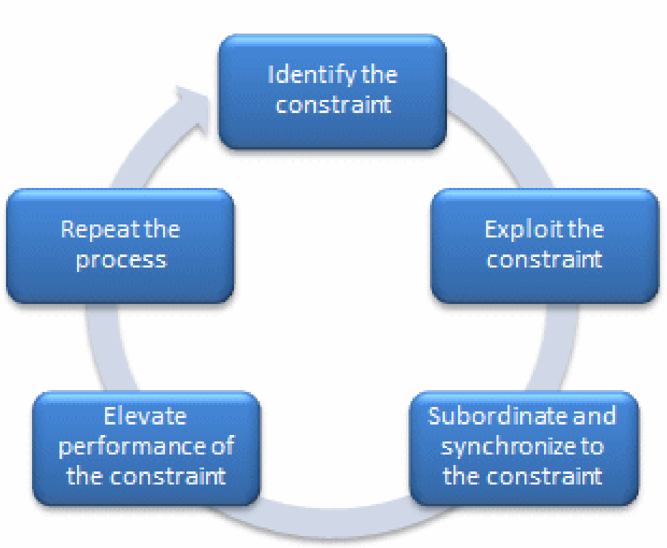


Figure 1 – The steps regarding TOC

The basis of the theory of constraints is that every operation have must have at least one constraint that limits its overall performance. The theory of constraints views the different processes as part of the same operation, instead of thinking that they are independent from each other. At the same time, the focus is on identifying the weakest part of the operation. This part is identified as the bottleneck, and the focus goes to study the relationship between the bottleneck and the rest of the operation. The general idea is that the operation as a whole can't perform better than its weakest link, and making improvements elsewhere only enhances the effect of the bottlenecks limitation. The changes made must aim at solving the root of the problem by improving the bottlenecks performance. As shown in figure 1 the processes of improving the operations overall performance, goes through several steps in what can be considered a continuous improvement process. The objective is to identify and exploit the process considered to be the bottleneck to the fullest. The following step is to evaluate whether the bottlenecks performance has improved, before repeating the process. (Goldratt.E 1990)

2.4 Simulation with GPSS

The shortening name GPSS stands for a General Purpose Simulation System. The program aim to model different business processes by using a graphical use interface to build a simplified picture of a real system. The creators emphasized simplicity so the program would be easy to learn, which have lead the simulation system to also attract student users.

GPSS is mainly used to simulate stochastic and dynamic processes. Stochastic implies that one can take uncertainty and risk into account, and dynamic implies that one can follow processes in detail over time. Ingolf Ståhl, one of the creators, also refers to the GPSS as a discrete event simulation since the noticeable changes in the states of the system components can be caused by occurrence of significant events over time. (Ståhl, 2015)

Compared to other simulation systems, which often are animated oriented systems (AOS), GPSS is a block based system. In practice this means that we can build the same storage or other facilities several places in the same simulation, even though in reality it is in only one place. That isn't so easy to manage in an AOS. The block based system also manage to investigate the effect of the uncertainty more directly, due to a focus on multiple runs. (Ståhl & Born, 2013)

The GPSS program also aim to simplify the work of extracting the results of the simulation, by using print and graph blocks one can transfer the results directly to other types of software. (Ståhl & Born, 2013)

3. Methodology and Research Design

3.1 Reseach Design

To capture a real picture of the situation at Husøy Port the research design consisted of a field research, conducted at the container terminals. This research corresponds to an exploratory research initiative. It is a research strategy which focuses on understanding the dynamics present within single settings that we initially have little information about .(Ghauri & Grønhaug, 2010) This design able us to use both the data that Karmsund Port Authority already have collected, and go deeper into other sources of information that could be of relevance.

3.2 Data Collection

The first step to answer the research question and evaluate our objectives, is collecting data relevant for our study (Saunders, M. Lewis, P and Thornhill, A. 2009). As data collection method we found semi-structured interviews as the most appropriate, in order to understand different processes and for the development of a simulation model. To capture the stochastic dynamic part of the simulation we also collected information about ships inter arrival times, container amount loaded and discharged and each ship's time at berth. This information was given to us by the Karmsund Port Authorities through historical data from the last 9 month.

This thesis is build up with both qualitative and quantitative data. Further we describe each data collection method as primary data (interviews and observations) and secondary data (historical data from database)

3.3 Primary Data

An interview is a discussion between two or more people. It can be a very useful approach when gathering data for a study. There are several types of interviews that can be conducted. Semi structured interviews are used to gather data, which are normally analysed qualitatively, for example as part of a case study. They are useful in helping you explore “why” certain events occur, and not only exploring how and what. Making semi-structured interviews an ideal approach in order to investigate the connection between different variables, such as those revealed from a descriptive study. (Saunders, M. Lewis, P and Thornhill, A. 2009)

The main objective behind our primary data collection, was to develop a better understanding of the port operations at Husøy. In order to present a realistic simulation model of the port, it was vital for us to understand to relationship between the different variables that have an impact on the port's overall performance. Through our main contact at the port authorities Harbourmaster Leiv Sverre Leknes, we were given the name of two potential contact at the different stevedore companies. Jarle Hauge at Sea Cargo, and Torfinn Gaupås at KTM shipping. From whom we were able to acquire additional information about the subject. They were positive to contributing and we were able to book a meeting with both. By being able to ask for advice considering interview object, we felt confident that our contacts would be in possession of the knowledge we desired.

As part of the meeting, with the representatives of the stevedore companies, we were given the opportunity to gather information through interview and observation. By observation we refer to a guided tour, and an observation of the container handling processes at the terminal. However, it needs to be emphasized that the observation was preformed over a short time horizon. It is therefore only to be considered as a contribution to the data collected in the interviews. The observation greatly help our understanding of the port activities. This made it easier to form the dynamics between the segments when designing the simulation.

When building up the interview guide to a semi-structured interviews, the most normal approach for the researcher is to have a list of themes and questions to be covered. Allowing the questions to vary through the interview, based on the response and flow of conversation. Semi structured interviews also allows you to conduct follow up questions, if the response in some way was unclear. This gives you the opportunity to ‘probe’ answers, if you want your interview subject to explain further, or build on their previous responses. This is important in order to understand the meaning of the participant’s description of various situation or procedures. The subject might use words or ideas in a special context, and the opportunity to request a closer description of their meanings will add depth to the data you obtain. (Saunders, M. Lewis, P and Thornhill, A. 2009)

During this research we have had four meetings with the Harbormaster Leiv Sverre Leknes. This meetings are also to define as semi structured interviews, regarding different topics each time. One of the meetings also included getting statistical data which will be discussed later. Several meetings with the same interviewee have made it possible for us to create a better understanding of the situation to be simulated.

Give the definition of a semi- Structured interview, it was evident that this was a suitable approach for our meetings. Our basic understanding of the terminal operations were limited, and the possibility to change the order of question and potentially probe for a more detailed explanation was absolutely necessary. Beforehand we developed an interview guide stating the main topics relevant for our simulation and what data we were needed to acquire from the interview. This helped us present our questions in a manner that guided the conversation towards our main topics. The topics included in the interview guide are to find in appendix 1.

3.4 Secondary Data

Secondary data collection consist of reanalysing data that have been collected by others, but for some other purpose. Secondary data can include both quantitative and qualitative data, and is suitable to be used in both descriptive and explanatory research. The data can be considered as raw data that require some form of processing. (Saunders, M. Lewis, P and Thornhill, A. 2009)

One of the main advantages of using secondary data is the timesaving when collecting the data. It is considered much less expensive to use secondary data than to collect the same data yourself. As a consequence you might be able to analyse much larger amounts of data and will have more time to work on other issues of the research. With the data available, you might use more time on analysing the data, acquiring the information you desire. (Saunders, M. Lewis, P and Thornhill, A. 2009)

The Karmsund Port Authorities logs all data considering the ship's arrival time, the purpose of their visit and what cargo have been delivered or retrieved. We were granted access to their database, and were able to retrieve large amount of data regarding the ship's arrival and departure, and the cargo flow to and from the port. Providing us with a solid data foundation for further processing.

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A potential disadvantage using secondary data, is that the data you acquire will be collected for a specific purpose. This purpose does not necessarily fit well your study, and it might be too time consuming to process the data. The data might also be presented in such a manner that it is difficult to interpret. It is therefore important to evaluate carefully any secondary data you intend to use. (Saunders, M. Lewis, P and Thornhill, A. 2009)

The data collected by Karmsund Port Authorities were originally collected for a statistical purpose. Nevertheless the data required by us, in order to implement the different aspect of the port operation into the simulation program, was not that different from the data presented in the port authority’s logs. Some processing of the raw data were required to estimate valid probability distributions in regards to the ship's inter arrival time and the amount of containers to be loaded and discharge. However with the database consisting of large amounts of historical data considering these topics, the issue of extracting data from a dataset collected for a different purpose was not an overwhelming problem.

3.5 Simulation as a Method

Simulation can be a very accurate and powerful tool for the analysis and planning of seaport operations. Pachakis and Kiremidjian stated that a well-designed and calibrated simulation model can provide a much more accurate insight to the complex nature of port operation than analytical models. (Pachankis & Kiremidjian, 2003)

While analytical models offer fast and general approach for representing a given problem, they are not able to give the detailed and flexible insight that simulations models can provide. Simulation models is better suited for the random and complex situations that occurs on a container terminal, especially when taken into consideration the ability to investigate several parameters and their interaction. (Sgouridis et.al, 2003)

The container terminal includes large quantities of interacting factors, such as personnel, ships and truck arrival patterns and several kind of cargo-handling equipment. Therefore, it’s not the ideal environment for the application of an analytical and deterministic model. The randomness and complexity of the container terminal makes it suitable for simulation modeling. A simulation model designed for port facilities can make a great contribution in determining the effect of changes in operational processes, throughput, or evaluating investment options. (Sgouridis & Angelides, 2002)

Most studies concerning port planning and simulation focus on the service of ships rather than trucks. This could be due to the fact that ships downtime cost and customer demand are more pressing than that of the trucks. Nevertheless this does not mean that optimizing trucks utilization and service level could to some extent improve the overall port performance. Since a terminal overall performance is decided by the performance of its individual components. (Sgouridis & Angelides, 2002)

As stated in our research objectives, we wish to conduct an analysis of the individual components contributing in the discharge and loading operation at Husøy port. Capturing accurate estimations of the different components and their interaction will be of the highest importance, to make a detailed investigation on the effects of the planned move to KCT 2. Making simulation an ideal approach when choosing methodology.

3.5.1 Static vs Dynamic Simulation Models

A static simulation model is a representation of a system at a particular time, or where time is not of the essence. Monte Carlo models can be a typical example. On the other hand, a dynamic simulation model enables you to see how it evolves over time, for example a factory's conveyor system. (Law, 2015)

3.5.2 Deterministic vs. Stochastic Simulation Models

If a simulation model does not contain any probabilistic or random components, it is called a deterministic model. In a deterministic model the output of the model is determined once the set of input quantities and relationships are specified. Systems that have at least some random input components, are called to stochastic simulation models. The output produced by these models is in itself random, and can therefore be seen as only an estimation of the real system. (Law, 2015)

3.5.3 Continuous vs Discrete Simulation Models

A discrete system is one for which the state variables change instantaneously at separated points in time. For example the number of people in a bus, only change when a people enter or leaves the bus. A continuous system is one for which the state variables continuously change with respect to time. (Law, 2015)

In order to decide whether to use a discrete or continuous model for a particular system depends on the specific objectives of the research. For example, a model of traffic flow on a freeway would be discrete if the characteristics and movement of individual cars are important. Alternatively, a more aggregate view on the traffic flow can be described in a continuous model. (Law, 2015)

3.5.4 Choice of Simulation Program

Based on the definitions above it is evident that we require a dynamic simulation model to capture the changes at the port as ships arrive over time. As the probability distributions defining both the ships inter arrival time and amount of containers discharged and loaded are based on random number streams, it would be safe to state that the simulation approach will be stochastic. Law claimed that deterministic models are a special case of stochastic models, and thereby restricting the research to stochastic models involves no loss of generality. (Law, 2015)

In our simulation the characteristics and movement of both individual ships and cargo handling equipment are important. This in order to estimate the different measurements described in the research objectives. Giving a clear indication that we require a discrete event simulation system.

In GPSS, the noticeable changes in the states of the system components can be caused by occurrence of significant events over time (Ståhl & Born 2013). As mentioned earlier in the GPSS program presentation Ingolf Ståhl therefore refers to the GPSS as a discrete event simulation. It is mainly used to simulate stochastic and dynamic processes, making it an ideal choice for our simulation.

4. The Simulation

This chapter concentrates on the development of the simulation model using GPSS. The aim was to present a realistic model of both the current terminal, and the planned development of KCT2. We will go through each segment of the model and the data input that has been estimated using the historical data. Due to the complexity of the real system, several assumptions were taken into consideration when developing the simulation model. Resulting in a simplified version of the real system.

Simulation studies requires a broad understanding of the real system when formulating the model representation. Verifying the representation and validating the output was therefore considered a key aspect in documenting the findings.(Kelton et al., 2007).

4.1 Simulation Model Segments

As previously mentioned GPSS allow the user to build the simulation model in a graphical interface, with a block based system. This enables us to present the simulation model in a more illustrated manner (see figure 2 on the next page) as well as the text code (see appendix 2 and 3).

The following segments are included in the simulation model, representing the various segments of the container handling process at the current situation.

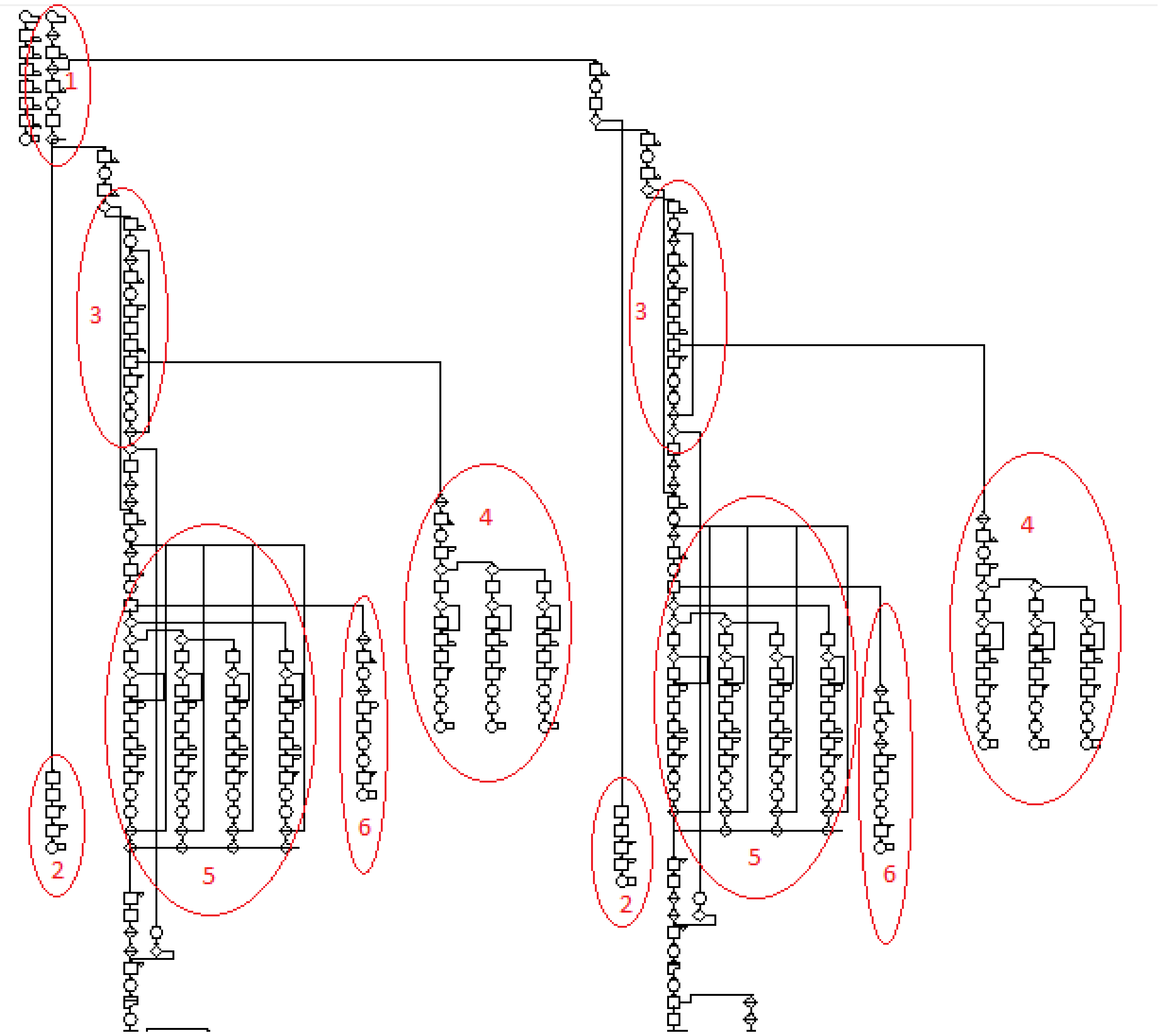


Figure 2 – Illustration of the simulation

1: Ship arrival

The function of the first segment is to generate the ship's arrival. The distribution of the ship's inter arrival time is computed into the simulation, creating a new ship arrival according to the given pattern. The Export berth and KCT1 have their own generate segment creating ships arrivals independently. At KCT1 the simulation decide which berth the ship will go to, with a priority of using KCT 1 –A if the berth is available. The number of ships that isn’t delivering or receiving containers are separated according to probability and sent to segment 2. This probability is based on the historical data (See appendix 4, tab 3).

2: General cargo

The ships carrying general cargo isn’t included in the container handling operation. However the number of vessels in this category is large enough to affect potential congestion in the berthing facilities. They are therefore given a separate section where they will spend time performing their own operation, while occupying 1 of the berth spots. The time spent in this section is given a probability distribution based on historical data described in the input parameter chapter.

3: Crane discharging operation

Before the discharging operation commence, a probability function based on historical data states whether or not the current ship will discharge any containers (see appendix 4 tab 3). If the ship is to discharge containers, the operation begins with the crane discharging a given number of containers to the portside. The crane is instructed to stop its operation if the portside is full. The amount of containers is given by a distribution based on historical data. The section is connected to section 4 which represents the reachstacker. Making sure that for each container discharged, the reachstacker will deliver it to a given container depot. The end of the section is connected to section 5, which represent the loading operation. Making sure that the discharge operation must be finished before the loading operation can commence.

4: Reachstacker discharging operation

As stated in the crane operation, each container placed on the portside signals the reachstacker to perform a delivery to a given depot. The depot that is to receive the container, is given by probabilities estimates based on the types of containers that is received historically (see appendix 4, tab 4). The type of container decides at what speed the reachstacker can operate, and the distance to the correct depot. The reachstacker is instructed to wait if portside is empty.

5: Reachstackers loading operation

Before the loading operation commence, a probability function based on historical data states whether or not the current ship will load any containers (see appendix 4, tab 3). If the ship is to load containers, the simulation will state a number of containers for the ship to load. The amount of containers is given by a distribution based on historical data, as described in the input parameters chapter. The reachstacker will collect the correct amount of containers from the various depots, placing them on the portside for the crane to load. The reachstacker is instructed to wait if the portside is full. The type of container will again affect the reachstackers speed and the distance travelled to and from the depot. A potential request for a container located in the competing company’s depot is included, which will significantly increasing the distance travelled by the reachstacker.

6: Cranes loading operation

The section is connected to section 5 in such a way that for each container placed at portside, the crane gets a signal to load it on to the ship. The connection between the two segments also make sure that the ship will wait until it has acquired the correct amount of containers, before leaving the berth. The crane will be instructed to wait if the portside is empty.

4.1.1 Changes at the New Terminal

The structural build-up of the two simulations are quite similar (in GPSS), given that the operational sequences does not change significantly with the change between the two terminals. It is however some changes in the operational limitations, as well as the terminal layout, that must be included in the simulation. As described in the map overview, the depot locations at the new terminal will be in a much closer proximity to the berthing areas. The various container depots will also be in close proximity to each other, eliminating the large spread in the reachstackers travel distance to the different depots. The assumption is that the terminal will be operated in close cooperation between the two companies, eliminating the extra time spent acquiring containers at the competing company's depot. This also gives the terminal 2 available reachstackers operating the 2 berth spots, removing the limitation at KCT1, where 1 reachstacker operated 2 berth spots.

As a result of the construction of the new terminal, the various cargo operations at the port will become more segmented. As mentioned in the map overview, the various cargo types such as bulk, roro containers, pallets and lolo containers will be given separate terminals. This eliminates the incidents from the old terminal where other types of cargo vessels occupies the same berth spots as the container ships. As a result the ships carrying other types of cargo than containers will be sent to a separate terminal in the simulation.

4.2 Input Parameters

To process the data acquired from the port authorities, empirical distribution for the various input parameters were fitted using Easyfit software. Easyfit is design in a way allowing us to enter the data as a spreadsheet (see image 4). This enabled us to test the compatibility of our data samples with theoretical probability distributions. Finishing the overall data analysis process (see figure 3), using different goodness of fit tests, such as Kolmogorov-Smirnov, Anderson-Darling and the Chi-Squared test. The estimated distribution are used as input variables in the simulation model.

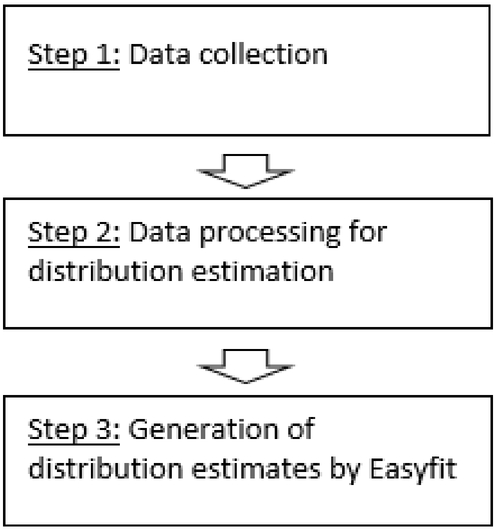
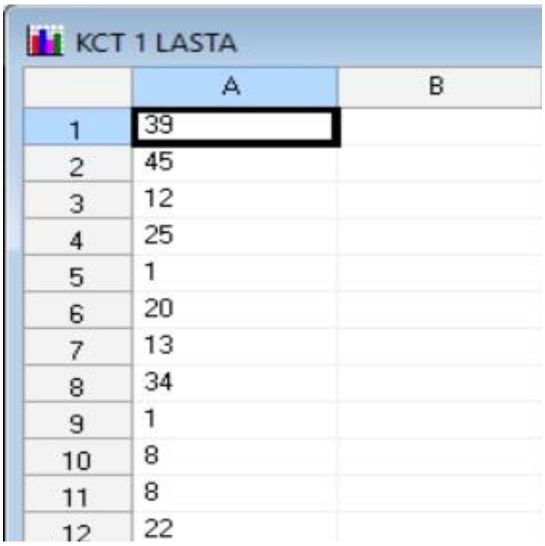


Figure 3 – Steps in datainput



	A	B
1	39	
2	45	
3	12	
4	25	
5	1	
6	20	
7	13	
8	34	
9	1	
10	8	
11	8	
12	22	

Image 4 – Data input sample from Easyfit

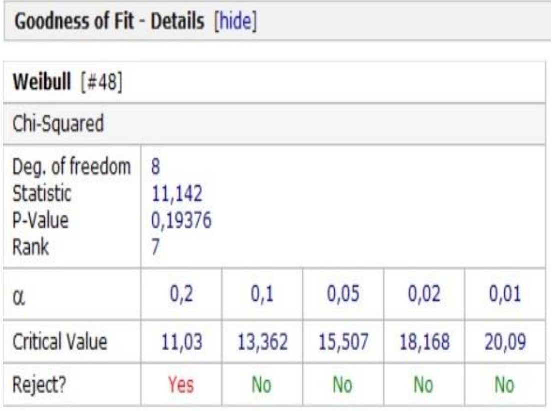
4.2.1 Inter-Arrival Time of Ships

The collected data was tested with both Chi-square and Kolmogorov-Smirnov test at a 5% significance level. Estimating both the KCT 1-And KCT 2 terminals inter-arrival times to fit the Weibull distribution. This can be supported by the findings of Dragovic, also stating that the ships inter-arrival time is assumed to fit the Weibull distribution (Dragovic, B et al, 2005)

The inter-arrival times at the Export berth did on the other hand follow a different pattern. Due to a large degree of set weekly arrivals, the selection presented a much less scattered arrival pattern. Estimating the inter-arrival times at the berth to follow a uniform distribution.

KCT 1

Weibull: $\alpha = 1{,}0014\ \beta = 0{,}66317$



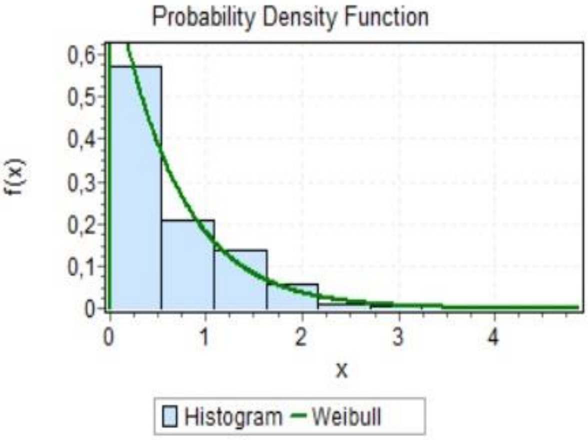
Goodness of Fit - Details [hide]

Weibull [#48]

Chi-Squared

Deg. of freedom Statistic P-Value Rank	8 11,142 0,19376 7				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	11,03	13,362	15,507	18,168	20,09
Reject?	Yes	No	No	No	No

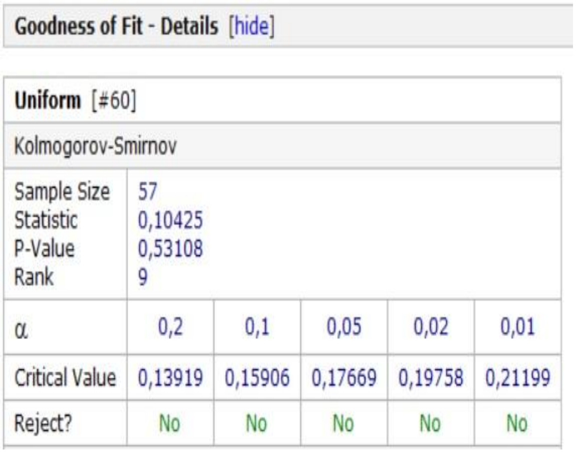
Table 1 – GOF IAT KCT 1



Graph 2 – Distribution of IAT KCT 1

Export

Uniform: $\alpha = 0{,}89072\ \ \beta = 8{,}02$



Goodness of Fit - Details [hide]

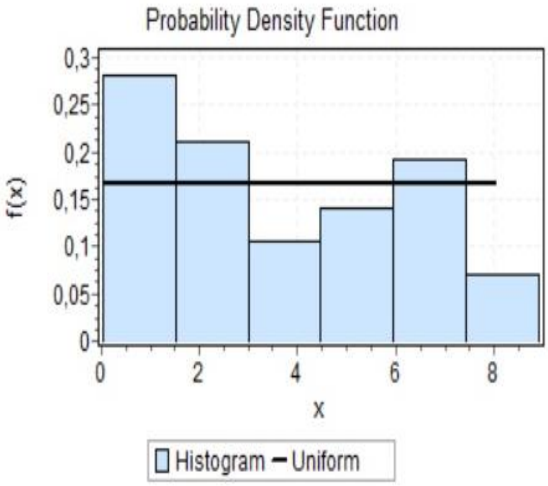
Uniform [#60]

Kolmogorov-Smirnov

Sample Size	57
Statistic	0,10425
P-Value	0,53108
Rank	9

α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,13919	0,15906	0,17669	0,19758	0,21199
Reject?	No	No	No	No	No

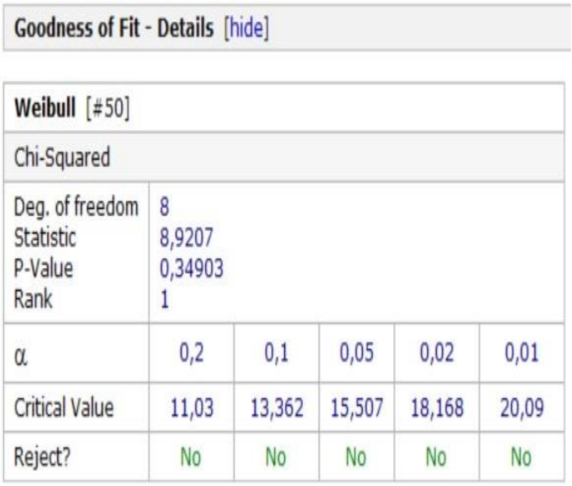
Table 2 – GOF IAT EXP



Graph 3 – Distribution of IAT EXP

KCT 2

Weibull: $\alpha = 0{,}99831\ \ \beta = 0{,}56787$



Goodness of Fit - Details [hide]

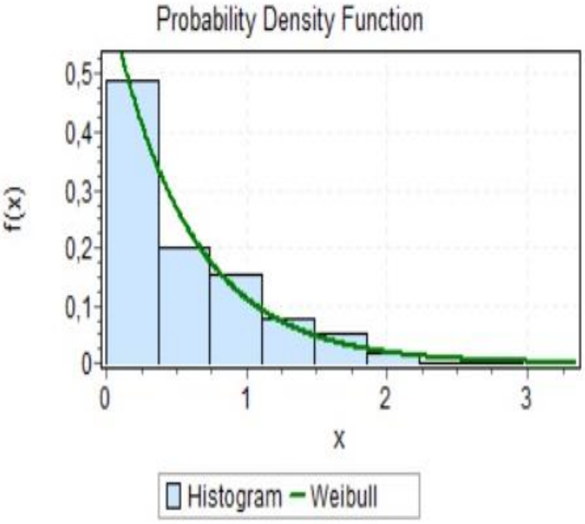
Weibull [#50]

Chi-Squared

Deg. of freedom	8
Statistic	8,9207
P-Value	0,34903
Rank	1

α	0,2	0,1	0,05	0,02	0,01
Critical Value	11,03	13,362	15,507	18,168	20,09
Reject?	No	No	No	No	No

Table 3 – GOF IAT KCT 2



Graph 4 – Distribution of IAT KCT 2

4.2.2 Service Time

The service time becomes relevant for the vessels arriving at the terminal for other purposes than container shipment. Service time defined as the time they spend occupying one of the berths at the terminal, serving the purpose of their visit. The importance of presenting these arrivals realistically, comes from the effect they may have on the overall congestion at the berths. The amount of vessels in this category will be retrieved from the percentage of vessels historically arriving at the port for other purposes than container shipment. Vessels with 0 containers delivered and received were extracted from the data regarding number of containers discharged and loaded.

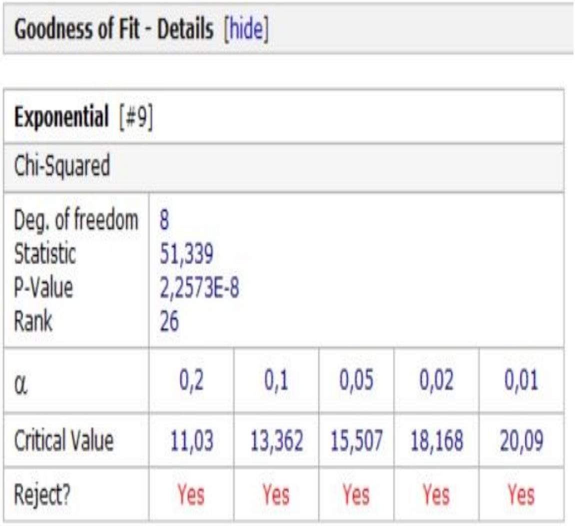
The collected data was tested with Anderson-Darling, Chi-square and Kolmogorov-Smirnov test at a various significance level. Fitting the data considering the service times of ships not carrying containers did however prove to be difficult. The existing data showed service times of a large variety of vessels, with a very high spread in the different service times. Classifying the different vessels according to what operation they potentially performed while at berth, resulted in too few values in each group. This made it impossible for us unable to perform a valid distribution test on this subject at the KTC1 berth.

K. Bichou stated in his book “Port operations, planning and logistics” that for general cargo ships, it is generally an accepted approach to assume exponential service time distribution. An assumption is on this basis made with regards to the ship's service time being exponential distributed on all the berths in our simulation. (Bichou, 2009)

For the new terminal no data were available for distribution estimation. The new terminal were therefore given the same distributions as the old terminal in this context.

KCT 1

Exponential: $\lambda = 3{,}8084$



Goodness of Fit - Details [hide]

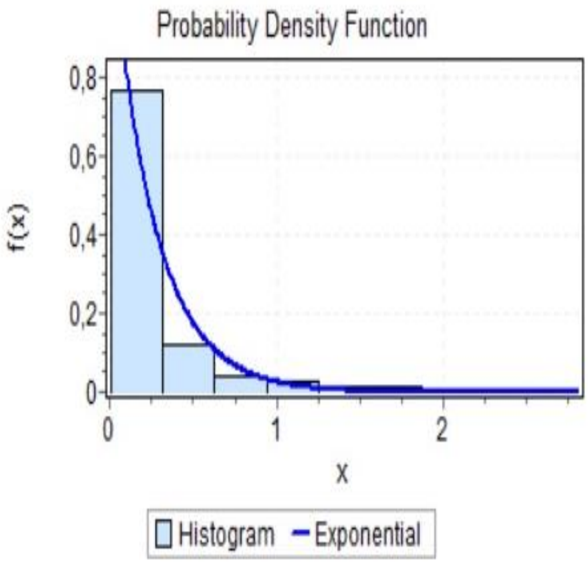
Exponential [#9]

Chi-Squared

Deg. of freedom 8
Statistic 51,339
P-Value 2,2573E-8
Rank 26

α	0,2	0,1	0,05	0,02	0,01
Critical Value	11,03	13,362	15,507	18,168	20,09
Reject?	Yes	Yes	Yes	Yes	Yes

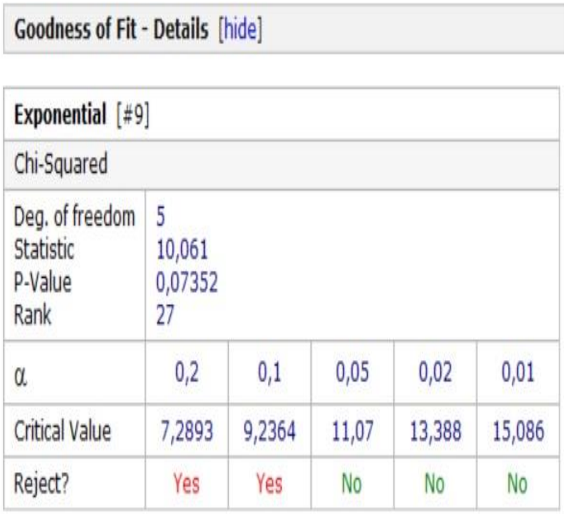
Table 4 – GOF ST KCT 1



Graph 5 – Distribution of ST KCT 1

Export

Exponential: $\lambda = 3{,}086$



Goodness of Fit - Details [hide]

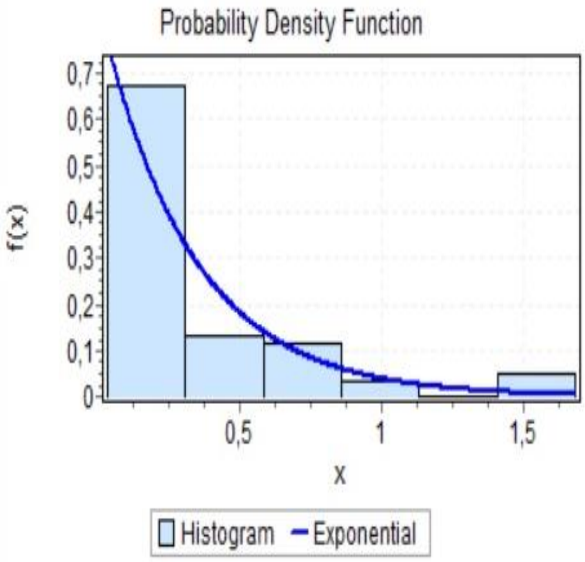
Exponential [#9]

Chi-Squared

Deg. of freedom 5
Statistic 10,061
P-Value 0,07352
Rank 27

α	0,2	0,1	0,05	0,02	0,01
Critical Value	7,2893	9,2364	11,07	13,388	15,086
Reject?	Yes	Yes	No	No	No

Table 5 – GOF ST EXP



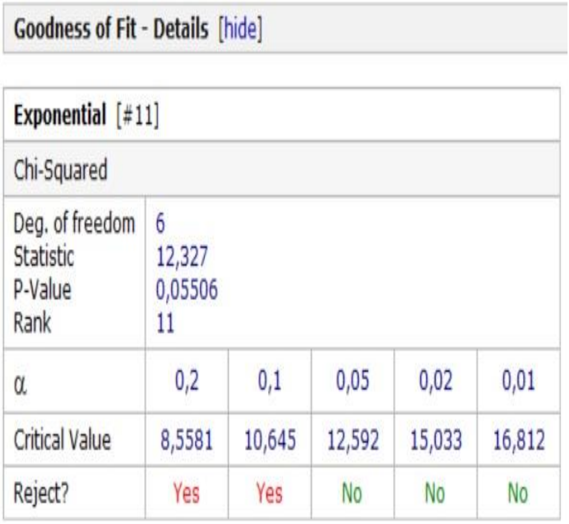
Graph 6 – Distribution of ST EXP

4.2.3 Containers Loaded

As previously mentioned the vessels not acquiring any containers at the port were excluded from the data sets before distribution testing. The remaining data was tested with both Chi-square and Kolmogorov-Smirnov test at a 5% significance level. The amount of containers loaded at the current situation fit the exponential distribution. To estimate the amount of containers to be loaded at the new terminal, the data selections of the different terminals at the current situation was merged into one selection. This selection was fitted with the Weibull distribution.

KCT 1

Exponential: $\lambda = 0{,}06817$



Goodness of Fit - Details [hide]

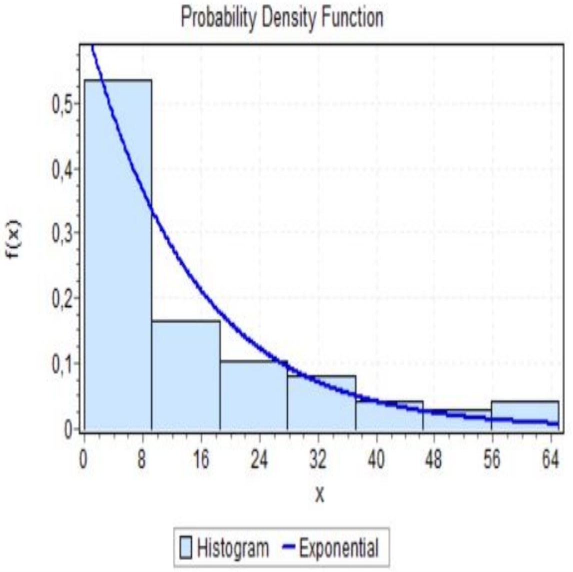
Exponential [#11]

Chi-Squared

Deg. of freedom 6
Statistic 12,327
P-Value 0,05506
Rank 11

α	0,2	0,1	0,05	0,02	0,01
Critical Value	8,5581	10,645	12,592	15,033	16,812
Reject?	Yes	Yes	No	No	No

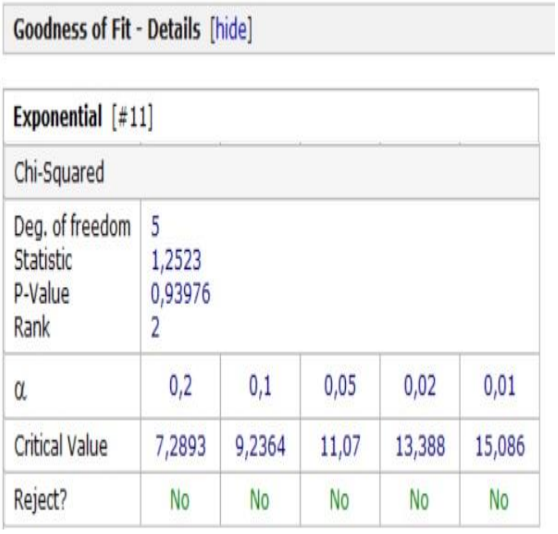
Table 6 – GOF loaded containers at KCT 1



Graph 7 – Distribution of loaded containers KCT 1

Export

Exponential: 0,11785



Goodness of Fit - Details [hide]

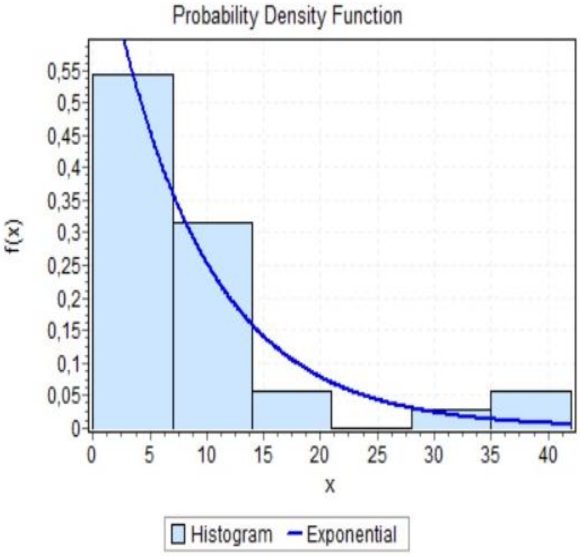
Exponential [#11]

Chi-Squared

Deg. of freedom	5
Statistic	1,2523
P-Value	0,93976
Rank	2

α	0,2	0,1	0,05	0,02	0,01
Critical Value	7,2893	9,2364	11,07	13,388	15,086
Reject?	No	No	No	No	No

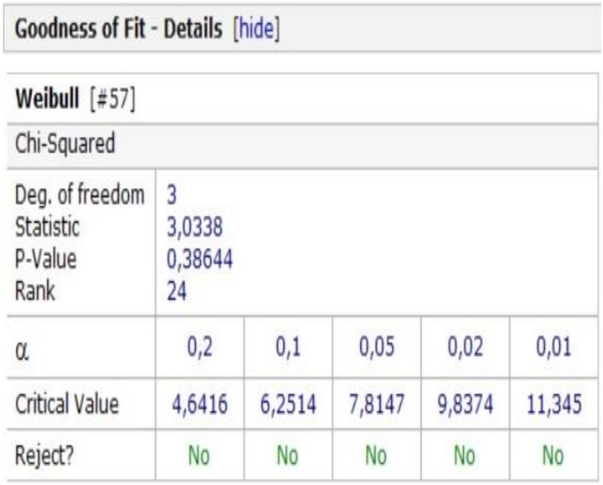
Table 7 - GOF loaded containers at EXP



Graph 8 - Distribution of loaded containers EXP

KCT 2

Weibull: $\alpha = 1{,}0928 \quad \beta = 9{,}6444$



Goodness of Fit - Details [hide]

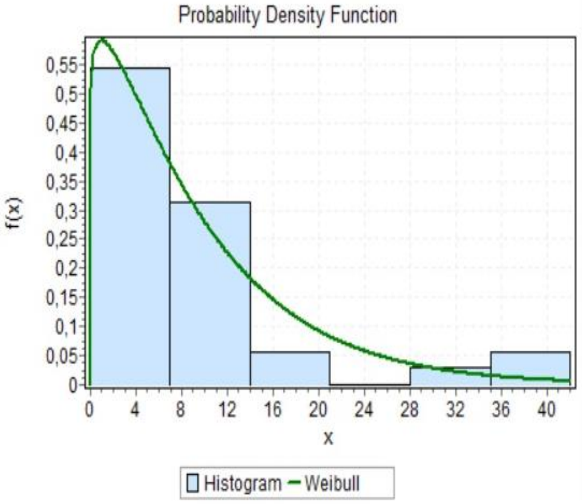
Weibull [#57]

Chi-Squared

Deg. of freedom	3
Statistic	3,0338
P-Value	0,38644
Rank	24

α	0,2	0,1	0,05	0,02	0,01
Critical Value	4,6416	6,2514	7,8147	9,8374	11,345
Reject?	No	No	No	No	No

Table 8 - GOF loaded containers at KCT 2



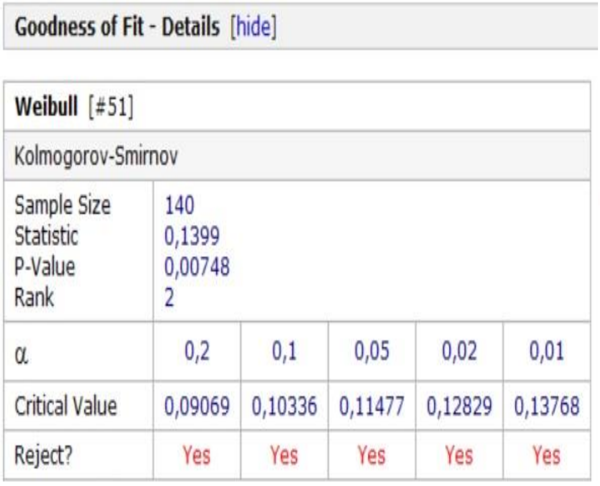
Graph 9 - Distribution of loaded containers KCT 2

4.2.4 Containers Discharged

As with the amount of containers loaded, the vessels not delivering any containers at the port were excluded from the data sets before the distribution testing. The remaining data was tested with Anderson-Darling, Chi-square and Kolmogorov-Smirnov test at a various significance levels. With a large variety of deliveries to the KCT1 berth, the various goodness of fit test were not able to provide us with a distribution passing the tests at any significance levels. The Export berth was shown to fit with the exponential distribution. While the combination of the two data sets, representing the amount of containers to be received at the new terminal was fitted to the Weibull distribution. With the combination of the two data sets being a fit with the Weibull distribution, an assumption was made in respect to the amount of containers delivered to the KCT 1-Berth will be of the same distribution. An assumption supported by the research of Arnaout. et.al, also showing the amount of containers to be discharged follows the Weibull distribution. (Arnaout.et.al, 2013)

KCT 1

Weibull: $\alpha = 0{,}76319 \;\; \beta = 10{,}397$



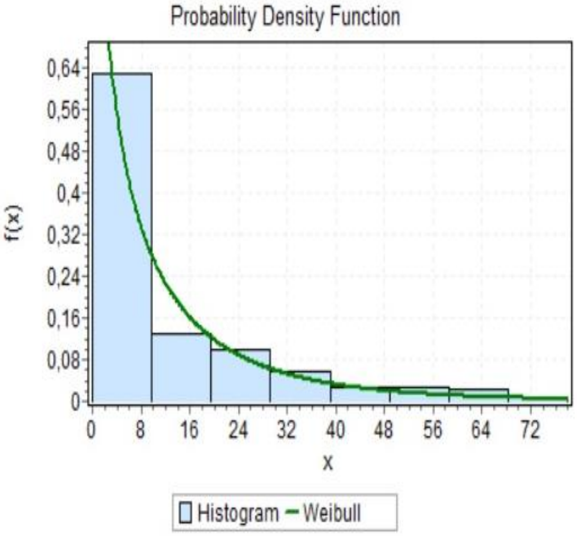
Goodness of Fit - Details [hide]

Weibull [#51]

Kolmogorov-Smirnov

Sample Size Statistic P-Value Rank	140 0,1399 0,00748 2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,09069	0,10336	0,11477	0,12829	0,13768
Reject?	Yes	Yes	Yes	Yes	Yes

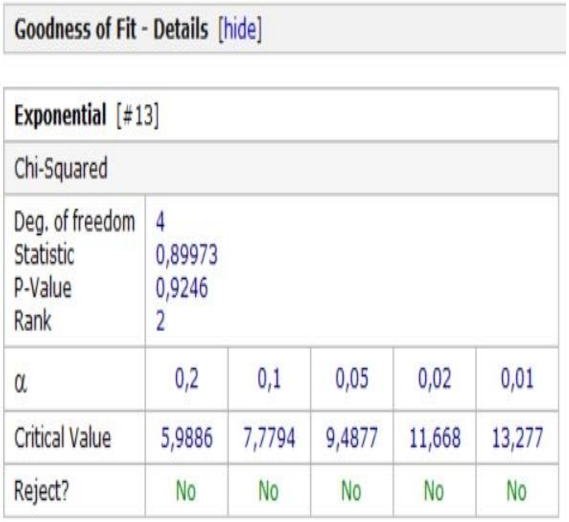
Table 9 - GOF discharged containers at KCT 1



Graph 10 - Distribution of discharged containers KCT 1

Export

Exponential: $\lambda = 0{,}0486$



Goodness of Fit - Details [hide]

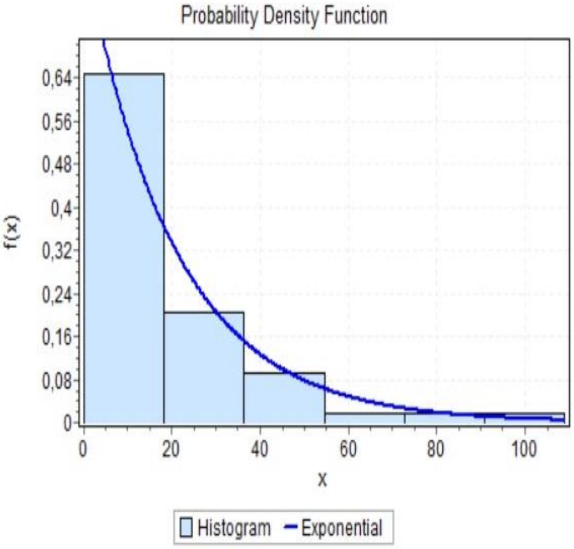
Exponential [#13]

Chi-Squared

Deg. of freedom	4
Statistic	0,89973
P-Value	0,9246
Rank	2

α	0,2	0,1	0,05	0,02	0,01
Critical Value	5,9886	7,7794	9,4877	11,668	13,277
Reject?	No	No	No	No	No

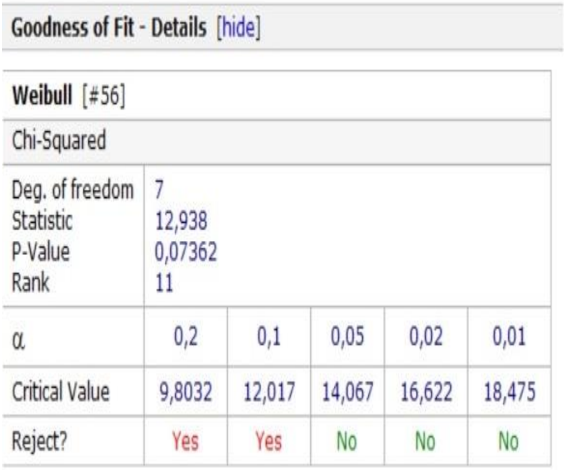
Table 10 - GOF discharged containers at Export



Graph 11 - Distribution of discharged containers Export

KCT 2

Weibull: $\alpha = 0{,}80461\ \beta = 13{,}004$



Goodness of Fit - Details [hide]

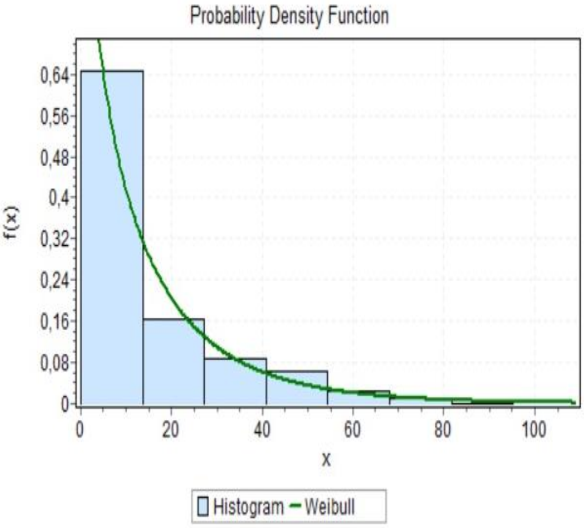
Weibull [#56]

Chi-Squared

Deg. of freedom	7
Statistic	12,938
P-Value	0,07362
Rank	11

α	0,2	0,1	0,05	0,02	0,01
Critical Value	9,8032	12,017	14,067	16,622	18,475
Reject?	Yes	Yes	No	No	No

Table 11 - GOF discharged containers at KCT 2



Graph 12 - Distribution of discharged containers KCT 2

4.3 Model Assumptions

When modelling a business process we shall focus on the modelling activity in form of building a simplified picture of a real system (Ståhl & Born, 2013). The activities at a container terminal are in reality a complex picture, affected by a lot of different factors. The following assumptions have been made when creating the model.

- The model only focus on the structural changes effect on the container handling process. All other activities are assumed to be equal from old to new terminal.
- Loading and discharging are only affected by the activity between port side and the depot. All hinterland processes are not to be considered.
- The capacity of the different depots are not included in the simulation, due to the large amount of containers entering and leaving the depots by other means than sea transport.
- Delay due to weather or other natural incidents are not taken into consideration.
- The resources at the terminal are fixed. Extra reachstacker or land cranes are assumed not to be an option.
- At the new terminal we assume all activities to be coordinated with perfect cooperation between the stevedore companies.
- With regards to the operation at the different container yards at Husøy port, we were not able to get access to and incorporate the different company's routines when stacking containers inside the yard. In order to make the simulation more realistic with regards to the yard operation, we used the numbers discovered by the research of Chen.T Lin. K & Juang.Y (2000) in our simulation. An assumption is made in regards to these numbers being fairly generalizable. The simulation therefore include a probability function, that states that the operators has a probability of 21 % of having to perform a housekeeping move when discharging, and 17% of having to perform a shift move when loading (Chen.T, Lin.K & Juang.Y, 2000). The time spent performing these extra operational procedures was discussed with the port

operators at Husøy, and incorporated in the simulation model (Gaupås, 2015).
- As mentioned in the data input analysis chapter, an assumption made with regards to the ship's service time being exponential distributed on all the berths in our simulation. (Bichou, 2009)
- As mentioned in the data input analysis chapter, the amount of containers to be discharged at KCT1 is assumed to be Weibull distributed. (Arnaout,J et al, 2013)

4.4 Number of Simulation Runs

The container terminal at Husøy is being operational 24 hours day, 7 days a week and can therefore be seen as a continuously operating system. The length of each simulation therefore becomes important. With a non-terminating simulation it’s important that each run is long enough to capture the steady state of the system. Providing us with a large enough number of observation after passing the transient state. The normal season at the terminal range for approximately 9 months, where the terminal receive about 450 ship arrivals. On this basis the simulation were set to run for the same period.

In order to measure the given objectives of the simulation, the level of the analysis had to be considered when extracting the data. For the measurements regarding the reachstacker, crane and ships berth time, it was interesting to measure the individual performance of the unit while performing the given operation. With each simulation run consisting of 450 ship arrivals, each ship arrival was analysed individually to capture the spread of the different operations.

Berth congestion was on the other hand a more stochastic event, making the characteristics of each simulation run more independent. Making it natural to perform the analysis on a more aggregate level, comparing the individual simulation runs to each other. Thus 20 independent simulation runs were conducted.

4.5 Validation and Verification

According to Law, validation is the process where it is determined if the simulation model present an accurate enough picture of the real system. (Law. S, 2006). Huynh and Walton on the other hand stated that verification is the process where the creator ensures that the model behaves as intended. (Huynh & Walton, 2005).

However the result of validation and verifications shouldn’t be seen as definitive answer to these questions, where the result can be interpreted as absolutely correct or absolutely incorrect. The main objective of this process is to increase the credibility of the model for the people making decisions based on the result. The model is built to answer the objectives of its creators and its credibility should be judged based to these goals. (Leal, et al. 2011)

Validation of a computer simulation model can be performed through different tests. Normal divided into subjective and objective tests. Subjective test often involve the experience and knowledge of people who are very familiar with the original system. It involves feedback from these individuals regarding the model and its output. Objective tests often involves some sort of mathematical estimations or statistical test. It requires data about the real system's behaviour and comparable data from the model. (Banks et al. 2005)

4.5.1 Validation Techniques

A combination of both subject and objective techniques are normally used to validate the simulation model. Sargent,R,G defined the following validation techniques for this purpose. Sargent. (2013)

Historical data validation
Use historical data to determine whether the model behaves in the same manner as the actual system. The data collected specifically for building the model is compared to the output of the simulation.

Face validity
Consulting with individuals that have good knowledge about the system that is to be simulated, and get their opinion if the simulation behaves in a reasonable manner. For instance in regards to the input-output relationship.

Event validity
Evaluate if the events that occurs in the simulation match well with those of the real system.

Extreme condition test
The levels and factors affecting the simulation will be put to “extreme” values. This being unlikely combination or very high/low values. The model's output should then be produced accordingly. (Sargent, 2013)

4.5.2 The F-test

In the literature concerning statistical validation, different tests, such as the F test are used to compare historical data with the data produced by the simulation. The f-test checks the similarity between the variance of the historical data and the variance in the output of the simulations. The F-values is computed and compared to the critical value for F with a given significance level α and degrees of freedom. (Taken from a table of F-Snedecor distribution). (Sargent, 2013)
F-value represented by the equation (F):

$$\mathrm{F} = \frac{S_M^2}{S_m^2}$$

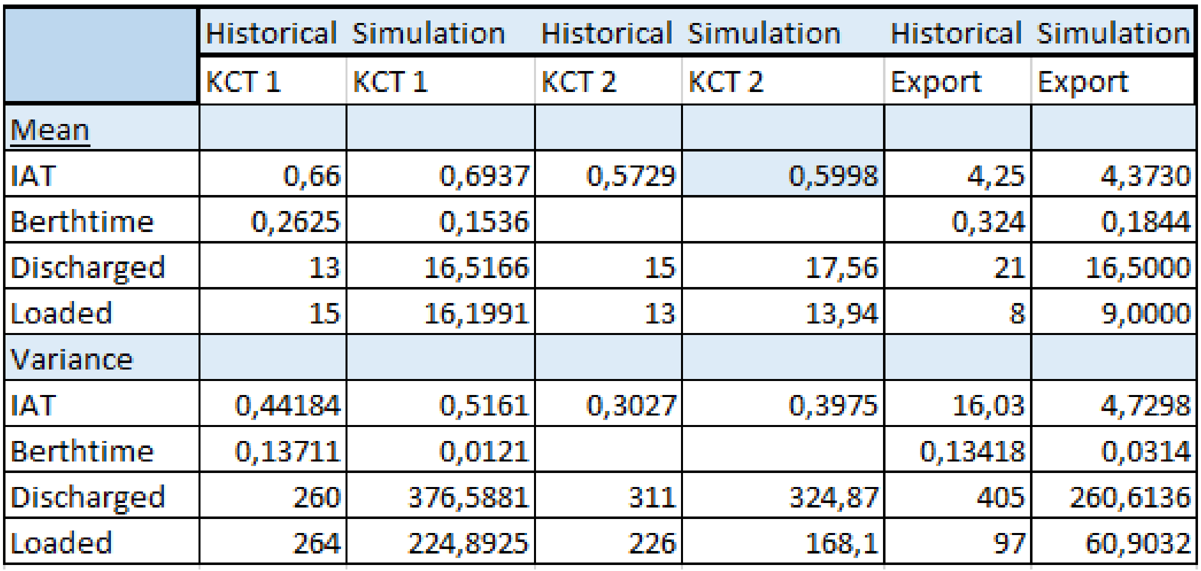
With: S_M^2 = variance of the data set with the highest variance
S_m^2= variance of the data set with the lowest variance

4.5.3 Model Validation

The validation techniques described by Sargent,R,G was performed on our simulation. In the simulation the number of ships to arrive control the runtime of the simulation. The simulation were told to run with the arrival of 450 ships, resulting in a total simulation period of 256 days. Giving a daily arrival of 1.75 vessels. According to the historical data of the harbour combined, it arrived an average of 1,746 ships a day. Giving an indication the event controlling the models runtime is acting in accordance with the real system. The occurrence pattern of this event was closer analysed in the historical data validation.

In order to test the different variables effect on each other, we performed extreme condition test on values deciding the operational time of both the reachstacker and the crane. The simulation responded accordingly, causing large queues in the respective areas.

Three values were collected from the simulation run to be compared with historical data. Ships inter arrival times, numbers of containers and the overall berth time of the vessels. Ships IAT and numbers of containers are directly affected by the distributions included in the simulation. The comparison with historical data was therefore mainly a validation in regards to the distribution fitting of the historical data and the model's ability to interpret the distributions. Providing us with an assessment of our secondary data collection. On the other hand the ship's service time was affected by several events and parameters in the simulation. The comparison of these output values to those of the historical data gave us a clear indication about the simulation model's ability to represent the real system. A comparison of the data produced by the simulation and the historical data, presented us with the following result (table 12).

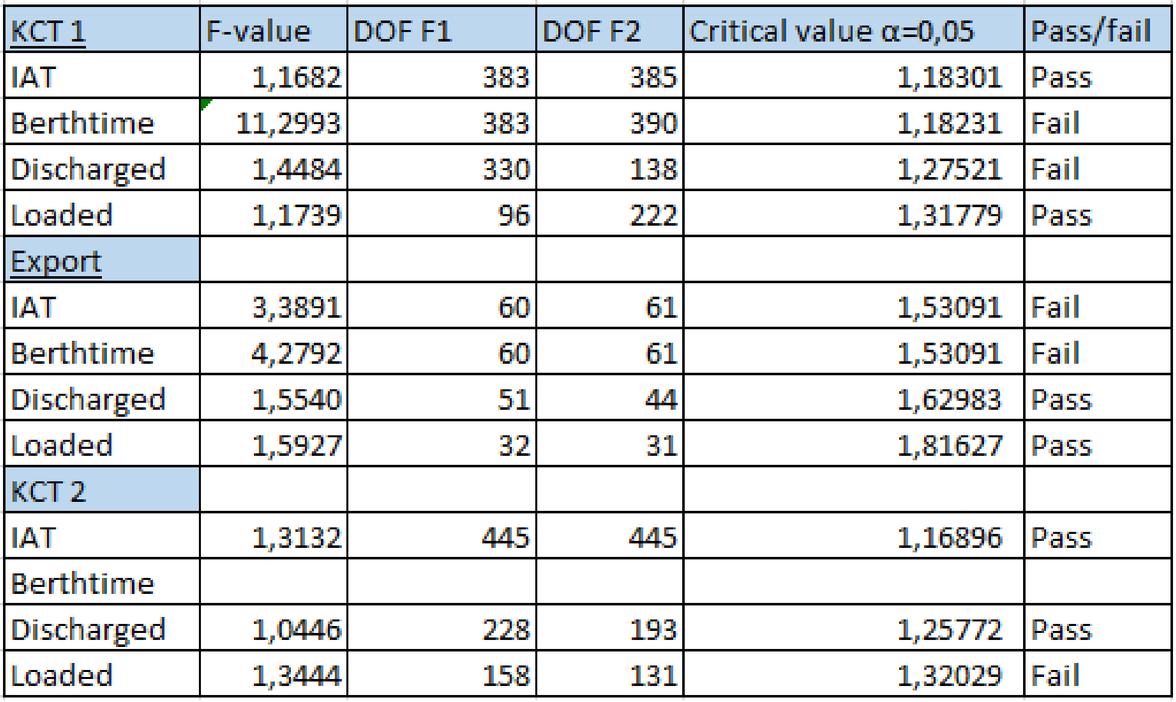


	Historical	Simulation	Historical	Simulation	Historical	Simulation
	KCT 1	KCT 1	KCT 2	KCT 2	Export	Export
Mean						
IAT	0,66	0,6937	0,5729	0,5998	4,25	4,3730
Berthtime	0,2625	0,1536			0,324	0,1844
Discharged	13	16,5166	15	17,56	21	16,5000
Loaded	15	16,1991	13	13,94	8	9,0000
Variance						
IAT	0,44184	0,5161	0,3027	0,3975	16,03	4,7298
Berthtime	0,13711	0,0121			0,13418	0,0314
Discharged	260	376,5881	311	324,87	405	260,6136
Loaded	264	224,8925	226	168,1	97	60,9032

Table 12 – Comparison simulation and historical data

From the data collected we could see a slight overestimation in the average values produced by the simulation in regards to IAT, number of containers loaded and discharged. The Export berth also receive a lower numbers of containers then in the historical data. The main concern was however the large underestimation of the ship's average berth time. This issue was brought on to the face validation with the management at the port authorities.

An f-test were performed in regards to the data sets variance, presenting us with the following result (table 13).



KCT 1	F-value	DOF F1	DOF F2	Critical value α=0,05	Pass/fail
IAT	1,1682	383	385	1,18301	Pass
Berthtime	11,2993	383	390	1,18231	Fail
Discharged	1,4484	330	138	1,27521	Fail
Loaded	1,1739	96	222	1,31779	Pass
Export					
IAT	3,3891	60	61	1,53091	Fail
Berthtime	4,2792	60	61	1,53091	Fail
Discharged	1,5540	51	44	1,62983	Pass
Loaded	1,5927	32	31	1,81627	Pass
KCT 2					
IAT	1,3132	445	445	1,16896	Pass
Berthtime					
Discharged	1,0446	228	193	1,25772	Pass
Loaded	1,3444	158	131	1,32029	Fail

Table 13 – F-test results

As mentioned in the input parameter chapter, the IAT at the Export berth was found to match best with a uniform distribution due to a large number of regular arrivals with the same pattern. This resulting in the simulation not being able to capture the variance in the overall arrivals. The mean number of arrivals at the berthl was however in accordance with the historical data.

From the result we could see that the berth time was the measurement at which the result was off in the f-test. The simulation also had some difficulties capturing the variance in regards to number of containers loaded at the new terminal, this measurements were however only slightly off. The number of containers discharged at the KCT1 berth originates from the data set that proved difficult to fit to any distribution. As a result an assumption was made about it being Weibull distributed, based on previous research. We can see as a result the mean and variance of the output being slightly off, but not to a degree that is likely to have a large affect the overall result of the simulation.

When it comes to the berth times in the simulation, we conducted a follow up interview with the port authorities to address the concerns about a potential mismatch. The relative lower overall berth time in the simulation, in relation to the historical data was explained to us by the port authorities. The high overall berth time in the historical data originated from a few of the shipping lines regular vessels often spending the night at the port. This is done to avoid night travel or to arrive in Bergen in time for the day shift at terminal there. This was an aspect the port authorities was familiar with, which had proven to be an issue in other efficiency measurement performed at the port. The numbers we could present from our simulation was deemed to be a valid estimation of the minimum required berth time to perform the discharge and loading operation at the port.

The overall validation and verification shows that the model acts reasonably in accordance with the real system, and that the results is comparable to real data. We therefore believe that the model is solid for the purpose of our research. We would however like to emphasize that it is a simplified version of reality and that several assumption has been made while creating the model. The results must therefore be interpreted with caution.

5. Analysis of the Simulation Result

In order to conduct analysis on the present and future situation at Husøy Port, we will now focus on the outcome of the simulation model, presented in chapter 4. Based on the primary and secondary data collected to build the simulation, the analysis will be presented as quantitative data.

Each measurement presented in chapter 4 will be analysed. First, we will look at the results from the first simulation of Husøy Port. This will be the results that are realistic to assume can measure the current situation at the port. Second we will present the results of the simulation representing the planned development at KCT 2. Finally we will compare the results of the two simulations, in order to evaluate the effect of the structural changes.

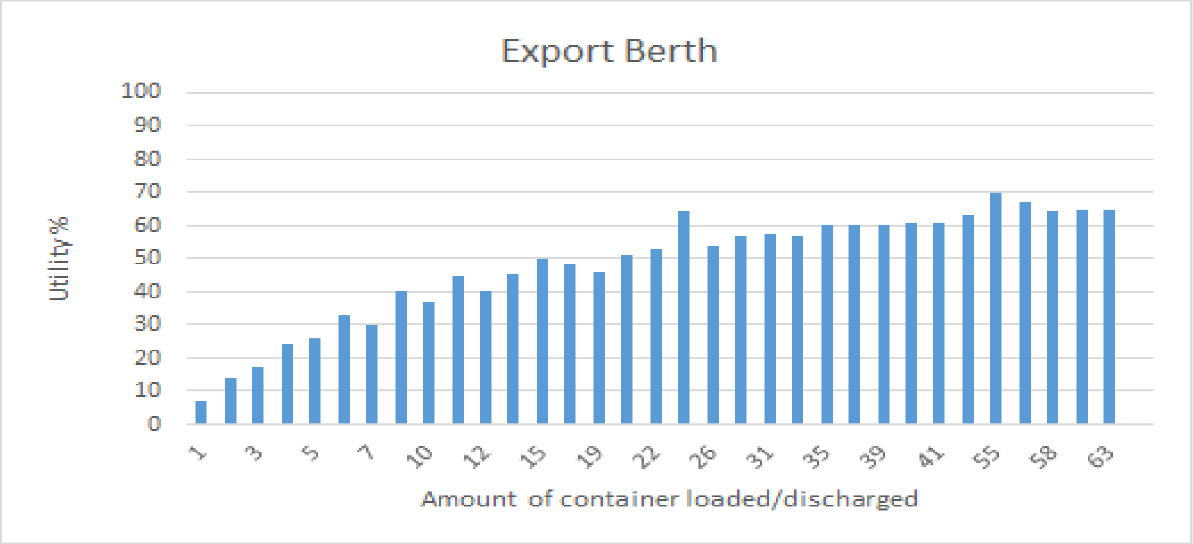
5.1 Objective 1 - Crane Utility

In the real world each ship and each crane operator will handle the cargo differently and at various speed. In this situation we are interested in the activities that affect the work rate of the crane. This will concern the portside capacity, and the port activities such as the reachstacker operations and the control of the depot. The crane operating speed will therefore be dependent on the various sequences in the discharging and loading operations.

To determine the crane utility we measure at the total work time of the crane in percentage of the total berth time of each vessel. Since each ship are using approximately one hour for berthing, the crane utility will increase simultaneously with the amount of containers loaded/discharged. Considering the berth times effect on the entire operation, ships with a low number of containers will naturally have a low crane utilization. This due to the berthing time being a larger proportion of the overall operation. This makes it important to emphasize the focus on both average utilization, but also the maximum utilization.

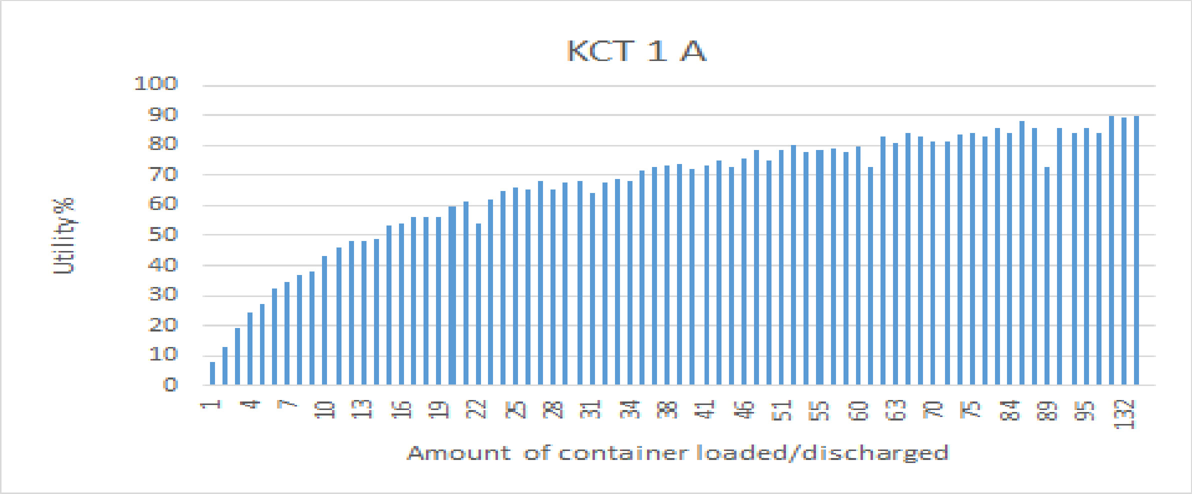
The results is presented in a graph showing the utility in relation to the amount of containers. Each port is presented in their own graph.

5.1.1 Simulation of the Current Terminal



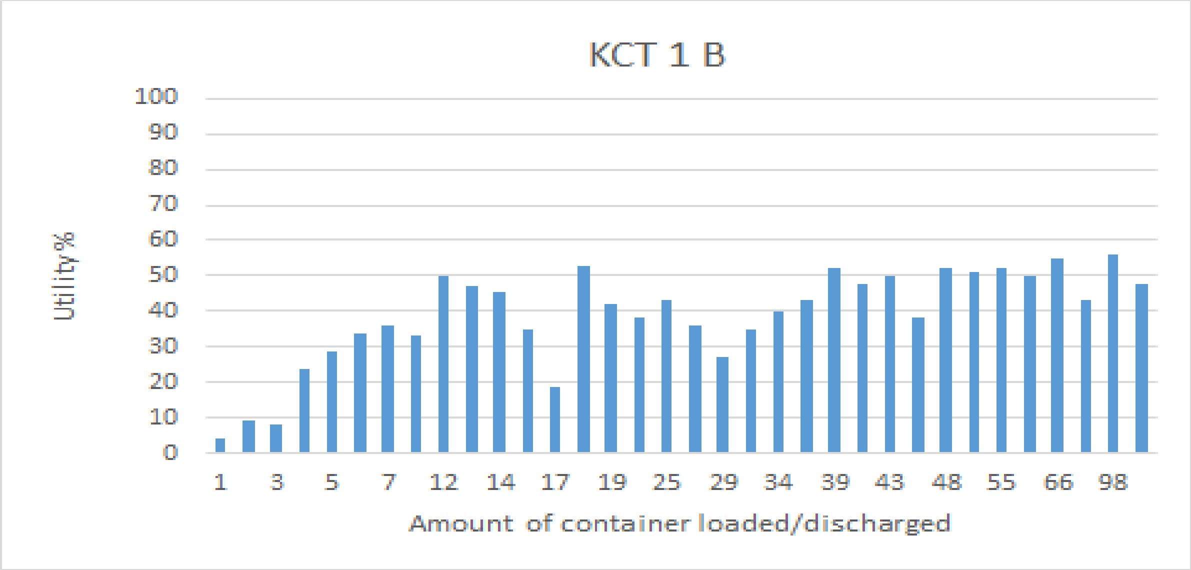
Graph 13 - Crane utilization at Export

At the Export berth we observe that the crane utility are increasing up to around 20-25 containers (the horizontal axis). Then it is stagnating due to the limitation at the port side and the waiting time for the crane are increasing. The average utilisation is 43 % of the total berth time, but the most interesting aspect is that the maximum utilisation are only at 70%. The cranes idle time indicates that it’s waiting for the port side operation.



Graph 14 - Crane utilization KCT 1-A

KCT 1-A are able to utilize the crane up to 90% of the total berth time. At this side of the port the ships at berth A and B are depending on the same reachstacker. This means that the berth time will increase when there are two ships at the port simultaneously. Despite this limitation, the A berth close proximity to the depots enables it to have a crane utilization close to a maximum level. Indicating that further improvements of the port side operation might not have an effect on the overall performance. The average crane utilization are 53%, 13% higher than the Export berth.

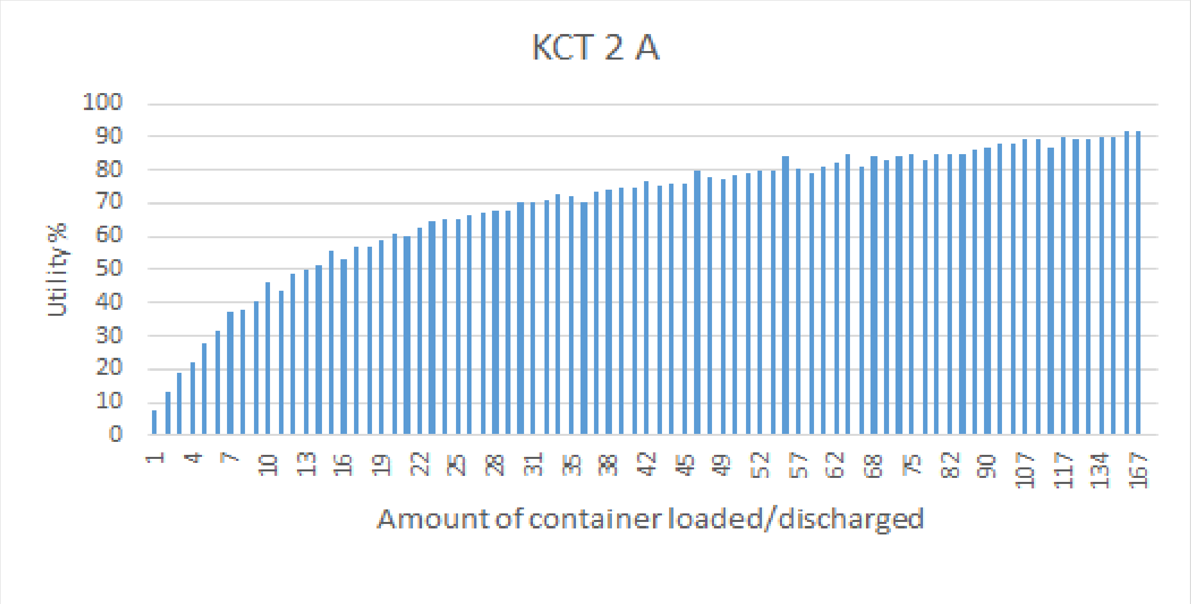


Graph 15 – Crane utilization KCT 1-B

The crane utilization at KCT 1-B are already stagnating with amounts of 12-14 containers. The maximum crane utilization is 55%. As previously mentioned the two berths are sharing the same reachstacker. In addition to this KCT 1-B is also located further away from the depots, and therefore the portside is often filled up/empty, forcing the crane to wait. The average crane utilisation is 34 %. During the interview with Sea Cargo they told us that KCT 1-B was a definite bottleneck and that the crane was idle in approximately half the loading and discharging operation. (Hauge, 2015)

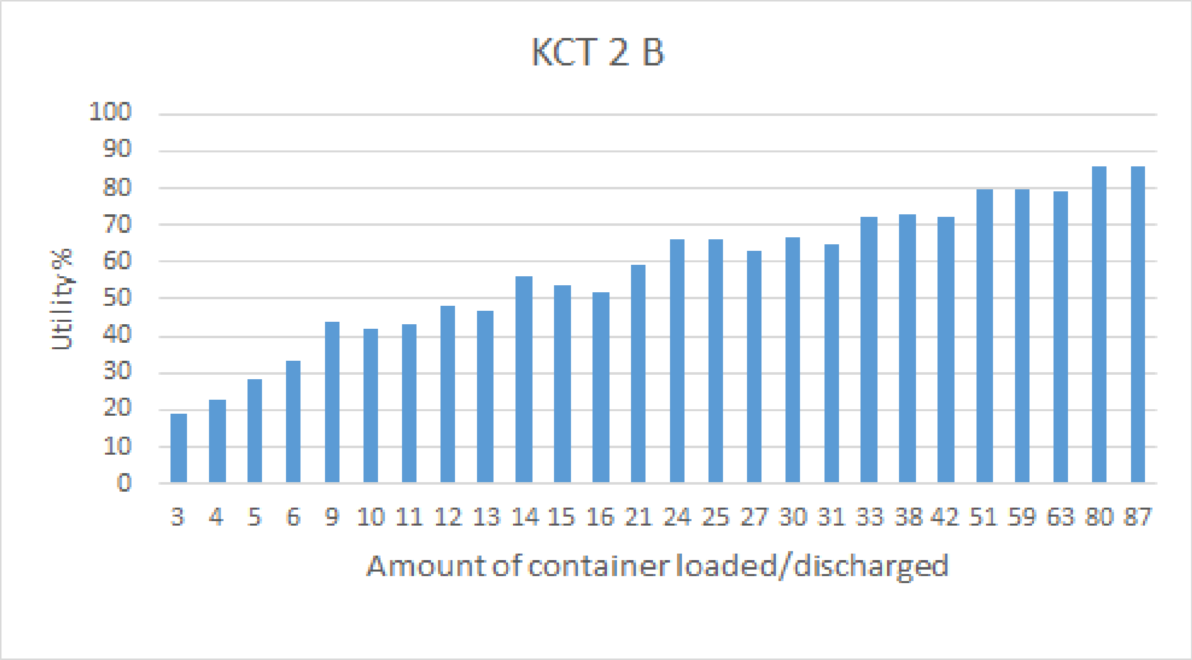
The three different berths shows fluctuated results for the crane utilization at each ship arrival. When we look at KCT 1-A and B we can see the ships arriving at B sometimes could have saved time by waiting for the A berth to be available. This option is nevertheless not included in this simulation. Ships arriving at KCT 1 with bulk and roro cargo (not containers) are also using the same berth, resulting in a more frequent use of the B berth when A is occupied. The issues occurring at KCT 1-B could clearly have been avoided, if the reachstacker at the Export berth could have been available if it was idle. Showing that the limitation of one reachstacker clearly affects the performance of the crane at this berth.

5.1.2 Simulation of the New Terminal



Graph 16 – Crane utilization KCT 2-A

At KCT 2-A the average crane utilization is 55 % in the simulation. We can also see that when a vessel is discharging and loading a large amount of containers, the crane utilization are over to 90%. The waiting time for the crane are close to zero, and the limitation of the portside and reachstacker movement can no longer be seen as a bottleneck. This berth always has reachstacker available, which means that the berth time no longer are affected by the waiting time for a reachstacker to be available.



Graph 17 – Crane utilization KCT 2-B

The simulation is told to prioritize the A berth, which means that B are only in use when A i occupied. This makes the number of ship arrivals lower and the graph contains less events. We can still see that the crane utilization aims to reach 90 % of the total berth time. The average crane utilization is 56 % at KCT 2-B. Through these numbers we can assume that the ship can achieve the same crane utilization regardless of berth spot.

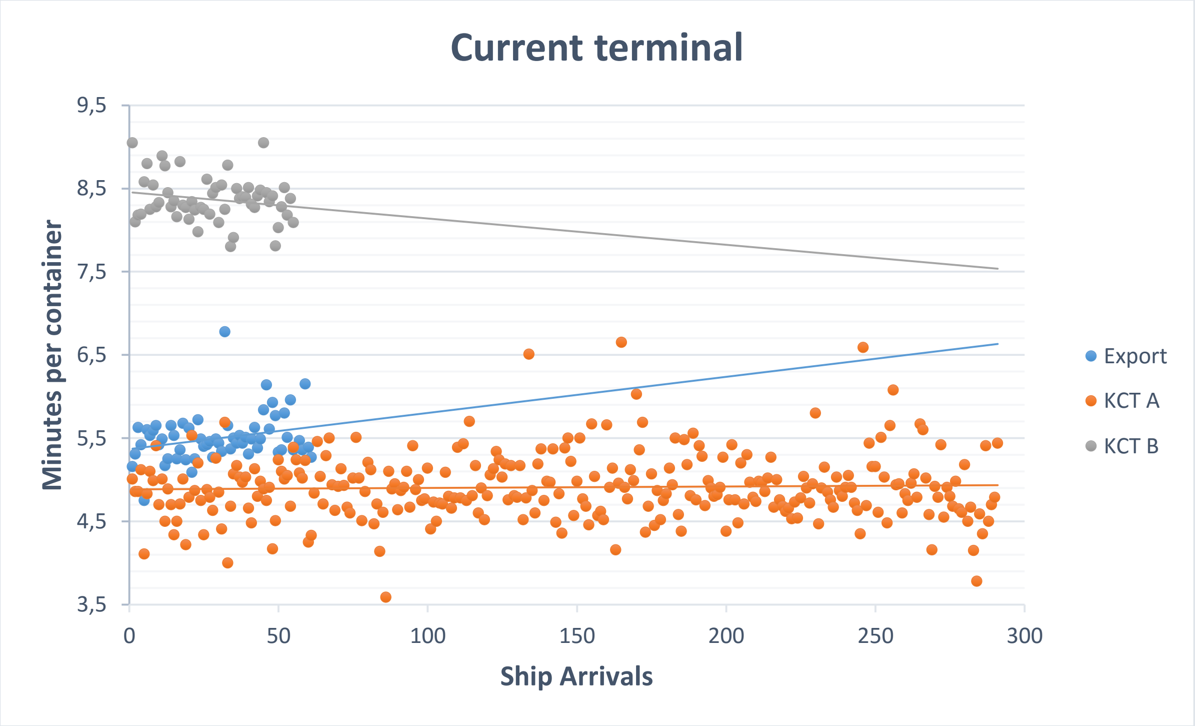
5.2 Objective 2 - Reachstacker Efficiency

When we are measuring the reachstackers efficiency, we are interested in the time spent moving each container. Each move consists of driving to the storage, picking up or stacking the container, and return to the portside. The operational time of one container depends on a several factors. The type of container and whether it is full or empty, will affect both the operational speed of the Reachstacker, and the driving distance to the correct depot. Inside the depot, the container density will affect the time spent acquiring or placing the given container.

Since the waiting time at portside were taken into consideration at the crane utility, we were only interested in the operational activity of the Reachstackers. This means that the waiting time for empty/full portside not is measured. The outcome will therefore give us the reachstackers potential efficiency, and tell us whether the bottleneck is the reachstacker or somewhere else in the container handling process. To avoid regular waiting time for the crane, the average time spent per container should be lower than the cranes approximate average of 5 minutes.

As in objective 1 we will first present the numbers from the simulation of the current terminal. Then we will present the numbers from simulation of the new terminal. Finally we will present a comparison of the results.

5.2.1 Simulation of the Current Terminal



Graph 18 – Reachstacker efficiency at current terminal

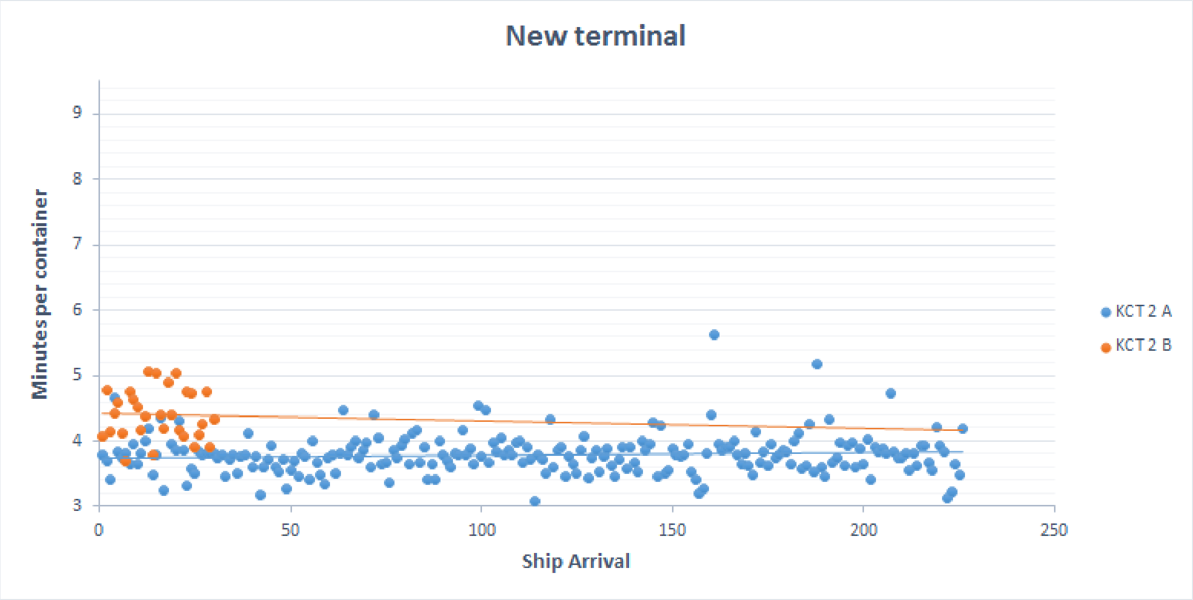
All three berth spots from the simulations is shown in one graph (graph 18).

At the Export berth the average time per container is 5,5 minutes. According to the stevedore company the Reachstacker could handle about 13 containers per hour (Gaupås, 2015). This number from Gaupås fits well with the result of the simulation, but we are also able to see that it is some spread in the reachstackers operational time, as it varies for each ship arrival. At the highest, the reachstacker uses almost 7 minutes per container. This means that the reachstacker are only able to move 7-8 containers per hour, causing congestion of containers at the port side. When these incidents occur the reachstacker has probably been picking up containers at Sea Cargos depot, and increased travel distance is reducing the efficiency. At the best case scenario the reachstacker are using less than 5 minutes per containers, and there is not any container congestion at the portside.

As we can see from the scatter graph, KCT 1-A has a lower average operational time than the Export berth. With an average time of 4,9 minutes per container, it is the most efficient berth in this simulation. However we can observe that results vary considerably between the different ship arrivals. On several occasions the reachstacker uses over 6,5 minutes per container. At its best the reachstacker is able to perform the work in 3,5 minutes, in which case the reachstacker probably has to wait at portside for the crane to load/discharge.

At KCT 1-B the reachstacker are not able to stack more than half the amount of containers, compared to when it's working for the same time at KCT 1-A. The average time spent per container is 8,4 minutes. Even with the reachstacker at its most efficient, there is container congestion at the port side and the crane has to wait. KCT 1-B also affects the total berth time at KCT 1-A when it occupies the reachstacker. Since the two berths are using the same depots, and moving the same type of containers, we know that the delay is probably caused by the location of the depots. The results of this analysis are also substantiating the information from the interviews with the stevedores company; that the total container handling process is too time consuming at KCT 1-B.

5.2.2 Simulation of the New Terminal



Graph 19 – Reachstacker efficiency at new terminal

In the simulation of the new terminal the reachstacker efficiency are affected by the reorganized depots, both the location and their internal density. Every ship arrival are loading and discharging containers from the same depots and the two reachstackers are available for the two berths. The portside limit are unchanged, but since the waiting time not are included in the estimations, the graph shows us the theoretical efficiency of the reachstacker.

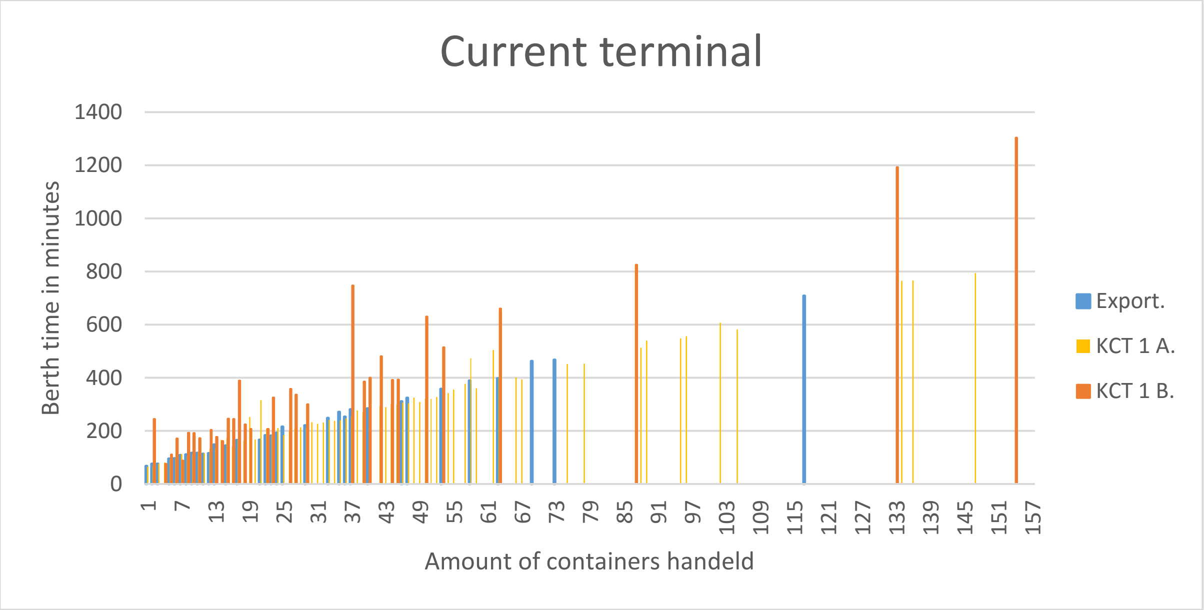
When working out of KCT 2-A the reachstacker spends an average of 3,8 minutes per container. Since this berth spot is located closest to the most commonly used depot, it is also considered the prioritized berth spot in the simulation. Therefore we can see that over 80% of the container ships are able to use the most efficient berth spot. It does sometimes occur that the Reachstacker are using over 5 minutes per container, in those cases it is due to the storage density and that most of the containers are full (reduced speed). Overall we can see that the spread at the vertical axes are significantly reduced resulting in a more stable efficiency level and a much lower average number.

KCT 2-B is located a bit further away from the depots, but still achieves a good average efficiency, using 4,4 minutes per container. This avoids waiting time for the crane and the reachstacker are no longer considered a bottleneck at the port. We observes that the reachstacker in three cases are using more than 5 minutes per container, but due to the port side capacity of 5 containers, the crane avoids any waiting time.

5.3 Objective 3 - Overall Berth Time

In this object we will measure the overall berth time and make a comparison between each berth. The total berth time includes the loading and discharging process, berthing time and the total waiting time between and during each process. By measuring the overall berth time for each ship arrival, we are able to look at the total effect on the container handling process at the new terminal.

5.3.1 The Current Terminal



Graph 20 – Berth time current terminal

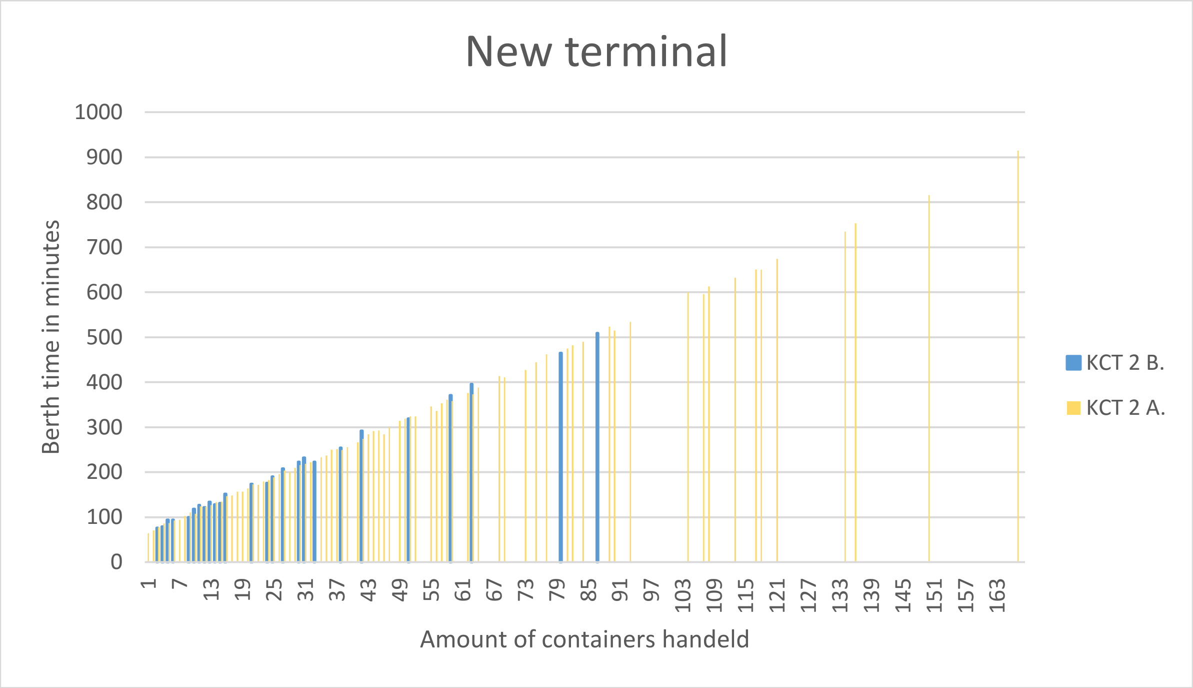
To get a closer look at the outcome, graph 20 are also to find in appendix 5 due to the large amount of observations. Each colour represent the three berth spots at the current terminal. The graph tell us the relationship between the overall berth time and how many container that was loaded and discharged.

At the Export berth there are no extreme values, and we can observe that the overall berth time increase steadily together with the amount of containers. The graph can tell us that the total berth time at the Export berth are slightly higher than the KCT 1-A irrespective of the amount of containers that are loaded and discharged. As mentioned earlier the Export berth never needs to wait for a reachstacker to be available, resulting in a much more predictable outcome. The reason why the total berth time is slightly higher we can assume is mainly due to the facility location.

KCT 1-A have a steady increase in the total berth time compared with the amount of containers. The berth spot doesn't have any extreme values, but we can observe that some of the ship arrivals has to stay a while longer, mostly when the reachstacker is occupied at KCT 1-B. Despite some unnecessary waiting time, the situation today at KCT 1-A are at an acceptable level in regards to the overall berth time. We know, from the results in objective 1 and 2, that the berthing area at KCT1-A are the terminal with highest operational efficiency. Indicating that the delays caused by the reachstacker being occupied at KCT1-B, will not be significantly enough to cause problems.

KCT 1-B are causing some extreme values. At one of the ship arrivals the overall berth time are twice as long as the other berth spots when discharging and loading 37 containers. At another arrival, when loading and discharging 50 containers the berth time are 60% longer, compared to KCT 1-A, using over 8 hours at berth. Since the KCT 1-A always are prioritized, we know that the Reachstacker always are occupied when a ships arrive to KCT 1-B, given that the ship at KCT 1-A are a containership. In the cases where the ship at KCT 1-A only are loading bulk or pallets, we know from objective 1 that the crane are poorly utilized due to several factors and the ships still have to stay longer than necessary.

5.3.2 The New Terminal



Graph 21 – Berth time new terminal

At the new terminal there are no significant difference between the two berth spots. At Husøy the most common type of container are the empty regular, as discovered in the data collection (see appendix 4, tab 4). Since this depot are located closer to the KCT 2-A berth, ceteris paribus, this constitutes a small, but insignificant, change in the berth time between the two berth spots (graph 21).

Compared to the current terminal the average berth time for the ships at the new terminal are more steady, however the berth time have not decreased significantly compared to KCT1-A. The overall berth time at the new terminal have on the other hand decreased in comparison to the export berth and KCT1-B. In objective 2 we saw that the reachstacker efficiency was significantly improved at the new terminal, but due to its increased waiting time at portside this doesn't have any major effect on the overall berth time.

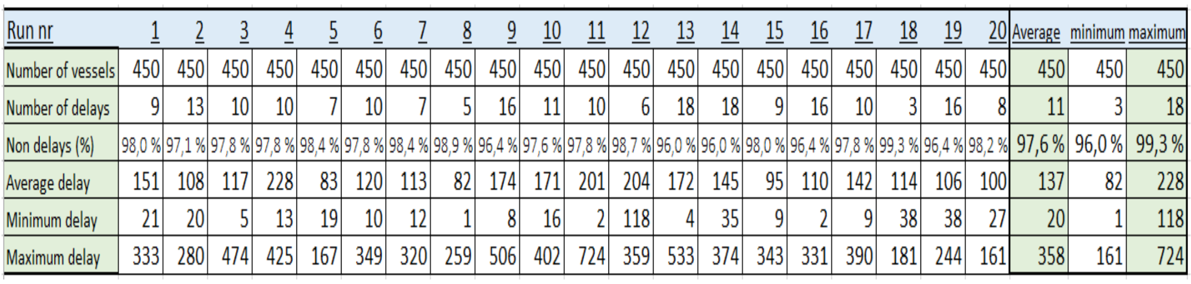
Both KCT 2-A and KCT 2-B are at an acceptable level for all ship arrivals in the simulation. We can also observe from the graph that both spots are increasing steadily, making the stay at Husøy more predictable for the ships and the shipowners.

5.4 Objective 4a: The Rate of Congestion at the Berths

As stated in chapter 2, potential congestion at the berths could greatly affect how the port performance is perceived by the shipping lines. At the moment congestion at the berthing facilities are an increasing issue according to the port authorities. (Leknes, 2015) The simulation runs performed on the current situation should therefore provide us with an overview of how the current level of congestion affect the operation. It's however important to emphasize that the simulation doesn't take into consideration potential actions to prevent congestion, such as ship scheduling. The result must therefore only be view as a presentation of theoretical congestion given the normal arrival pattern

The simulation was run for a total of 450 ship arrivals. In order to capture potential variance in the result, each run was performed 20 times. Providing us with the following result.

5.4.1 Current Terminal

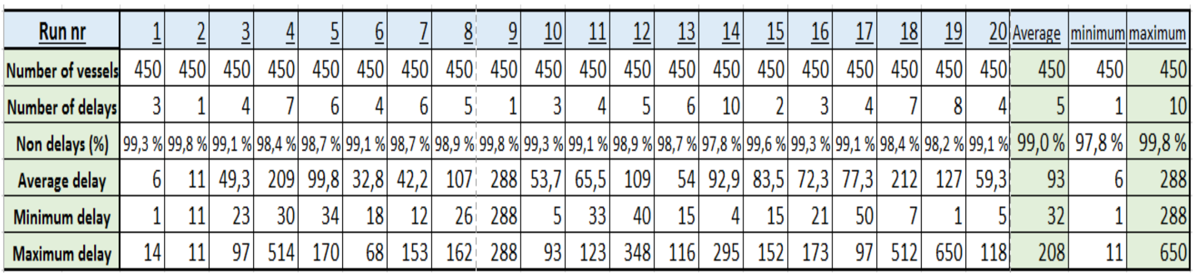


Run nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Average	minimum	maximum
Number of vessels	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Number of delays	9	13	10	10	7	10	7	5	16	11	10	6	18	18	9	16	10	3	16	8	11	3	18
Non delays (%)	98,0 %	97,1 %	97,8 %	97,8 %	98,4 %	97,8 %	98,4 %	98,9 %	96,4 %	97,6 %	97,8 %	98,7 %	96,0 %	96,0 %	98,0 %	96,4 %	97,8 %	99,3 %	96,4 %	98,2 %	97,6 %	96,0 %	99,3 %
Average delay	151	108	117	228	83	120	113	82	174	171	201	204	172	145	95	110	142	114	106	100	137	82	228
Minimum delay	21	20	5	13	19	10	12	1	8	16	2	118	4	35	9	2	9	38	38	27	20	1	118
Maximum delay	333	280	474	425	167	349	320	259	506	402	724	359	533	374	343	331	390	181	244	161	358	161	724

Table 14 – Congestions old terminal in minutes

From table 14 we can see that the both the number of delays and the length of each delay greatly varies between each run with delays ranging from 1 to 724 minutes in the extreme cases. However the number of vessels delayed never exceed 4 % of the total arrivals. As stated by the port authorities the current level of traffic is only beginning to indicate a problem of berth congestion. This substantiates that the theoretical congestion rate presented by the simulation, in fact can be handled by different ship scheduling approaches. Providing us with a benchmark to evaluate the theoretical congestion level which is highlighted here, in the simulation runs of KCT 2.

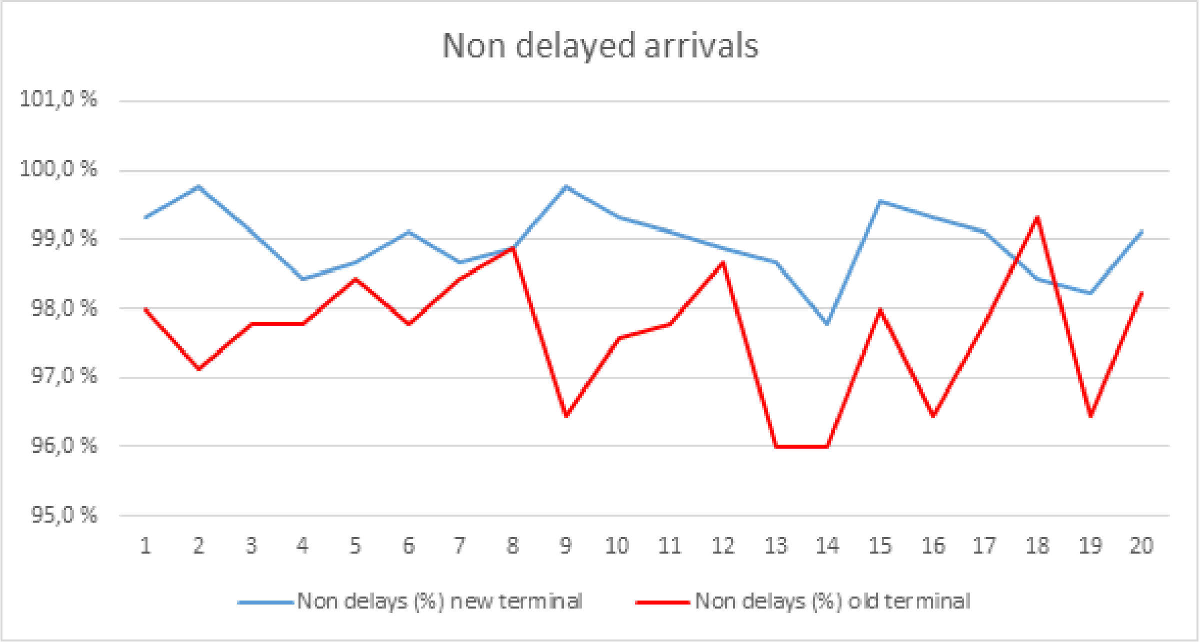
5.4.2 New Terminal



Run nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Average	minimum	maximum
Number of vessels	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Number of delays	3	1	4	7	6	4	6	5	1	3	4	5	6	10	2	3	4	7	8	4	5	1	10
Non delays (%)	99,3 %	99,8 %	99,1 %	98,4 %	98,7 %	99,1 %	98,7 %	98,9 %	99,8 %	99,3 %	99,1 %	98,9 %	98,7 %	97,8 %	99,6 %	99,3 %	99,1 %	98,4 %	98,2 %	99,1 %	99,0 %	97,8 %	99,8 %
Average delay	6	11	49,3	209	99,8	32,8	42,2	107	288	53,7	65,5	109	54	92,9	83,5	72,3	77,3	212	127	59,3	93	6	288
Minimum delay	1	11	23	30	34	18	12	26	288	5	33	40	15	4	15	21	50	7	1	5	32	1	288
Maximum delay	14	11	97	514	170	68	153	162	288	93	123	348	116	295	152	173	97	512	650	118	208	11	650

Table 15 – Congestions new terminal in minutes

Running the simulation with the same overall arrival pattern at the new terminal. The results show us a significant decline in the number of delays. The maximum number of delays in a period of 9 months has decreased from 18 to 10. While the minimum number of ships not having to wait for a berth space has increased to 97, 8 % of all arrivals. The spread in overall waiting time did however not changed significantly. The results of the two simulation in terms of ships not experiencing any congestion upon arrival is shown in the following graph.



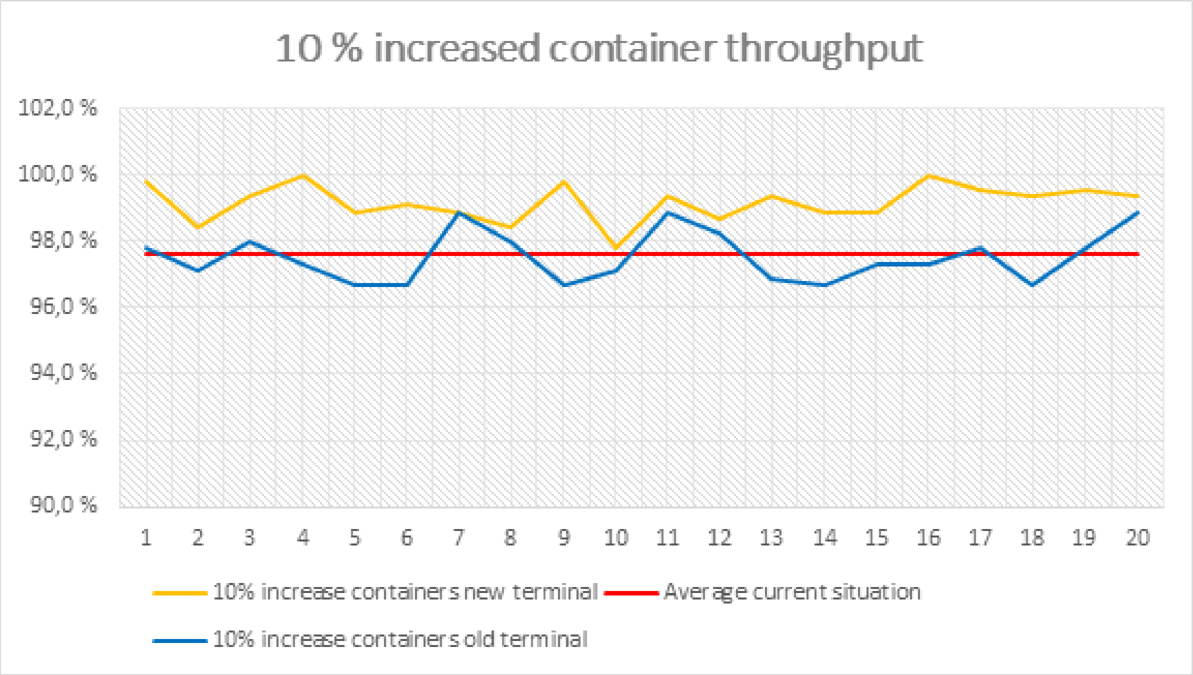
Graph 22 – Non delayed arrivals

This shows a clear pattern in the different simulation runs, that the number of vessels not having to wait for a berth spot is lower at the current terminal. Indicating move to KCT 2 could help prevent congestion with the current throughput at the terminal.

5.5 Objective 4b: Measure the Effect of Increased traffic

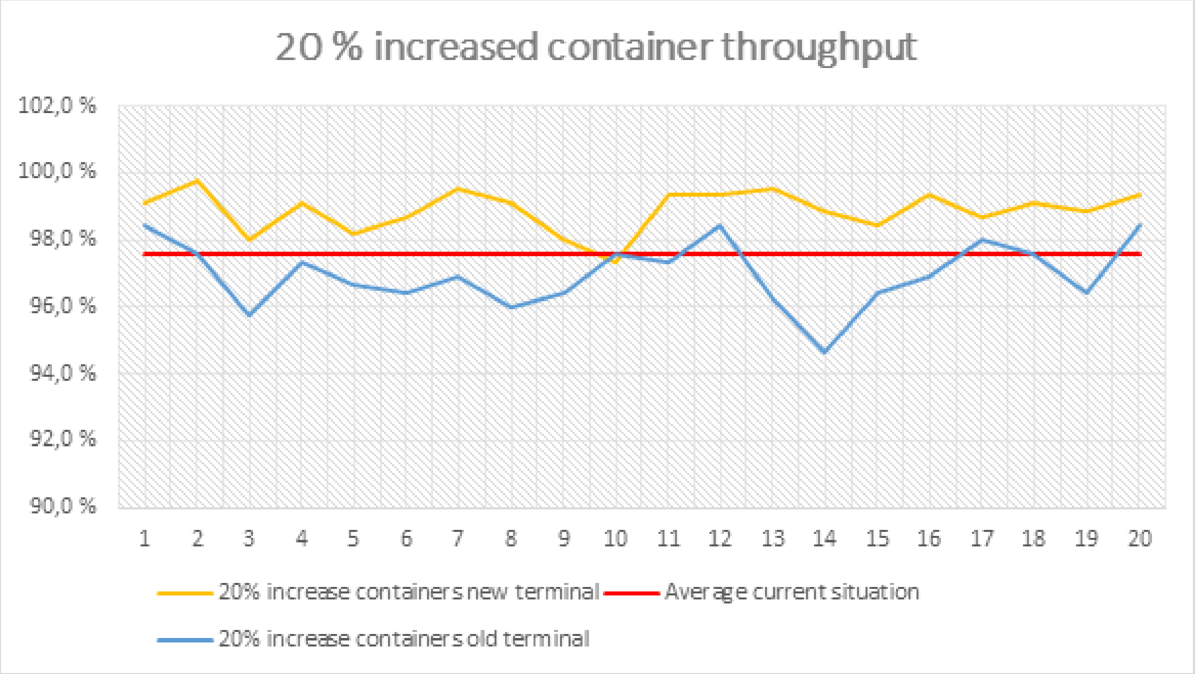
One of the main criteria for the planned move to KCT 2, are reports that the current facilities no longer will be able to handle a continued growth in the traffic level to the port. (Leknes, 2015) By performing a sensitivity analysis increasing the container throughput at the terminal we would get an indication on the effect this could have on the congestion level at berth. The port authorities stated in the interview that the expected future growth will originate from an increased amount of containers on the current vessels. Not necessarily from an increased number of vessels. (Leknes, 2015) On this basis the sensitivity analysis was performed by increased the container throughput with the current arrival pattern. However a growth in throughput of 30% or more, have been tested with a decrease in IAT of 10%, to represent a growth in number of ships carrying an extra number of containers. As a result the time of the simulation decreased, presenting us with a higher container throughput in a shorter period of time. The number of vessel not having to wait at the new and current terminal are compared on the basis of the same traffic growth. Giving us an indication of the new terminal's ability to handle increased traffic to the port in relation to the current situation. The average number of non-delays measured at the current situation, was used as a benchmark to estimate the level of traffic growth the new terminal potentially can handle.

The simulation was run for a total of 450 ship arrivals. In order to capture potential variance in the result, each run was performed 20 times. Providing us with the following result.



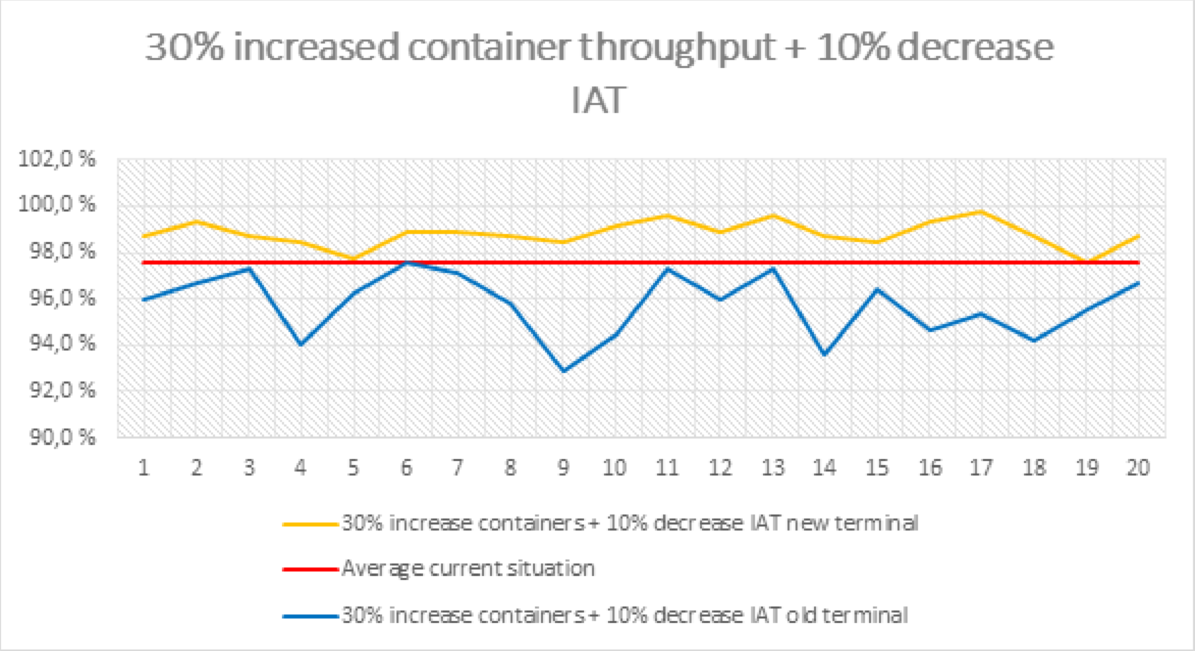
Graph 23 – Simulation results with 10% increased container throughput

At a 10 % growth in the container throughput, the current terminal is handling the traffic at approximately the same level as the current situation. The new terminal is however presenting better results in 20 of 20 runs, and we are beginning to see a difference in the theoretical congestion level of the new and current terminal.



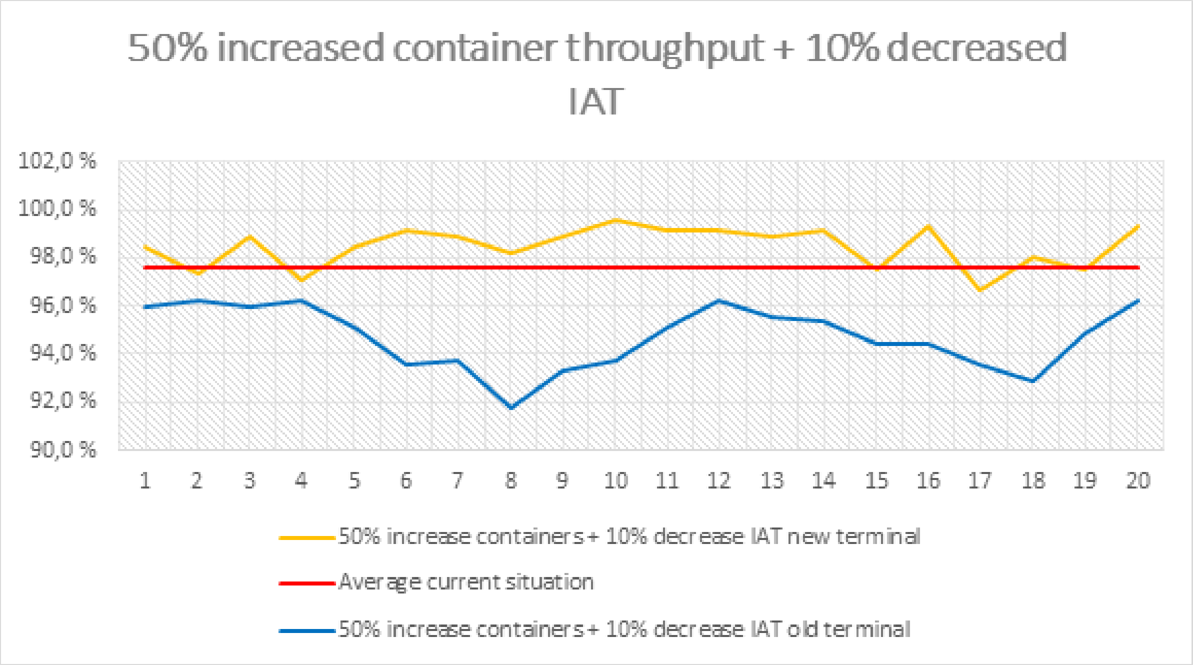
Graph 24 - Simulation results with 20% increased container throughput

With an increase in the container throughput of 20% we are clearly starting to see the current terminal having a level of congestion that is mostly higher than the current situation. The difference between the two terminals seems somewhat stable.



Graph 25 - Simulation results with 30% increased container throughput

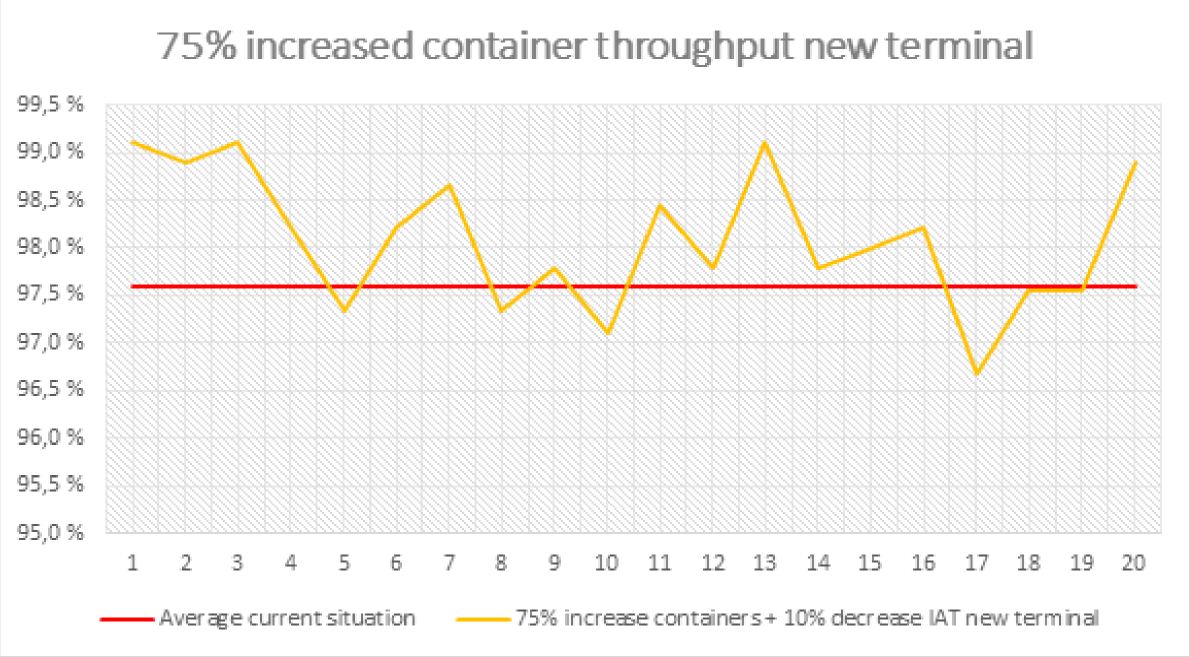
When including the aspect of decreased IAT, the difference between the two terminals becomes more evident. The current terminal is now in 19 of 20 runs having a higher level of congestion then the average of the current situation.



Graph 26 - Simulation results with 50% increased container throughput

When increasing the container throughput by 50% and decreasing the IAT by 10%, we can clearly see a large level of congestion at the current terminal. In the worst cases, almost 1 out of 10 vessel might potentially have to wait for a berth space upon arrival. The new terminal is still performing on a level indicating less congestion than the current situation. The difference between the two options is on this basis becoming very evident.

Further growth in container throughput were tested on the new terminal, showing gradually increasing signs of congestion. With a traffic growth of 75 % and with a decrease in IAT by 10 % we could see that the new terminal showing some signs of potential congestion.



Graph 27 Simulation results with 75% increased container throughput

The lowest number of ships not having to wait for a berth spot was 96, 7%, the same minimum level as the current situation. Indicating that the port authorities might experience some of the same challenges as they experience today with the current traffic level.

6. Evaluation of the Result

As stated in the introduction the overall objective of this thesis was to evaluate what effect structural changes at a container terminal could have on the dynamics of the container handling processes. On this basis the simulation was divided into 4 sub objectives, capturing the effect on the various operational sequences of the container handling process. To further evaluate the effect of the structural changes, the result was measured against key performance indicators of the port's overall performance. This enabled us to make an assessment of the impact changes in the container handling process potentially could have on the port as a whole. The result will be evaluated with regards to their potential effect on the port productivity and the port competitiveness.

6.1 Port Productivity

To evaluate the effect the structural changes could have on the overall port productivity, we need to see the effect of multiple measurements aggregated and in relation to each other. The productivity oriented class of measurements showed us the effect on crane utilization and reachstacker efficiency. As the main operational resources at the terminal, it is important to evaluate their performance in relation to each other, given the various constraints such as port side limitations, depot location and depot density. The simulation results of the current situation, showed an unsatisfactory crane utilization both on the export berth and at KCT1-B. The situation at the Export berth can seem to originate from a low efficiency on the Reachstacker, indicated in objective 2. Where the Reachstacker at the Export berth was shown to be slower in performing the operation, than its counterpart on KCT1-A.

The berth at KCT1-B also suffered from a low crane utilization, however the reason here seem to originate from both a slower operation of the Reachstacker, as well as the Reachstacker frequently being busy conducting some operation on KCT1-A. This leaves the ship at the B-berth waiting before being able to start the

discharge/loading operation. As a result, overall longer and more unstable berthing times could be observed in objective 3 on the Export and KCT-B berth.
Given the connection between the two berthing facilities and the delays, we can see clear indications that the reachstacker, or in the case of KCT1-B lack of reachstacker, can be seen as the bottleneck of the operation. We can see some similarities between the reachstackers operational speed, and the operational speed of the entire process. While the process is stable and predictable at KCT1-A, the spikes in operational time at KCT1-B consists mainly of waiting time connected to the reachstacker. Supporting the foundation of the theory of constraints that the operation as a whole can’t perform better than its weakest link.

The theory of constraints becomes interesting when evaluating the simulation result of the new terminal. We can see a clear decrease in the operational time of the reachstacker. The spikes in overall berth time does no longer occur, clearly showing the effect of each terminal having its own designated reachstacker. With both terminal KCT2-A and KCT2-B having a stable high crane utilization when moving large amounts of containers, we see indications that portside container congestion is no longer causing delays or making the ship crane idle. The overall impression is that the move to the new terminal have shifted the bottleneck of the container handling process from the reachstacker to the ship crane.

6.2 Port Competitiveness

As previously mentioned, the service oriented measurement category addresses the service level provided to the clients using the port. The result of these measurements can therefore be seen in context with the overall port competitiveness. It is evident that the effect of the planned move to the new terminal, should be seen in relation to the qualities that are considered important by the various port players.

An important aspect for the shipping lines visiting Husøy, is being able perform the discharge and loading operation in a fast and stable manner. Providing them with a fast turnaround time when visiting the port. Objective 3 showed us an overall decrease in the minimum required berth time at the new terminal. The operation were also seen to be more stable, avoiding the spikes in berth times originating from the KCT1-B and Export berths. In objective 4 we identified the new terminal's ability to better handle growth in traffic to the port. We saw an increasing difference in the congestion level at the various terminals, when increasing the container throughput and decreasing IAT in objective 4 b. The new terminal was shown to be much better suited for receiving both an increased amount of containers as well as ships. Giving the impression that the port authorities with the construction of the new terminal, are showing ability to develop their terminals in compliance with the anticipated market development.

The port's ability to provide a stable and reliable capacity for the shipping lines could also affect the overall port cost through higher efficiency, both for the shipping lines and the port itself. Making the port of Husøy a more desirable port of call for various shipping lines. With the ports close proximity to the planned development of E134 and E39, it's reasonable to assume that the potential increase in productivity at the new terminal, in addition to the terminals ability to provide a more stable capacity, will make the port of Husøy a more desirable connection in different supply networks.

7. Summary

The port at Husøy have been experiencing a rapid growth the last year, which has led to the development of the new container terminal KCT2. This thesis aims to evaluate what effects the planned structural changes at the port could have on the dynamics of the container handling process. In order to address the topic, the overall objective was divided into 4 sub objectives. Each of them were evaluated separately as well as in connection to each other.

Due to the number of complex situations affecting the container handling process, computer simulation was shown to be the idle approach to closer investigate the effects of structural changes at Husøy. GPSS was decided be a suitable program for this purpose.

Data for the simulation, both qualitative and quantitative data were collected through interviews with several of the port stakeholders, as well as a through the database belonging to the Karmøy port authorities. For the modelling purpose the collected data were fitted to various empirical distributions using Easyfit. Two simulation were created, one for the current terminal and one for the new terminal. Based on the 4 sub objectives, several measurements were included in the simulation, enabling us to capture the effects caused by the relocation of the terminal.

The results presented us with indications that by moving to the new terminal, the overall bottleneck of the operation potentially could shift from the stevedore company’s reachstackers to the ship's crane. The new terminal was also proved to be better suited, handling the expected traffic growth to the terminal. Giving the stevedore companies a solid foundation, from which they can provide their clients with a more efficient and stable cargo handling operation. Potentially increasing the overall competitiveness of the port.

7.1 Research Limitations

During the development of this research project, we had to make various simplifications of the actual processes described in the study. While much relevant information and inputs can be derived from the result, it's important to mention the limitations of the study.

The major aspect of the simulation is as previously stated the operational side of the container handling process. The change that have been highlighted and analyzed in the simulation, is that of the structural relocation of the container terminal. Improvements potentially caused by operational procedures such as pre-marshalling and stowage planning, achieved through increased cooperation between the stevedore companies have not been investigated. It's important to emphasize that the results of our simulation in this context only should be seen as the potential improvement due to a more functional layout of the terminal. The stevedore company’s ability to take advantage of this potential is outside the scope of this thesis.

By not including the depot capacity in the simulation, the potential influence of larger container depots is limited to reduced storage density. This might not allow us to capture all the potential benefits of developing the new container terminal, regarding better working conditions inside the depots.

The historical data used for the quantitative analysis and the simulation model consists of real life events from a period of 9 months. As a result, several extraordinary events in this period might have influenced the analysis.

The reports from the port authorities have been used as a foundation when testing the new terminal's ability to handle increased traffic to the port. No research have been made in terms of estimating what effects the planned development in hinterland connections could have on the traffic to Husøy. ‘

This thesis is based on the current conditions at the port of Husøy. The result presented can thus not be generalized to apply to other container ports. We would however like to think that some aspects of the simulation design could prove to be of value when constructing simulation models for other container ports.

7.2 Future Research

The main topic of this thesis was the effect the structural changes at the container terminal could have on the dynamics of the container handling process. Evaluations was made in terms of potential increased efficiency in the container handling process. A potential extension of this thesis could thus be done by including the financial aspect in the development of the new terminal. Conducting some sort of cost/benefit analysis in relation to the expenses of the development.

The port authorities believes that development in hinterland connection will cause increased traffic to the port. It could be very useful with an investigation to estimate the potential effect the new E134 could have on the traffic to the port at Husøy.

The new terminal provides the stevedore companies with a large geographical area for their container handling operation and facilities. Estimations in terms of facility layout and potential optimization of the container stacking operation would be of great benefit in the further development of the area.

In addition, with the new terminal providing the port authorities with the possibility to further segment and specializes the different terminals. It could be of very valuable with some research concerning the effect various ship scheduling techniques could have on the berth congestion.

In this study we identified that the ship crane was likely to be an operational bottleneck at the new terminal. Evaluating a potential investment in a mobile harbour crane, could therefore be of great value to the port authorities. A feasible approach would be a cost/benefit analysis of the investment, which could be substantiated by this thesis.

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8. Appendix

Appendix 1	Interview guide x 2
Appendix 2	Text Edit from simulation at the new terminal
Appendix 3	Text Edit from simulation at the current terminal
Appendix 4	Historical data from Karmsund Port Authorities (1.1.15 – 1.9.15)
Appendix 5	Detailed graph 20
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