Analysis and Simulation of a Break Bulk Terminal in the steel industry

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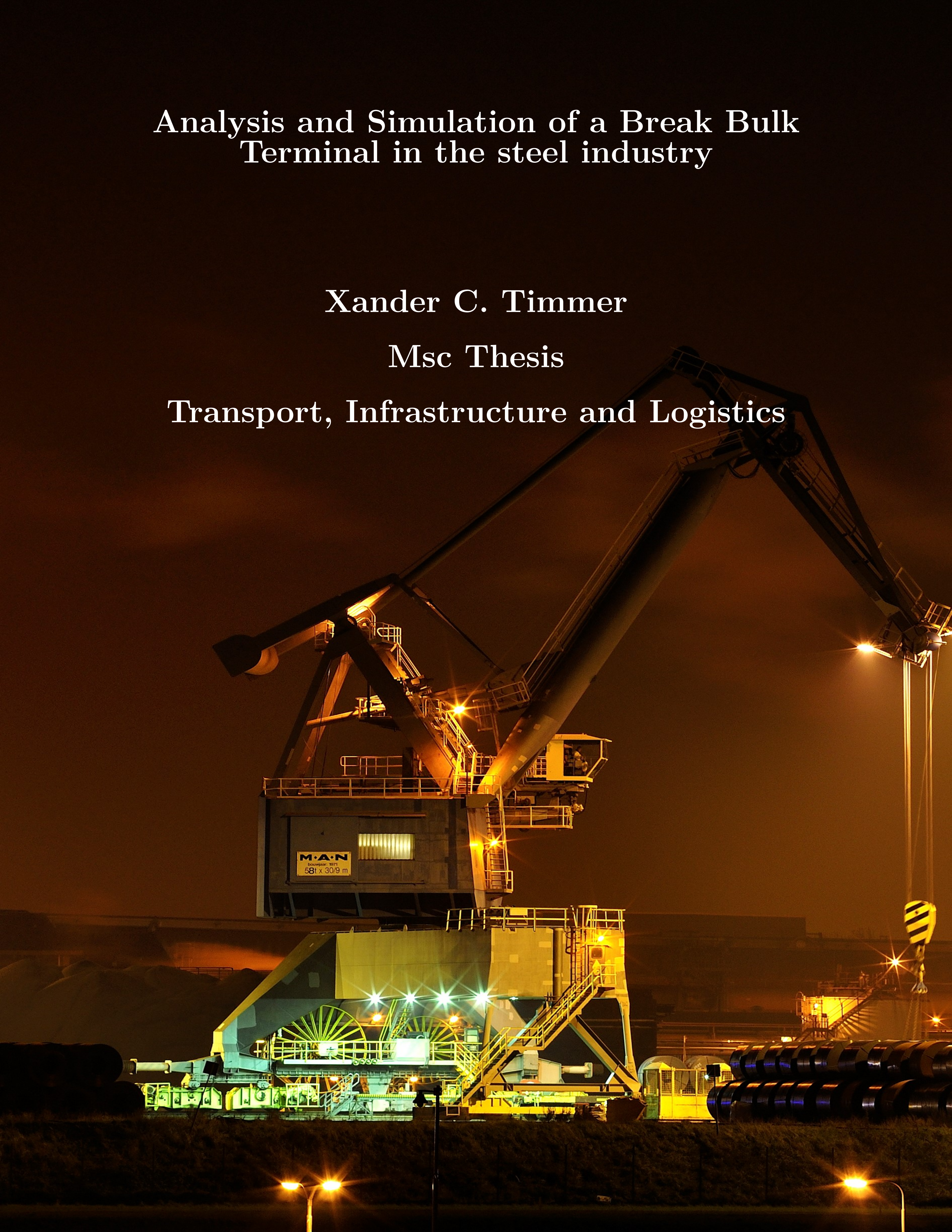
Msc Thesis

Transport, Infrastructure and Logistics



Delft University of Technology

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Preface

This thesis is the final work of the master program Transport, Infrastructure and Logistics the Delft University of Technology. It was written in the past 8 months and it summarises the work performed in cooperation with Tata Steel IJmuiden. It has been an interesting and educational journey and being able to write my thesis at a company allowed me to learn more than I could have hoped for, both on a personal level and on a professional level.

I would like to thank my thesis committee from the university consisting of Dingena Schott, Mark Duinkerken and Adam Pel for their valuable guidance throughout the process. Each of the members has contributed to this thesis in their own way. The feedback received during the formal and informal meetings guided me in the right direction and during the last phase of the project also gave me the energy to finalise the report.

Tata Steel IJmuiden has provided me the opportunity to conduct my research and write my thesis as a graduate intern. In particular I would like to thank Stefan Janse for mentoring me through the process. He has been heavily involved and provided me with guidance from the first moment. Asking difficult questions and challenging me throughout the process has benefited the end product undoubtedly. I also would like to thank everyone I have worked during the last 8 months. I have truly felt interest from the people working at Tata Steel in my research. Their helpfulness in finding the correct people and data on numerous occasions is appreciated.

Enjoy reading the report!

Xander Timmer

Executive Summary

Break-bulk cargo still currently accounts for a considerable amount of the maritime trade. In 2005, the total break bulk fleet size in dead weight tonnage more than 10%. Break bulk cargo thus differs from other cargo is the fact that these type of goods are processed per piece instead of bulk or containers for example. despite this difference, the operations and processes associated with break bulk terminals are very similar to dry bulk or container terminals. Products are transferred (transshipped) from one mode of transportation, for example vessel, barge, truck or train to another. In order to do so, terminals are provided with shore cargo handling equipment. In this research the outer-harbour 3 of Tata Steel IJmuiden is investigated, specifically all processes related to the loading of deep sea vessels. This investigation resulted in a set of recommendations for the company. These recommendations entail what machines and resources are currently the bottleneck in these processes and where the company should improve their operations to realise the highest growth in performance.

The starting point of this research is the observation made by Tata Steel that the quay cranes currently in operation in the outer-harbour 3 of Tata Steel IJmuiden are becoming old. Tata Steel thinks that substituting one of these cranes for a newer hydraulic quay crane brings several advantages, one of which is an increasing throughput of volume during loading deep sea vessels. However, the combination of machines, resources and processes necessary to load these vessels is highly complex. Once a vessel arrives, the required machines, resources and workers work together to execute the loading as efficient as possible. Delays in the departure of loaded vessels can result in major fines to be paid. Due to the complexity of the operations, it is not sure where in the system bottlenecks are located which cause the performance to be sub-optimal. Although the performance is not considered bad by Tata Steel, there are ambitious to work ever more efficient and therefore would like to know where they could improve their organisation the best. In this research academic methods and expertise from practice are combined to tackle this challenge and to provide Tata Steel with valuable insights.

At first field research was done, including visiting the outer-harbour 3 multiple times and interviewing employees. Subsequently academic literature was consulted to find a set of methods to analyse the processes in a structured way. In essence the question Tata Steel wanted to be answered was to provide possibilities to improve the performance of the harbour. To do so it was necessary to test several solutions, or alternative configurations, to eliminate the bottleneck as to help in the decision-making process related to improving the performance of their operations, but without the direct need for costly investments. Literature on similar cases showed that discrete-event simulation models are best suitable to mimic complex logistical processes and to test several solutions with. In order to build such a model a structured system-thinking methodology is used. This helps to identify the most important elements in the system and also how to draw the boundaries surrounding the system, in other words what to take into account and what not during the research. In addition

to the analysis of the physical system, the KPIs used by Tata Steel have also been compared to literature and with key performance indicators (KPIs) used by other departments. This resulted in five main KPIs, productivity (volume and quantity), additional operational costs, demurrage costs, average vessel loading times and punctuality. Besides these five KPIs, three performance indicators (PIs) are used to identify the bottleneck in the system, being blocking times, idle times and occupancy of machines. In addition 7 elements were identified to be potential candidates as bottlenecks in the system. These are the assembly of trains with load in the hinterland, referred to as the CE, the locomotives, the Transit Hall crane, the quay forklift trucks, the quay cranes, the vessel hold forklift trucks and the securing teams.

Based on the gathered information, a conceptual model of the system is made which includes the most important aspects of the system and to allow for a smooth transition towards the computerised model. The computerised model is developed in Python using the Salabim discrete-event simulation software package. The computerised model is verified using a set of tests and validated using Tata Steel expertise as well as available data. The model is deemed to be able to calculate most of the KPIs within boundaries of a 95% confidence interval. However, the model calculates higher volume productivity (tonnage/day) than compared to historical data. The model does not take into account several of the process steps that are required in the real system, such as the loading sequence of steel products and changing of material between holds. Therefore, as these steps are not modelled, also do not take additional time, which in turn leads to higher volumes to be loaded per unit of time. Despite this lack, the model is overall valid and used to perform a set of experiments with.

With the model build, an assessment of the current performance, in terms of the (K)PIs, is done. The model processes 50 vessels and calculates requires statistics of the three PIs. These statistics are used for two bottleneck detection methods found in the academic literature. This assessment shows that the supply of trains, the CE, towards the outer-harbour 3 is the main bottleneck, with the locomotive capacity being the second element that is reducing the performance of the system. Based on these findings three experiments are executed. For each of the experiments the scenario data of 50 vessels remains the same. For experiment 1, the capacity of the CE is gradually increased. For experiment 2 the locomotive capacity is increased and experiment 3 aims to assess what the impact is of using the harbour coil storage warehouse, the Transit Hall more. Experiment 1 shows that for each hour that the supply duration from the CE can be reduced the average loading time of vessels is reduced by 8 hours. In the current system the average loading time is 3.4 days, thus it shows that small improvements in the supply rate can result in large overall improvements. Moreover, to achieve a 20% increase in productivity in terms of volume and products loaded per day, Tata Steel has to achieve 45% increase in the supply from the CE. Results from experiment 2 show that increasing the locomotive capacity has no statistically significant affect on the performance of the system. The KPIs remain the same and one has to take into account that adding locomotive capacity does also involve additional operational expenses. Experiment 3 shows that an increase of 18% in productivity can be expected if 25% more coils are loaded from this storage point rather than directly from trains and an overall reduction of vessel loading time of 10 hours.

The Python DES model is built specifically to mimic the processes related to the loading of deep sea vessels in the outer-harbour 3. It has shown it benefits in supplying the decision-making processes of Tata Steel with valuable insights regarding the impact of changing the configuration of their existing system. However, as with all models there are limitations that have to be taken into account. The model is built by applying a set of assumptions and simplifications discussed in chapter 5. Only deep sea vessels are considered in this research. Moreover, the sequence in which collo are loaded into the vessel is not considered as well, but remains a complex task as Schoenmaker (2016) has shown. The model can thus be improved by incorporating these aspects, however care must be taken that the model is not becoming too complex as this will eventually not benefit the user.

Overall the aim of this research is to answer the main research question *How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?*. The largest improvements can be achieved by improving the supply of loads towards the outer-harbour 3. To a lesser extent it helps to increase the use of the Transit Hall. Adding locomotive capacity alone does not solve any of the challenges faced and at the same time even increases operational expenses. Based on these results it is recommended for Tata Steel should focus mainly on improving the supply of colli by the CE directly towards the quay. The second best option is to utilise the Transit Hall more by sending more trains with coils towards this storage point. Looking at the financial aspects, the OSL department is not necessarily focusing on increasing profits, bur rather increasing efficiency and decreasing costs. With this in mind, an indirect result of improving the supply rate is that the demurrage costs will decrease which allows this money to be used for these improvement projects. In short, the budget that can be made available for such projects depends on the desired improvement in performance.

Contents

Chapter 1

Introduction

Since 1918, Tata Steel, previously known as Hoogovens and more recent Corus, produces high quality steel in the area of IJmuiden. On a yearly basis Tata Steel produces around 7 million tons of steel. Steel that is used in the automotive industry, packaging industry such as cans, battery's, heavy lifting equipment and kitchen appliances. At the manufacturing site in IJmuiden is an integrated site where all steps in the process of making steel are performed. From the delivery of raw materials, to the shipment of finished coils and slabs of steel. These products are categorised as break-bulk cargo as they are stowed on board of vessels, barges, trains and trucks in individually and non-standardised units. The finished steel goods considered in this thesis are categorised in either 'eye to the sky' (ETTS), vertically placed coils or standard horizontally placed coils. The shipment of this break-bulk cargo is done via waterways, short and deep sea, road, train and container transportation to customers located worldwide. As the customers of Tata Steel demand high quality products as well as on-time and in-full delivery, well organised on-site and off-site logistics are an absolute necessity. This thesis research focuses on the workings of one of Tata Steel's exporting harbours used primarily for exporting the steel break-bulk cargo. The harbour is directly connected to the North Sea, which provides ships of several sizes the opportunity to visit the port as well as the possibility for quick arrival and departing processes. The on-site logistical processes as described, fall under the responsibility of Tata Steel IJmuiden's On-Site Logistics (OSL) department. A sub-department of OSL, Stevedoring & Warehousing (S&W), is responsible for operations of the warehouses and harbours. The department is interested in how to increase the volumes/day loaded onto deep sea vessels visiting their outer-harbour 3. The aim of this research is thus to identify performance indicators, and main contributing factors that determine the performance of the harbour, how to measure these indicators and most importantly whether the performance of the port can be increased by changing the configuration of the harbour.

This proposal is structured as follows. In this chapter the main research questions and sub-research questions are defined based on on-site analysis and literature research. This is followed by an elaboration on the methodology which includes the software, data, research questions and frameworks used. In chapter 2 a review of relevant literature for this particular research is given. In chapter 3 an extensive system analysis of the S&W department and specifically the outer-harbour 3 is performed to understand the functions, elements and their relationships and the processes of this system. Subsequently a problem analysis is executed to identify where challenges are faced in the system. Based on the findings of this analysis, the problem statement and a research goal are defined as well as the contribution to academic literature of this thesis. In chapter 4 the conceptual model representations of the system as well as the assumptions and simplifications made during the design and creation of this conceptual model are discussed. In chapter 5 the verification and validation of the computerized model is explained as well as the assessment of the performance of the current system as calculated by the model. In chapter 6 the experiments executed in this research are further elaborated upon. Subsequently in chapter 7 details of the results of these experiments are discussed. In chapter 9 and chapter 8 the final conclusions & recommendations and discussion discussed respectively.

1.1 Problem statement

On a yearly basis the outer-harbour 3 of Tata Steel IJmuiden is responsible for loading roughly 1 million tons of steel into barges and short sea, and another 1.1 million tons of steel in deep sea vessels. Each vessel has a contractual and scheduled arrival and departure time. In case a vessel leaves the harbour later than the contractual departure time, Tata Steel has to pay demurrage costs, because the ship is not available to make money elsewhere due to the delay. The total loading time is, amongst others, heavily dependent on the speed at which the ship is loaded and therefore depending of the speed of the processes associated with the loading of these vessels. In this context and because the current quay cranes are 50 years old, Tata Steel thinks there is potential to increase the performance and safety of their outer-harbour 3 as well as to decrease the overall costs, by replacing one of the quay cranes by a hydraulic crane. The department is aware of the fact that bottlenecks, if any, will hinder this expected performance increase of their outer-harbour 3. Therefore, before investing in a new crane, they would like to gain insights in their current processes and solutions to increase the performance. The problem statement can be described as follows:

Tata Steel IJmuiden aims to increase the performance of their outer-harbour 3, in terms of volume loaded per day on deep sea vessels, by 20%, as well as the overall safety around the harbour. However, Tata Steel is not sure which of their current processes are the bottlenecks, if any, and which of these should be invested in first to achieve the desired increase in performance.

1.2 Research goal

From literature research in chapter 2 it follows that the identification of relevant (Key) Performance Indicators (K)PIs for break-bulk terminals can contribute significantly to optimal monitoring a systems performance and thus the identification of bottlenecks. Testing of possible solutions to the aforementioned problems is possible by using discrete-event simulation models, as these can contribute in the identification of potential bottlenecks inside complex systems as well as the testing of methods to tackle them, without the need for large investments immediately. The focus of this specific research will be on understanding the current logistical processes surrounding the outer-harbour 3 of Tata Steel IJmuiden and testing potential solutions to improve its performance. The research goal is stated as follows:

To gain additional insights in defining the performance of break bulk sea ports on tactical and operational level using an appropriate selection of (K)PIs. Subsequently use these (K)PIs and discrete-event simulation (DES) model techniques to assess the performance of 'as-is' processes in break bulk terminals, to identify bottlenecks and to research what changes to the performance can be expected when using resources differently. Finally to gain knowledge on what contribution DES models can make to decision-making processes in the context of break bulk terminal operators.

In order to achieve the research goal, a main research question has to be determined. From literature and problem analysis on-site, a research gap was found. Through literature research, it can be said that there is extensive literature available on container terminal operation optimization e.g. yard storage, stowage planning, crane scheduling or ship planning. However, to a far lesser extend there is research done on break-bulk cargo terminals, its operations and how to find and eliminate bottlenecks that occur in these logistical settings with the goal of improving performance. The combination of the aforementioned context and simulation methods has not been researched to the author's best knowledge, and therefore provides a gap in academic literature and leads to the following main research question:

How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?

In order to answer the main research question, 6 sub-research questions have been formulated. These are as follows:

1. Which logistical processes at the break-bulk sea terminals are found in literature?
2. Which logistical processes are present at Tata Steel IJmuiden?
3. What defines the performance of break-bulk harbours and what methods are used to quantify bottlenecks and improvements?
4. What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals and what should this model look like in terms of its design?
5. What type of experiments, in terms of potential future terminal configuration alternatives are relevant to execute?
6. What will the expected performance of the terminal be, when these potential terminal configurations are tested?

1.3 Scope

The OSL department of Tata Steel IJmuiden has three harbours at their disposal for importing and mostly exporting steel products. These are the inner-harbour 1, the outer-harbour 1 and the outer-harbour 3. Three types of vessels visit these harbours. Deep and short sea vessels and barges. The scope of this thesis research is focused on exporting operations taking place within the outer-harbour 3 during the loading of deep sea vessels. In short this entails:

1. Export loading processes
2. Outer-harbour 3
3. Deep sea shipments
4. Coils and ETTS, no slabs

As the operations related to the loading procedure of deep sea vessels are considered to be most complex and the use of machines and resources involved with these operations and the potential delay in loading times are considered to be most costly for Tata Steel IJmuiden. Thus all importing and exporting operations taking place in the outer-harbour 1 and inner harbour 1 regarding short sea vessels and barges as well as the importing operations of deep sea vessels in the outer-harbour 3 are left out of the scope.

1.4 Methodology

In this section a brief elaboration of the research methods used will be given. This entails what data, frameworks, literature and other methods are used to answer the sub-research questions. Per sub-research questions a proposed method to answer the question is elaborated upon.

To answer the first question, *Which logistical processes at the break-bulk sea terminals are found in literature?*, it is important to understand the material and information flows in break bulk sea ports. Answering this question will lead to a clear view on the background and the context in which the research will take place. This question will mainly be answered by reading literature on the on-site logistical processes of businesses dealing with break-bulk cargo in general and by performing interviews with Tata Steel employees and on-site field research. These two methods combined will enable for a clear view on how the processes of Tata Steel relate to the academic literature.

The second question, *Which logistical processes are present at Tata Steel IJmuiden?*, is related to the first sub-research question. However, the answer to this question should give insights into the logistical processes at Tata Steel IJmuiden. By means of a system description and analysis this question is answered

The third question, "What are break-bulk sea port loading strategies and how can these be used to improve break-bulk terminal operations??", is important to answer as not one break bulk sea port is exactly the same. Different ports operate their harbours differently. The logistical concepts, use of resources and strategies applied are useful to get familiar with. The purpose of answering this sub-research question is to identify whether certain strategies might align better with the logistical processes and objectives of break-bulk terminals and whether these strategies can be tested to see which (combination) results in better performance of Tata Steel IJmuiden's harbour. This question will be answered by both assessing (academic) literature to identify how break bulk ports operate, but also largely by interviewing Tata Steel actors and stakeholders as to determine what strategies are realistic for their harbour.

The fourth question is: *What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals and what should this model look like in terms of its design?*. The answer to this question gives a clear perspective on what type of quantitative models are used in literature to assess as-is logistical processes in terms of performance and importantly, to give useful insights on the impact of the changes to these performance of these logistical processes before investments of time, energy or money are done. As said, literature will be used to find an appropriate type of quantitative model and to find a designing method to make this model. For example, it is necessary to make a conceptual model based on the system to be researched, before a executable model is programmed. This is important such that each potential aspect of the, to be researched system, is considered and such that validation and verification is be done after the executable/computerized model is realised and is able to provide results. The research goal is to come with a good definition of the performance of break bulk sea ports on tactical and operational level, (K)PIs to assess the performance, identify bottlenecks and try to solve some of these bottlenecks. A mathematical model can help to quantitatively assess the aforementioned. Based on the literature research, one can conclude that there are several mathematical models, such as simulation models and MILP used in container terminal and steel coil warehouse contexts to optimise the performance. However steel coil harbour operations are to the authors knowledge not yet researched. In order to determine which exact model fits best in achieving the research goal requires a combination of more literature research and extensive collaboration with Tata Steel to understand what data is required, as this also influences mathematical model choice.

The fifth question: *What type of experiments, in terms of potential future terminal configuration alternatives are relevant to execute?*. The design of the experiments should be done in such a way that every time only 1 parameter is changed. Subsequently all KPIs are measured and the results are analysed to assess whether significant changes are realised. The number of experiments should be limited due to time constraints.

The sixth question: *What will the expected performance of the terminal be, when these potential terminal configurations are tested?*. Once the simulation model of the "as-is" situation is created proper validation and verification is done, the configuration of the model will be changed. Subsequently the model is run again and the outcomes are compared to results of the base model.

Overall the step-by-step modelling process of (Suprun et al., 2016), which in turn is based on (Sterman, 2000), Figure 5.1, the Process Interaction Modeling and Simulation perspective on model design steps by (Ottjes and Veeke, 2012) is used to develop an own structure for this research.

1.5 Contribution

There is a lack of academic literature on break-bulk port performance improvement by means of quantitative models such as MILP and simulation models. As break-bulk trade still makes up a significant part of the total maritime trade, research done on topics as these, is still relevant and provides room to increase the existing knowledge on this research field. Both, from literature and from interviews with experts in the field, it was made clear that there is need for academic research methods that can provide insights in potential expected performance increase of logistical systems without the need for investing in expensive additional resources or machines. The research done and elaborated upon in this thesis report provides additional knowledge to this relatively underexposed topic. More specifically, this thesis contributes knowledge to the academic literature by combining (key) performance indicator selection, system thinking and discrete-event simulation methods. Firstly, this research shows that system thinking methods are well suited to identify the main elements and system boundaries of break-bulk cargo terminals as well as to identify which KPIs such organization could steer upon. Secondly, the results of this research show that discrete-event simulation models in combination with average bottle neck identification methods provide valuable insights with respect to bottleneck detection. Particularly in the context of Tata Steel IJmuiden, the results highlight current bottlenecks in the processes and moreover, show that by improving the supply of products towards the outer-harbour 3 by an average of 3 to 4 hours average vessel loading time will decrease by almost 20%. This implies that large investments into new equipment are not necessarily the most optimal way of achieving higher performance as it is beneficial to first improve current processes. Overall the benefit of DES models in decision-making is demonstrated in this thesis. The benefit is found in the insights into the processes of Tata Steel that should be improved first. Direction is provided and also the expected impact on performance is measured.

Chapter 2

Literature research

In this chapter, relevant literature on break bulk sea port operations, strategies, performance indicators and bottlenecks is further elaborated upon such that a gap in literature is identified and to answer a number of sub-research question. This chapter is set up as follows. Firstly, the function and logistical concepts of break bulk sea ports are reviewed and described. Subsequently research is done on different port strategies. Hereafter, known bottlenecks within break bulk sea ports and container terminals are discussed. Following this, is the elaboration on used (K)PIs and Performance Indicators (PIs) within logistics and sea port logistics and which frameworks are used to determine these. Subsequently, literature is consulted to find a proper quantitative simulation model to use during this research. This chapter is finalised with a conclusion on the found literature and an answer is given to sub-research question 1 as well as to the highlighted part of sub-research question 4, in bold. The answer to the second part of this sub-research question is discussed in chapter 4 :

- Sub-research question 1: *Which logistical processes at the break-bulk sea terminals are found in literature?*
- Sub-research question 4: ***What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminal*** *and what should this model look like in terms of its design?*

2.1 Break bulk port function and operations

Handling break bulk cargo is not so different than general cargo such as containers. However, what makes break bulk different from other cargo is the fact that these type of goods are processed per piece instead of in containers in bulk for example. despite this difference, the operations and processes associated with break bulk terminals are very similar to dry bulk or container terminals (Schott and van den Hoed, 2017). Steel coils are such general cargo as these products are transported as individual pieces of cargo. In most cases the production, on-site transportation and outbound transportation of these steel coils are executed by steel manufacturers themselves as well as by third-party logistics service providers (3PL). Once the products are finished, there are three main modes of transportation, rail, road and waterways, that can be used to supply products to the customers. Ports associated with the handling of break bulk cargo are referred to as break bulk ports, and are used to execute the in,- and export of break bulk products by using barges, coasters and large sea vessels. The function of these type of ports can therefore be described as the temporarily on-site storage of general cargo and the realisation of the transfer of this cargo to and from storage or from one mode of transportation to another (Schott and van den Hoed, 2017). In order to do so, equipment handling machines are required, such as forklift trucks, trains, trucks and quay cranes. Understandably, the costs associated with these storage, handling and transportation of (semi) finished products are significant cost items for steel manufacturers. Being able to decrease these can increase profit margins of steel coils even more than applying technical improvements to the production processes as these are limited due to technical limitations (Li and Tian, 2015). Figure 2.1 illustrates an example of the transportation logistics of (semi) finished products in the steel and iron industry. The figure shows the transportation of these goods between warehouses, a central consolidation point and the dock yard through means of a mode of transportation which is usually truck or train.

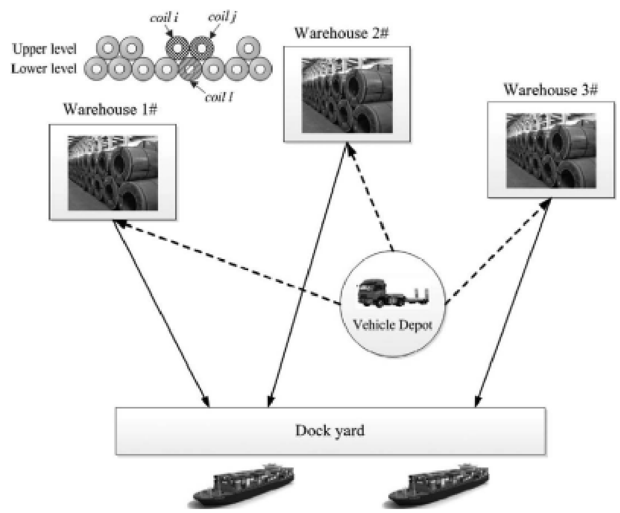


Figure 2.1: Shipment logistics of finished products in the iron and steel industry(Li and Tian, 2015).

Products are transferred (transshipped) from one mode of transportation, for example vessel, barge, truck or train to another. In order to do so, terminals are provided with shore cargo handling equipment. (Meurn and Sauerbier, 2004) distinguished two types of shore equipment's, handling equipment and hailing equipment. The former is equipment used primarily for lifting cargo vertically, whereas the latter type of equipment is used to transport cargo horizontally. Due to the varying size, shape and weight of break bulk cargo, it is not uncommon for break-bulk terminals to use tools such as hooks and slings or grabs to handle cargo. Forklift truck use around break-bulk terminals has increased significantly. They are used for short distance transportation in and around the docks and are flexible in terms of what shapes, sizes and weights of cargo they can handle (Branch, 2007). A substantial number of break bulk product groups are likely to be shipped in containers within the near future. The authors of (Schott and van den Hoed, 2017) have identified five major break-bulk product groups that will still be considered break-bulk in the future:

1. Bags
2. Bananas
3. Project cargo
4. Roll-on roll off

5. Timber & steel

Being the focus of this research, steel products come in several shapes, such as slabs, pipes and coils. The latter are preferably stowed on their sides, however due to the direction of the handling equipment there are usually stowed on their rolling side. To prevent cargo from moving during transporation over water, the coils have to be braced, shored and lashed such that rolling is prevented (Schott and van den Hoed, 2017).

2.2 Bottlenecks

In this section, literature on the definition, detection and elimination of bottlenecks is elaborated upon. Per theme relevant literature is considered and the most important findings are written down.

2.2.1 Definition of a bottleneck

Unfortunately the definition of a bottleneck is not set in stone. For each production or logistical process, the description of the bottleneck could mean something different. However, in order to provide some clearance, in this section some definitions of bottlenecks found in literature are discussed. According to (Urban and Rogowska, 2020), a bottleneck in a production or logistical process is defined as a point in the process where congestion occurs. This happens when the arrival rate of workload for one of the production or logistical processes is larger than the that particular process is able to handle. Due to these bottlenecks the output of a system of process is smaller than the theoretical maximum. (Mukherjee and Chatterjee, 2007) define five categories of bottlenecks:

- Capacity based definitions
- Critical path based definitions
- Structure based definitions
- Algorithm based definitions
- System performance based definitions

(Roser et al., 2003) has constructed a definition of a bottleneck based on (Chiang et al., 2000), which defines a constraint (or bottleneck) as a machine or process step whose work-rate or throughput has an effect on the work-rate of the whole system and the scale of the bottleneck's is defined as the effect of that bottleneck on the whole system. The paper also provides two levels of bottlenecks. Firstly the authors define a separation of the primary bottleneck and secondary bottlenecks. The primer, is the main bottleneck, the machine or process step that affects the overall system's performance to the largest magnitude. The latter are machines or process steps that, to a lesser extend though, still constrain the system. To complete the categorisation of all machines, the paper refers to machines or process steps that are no bottleneck at all, as non-bottlenecks.

2.2.2 Identification of bottlenecks

In general bottleneck identification models can be categorised into two groups which are analytical and simulation models. Analytical models work on the principles that the performance of a system can be described using statistics. Analytical models are useful to predict the bottleneck on the long term. A disadvantage however is that usually the system under investigation is complex to such an extend that it is near to impossible to apply these methods. Simulation models provide a solution to this problem as they are able to simulate dynamical, often stochastic processes. A disadvantage of such simulation models however is the time spend on developing such models to an extent that they are useful for providing insights (Eskandari et al., 2013b),(Al-Harkan and Hariga, 2007). The authors of (Roser et al., 2002) split the methods that work with simulation methods in momentary bottleneck detection methods and average bottleneck detection methods as these models are able to measure the requires inputs for these methods. Authors of (Leporis and Králová, 2010) and (Eskandari et al., 2013a) both researched several bottleneck detection methods in combination with simulation models and both concluded that of those methods, the Critically based method was proven to generate the best result. This method is suitable for use on simulation models as the required inputs of average utilisation, idle, blocking and waiting times of the resources/machines can be calculated by simulations models. For each machine in the system, these rates are used to calculate the critical indicator of a machine and compare it to the average critical indicator value of the whole system (Leporis and Králová, 2010). This gives insight into the machines or resources that require capacity expansion as well as those machines or resources that have capacity reserves and thus could be utilized better. A downside of this method however is that it uses averages and therefore it is harder to detect shifting bottlenecks. The Critical indicator value of the *ith* machine can be calculated as follows:

$$KR_i = \left(\frac{\sum_{i=1}^{n} B_i}{n} - B_i\right) + \left(I_i - \frac{\sum_{i=1}^{n} I_i}{n}\right) + \left(BI_i - \frac{\sum_{i=1}^{n} B_{Ii}}{n}\right) + \left(Li - \frac{\sum_{i=1}^{n} L_i}{n}\right) \tag{2.1}$$

Where:

- KR_i, the critically indicator for the i-th workplace [%]
- B_i, the average utilization rate for the i-th machine (Busy) [%]
- B_{Ii}, the average blocking rate for the i-th machine (Blocked) [%]
- I_{Ii}, the average starvation rate for the i-th machine (Idle) [%
- L_i, the average waiting rate for labor for the i-th machine (Labor) [%]

2.3 (Key) performance indicators logistics

In this section relevant literature on performance measurements in logistical systems is discussed The section is split in two. The first part discusses the definition of (K)PIs in logistical systems according to literature and the second part focuses on the selection of performance indicators in general and specifically in port logistics according to previously done research. The relevant information found in the literature will subsequently be used to assess the (key) PIs used by the OSL and SW department and potentially supplement them with additional indicators to make it possible to assess the performance of the outer-harbour 3.

2.3.1 Definition of Key Performance indicators

In order to understand the function of key performance indicators it is worthwhile to discuss what the definition of, and differences between KPIs, PIs and performance indicators are. Firstly KPIs. (Greeff and Ghoshal, 2004) states that KPIs are tools that can be used to:

- Manage performance
- Enable sustainable business improvement
- Drive change

(Papavinasam, 2014) mentions that KPIs enable to assess high level statistics of an organization's processes. KPIs are indicators used by businesses, and specifically by management to support decision-making processes. At the same time they provide information on how well management and technical processes are performing, for example compared to certain standards set by an organization (Mack, 2014). Clearly defining KPIs, is a process of determining who will use them, how to compute the indicators and how to provide them to the right people, such that these people can act upon them. Although not being an academic source, (Web, 2017) describes the difference between a KPI, a PI and a metric in an understandable way:

- A metric is simply a numerical measurement used to provide information
- A PI is a metric which informs about some element of performance
- A KPI is a metric used by leaders and managers to understand performance in business-critical elements of a supply chain operation.

The authors put emphasis on the fact that understanding the difference is important as it helps to explains the degree to which assessing the performance indicator is critical for the performance of the overall business. Improving KPIs should have a direct and significant impact on the performance of an organization, whereas improving upon PIs might not be influential directly, however it provides operational and tactical teams responsible for those processes the right information to work with.

From an academic substantiated definition of performance, a step in made towards the workable definition of performance indicators. In the context of supply chains, (Council, 2007) categorises KPIs in five sections being:

1. Reliability
2. Responsiveness
3. Flexibility
4. Cost
5. Assets

These are further assessed by (Surie and Wagner, 2008) and the authors of the paper combine into four categories:

1. Delivery performance
2. supply chain responsiveness
3. assets & inventory
4. Cost

Function and selection of (Key) Performance indicators

Performance indicator systems are significant contributors in managing businesses as they are key in providing information to companies, necessary by informing, controlling and steering in the process of decision-making (Gunasekaran and Kobu, 2007) (Surie and Wagner, 2008). These PIs are important for correct steering of a business in a competitive direction by operators and management in logistical environments. Apart from the purpose of PIs, the selection of a set of these that fits an organisations strategy is as important as determining the right PIs and accurately measuring them. It is important to realise that the decision-making level, strategic, tactical or operational, makes a difference in the type of performance indicators to manage. Strategic KPIs are largely built up out of financial indicators, whereas tactical and operational are more related to throughput, lead times and In-time-and-in-full to name a few (Gunasekaran and Kobu, 2007). The authors state that, while selecting (K)PIs, what must be taking into account are the following points:

1. What is the strategy and the objectives of an organization
2. The type of business
3. The nature of the market
4. Technological competences
5. Data collection and analysis
6. Participation of senior executives to highlight overall organizational objectives and goals and align targets at all levels, strategic, tactical and operational.

However, the selection of these PIs might be subject to a set of requirements, often not clearly defined by companies and often not in line with the strategy a company follows. Traditionally, financial indicators predominated the list of PIs, however, nowadays non-financial indicators are widely used as well (Poveda-Bautista et al., 2012). despite the trend of including non-financial PIs in the assessment of a company's performance, issues still arise in the selection of these PIs, issues such as identifying too many indicators, or indicators that are not relevant for monitoring and steering an organization's processes because they are not in line with the strategy (Shaw et al., 2010). (Gunasekaran and Kobu, 2007) provides a list of six purposes of measuring organizational performance:

- Purpose of identifying success
- Purpose of knowing whether customer needs are met
- Purpose of helping businesses and organizations in understanding their processes and to confirm what they already know or bring to light what they did not know

- Purpose of identifying bottlenecks and waste in processes exits and where improvements are to be made
- Purpose of making sure that decisions are not made based on supposition, emotion, faith or intuition, but rather on facts
- Purpose of comparison, hence being able to determine whether improvements to processes actually are realised.

2.3.2 Port (key) performance indicators

Performance indicators (PIs) are a way of measuring the performance of an organization in a way such that can be seen whether the strategy is working out. As the context of this research is set in port logistics, it is valuable to also address literature on (K)PIs that are specified to this context. (Ha et al., 2019) proposes a measurement instrument for port performance in the container transport logistics, by combining the perspective of different port stakeholders. They combine port PIs from several studies and refine those indicators that are associated with the effectiveness and efficiency of port operations in the context of container terminal logistics. The result can be seen in Figure 2.2. Five dimensions are distilled. Starting with (1) the core function of terminal which can be seen as the capability of a terminal to effectively and efficiently operate its core functions such as cargo operation, vessel operation, labour, resource and machine utilization. What follows is (2), the supporting functions, which entails qualitative indicators such as knowledge, skills, capability of personnel for example. (3) User's satisfaction, the degree to which users of the port are satisfied with quality and price of service. Dimension (4) is the container logistics integration which includes the connectivity, both on sea,- and land side as well as reliability of multi-model operations. Lastly (5), the reliability of the terminal's information and communication integration. This includes, but is not limited to, it systems, databases and collaboration with channel members.

Dimensions	Principal-PPIs	PPIs	Literature	Note[a]
Core activities (CA)	Productivity	Berth occupancy (PD1) Crane efficiency (PD2) Yard utilization (PD3) Labour utilization (PD4)	UNCTAD, 1976; De Monie, 1987; Cullinane et al., 2002; Brooks, 2006; Woo et al., 2011	QT; Data input from TO and PA database
	Lead time	Vessel turnaround time (LT1) Truck turnaround time (LT2) Container dwell time (LT3)		
Supporting activities (SA)	Human capital	Knowledge and skills (HC1) Capability (HC2) Training and education opportunity (HC3) Commitment and Loyalty (HC4)	Marlow and Paixão Casaca, 2003; Kaplan and Norton 2004; Alavi et al., 2006; Brown et al., 2011; Woo et al., 2013	QL; Data input by TO
	Organisation capital	Culture (OC1) Leadership (OC2) Alignment (OC3) Teamwork (OC4)		
Users' satisfaction (US)	Service reliability	Responsiveness to special requests (SR1) Accuracy on documents & information (SR2) Incidence of cargo damage (SR3) Incidence of delay (SR4)	Marlow and Paixão Casaca, 2003; Woo et al., 2011; Brooks and Schellinck, 2013	QL, Data input by PU
	Service costs	Overall cost of container loading/discharging and (re) stows and other ship operations (i.e. hatch cover locking/unlocking, reefer plug/unplug on board vessel) except for lashing, tally, line handling, vessel dockage (SC1) Container handling charges at CY (yard move, gate move, reefer services, storage, etc.) (SC2) Cost of terminal ancillary service (flat rack bundling, applying/removing labels, sealing containers, container weighing, inspection fee, leaking tray rental, etc.) (SC3)		
Container logistics integration (CLI)	Intermodal transport systems	Sea side connectivity (ITS1) Land side connectivity (ITS2) Reliability for multimodal operations (ITS3) Efficiency of multimodal operations (ITS4)	Notteboom and Rodrigue, 2005; Panayides and Song, 2009; ESPO, 2010; Ferrari et al., 2011; Woo et al., 2013	QL, Data input by TO, PU and AD
	Value-added services	Facilities for adding value to cargoes (VAS1) Service adaptation to customers (VAS2) Handle different types of cargo (VAS3) Capacity to launch tailored services (VAS4)		
Information/communication integration (ICI)	IC systems	IT systems (ICS1) Databases (ICS2) Networks (ICS3)	Kaplan and Norton 2004; Albadvi et al., 2007; Panayides and Song, 2009; Woo et al., 2013	QL, Data input by TO, PU and AD
	IC integration practices	Integrated EDI for communication (ICP1) Integrated IT to share data (ICP2) Collaborate with channel members (ICP3)		

[a] Note: QT, quantitative PPI; QL, qualitative PPI.

Figure 2.2: Port performance indicators (PPIs) in container transport logistics (CTLs) (Ha et al., 2019)

2.4 Industrial port optimization

Many research papers focus on the optimization of container terminal operations. From quay-crane allocation problems, vessel scheduling problems to yard stacking optimization. To a far lesser extent, research is focused on break-bulk port optimization. Where container terminals are often very large in scale, break-bulk terminals are more often than not small and located on large manufacturing sites that have to export their products. Break-bulk trade still accounts for a considerable amount of the maritime trade. In 2005, the total break-bulk fleet size in dead weight tonnage equalled 11% (Schott and van den Hoed, 2017). In addition (Guenzani et al., 2017) concluded that despite the not-to-be underestimated portion of break-bulk trade, the aforementioned abundance of container terminal mathematical optimization literature is the only available literature, leaving a large gap for applying these type of models to break-bulk cargo such as granite blocks or steel coils. The authors propose a 3D yard allocation model for granite blocks for yard storage where small blocks can be stacked on top of large blocks and only blocks bound for the same vessel can be stacked in one stack. (Bruglieri et al., 2015) solved the 3D Yard allocation problem for granite blocks to minimize the handling time to move the cargo to and from the vessel by applying a Variable neighbourhood Search and Branching based on a MILP formulation. (Tian et al., 2018) also dived into the relatively unexplored world of break-bulk/general cargo port optimization. Their two-dimensional rectangular layout theory based storage allocation model aims to maximize the storage yard utilization.(Li and Tian, 2015) provides a two-layer multi-objective variable neighbourhood search (TLMOVNS) to solves the consolidation of finished goods in the iron and steel industry planning, the transportation planning and vehicle allocation problems, while handling the objective of two conflicting objectives being the maximum loading efficiency of ships versus the overall logistic process efficiency. Apart from these studies, which were relatively hard to find, no additional literature on break-bulk port related studies were found.

2.5 Simulation models in the context of logistical systems

In search of an appropriate simulation model to mimic the system of Tata Steel, literature is once more consulted. (Hans et al., 2008) states that a simulation model is capable of capturing the time-dependent behaviour of logistical systems. These logistical systems are often seen as complex systems, where stochastic behaviour is exhibited by a large number of elements that mostly have a multitude of interrelations with each other. These models can be used to perform experiments on these systems as if they were operational without having to make high risk and high cost investments. (Koturiak and Gregor, 1999) elaborates and summarises how discrete-event simulation (DES) can be used to enable design, operate and improve logistical systems. The authors state that simulation is an ideal tool to identify the bottlenecks in a system and to test and measure countermeasures to tackle these bottlenecks. (Al-Harkan and Hariga, 2007) elaborates on the advantage of simulation based model compared to analytical models to mimic complex logistical systems and to find bottlenecks in the system. (Cimpeanu et al., 2017) agrees with this advantage and argues that discrete-event simulation models are a preferred model for their study of the process of bulk carrier loading and discharge. They choose to do so, due to a large number of variables and a degree stochastics that would generate an analytically uncontrollable system. Furthermore numerous successful examples of DES models applied to tackle the dynamic environment of port systems entailing multiple components (Longo et al., 2013), (Cartenì and de Luca), (Cimpeanu et al., 2015).

2.5.1 Simulation modelling approach

An appropriate modelling approach for this simulation study is a prerequisite for a successful course of this thesis report. (Suprun et al., 2016) used a simulation model design framework based on the work of (Sterman, 2000). The first two steps, *problem definition* & *conceptual model* are qualitative steps, whereas the latter, *system dynamics model*, *model testing* and lastly *final model simulation* are considered to be quantitative. As one can see this process is one of continuous feedback between the steps as well as the exchange of data in the form of existing knowledge, exploratory study, quantitative and qualitative data collection. it starts with the problem definition, which requires a thorough analysis of the as-is situation of a, to-be studied system. The context is clear, analysis of data can be done to determine what the problem definition is and what research goals and objectives can be set in line with this definition. This result in a set of (sub)research questions that have to be answered to finalize the study. The conceptual model is used to list the aspects of a real system that should be represented in executable models and those that should not. (Ottjes and Veeke, 2012) considers the conceptual model as informal intuitive process-interaction model. Subsequently the simulation model itself is created, followed by model testing and final model simulation of (future) scenarios and possible decision making.

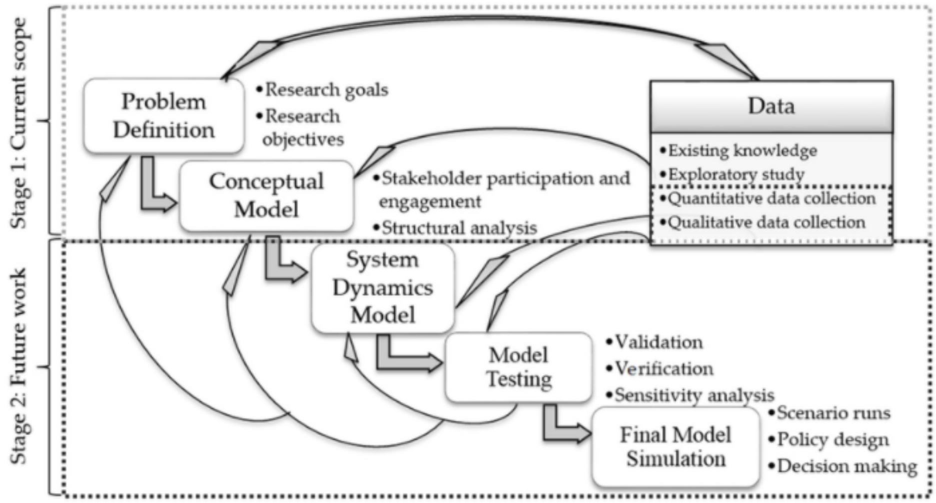


Figure 2.3: Model of the Russian Federation Construction Innovation System: An Integrated Participatory Systems Approach (Suprun et al., 2016)

(Koturiak and Gregor, 1999) provides more insights in relevant components of simulation models for each level, strategic, tactical or operational, of an organization. The authors state, that particularly in the tactical level of an organization, detailed simulation analysis can be used to improve, or optimize the performance of the system. This statement is useful in this research thesis, as the goal is to increase the performance of a logistical system on a both a strategic level, by assessing the influence of new resources, and a tactical level, by assessing the different use of the currently available resources.

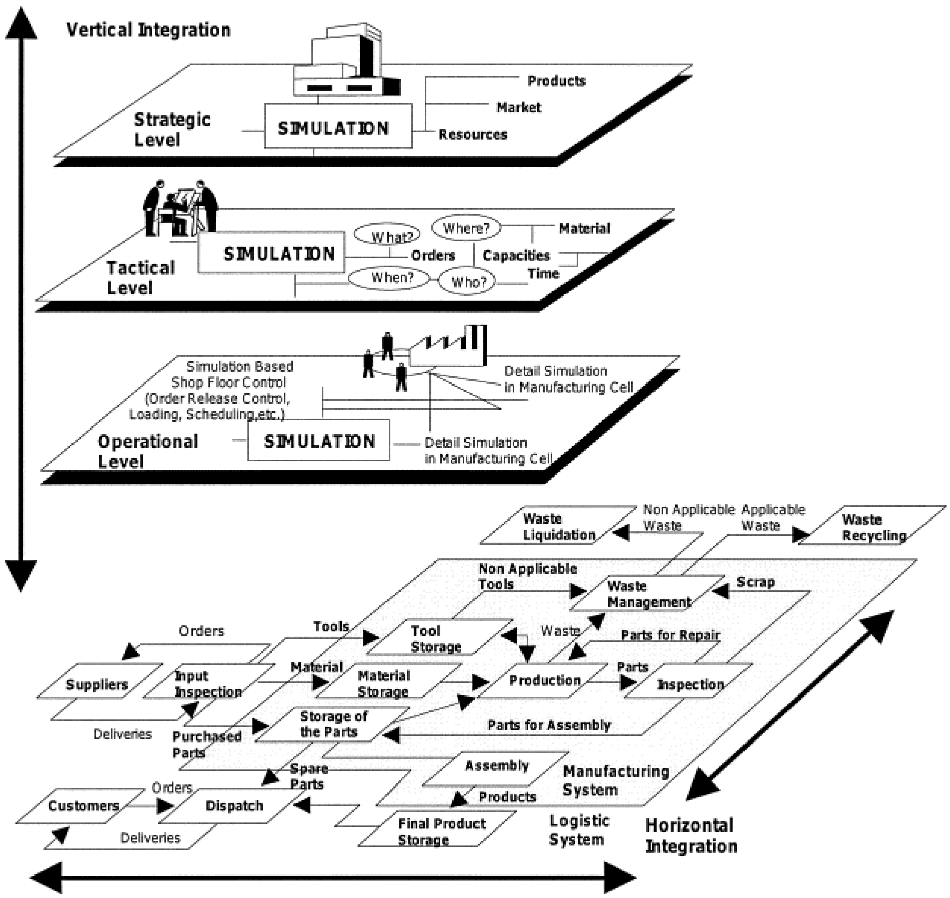


Figure 2.4: Integration of simulation modelling in enterprise (Koturiak and Gregor, 1999)

The definition of the system to be studied depends on the functions that we would the system to achieve and the questions to the answers that are being asked. Setting the physical scope of a research project, therefore also depends on the extent to which the goals/performance can be measured as well as the ability to measure the means necessary to set the function (Hans et al., 2008). In chapter 3, this book is used to define the system's boundaries. The authors state that the system should be a cohesive whole. The elements considered to be part of the system should have a larger cohesion between them, compared to the cohesion of these elements with the environment of the elements. To draw this fictional boundary, the authors give the reader four points of attention. This boundary should be chosen as follows:

- Such that the exchange of the temporary elements—such as material or patients or, with further abstraction, data—across the boundary is less than within the boundary. In this case, it should be that the exchange takes place via a number (as small as possible) of permanent elements.
- And/or on the basis of the number of relationships dissected by the boundary. Whether or not we wish to consider a particular element as belonging to the system is thus dependent on whether the number of relationships among the elements already incorporated in the system is greater or less than the number of relationships with the environment. It is not about all conceivable relationships here, only relationships that are considered relevant to the problem.

- And/or on the basis of the energy required for transmission through the boundary. Transmission through the boundary requires more energy than a transmission that takes place within or beyond the boundary.
- And/or such that we are able to clearly formulate the function of the chosen system in the environment. Does the (sub)system have clear emergent properties? The omission or addition of an element can influence this.

2.6 Conclusions on the literature research

This chapter elaborated on relevant literature with respect to the topic of this research. The literature study elaborated on literature on on-site logistics, break bulk terminal logistics, bottleneck identification and elimination methods and mathematical models suitable assess 'as-is' and 'what if' scenarios and configuration alternatives. Referring back to the beginning of this in which the goal of this chapter is stated, three sub-research questions had to be answered using literature. Firstly sub-research 1:

- *Which logistical processes at the break-bulk sea terminals are found in literature?*

in order to answer sub-research question 1, section 2.1 is used. The break-bulk cargo is transported in individual pieces by ships, trains and trucks mostly rather than in closed spaces such as containers. This has largely to do with the fact that pieces of break bulk cargo usually have differences in size, weight or shape, making it complex to handle them in a standardised way. Break-bulk cargo can be generalised in five product groups:

1. Bags
2. Bananas
3. Project cargo
4. Roll-on roll off
5. Timber & steel

In many industries such as the steel industry designated logistical service parties are responsible for the on-site movement of either finished or semi-finished break-bulk cargo, but also for loading those products onto ships, trucks and trains bound for the customer. These departments execute the transportation between each on-site factory as well as the transportation towards the export points of these plants. In order to do so most plants have there own export and import terminal systems, where raw materials are supplied and finished products are send towards the customer. These terminals function as a means to transfer products from one mode of transportation to another. The logistics inside steel manufacturers are usually arranged in such a way that multiple warehouses are spread over the steel plant factory where several types of (semi-)finished goods are temporarily stored. From these warehouses the products are either transported directly towards the docks or firstly consolidated at a central point from which the products are subsequently moved to the docks. For the transportation between warehouses and other locations on-site, usually either trucks or trains are used. Once arrived at the docks, products are usually either stored temporarily or loaded onto a docked ship immediately. During both, forklift trucks are usually deployed for short distance transportation due to their relative flexibility and quay cranes are used for transportation to and from ships.

In chapter 4 the knowledge gained through literature research done and written down in this chapter is put into practice to design the quantitative model. This chapter provides the knowledge to answer the first part of sub-research question 4, highlighted in bold:

- ***What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals*** *and what should this model look like in terms of its design?*

From literature discussed in section 2.4 it is clear that, for the limited studies performed on break-bulk terminals, non included simulation models methods used in similar contexts as the one studies in this thesis research and thus answering the sub-research question using this literature is not possible. In section 2.5 an answer can, however be given to the above sub-research question. In a multitude of papers discussed, the advantages of using discrete-event simulation models to model complex logistical systems in which stochastic behaviour exist due to many interrelationships between elements in a system has draws its attention. Moreover the ability of such models to help in identifying bottlenecks in such systems is also clear. As will also be elaborated upon further in chapter 3, the system studied in this research thesis, is one where multiple types of elements and relationships amongst them exist. The system is complex and determining the impact of certain decisions on the whole performance of the system is therefore hard to determine on experience only. Yet another advantage of discrete simulation models is their ability to test 'what if' scenarios and strategies without the need for heavy investments and help in the decision-making process by contributing to additional insights. Combining these advantages, such a model is considered a good fit for the mimicking the system at hand. Lastly and in addition to the aforementioned advantages of designing, building and using a discrete event simulation model, another advantage of these models is the ability to generate statistics that can be used to detect the long term, average bottlenecks in complex logistical systems, which is part of the questions Tata Steel would like to receive answers to. Based on studies done on bottleneck detection is similar contexts it can also be concluded that the critically indicator based method and average utilization method are suitable to use due to the ability of discrete-event simulation models to generate utilization rates, waiting rates and blocking rates of complex systems where analytical methods are not sufficiently accurate.

Chapter 3

System Analysis

In this chapter an extensive analysis of the outer-harbour 3 system is performed. This includes the existing processes of Tata Steel IJmuiden, the On-Site Logistics department and the Stevedoring & Warehousing (S&W) department all of whom are related to the loading of deep sea vessels in this harbour. Subsequently, literature on (K)PIs is used and together with information from on-site Tata Steel employees, a (K)PI tree is made which is then exercised to assess the performance of 'as-is' and 'what-if' scenarios and configuration alternatives. This is followed by a Delft System Approach system thinking approach on the elements, relationships and system boundaries. These in turn are used to build the conceptual mode in chapter 4. This chapter is finalised with a general conclusion and answers to the following sub-research questions:

- Sub-research question 2: *Which logistical processes are present at Tata Steel IJmuiden?*
- Sub-research question 3: *What defines the performance of break-bulk harbours and what methods are used to quantify bottlenecks and improvements?*

3.1 Tata Steel IJmuiden

The 'system' during this research refers to the combination of elements, relationships, boundaries, processes and data as described in the introduction of this chapter. However, the system is part of a larger whole, which workings have to be understood before the behaviour of the system of interest can be explained in full. This rhetoric is used to describe the higher-level system of which the outer-harbour 3 is a part of. Overall Tata Steel IJmuiden's mission is to be a leading European sustainable steel manufacturer founded on 5 pillars: Customer focus, innovation, operational excellence, responsibility and people. In order for the production process and the delivery of the products to the client to operate smoothly, several departments and sub departments are responsible for different steps of this value chain process. The steel production process starts at the inbound transportation harbour where coal and iron ore are delivered through by large bulk carriers and mixed for quality reasons. After the raw materials arrive, several steps together transform the iron ore into liquid iron by using ovens that are heated by means of processed coals, also known as cokes. Subsequently steel is produced out of this liquid iron by means of an oxygen-steel factory. From here the steel products can take several routes, through hot rolled mills, cold rolled mills, galvanisation, pickling, tin plating and painting. Throughout the production process several samples are taken and tested in a lab to monitor and ensure the required steel quality. Eventually the products are packed based on the choice of modality. From this point, a finished and packaged steel product is referred to as 'collo *colliinplural*. Packaging is a necessary step to meet client requirements and to ensure product quality during transportation by trucks, trains and ships *Figure* 3.1. In this thesis three main collo types are referred to as can be seen in Figure 3.2a, Figure 3.2b & and Figure 3.2c. The latter, the slab is a product left outside of the scope of this thesis as also stated in section 1.3.

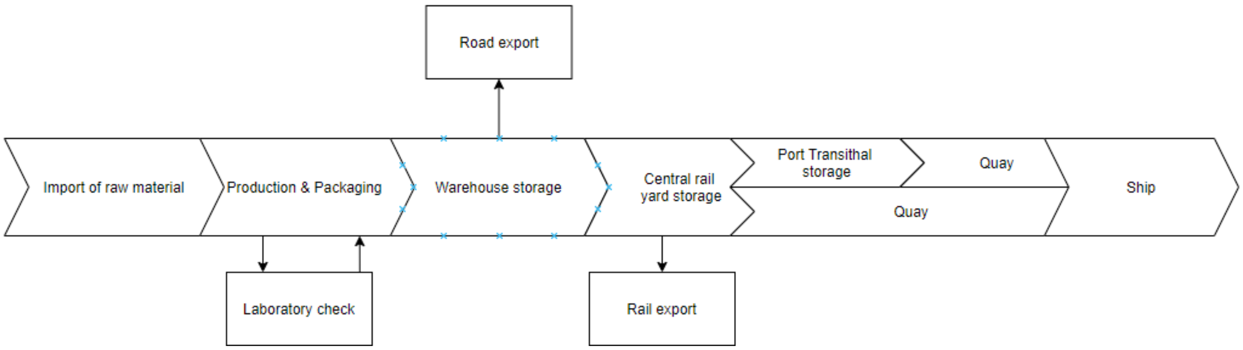


Figure 3.1: Tata Steel business functions

(a) Steel coils

(b) An Eye To The Sky (ETTS)

(c) A steel slab

Figure 3.2: Three main categories of Tata Steel products

3.1.1 Outbound Logistics Department

On strategic and tactical level the Outbound Logistics department (OTB) of Tata Steel IJmuiden is responsible for supply chain capacity planning, network management and development, sourcing and distribution logistics to end-customers. One of the tasks of this department involves the tactical assignment of finished steel products, that are sold by the sales department, to vessels made suitable for the transportation to end-customers. The selection or 'nomination' of ships is done in collaboration with the management of the shipping company owning the ship or management of the ship itself. OTB determines which load is assigned to which vessel once a vessel meets the requirements for the load. In addition a certain norm for the loading rate in volume throughput in tonnes/day is agreed upon by OTB and the shipping management which results in a certain period of time in which the vessel should be loaded. These loading rates are a function of type and quantity of products that must be loaded onto the ship. If these norms are not met by Tata Steel due to circumstances that are within their power, demurrage costs have to be paid by Tata Steel to the shipping management. Once a load is assigned to a ship the On-site Logistics department gets involved.

3.2 On-Site Logistics

Tata Steel's OSL department is responsible for the logistical processes between Tata Steel factories, warehouses and harbours as well as the logistical processes inside the warehouses and harbours. These processes include, transportation of semi-finished products, pig-iron mixers and slakpans between production facilities, and storage of (semi) finished products, operations inside storage facilities, the reallocation of (semi) finished products from storage to storage, loading of trucks bound to the hinterland, loading of trains bound to the hinterland, the loading of ships departing the inner,- and outer harbour and the unloading of ships arriving at the inner, and outer harbour. To realise these logistical processes, there is around 100km of rail network, divided into a west and a central area where 10 locomotives are active, 5 for the 'warm route' for pig iron and 5 for the 'cold route', consisting of coils and slabs. There are 16 warehouses in use to store (semi) finished products and from where different modes of transportation are loaded. There are three harbours used to realise the loading of vessels with colli. The inner-harbour has a roof and which allows for 'all-weather' loading of vessels. The inner-harbour is predominantly used to load barges bound to the inland waterways and short-sea vessels used to operate coastal routes to e.g. the Mediterranean, whereas the outer harbour 1 and 3 are for 60% used to load large deep-sea vessels using transatlantic routes towards Mexico and several destinations in the US. Note that the three harbours are used sporadically to unload vessels. OSL is divided in three sub-departments: Stevedoring & Warehousing (SW), Rail and On-Site Planning (OSP) as visualised in Figure 3.3. Further explanation of the sub-departments is given in the coming three subsections.

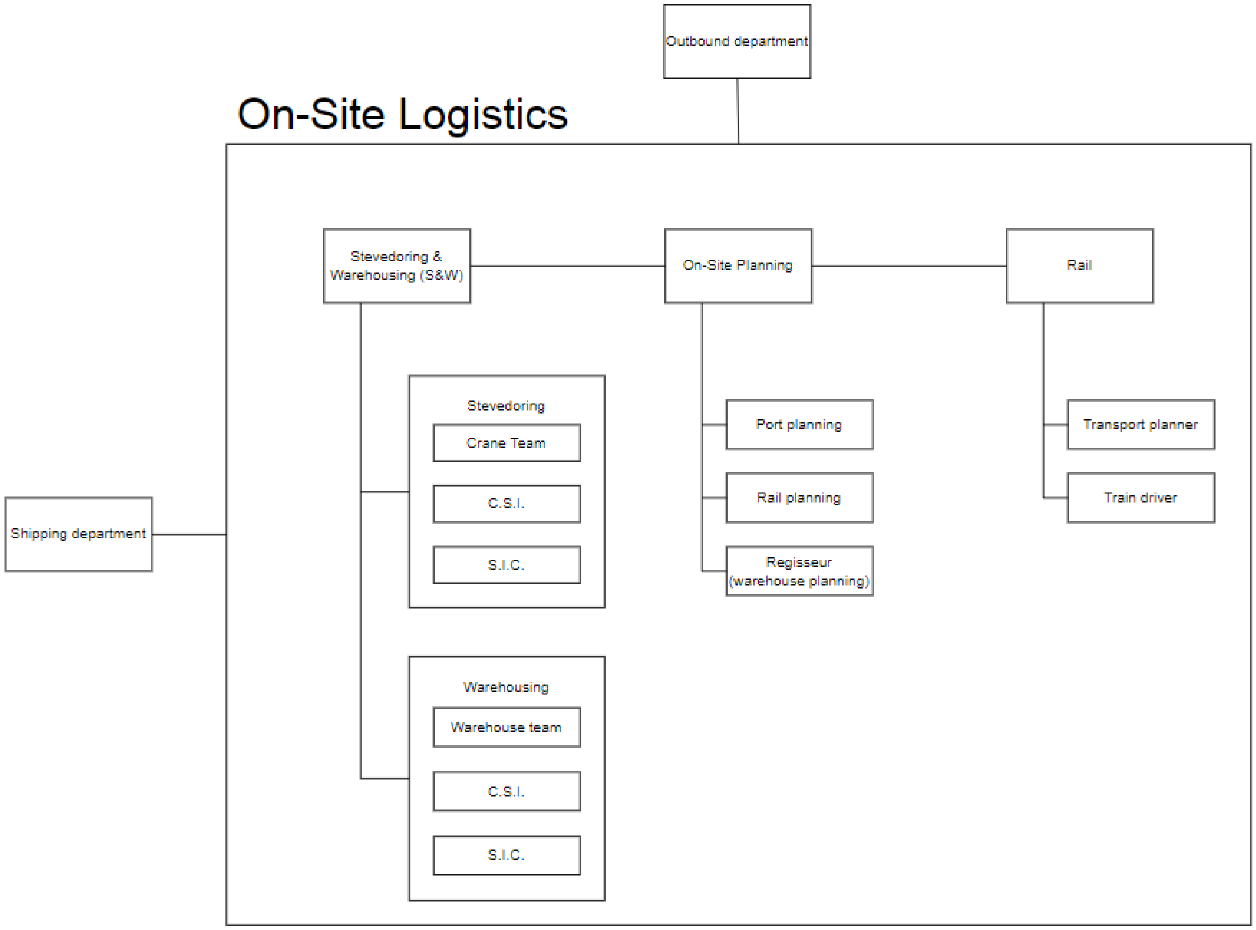


Figure 3.3: OSL simplified organogram

3.2.1 On-Site Planning

The On-Site Planning (OSP) department is responsible for the integral on-site planning such that shipment requirements as set by OTB are achieved. OSP prioritizes tasks such that the internal transportation and the export and import of coils, ETTS and slabs is balanced and on time. This department plans and schedules tasks which the S&W and Rail departments must execute. This includes the transportation of products from warehouses to the customers, by five modalities, trucks, trains, barges, containers and sea vessels. Apart from this, OSP also has the responsibility of monitoring the internal flow of products in such a way that the production outflow and distribution in and outflow are balanced to prevent overloaded warehouses. Lastly they oversee the operations regarding external trains leaving Tata Steel with products via rail. Per department, rail, harbour, warehouses an OSP planner is assigned to make planning schedules for the next 24 to 72 hours. The harbour planner assigns incoming ships to quays and also which crane(s) will be used to load the ship. The warehouse planner does a similar job which is for the next 24-72 hours of operational planning of the warehouses. They determine which wagon has to be loaded at what warehouse with which colli. An important task of the warehouse planner is to manage the stock levels of the warehouses. The rail planner makes sure that the required transportation for the coming 24-72 hours is planned. As these planners, plan ahead 1 to 3 days ahead, the 'regisseurs' are tasks with adjusting the planning if unforeseen circumstances require so. For example rain, as some colli may not be subjected to moist or if handling equipment breaks down. They also have the responsibility to determine what load should be transported by which wagon-sub type and at what time. A rule of thumb is to start loading specific train wagons at the warehouses around 8 hours before they are expected to arrive at the port for stowage of a vessel.

3.2.2 Rail

The rail department executes the planning made by the an OSP planner. They operate the locomotives used to transport empty and full train-wagons to the locations at which they are required. They manage the assignment of personnel to locomotives, maintenance of equipment and rail tracks. A transport coordinator (VC'er) is assigned with responsibility of dividing transporation tasks to locomotive drivers according to a planning made by the regisseur.

3.2.3 Stevedoring & Warehousing (S&W)

S&W manages the operational activities inside the warehouses and in the harbours. This includes the loading and unloading of ships from trains and from the warehouse located in the harbour and the transit hall. Every 8 hours a shift employees operates material handling equipment such as forklift trucks and cranes and is active inside the hold of the ship to coordinate the placing of colli by the crane drivers as well as the securing of the load once a hold is filled. Apart from the workers around the ship, there are also at any time two workers from the same shift manning the harbour control room referred to as the Stukgoed Informatie Center (SIC). These two workers oversee planning of the harbour operations and are responsible for executing this planning. This planning consists of certain sets of collo that are categorised based on product type size of weight and are referred to as clusters. These clusters are made in a certain order so as to smoothen the loading operations as similar products should be loaded together as much as possible. The SIC monitors the availability of these clusters on the quay and orders new ones, if the cranes are running out of colli. The colli assigned to these clusters are subsequently delivered via trains of via the temporarily storage location at the outer-harbour. The Coordination Support & Improvement (CSI) team is responsible for delivering a stowage plan together with the shipping company. This plan states in which hold which colli has to be loaded. Of course this is subject to many operational and practical constrains handled by both Tata Steel as well as the shipping company. As soon as this plan is confirmed, CSI produces earlier mentioned clusters according to a cluster plan which entails sets of colli together that are similar in size and width such that they can be easily loaded into the ship. A ship's hold can be filled with multiple clusters. Depending on the size of the ship this cluster plan is made by either CSI (in case of large America ships) or by the OSP harbour planner. Effort towards the optimisation of generating such stowage plans has been made by (Schoenmaker, 2016).

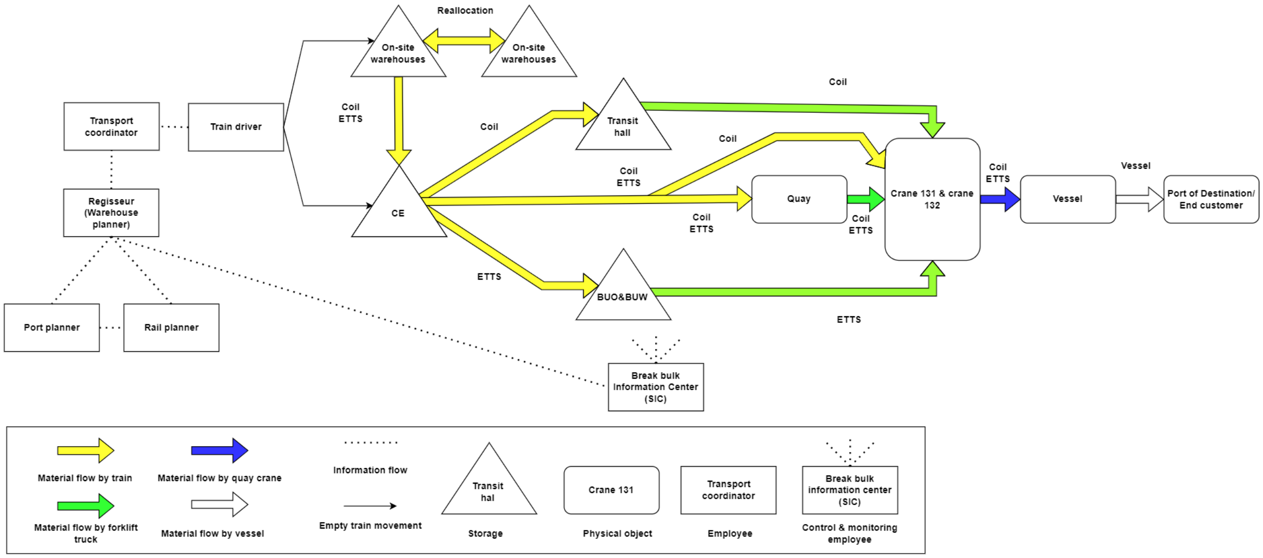


Figure 3.4: OSL Material Flow associated with the Outer-quay 3

3.2.4 Pre-stowage processes

After a ship is selected, S&W is responsible for the creation of the stowage and cluster plans. The vessel management has to approve this stowage plan, since they are responsible for the load as soon as the vessel sets sail. Subsequently the rail and warehousing planning departments are tasked with fabricating a planning, which honors the cluster planning, that determines the sequence of transportation of ETTS and coils towards the harbour. In order to add some additional context to what happens on the background, additional elaboration on the specifics of the information flows and the actors associated to these flows is given. The sequence from ship selection to the start of the loading procedure is visualised in Figure 3.5

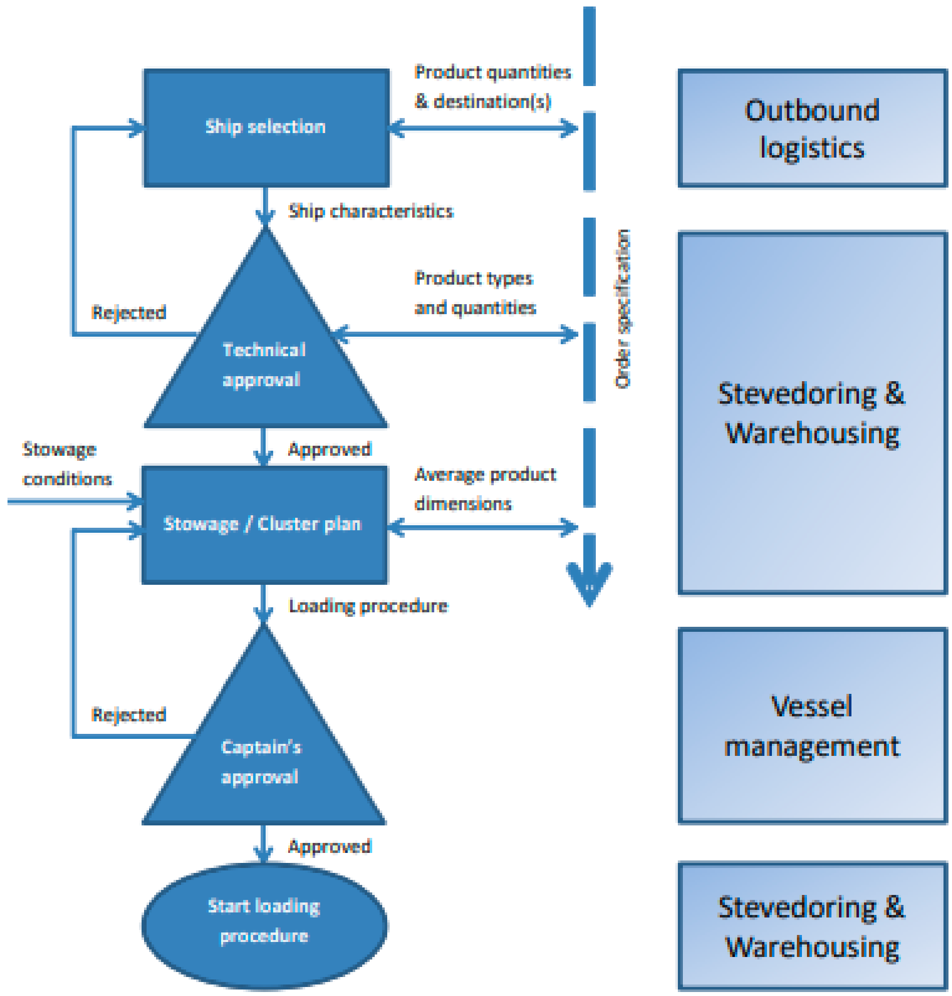


Figure 3.5: Information flowchart in dark blue and actors involved in light blue, in the process from ship selection to the actual loading of the vessel (Schoenmaker, 2016)

Placing Figure 3.6 parallel to Figure 3.5, shows what the timelines of current practices are. The planning procedure of OSL starts around 7 days before the vessel arrives and docks at the quay. Vessel are planned according to a predetermined time window, however it could be that due to circumstances, that the actual arrival time of a vessel differs. Planning which products are shipped from which warehouse towards the port is done 2 days in advance. Especially in case of deep sea ships, as is the focus of this research, OSL tries to transport as many products as possible towards the Transit hall in the weeks and days before a ship arrives at IJmuiden, such that the dependence of supply of rail during stowage is as little as possible. The supply of coils towards the Transit Hall is mostly done when both the coils required are ready as well as when on-site locomotive capacity allows for these extra rides.

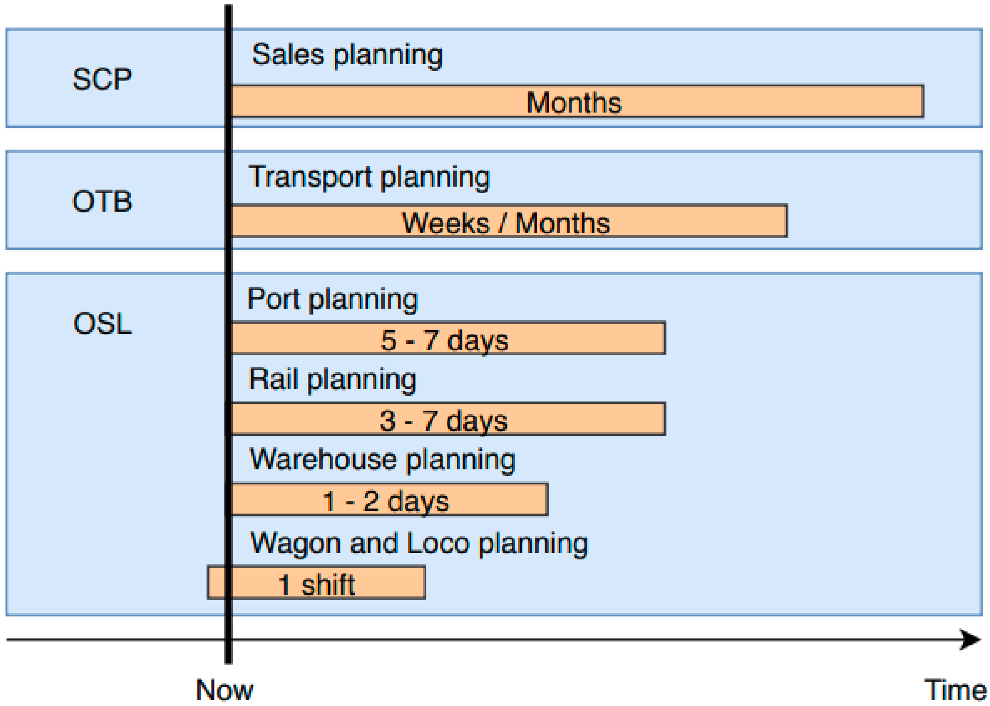


Figure 3.6: Planning horizon and departments involved, SCP: Supply chain planning, OTB and OSL sourced from Tata Steel internal documents. Found in (Joon, 2020)

3.3 Performance indicators

As stated earlier and confirmed by literature, the use of (key) performance indicators (K)PIs by businesses to accurately measure the performance of their logistical operations is key. In this context, accurate does not only mean that data must be saved and analysed according to standards, but also that the measured in fact are in line with the business's strategy and in fact provide the necessary information to steer the business in a correct direction. In this section, both relevant key performance indicators and relevant performance indicators used by Tata steel are discussed. Subsequently, these (K)PIs are compared to relevant literature on the use of (K)PIs in logistical contexts and thereafter combined into a (K)PI-tree and in the end validated by Tata Steel. This set of (K)PIs will be used to measure the performance of the system. The goal of this section is to provide an answer to sub-research question 4:

- *In terms of which (Key) PIs can the performance of break-bulk terminals be defined to (1) measure the actual performance of these break-bulk terminals and (2) to identify potential bottlenecks?*

3.3.1 The definition of (Key) Performance Indicators

In section 2.3 literature on (K)PIS is discussed and from researching this topic it can be concluded that the definition of,- and difference between performance indicators and key performance indicators are important factors to take into account for an organization. To refer to what was found in literature, the used definition of the two aforementioned terms are as follows:

- A PI is a metric which informs about some element of performance
- A KPI is a metric used by leaders and managers to understand performance in business-critical elements of a supply chain operation.

These definitions are used to assess the KPIs and Pis used by those departments that are involved with outer-harbour 3 operations during the loading of deep sea vessels. Whenever one of these terms are used in the report, the definitions stated here are used. The following is an assessment of the used (K)PIs by the relevant departments of Tata Steel IJmuiden.

3.3.2 (Key) Performance indicators used by Tata Steel

Firstly, research is done on (key) performance indicators used by the departments relevant for this research.

3.3.3 On-Site Logistics KPIs

The OSL department of Tata Steel contains five main categories of KPIs:

- Health, safety & environment
- Throughput
- Costs
- Quality
- Productivity

In addition to these KPI categories there are also subsets of PIs per category. OSL combines these into one (K)PI-tree as one can see in Figure 3.7

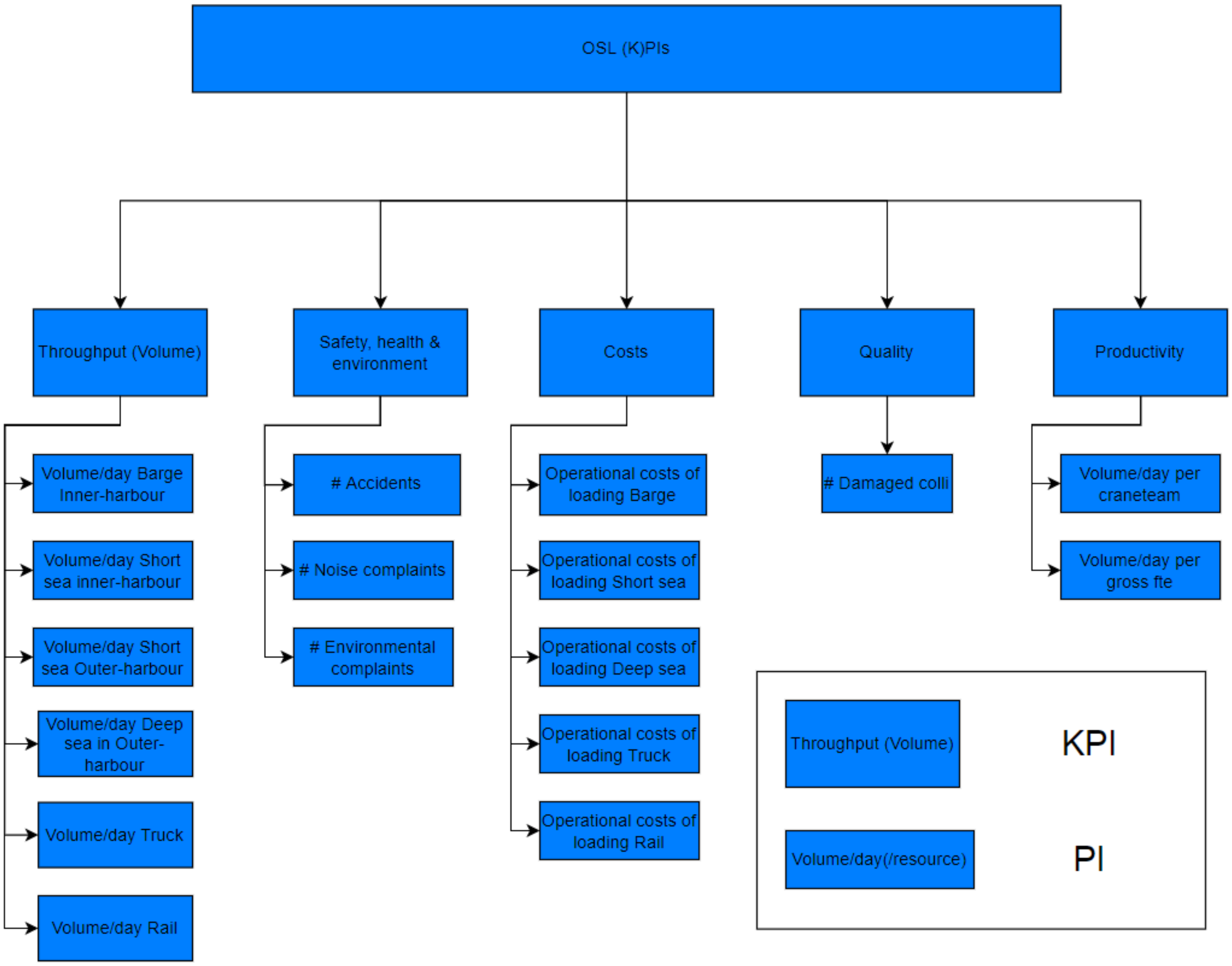


Figure 3.7: OSL (K)PI tree

Throughput

The OSL department is responsible for internal transportation of (semi-)finished goods. Therefore their objective is to handle the volume of products via several modalities and through several exiting points in IJmuiden. The throughput is measured in volume (tonnes)/day.

Safety

Safety is of the utmost importance for the OSL department. This KPI enables the department to steer towards an ever safer working environment continuously. Safety is measured by assessing the number of unsafe situations that could occur during operations. Teams have to make safety notices each time such an unsafe situation could occur. A very small percentage of these situations are in fact accidents. Health and the environment are also very important. These are expressed as the number of received noise and environmental complaints.

Costs

The costs of operating each department of OSL, and each process are combined into 'operational costs' per modality. In reality, there are a multitude of cost layers. However, for the sake of this research and to keep a clear overview only those visible in the figure are important to show. The viewpoint on these operational costs is as follows. OSL is a department who's responsibility it is to handle the volumes sold by Tata Steel and in order to do so handle certain tariffs to be able to execute these tasks. The department has no direct desire to make a profit, therefore it is assumed that the operational costs are equal to these tariffs.

Quality

Quality is also a central KPI for OSL. Quality is defined as the number of colli damaged, missing or switched during operation. This is significant as the costs of a collo being rejected can reach high numbers, even ignoring the operational delay caused by having to remove the damaged collo and being unable to deliver an customer order in full. Missing or switched collo can lead to a delay in the loading time of vessels, which could subsequently result in Tata Steel having to pay fines to the shipping company. These fines are referred to as demurrage costs and will be discussed in more detail in subsection 3.3.7.

Productivity

Besides the throughput of modalities, OSL also considers the volume throughput of crane teams per day as well as the throughput per gross fte operational in the crane teams.

3.3.4 Outbound Logistics KPIs

Secondly, the (K)PIs of the OTB Logistics department. As elaborated upon earlier, OTB Logistics is, in the context of export via water, responsible for the selection of vessels and for linking certain tonnages of load to these vessels. OSL and eventually SW are subsequently responsible for the loading processes of these vessels. The OTB Logistics department has a set of KPIs of their own as can be seen below:

- People & leadership
- Environment
- Health & safety
- Transport quality
- Transport cost/tonne
- Volumes throughput
- Service & delivery

From these (K)PIs only those related to Supply Chain and Logistics are taking into consideration as the full list of (K)PIs is far to extensive to visualise in this report. The seven KPI categories considered by OTB Logistics are filtered, resulting in the following three KPIs.

Transport quality

This performance attribute is calculated by looking at the quality of transport in terms of coil damages, performance of logistic service providers and customer claims.

- Coil damage
- Performance of Logistic Service Providers
- Customer claims

Transport cost/tonne

The cost of transportation is looked at by assessing the average cost of transporting a tonne via each of the modalities. As this research focuses on the loading of deep sea vessels in the outer-harbour 3, the other modalities are less relevant, but nonetheless sketch the full picture.

- Average transport cost/tonne rail
- Average transport cost/tonne barge
- Average transport cost/tonne deep sea
- Average transport cost/tonne short sea
- Average transport cost/tonne container
- Average transport cost/tonne truck
- Demurrage cost

Volumes throughput

The throughput of volume is assessed by looking at the planned and actual realised volumes that are exported via each of the modalities. For this particular research, the emphasis is to assess the performance of the outer-harbour 3 and specifically while deep sea vessels are loaded. Therefore most of the modalities can be ignored.

- Prognosed vs. actual volume rail
- Prognosed vs. actual volume barge
- Prognosed vs. actual volume deep sea
- Prognosed vs. actual volume short sea
- Prognosed vs. actual volume container
- Prognosed vs. actual volume truck

3.3.5 Stevedoring & Warehousing KPIs

The SW department has a set of KPIs similar to those used by OSL and therefore the KPIs visualised in Figure 3.7 are considered to be a good representation of the (K)PIs used.

3.3.6 Literature (K)PIs

The (K)PIs used currently by Tata Steel are combined into a tree, visible in Figure 3.8. This tree represents the set of (K)PIs that are in the eyes of the relevant departments of Tata Steel, key in assessing the performance of the department. As S&W is a sub-department of OSL, and the focus of this research due to the focus of loading of deep sea vessels, it is worthwhile to supplement the (K)PIs from Figure 3.8 by those (K)PIs deemed relevant by literature for studies such as this one.

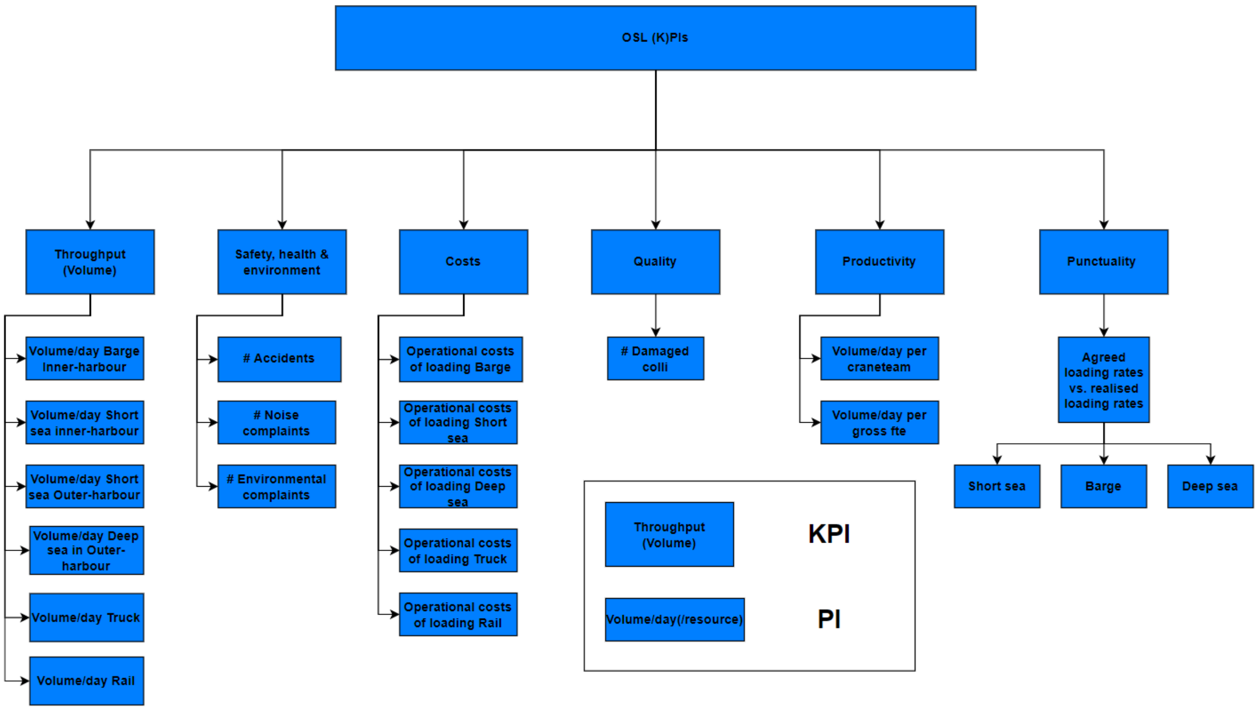


Figure 3.8: Combined OSL-SW-OTB (K)PI tree

As discussed in section 2.3, an organization can basically think of any (key) performance indicator to use in practice, however the skill is to select those that are of real value to the organization without drowning itself at the same time with a multitude of performance indicators. Furthermore (Ha et al., 2019) has developed a list of port performance indicators (PPIs) based on the perspective of different port stakeholders and combining those perspectives into a measurement instrument for ports as can be seen in Figure 2.2. Most interesting and relevant for this research are the following PPIs:

Productivity

- Berth occupancy
- Crane efficiency
- Yard utilization
- Labour utilization
- **Resource utilization**
- **Machine utilization**

What is not included in this list specifically, but can certainly be added are the resource and machine utilization, indicated in bold.

Lead time

- Vessel turnaround time
- Truck turnaround time
- Container dwell time

The list developed by (Gunasekaran and Kobu, 2007) includes and is consulted while going through the aforementioned KPIs used currently by Tata Steel. As a result of combining the two sources of (K)Pis and go through them using selection criteria from literature the following (K)PI tree was created and can be seen in Figure 3.9. Interviews at Tata Steel were held to validate the KPI tree and make necessary adjustments. In light blue those indicators that are used to measure the performance of the harbour during this research. The goal of assessing (K)PIs is to make sure that once the model is in use, potential performance increases can objectively be measured such that conclusions can be draws on whether certain alternative outer-harbour 3 lay-outs beneficial for the overall workings of the outer-harbour 3.

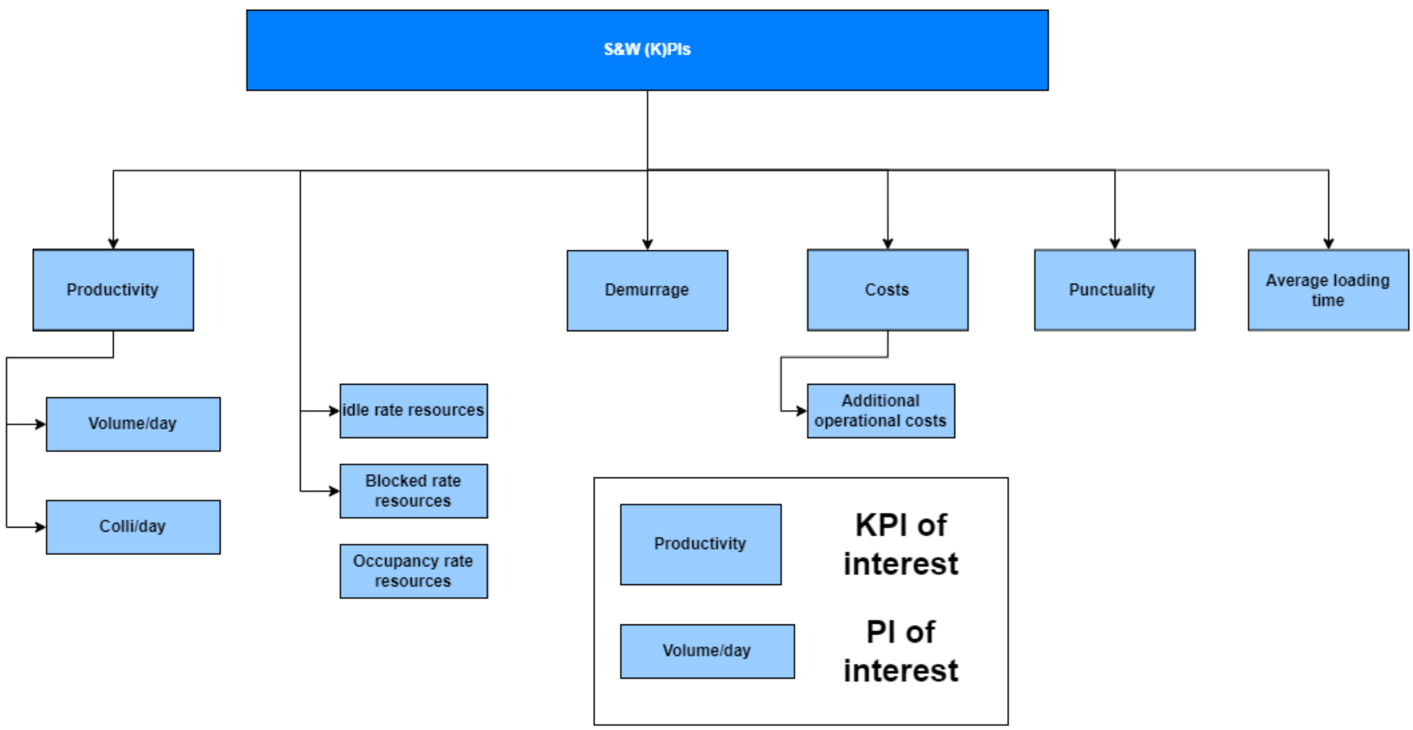


Figure 3.9: Final (K)PI tree

3.3.7 Case study (K)PI specification

In the previous section a KPI tree is presented containing those KPIs and PIs that are used to describe the performance of the outer-harbour 3. The KPIs Productivity in volume and quantity, Demurrage, Costs, punctuality and average loading time.

Costs

The key performance indicator cost is added to the KPI tree as it is relevant to compare the potential increase of performance with additional investments that have to be made. This KPI specifically looks at the additional operational expenses resulting from changing the configuration of scenario of the model.

Productivity

The Productivity is defined as the volume and colli moved into vessels on average during a certain period. The productivity of the system is split in two. First the volume productivity in tonnes per day moved through the outer-harbour 3 onto deep sea vessels. The Secondly the number of colli moved per day. The main benefit of looking at the number of colli moved additional to the volumes extracts from the fact that the colli processes have weights ranging from 7 tonnes up til 30 tonnes. However, despite this weight, the resources processing these colli are as busy with transporting or moving light products as they are with processing heavy products. Volumes in that sense does not give the full picture of how resources are in fact used.

Punctuality

Punctuality is an important contributing factor to the costs associated with loading deep sea vessels, and vessels in general. As discussed in subsection 3.1.1 the Outbound Logistics department agrees upon loading volumes/day, based on the product mix that has to be loaded onto the ship. They agreements are made both to forecast the duration a vessels is docked as well as to inform customers on when they can expect their steel colli. The punctuality is therefore measured as the time a vessel should have taken to load compared to the actual time needed to load that ship. It measures 1, if the loading of a vessel has taken place faster than, or equal to the agreed upon total loading time, and 0 if not. The punctuality KPI is the sum of all these individual vessel scores.

Demurrage

In addition to these base costs, potential demurrage costs have to be paid per day that a vessel is still loaded while the predetermined loading period is exceeded. To calculate the demurrage costs the following mathematical formula is used:

$$(Load_{vessel}/Rate_{act} - Load_{vessel}/Rate_{norm}) * DEM_{rate} \tag{3.1}$$

Where:

- $Load_{vessel}$ is the total load that has to be loaded onto a ship in tonnes
- $Rate_{act}$ is the actual realised volume in tonnes loaded per hour vessel, but only while the pre-determined loading period is not yet exceeded
- $Rate_{norm}$ is the agreed upon volume in tonnes loaded per hour
- DEM_{rate} is the demurrage rate per hour as agreed upon

Average loading time

This KPI indicates how long it takes for each vessel to be loaded. Starting from the time the vessel is docked until the last colli is loaded as secured. Another name for this KPI could be the lead time of vessels, however this term is not used in this research thesis.

Use of resources

Apart from the KPIs, three PIs are used to assess the use of resources in and around the outer-harbour 3. These three PIs are:

- Occupancy rate, defined as the $capacityused/capacityavailable$
- Idle rate time, the time a resource stands idle
- Blocked rate, the number of times a resource has finished its cycle time, but has to wait for a next resource to take over a product.

These three PIs are used as an input for the methods of identifying bottlenecks as discussed found in literature and subsequently discussed in . As stated in section 1.4 the results of these methods are compared to each other to be able to understand better what the bottleneck or bottlenecks in the system could be and to what extent.

3.4 System elements, relationships and boundaries

This section will elaborate upon a deep-dive of the system at hand and will discuss and explain each significant part of the system such that the reader is provided with a clear view in which context the research will take place. Moreover, this chapter also includes any assumptions made in the processes of going from a real world problem towards a system description.

3.4.1 Boundaries

The main objective of this research is to find answers to the question on how to increase the performance on the outer-harbour 3 of Tata Steel IJmuiden. Therefore, it is vital to identify which processes, the corresponding elements and the relationships between these elements should be taken into consideration during the research. The authors in (Hans et al., 2008) state that the definition of a system under consideration and the physical scope of a research project are depending on the questions to be answered and the ability to measure the goals and performance of that system. The authors give a set of handles that can be to choose system's boundary/physical scope such that the system, and subsequent research done on the system, is sufficiently manageable. The paper's first handle emphasises that the less points of entry for temporarily elements from outside the system into the system, the better. Where temporarily elements are seen as elements that are only inside the boundaries of a system for a limited amount of time. The interpretation in light of the outer-harbour 3 is that the input of temporarily elements, in this case individual coils, ETTS, trains, locomotives and vessels into the system should ideally be realised through one point only. If these temporary elements enter your system via multiple locations around your system boundaries, it will increase the complexity of the system at hand, which should be prevented as much as possible. For example the system as can be seen in Figure 3.10 only has input via the central emplacement instead of taking into account each of the many warehouses on site that feeds steel coils to the central rail shunting yard or the central emplacement (CE). Looking at permanent elements, which can be considered to be permanently situated inside the system's boundaries, the question whether one should consider to add an element to your system, depends on whether this element does have (a sufficient amount of) relationships with the already included elements in the system or maybe the potential new element only has a relationships with one element. Or for example it has, to a larger extent have relationships with elements located in the 'environment' on the system (Hans et al., 2008).

It can be concluded that overall, the definition of the physical scope/system boundaries depends heavily on the contribution of that function to the greater whole, or to the goal of the study. By drawing these borders, one should take into consideration that the least amount of relationships between elements already part of the system are broken and the least amount of temporary elements, steel coils, ETTS, vessels and trains, cross the physical scope via the least number of permanent elements possible. Taking into account these points, a system together with its boundaries is proposed. The system in Figure 3.10, contains nine main permanent elements and four temporarily elements as is shown in Table 3.1

Temporarily elements	**Permanent elements**
Trains	Transit Hall
Locomotives	Transit Hall crane
ETTS	BUO/BUW
Coils	Quay
Vessels	Quay cranes
	Quay track
	Quay forklift trucks
	Hold forklift trucks
	Securing teams
	Wagon pusher

Table 3.1: Temporarily & permanent elements within the system

The train, locomotive, coil and ETTS enter the system through two routes, both originating from one element being the CE from which train loaded with collo are delivered by locomotives inside the system. The vessels of course enter the system via water. Since the temporary elements (excluding the vessels) enter the system through one element a structured assessment of the input of the system can be made. For example, if the CE was to be included within the systems boundaries, over a multitude of flows of temporarily elements would have to be considered. These include transportation from every warehouse on-site and several other transportation which would add significant complexity to the system.

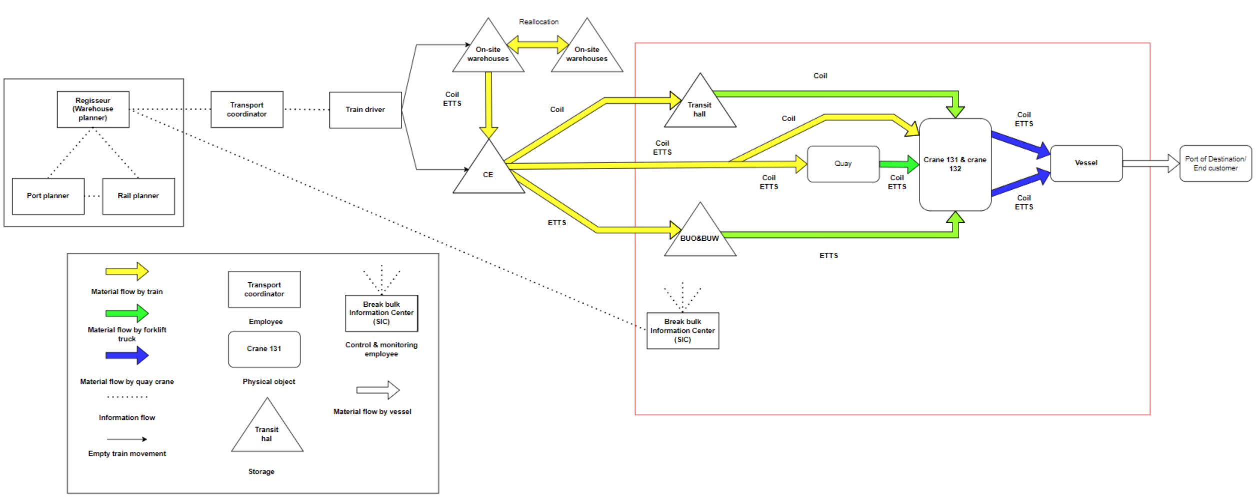


Figure 3.10: System and boundaries

In the next section the system within the red box will be analysed such that the full concept of the system is known. This knowledge is subsequently used to built the conceptual model in chapter 4.

3.4.2 Permanent elements

While looking at a system one can identify permanent elements that are defined as elements that are situated constantly within the system's boundaries. In this particular case there are nine in total, being the Transit hall, The Transit Hall crane, outer-harbour East and outer-harbour West, the quay, the quay crane(s), the quay forklift trucks, the vessel hold forklift trucks and the securing teams. In this section each element and its significant relationship with other elements is elaborated upon. Looking at the harbour, the operations include the acceptance of transported trains by locomotives. These trains are used for supplying coils and ETTS to the quay. Unloading these trains is done either directly with a quay crane or indirectly by placing the coils within the crane's range by using forklift trucks. The quay cranes move colli either directly from a train or are being fed via a forklift truck which can be used to move products from the train into the cranes reach or if originating from the Transit Hall or the ETTS storage 'Buiten kade Oost' (BUO) en Buiten kade West (BUW). The quay crane will subsequently place the collo inside the hold of the ship. If possible, the quay crane positions the collo directly on its final position. If not possible, a forklift truck inside the hold will be used to do so. Once a whole tier (layer) of coils is placed, the securing team inside the hold will secure the load. The flow of material and which elements are connected to which elements is visualised in Figure 3.10.

3.4.3 Data collection

To increase the understanding of the system and all of its components, norms and performance system specific data must be collected.The available data are specified in three categories. Firstly, configuration data which should entail the exact numbers of the permanent elements of the system. Secondly the scenario data giving information on the flow of temporarily elements through the system and thirdly the performance data containing the (K)PIs used, the standards being used and the actual performance of the system in terms of these (K)PIs and standards. What follows is a comprehensive analysis of the whole system by using available data and knowledge of the system. The goal of this is to generate useful data for the discrete-event simulation.

3.4.4 Configuration data

The configuration data specifies the physical resources there are to use and what the theoretical and standard performance of these resources are. In this section, for each element specified earlier, the configuration data is discussed.

Permanent element	Configuration data
Quay-cranes	2 Quay-cranes
Quay	Quay is circa 300 metres long
Transit Hall	2200 coils capacity
Tracks	3 tracks of each 270 metres
Transit Hall cranes	2 Cranes, only 1 used at the same time
BUO/BUW	Storage for 200+ ETTS
Quay forklift trucks	1 forklift truck per operational crane
Hold forklift trucks	Room for 1 forklift truck per hold
Securing teams	1 securing team per crane
Wagon pusher	Left out of scope

Table 3.2: Configuration data permanent elements outer-harbour 3

Temporarily elements	Configuration data
Trains	[-]
Locomotives	3 locomotives
ETTS	[-]
Coils	[-]
Vessels	[-]

Table 3.3: Configuration data temporarily elements

Quay crane 131 & crane 132

The outer-harbour 3 has two quay cranes at its disposal, crane 131 and crane 132. The cranes are used to lift collo from the quay into the hold of ships or directly from the train. The cranes are able to lift up to 60 tons, excluding the weight of lifting equipment including large industrial pliers, chains or special cages to handle ETTS. Effectively the crane can lift weights up to 55 tons. During the morning and afternoon shifts both quay cranes are operational, whereas only one is operational at night. This is referred to as the 3-3-2 quay crane configuration. The operational speed of the quay cranes is further elaborated upon in section 3.4.6.

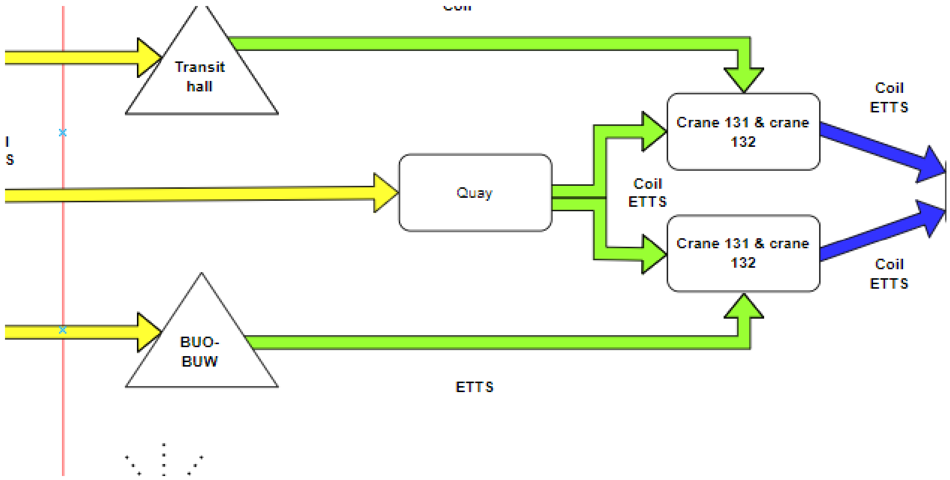


Figure 3.11: System element quay-cranes

Quay and the tracks

The outer-quay 3 is the location where the ships dock, the cranes are located, the trains arrive and forklift trucks move around. The quay has relationships to all temporary and permanent elements within the system boundaries, and is together with the transit hall and BUO / BUW the only element that has physical relationships with the central rail shunting yard. On the quay there are 3 tracks available, thus providing room for three trains.

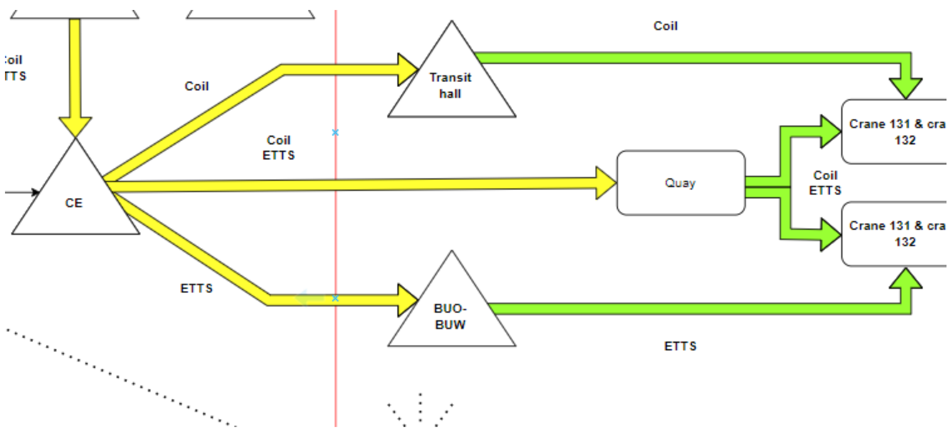


Figure 3.12: Quay system element

The Transit Hall

The transit hall is designed to act as temporally storage for steel coils, mostly assigned to large America going sea vessels. The S&W department aims to supply as many coils destined for deep sea vessels via this storage point in the period before the ship arrives. This would result in less dependence on the supply of colli via the train. The warehouse has space for circa 2200 coils depending on the mix of different widths and heights. However, as these colli dimensions are not within the scope of this thesis, it is assumed that 2200 coils can be stored. A crane operator inside the Transit Hall is responsible for picking coils place them near the door such that a forklift truck can transport it further towards the quay cranes. These cranes have a maximum loading capacity of 35 tons. Moreover, the same crane operator must unload trains supplying coils to the Transit hall and place them in designated places inside the warehouse.

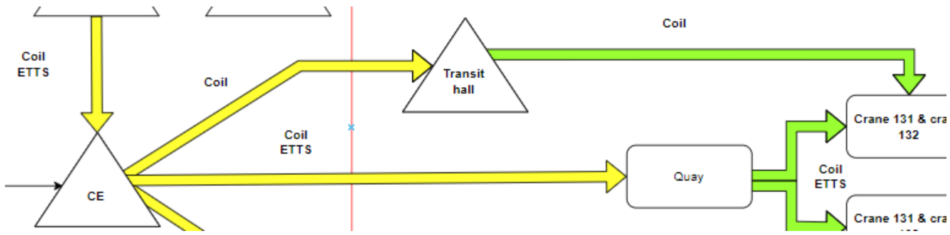


Figure 3.13: Transit Hall element

BUO & BUW

Where the Transit hall is used to temporarily store coils, BUO and BUW are used to temporarily store ETTS to smoothen loading operations or when the weather forces the ETTS to be stored in a dry environment, as to prevent them from getting wet. Storage space for ETTS in BUW and BUO is considered to be unlimited.

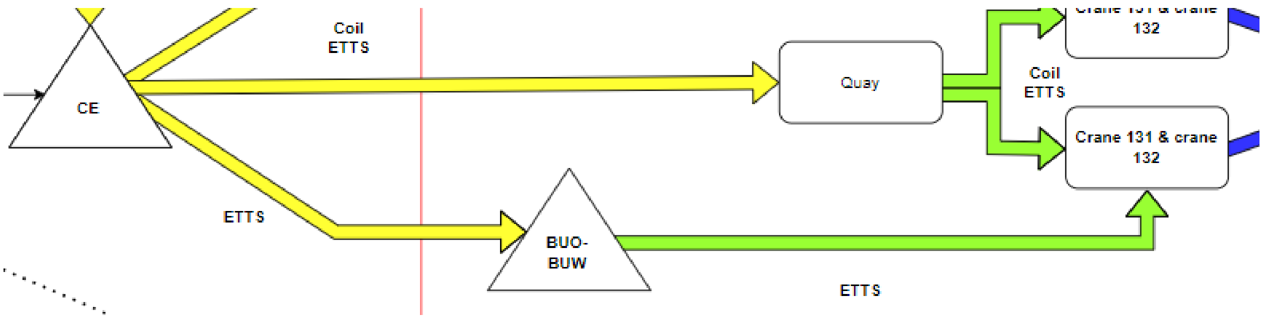


Figure 3.14: ETTS Storage element

Quay forklift trucks

For operations on the quay and in the hold of vessels a total of five forklift trucks are present. These trucks are used to transport coils from the Transit hall and ETTS from the BUO/BUW towards the quay cranes. The forklift trucks are also used to get collo from the train wagons on the ground in case of ETTS loading or such that two coils can be loaded simultaneously. Each forklift truck requires a driver to operate the machine. For each quay crane operational, one forklift truck is used.

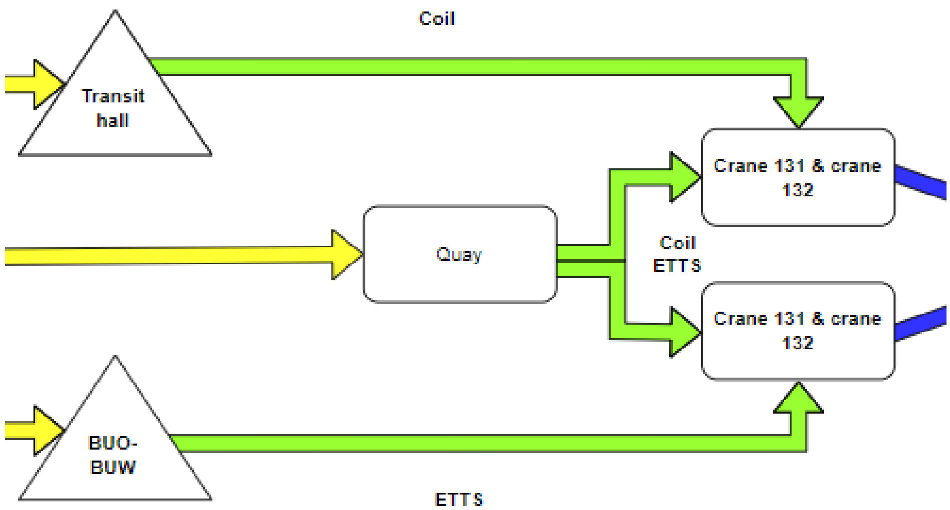


Figure 3.15: Forklift truck element

Securing teams

Part of the loading process is to secure the load in the hold of the ship such that the colli will not move during the transportation via sea. In general a team of workers is moved into the hold of the ship to execute these securing tasks in parallel to the quay crane moving colli into the hold. This makes that, for each quay crane in operation, one securing team is available for the hold that that quay crane is working one.

Hold forklift trucks

During operations inside the hold of a vessel, it could happen that a quay crane is not able to land a collo directly onto already secured colli. This could be the case when a segment of the hold of a vessel is underneath the hatch of that hold. In addition, ETTS collo cannot be loaded directly on top of other colli since this type of product requires the use of a special catch. In both cases, a forklift truck is used inside the hold of a ship to allow the colli to be loaded and secured. These forklift trucks are moved by the quay crane into the hold of the ship. Per quay crane operational and thus per hold one forklift truck in the hold is used.

Vessels

The ETTS and coils are loaded onto the ships using the quay cranes. Moreover, securing the coils and ETTS is considered to be part of the system as these movements are directly related to performance metrics such as speed-of-work of the crane and berthing times of the ships. As mentioned, the berthed ships are considered to be temporarily elements that trigger the whole logistics system of Tata Steel into operation. The capacity of the outer-harbour 3 allows for 1 deep sea vessel at the time. Therefore it is necessary to finish a ship before the next ship can dock.

Trains and locomotives

The rail department is responsible for all on-site transportation via rail. This includes transportation of semi-finished products between production facilities, rearrangements between warehouses, via the central shunting yard, or from the central shunting yard towards the harbours. The order times of collo by the harbour operational teams and transportation from the central emplacement to the harbour are as it is one of the main supply methods towards the cranes. The need for trains is dependent on the presence of an actual vessel that requires collo. In the system, the operational team orders new collo via rail when the supply at the quay is running out. However the supply of wagons is depending on the speed at which these wagons can be assembled at the central emplacement as well as the availability of locomotives to drive the wagons towards the outer-quay 3. The rail department is responsible for this transportation and has the ability to utilize 3 locomotives for both transportation to and from the outer-harbour 3, outer-harbour 1 and the inner-harbour, as well as transporation tasks between warehouses.

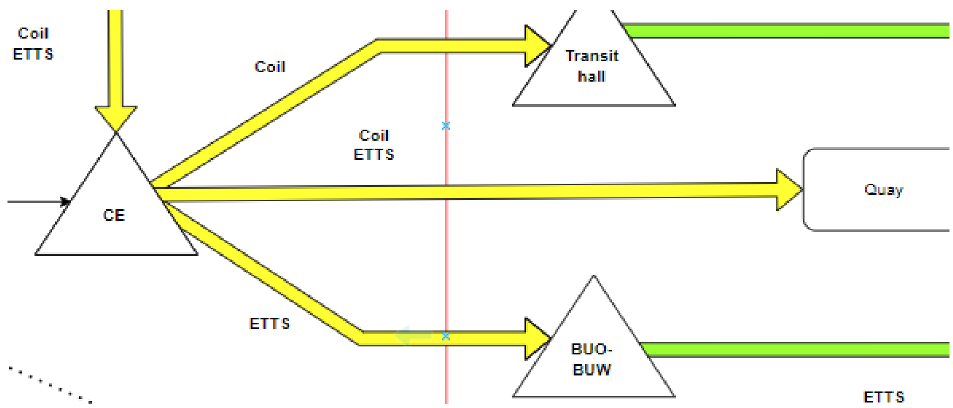


Figure 3.16: Rail element

3.4.5 Scenario data

Scenario data in this thesis refers to the number of vessels that are processed by the outer-harbour 3 and therefore the number of ETTS and coils that are flowing through the system.

Permanent element	Scenario data
Quay-cranes	[-]
Quay	[-]
Transit Hall	17000 coils for deep sea vessels 2021
Tracks	[-]
Transit Hall cranes	[-]
BUO/BUW	3300 ETTS for deep sea vessels 2021
Forklift trucks	[-]
Hold forklift trucks	[-]
Securing teams	[-]

Table 3.4: Scenario data permanent elements

Temporarily elements	Permanent elements
Trains	[-]
Locomotives	[-]
ETTS	Circa 22200 ETTS 2021
Coils	Circa 35000 Coils 2021
Vessels	Figure 3.17

Table 3.5: Scenario data temporarily elements

Transit Hall

As said, the Transit Hall works as temporarily storage for coils. From available data on the Transit Hall it is clear that 17168 coils were loaded from the Transit Hall onto deep sea vessels in 2021. This is around 60% of the total number of coils. This number is used as a validation point for the simulation model in chapter 5.

ETTS storage

Historical data on the use of BUO and BUW shows that each year around 15% of the total number of ETTS loaded onto deep sea vessels is loaded from either one of these storage facilities. As assumed is that the storage of ETTS is unlimited, each vessel requiring ETTS receives 15% from the BUO and BUW.

Vessels

The number of vessels visiting the outer-harbour 3, their inter-arrival time and the load these vessels require are based on historical data. InFigure 3.17 a plot is shown of the inter-arrival time of deep 165 deep sea ships in the period from 03-2019 to 12-2021 is used to generate ships for the model to handle. This histogram is used as input for the inter-arrival time of vessels as input for the model. The average inter-arrival time equals 6.2 days and is approached by an exponential distribution.

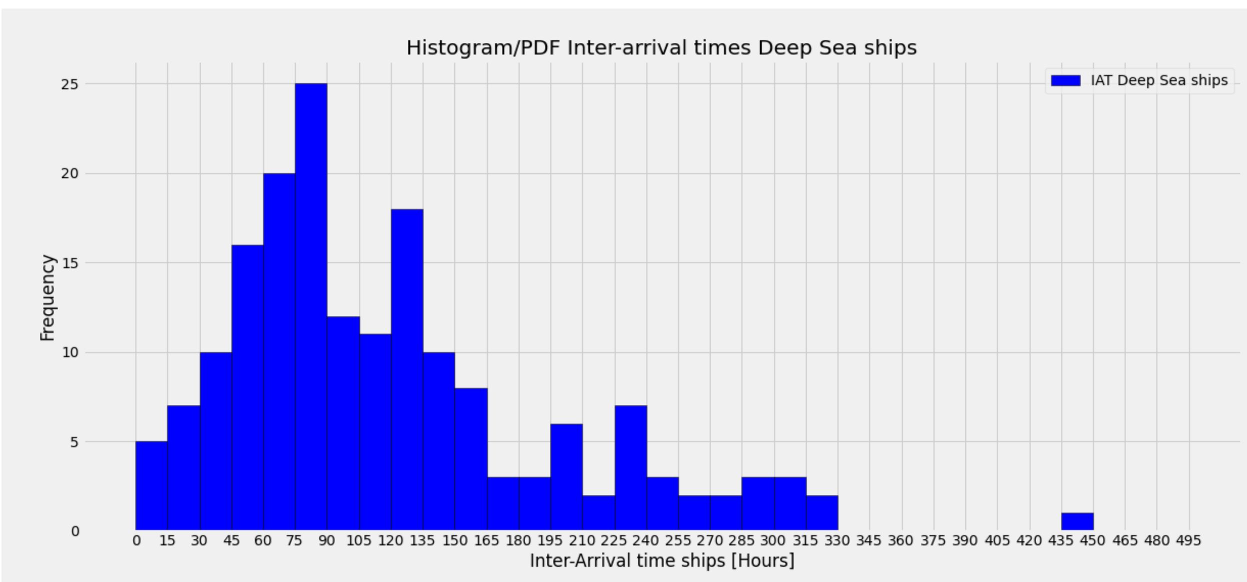


Figure 3.17: IAT Deep sea vessels

3.4.6 Performance data

In this subsection, the performance data of the system is discussed per element. The performance data here refers to data that gives insight into the actual performance of system elements in the real system. The simulation model requires this data to able to realistically mimic the system. In Table 3.6 an overview is given of all data points. Only those elements for which performance data are required are discussed in this section.

Permanent element	**Performance data**
Quay-cranes	Sampled distribution in Figure 3.18
Quay	[-]
Transit Hall	[-]
Tracks	[-]
Transit Hall cranes	Sampled distribution in Figure 3.19
BUO/BUW	[-]
Forklift trucks	4 forklift truck routes: Figure 3.20
Hold forklift trucks	Each movement takes 20 seconds
Securing teams	Securing coils takes on average 90 seconds Securing ETTS takes on average 120 seconds

Table 3.6: Performance data permanent elements

Temporarily elements	**Permanent elements**
Trains	Trains are assembled in the CE and hinterland warehouses with an uniform distribution between 6 and 10 hours
Locomotives	30 minutes from CE to outer-harbour 3
ETTS	[-]
Coils	[-]
Vessels	[-]

Table 3.7: Performance data temporarily elements

Quay crane speed-of-work analysis

Next is determining the cycle times of the quay cranes. Tata Steel has implemented a weight sensor in their quay cranes which creates a signal once the weight underneath the crane exceeds 15 tons, including handling equipment. This sensor detects when and for how long a weight of 15 tons or more was attached to the crane. An storage system linked to these sensors is able to save data for months and can be used to gain insights in the time a crane needs to lift a colli inside a ship's hold and the time the crane requires to move back to lift the next colli. The goal of the analysis of this signal data is to filter out a distribution of loading rates of the quay-cranes. For this analysis signals of the past 3.5 months were analysed. A plot of this data can be seen in Figure 3.18. Excluding outliers are identified as can be seen in Figure B.1 and excluded using the the IQR method resulting in Figure B.2. The plotted data in Figure B.2 much resembles a lognormal function. Arguments for this assumption are based on research done by (Saurí et al., 2014). The authors of this paper compare manned and automated handling equipment in container terminals and consider lognormal service times for the on quay,- and yard cranes they investigate. Plotting the lognormal values of the 'weight on' data set results in the following best fit values: μ equal to 4.00 and a σ equal to

0.325. Plotting the lognormal values of the 'no weight on' data set, results in a μ equal to 4.3 and σ equal to 0.275. The model is subsequently picks random values on this distribution for both the time a collo is attached to the crane and the move back without a collo. For the former, if the model picks a value 30 seconds, the area on the left, another value is picked. The same logic holds for the latter move. If the model picks a value smaller than 6o seconds, the model will pick another value until that condition is met. Excluding values smaller than 30 seconds for movements with weight and 60 seconds for movements without weight does have a reason. It was observed that the quay cranes are not able to move faster than 30 seconds. For the movement without weights, 60 seconds is the threshold as this equals 15 seconds for attaching weights to the quay crane, 30 seconds for movement and 15 seconds for detaching. Faster cycles times are assumed not to be possible.

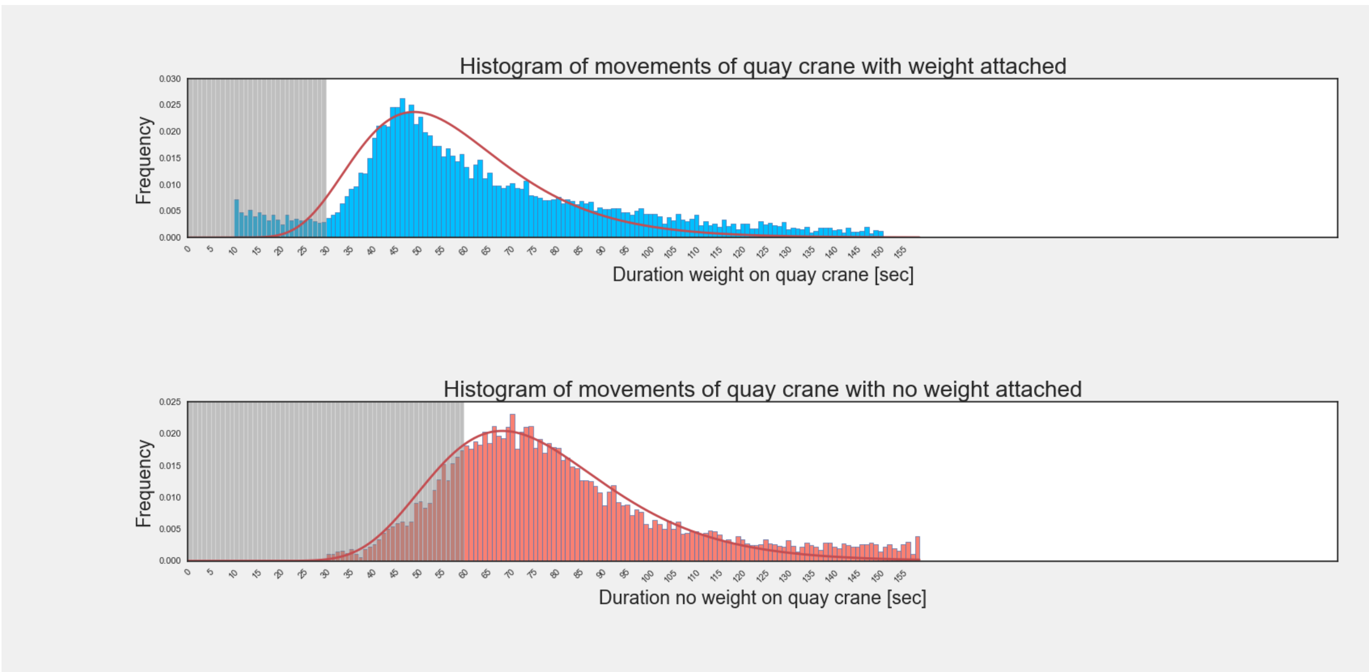


Figure 3.18: Approximation distribution of quay crane movements with, and without weight attached to the crane

The Transit Hall cranes speed-of-work

The cranes inside the Transit Hall are important elements in the logistical system of the outer-harbour 3. As said, the hall has two operational cranes available that can be used to unload coils from trains, reshuffle coils in storage and supply the quay with coils if a vessel is being loaded. As with the quay crane analysis, the IBA Analyzer weight sensor data is being stored and can therefore also be used to analyse what the realized work rate of these cranes are. Similar to the quay cranes, the actual cycle time of each collo moved inside the Transit hall is depending on the driver of the crane as well as on the distance that has to be travelled by the crane with and without colli. Both factors left outside of the scope of this research and therefore it is necessary to approximate the cycle times with a distribution from which the simulation model can draw random cycle times. Unfiltered data are plotted and can be found in the appendix in Figure B.3. Outliers are detected using a boxplot which can be found in Appendix B in Figure B.4 and are removed using the IQR method. Once the outliers are removed, further investigation is necessary to approximate this data with a lognormal distribution. Plotting the lognormal values of the 'weight on' data set results in the following best fit values: μ equal to 4.05 and a σ equal to 0.32. Plotting the lognormal values of the 'no weight on' data set, results in a μ equal to 4.25 and σ equal to 0.325. The final distribution used can be seen in Figure 3.19. The model draws random values from these distributions each time a collo is moved by the crane. If a value is picked in the grey area on the left, the model draws another value.

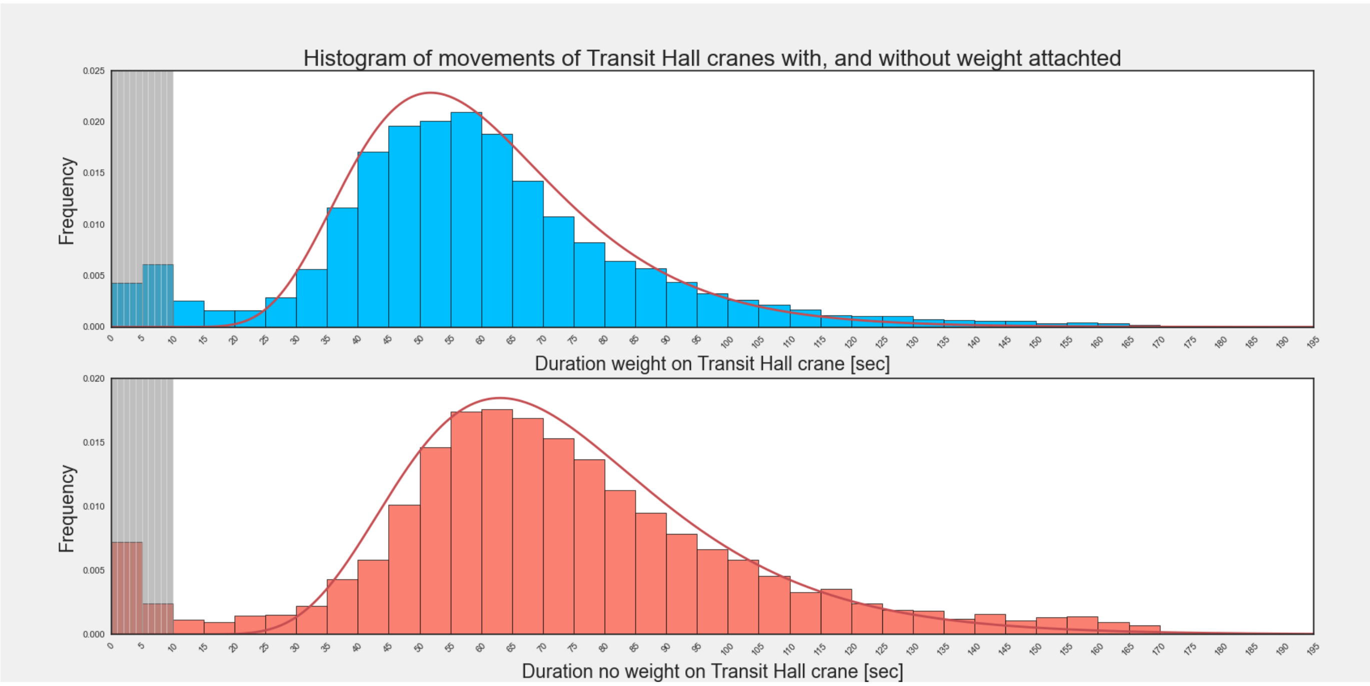


Figure 3.19: Approximation Lognormal distribution of Transit Hall crane movements with, and without weight attached to the crane

Forklift trucks

An interesting aspect of the forklift trucks is the maximum rate at which they can provide coils and ETTS to the cranes.The fastest a forklift driver could provide collo to the crane was determined in consolidation with the drivers of these machines and by executing field research in the form of timing processes where forklift trucks are used. As the forklift trucks do not have weight sensors on them this has to be calculated manually. Data are obtained by clocking operations around the quay in order to get an grasp of the speed at which these machines work during the loading of ships. From this analysis four routes were identified, each with a certain average time the route costs to succeed. These average times are used as input for the model. The 4 routes and their average times shown in Figure 3.20. These average times are based on on-site clocking of operations. This is done using a stopwatch and the results can be seen in Table B.1. The colours in this table match the colors in Figure 3.20. For the 'BUW to crane 132' and 'BUO to crane 131' routes no observations were made, however it is assumed that these values equal the values of the observations with respect 'BUW to crane 131' and 'BUO to crane 132' times 1.5 as the distances covered are approximately 1.5x longer.

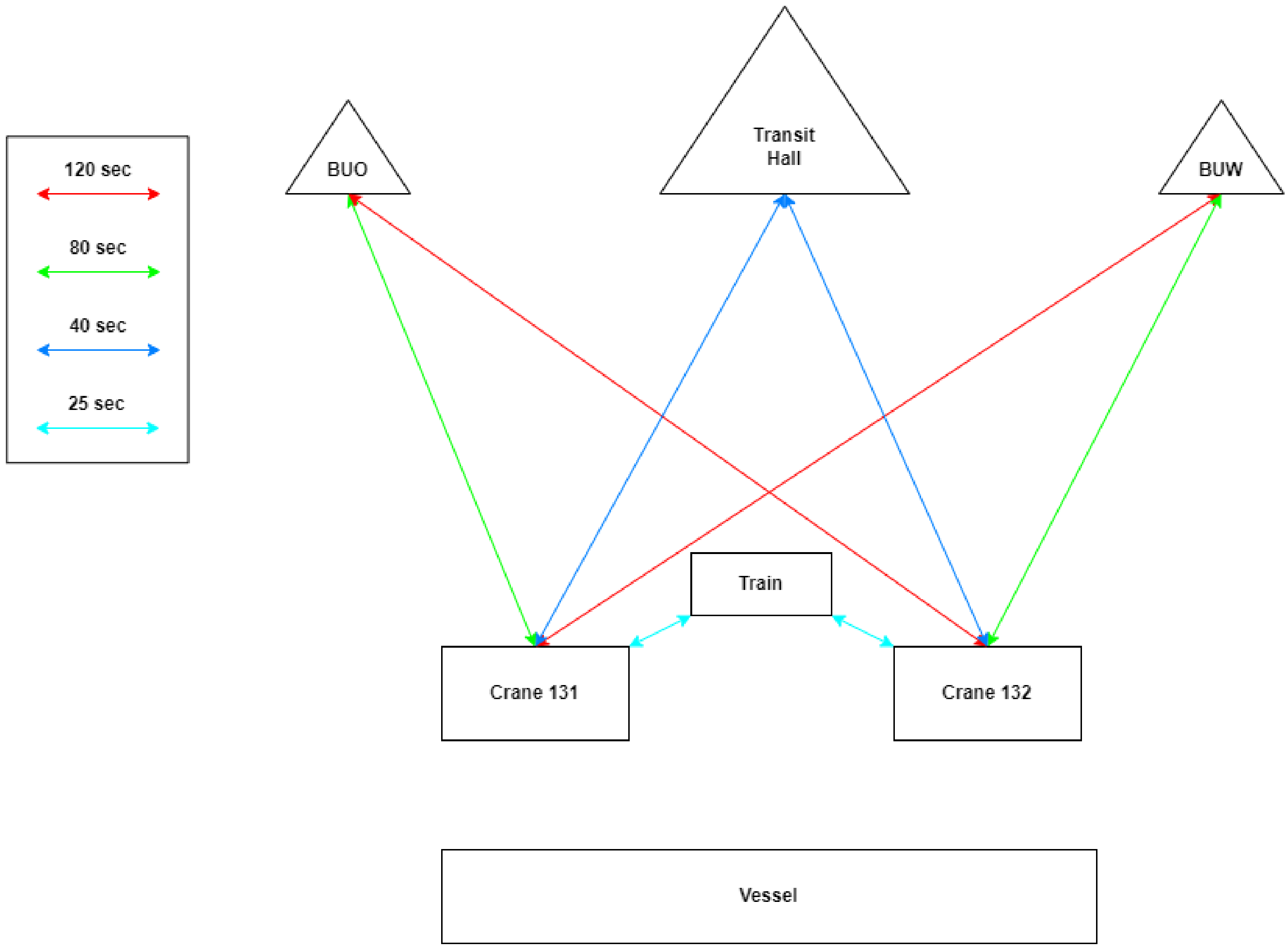


Figure 3.20: The four defined routes for forklift trucks on the quay

Securing

Securing the load inside a ship's hold is difficult to quantify as each situation differs from the previous and factors such as weather, crew, experience and ship type are to influence the realised loading per ship. In order to come to an estimated time it takes to secure one coil or ETTS it was decided to interview employees with experience on the matter. From these interviews an average was estimated for both securing coils and ETTS. For each connection on 1 coil to another, an average of 90 seconds is spend. For each ETTS connection to another ETTS, an average of 120 seconds is taken.

Trains and locomotives

The performance of rail is depending on two factors in this research. Firstly the availability of locomotives, which is the result of the capacity of the three locomotives and the request they receive to perform tasks. Trains are assembled in the CE with an uniform distribution with lower bound of 6 hours and an upper bound of 10 hours. This is based on expert insights from the OSP planners. Once a train is ready to be transported towards the quay a locomotive is required to execute this task. This drive takes 30 minutes and is considered to be constant.

Environment elements

(Veeke, Ottjes, Lodewijks, 2008) described a systems environment as the environment belonging to the system under consideration which entails those elements from the universe that influence the characteristics, or the value of the characteristics, of the system's elements; or in reverse, are influenced by the system. Using this definition, one environmental element is recognised, the central shunting yard (CE). The CE is a train assembly point, or a generator of requested finished goods to the outer-harbour 3. Data on the time used for these processes is lacking, therefore in consolidation with experts it is assumed that the trains are assembled and ready to be transported towards the outer-harbour 3 with an uniform distribution on 6 to 10 hours as in the real system a precept is to start loading wagons in warehouses 8 hours before they are required in the harbours, which is thus approached with uniform distributed.

Rain and machine failure

Loading operations can be interrupted by failure of the quay cranes or rain as colli are not allowed to get wet. Such events can delay the loading of vessels and therefore they are also taking into account in this research. Both the occurrence of rain and quay crane failure are approached using Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) methods. As not enough accurate data on the total failure and rain time is present to model rain and failure in detail it was chosen to model this component with help of Tata Steel experts and some of the available data. In chapter 5 this model component is validated using the data available. For the rain the MTBF, thus the time between two rain showers was set to be uniformly distributed between 720 and 1440 minutes. The MTTR, which is the time it rains was set to an uniform distribution between 54 and 90 minutes. For the failure of the two quay cranes and the Transit Hall crane the MTBF was approached with an uniform distribution between 9000 minutes and 12600 minutes and an uniformly distributed MTTR between 150 and 250 minutes.

Crane deployement, breaks and shift changes

As mentioned earlier one of the two quay cranes is not operational during the night shift. Therefore 16 hours per day two quay cranes are deployed and 8 hours only one. Breaks occur twice for 45 minutes each 8 hour shift. Lastly changing the shift teams also occurs once every 8 hours and takes 45 minutes as well. Thus each team is operational 6.5 hours.

3.4.7 System function, processes and control

The aforementioned elements and relationships are all part of a function that serve a greater good, which, in this case, is the on-time loading of coils and ETTS on deep sea vessels. In this section the elements, functions and processes, and the functions to control them, are elaborated upon in more detail. In Figure 3.21, one can see an overview of these components as present in the system being researched during this thesis and based on the Delft System Approach developed by (Hans et al., 2008). At the top there is the environment, OTB is this case, which sets requirements for the system to meet. These are high-level expectations/norms that OTB expects OSL to realise. However, these requirements are to be transformed into more tangible short-term goals that OSL and S&W can steer their processes on. This initiating of high level requirements into tangible and more short-term norms is realised by using (K)PI and norms for these (K)PIS as can be seen in the 'Function control' square in the figure. These norms are subsequently used as input for the process. The process contains both the execution process as well as the controlling process.

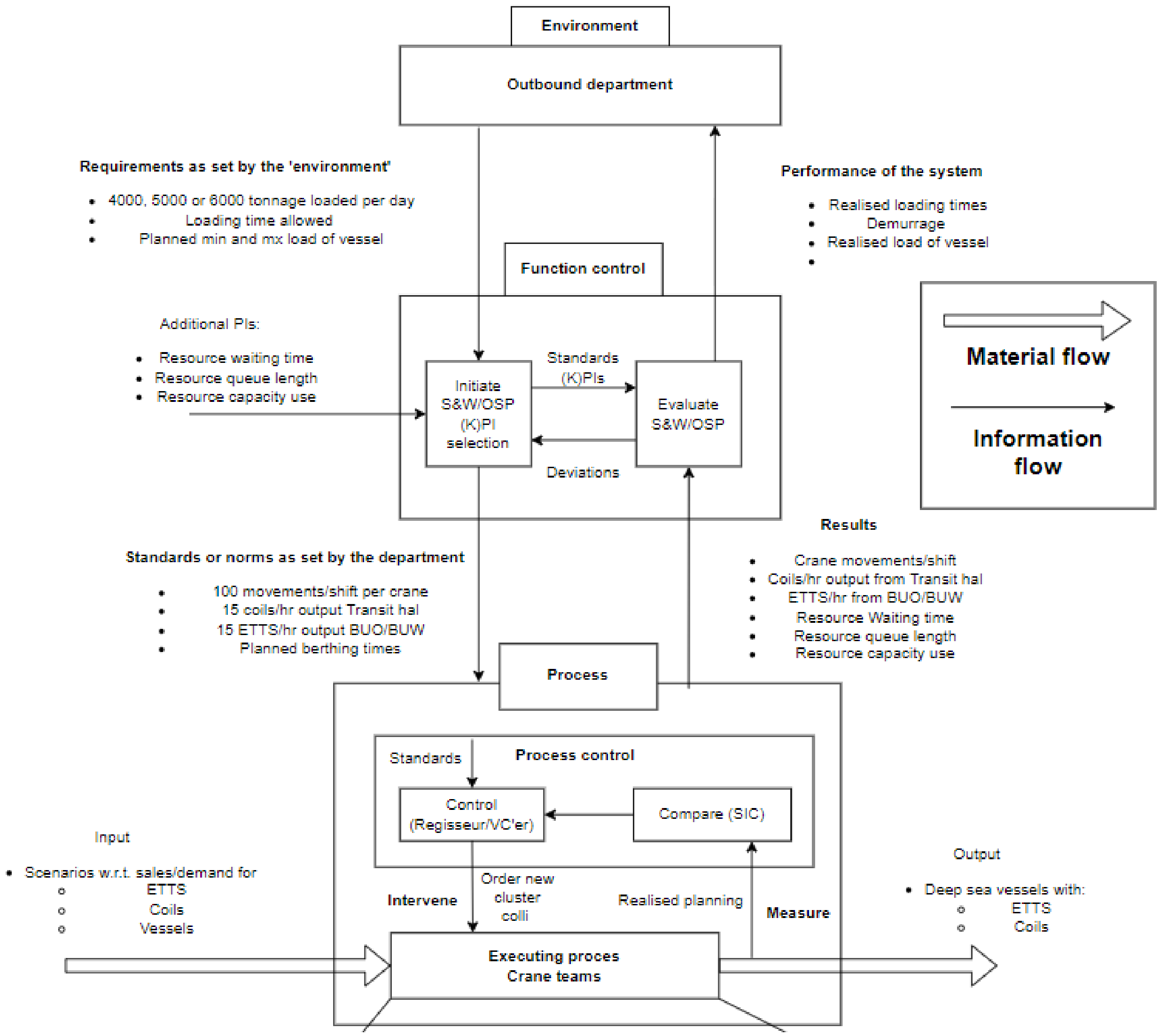


Figure 3.21: Function,- and process control of S&W outer-quay 3

3.4.8 Conclusions

At this point the system is described with guidance of The Delft System Approach (Hans et al., 2008). The method proposed by the author is used to analyse the system and determine which elements and relationships exist within the boundaries of the system. The goal of this chapter is to give answer to the two sub-research questions mentioned at the beginning of this chapter. Sub-research question 2 first:

Referring back to the beginning of this in which the goal of this chapter is stated, three sub-research questions had to be answered using the analyses made in this chapter. Firstly sub-research 2:

- *Which logistical processes are present at Tata Steel IJmuiden?*

The outer-harbour 3 of Tata Steel IJmuiden consists of nine permanent and four temporarily elements. A full overview of all elements is shown in Table 3.2 and Table 3.3. These elements are active in a set of processes that are partly in series to each other, but also partly in parallel. From outside the system locomotives are used to deliver coils and ETTS either directly to the quay or for temporary storage in the Transit Hall. Before a ship docks the delivery towards the Transit Hall is realised if locomotive capacity allows. Once a ship has docked, the transportation towards the Transit Hall for that particular ship stops and only direct supply towards the quay is executed. During stowage, the crane inside the Transit Hall moves coils towards the door where forklift trucks subsequently move these coils towards the quay cranes. The forklift trucks are also used for moving ETTS from the BUO & BUW towards the quay cranes as well as moving both coils and ETTS from the train on the quay if required. The quay-cranes are moving the colli from the quay into the hold of the ship where, depending on the type of colli as well as the stage of the stowage procedure, the colli is either landed directly onto its final position or otherwise placed in front on a forklift truck which is used to place the colli into its final position. Lastly a securing team is present inside the hold of a ship to secure the load. Once a series of coils or ETTS is almost loaded SIC orders new products such that the stowage processes are put to a stop. For each of these process steps configuration, scenario and performance data are collected and used as input for the simulation model, which is further discussed in chapter 4.

Proceeding towards answering sub-research question 3:

- *What defines the performance of break-bulk harbours and what methods are used to quantify bottlenecks and improvements?*

using KPIs serves multiple purposes. One of these is to identify bottlenecks and waste in processes such that improvements can be made where they are needed the most. The selection of which KPIs to use to steer an organization is depending on the objectives of that same organization. This should be kept in mind as well as the fact that an organization should only steer upon a limited set of KPIs as to prevent itself from drowning in numbers with a risk of loosing sight on what are in fact the most vital indicators to track. Literature on key performance indicators in the maritime world mentioned productivity and lead time as main key performance indicator themes to track the operational performance of container terminals. Productivity is usually considering berth occupancy, crane efficiency, yard utilization and labour, resource & machine utilization. Lead time entails vessel turnaround time, truck turnaround time and container dwell time. Those KPIs deemed use full for identifying bottlenecks are the idle time, starve time, block time, average length of queue and average waiting time in queue. These KPIs are tracked for each element identified in section 3.4 such that the input for bottleneck calculating methods is present. In addition to the perspective of the academic world of KPIs, the practical use of KPIs in the case of Tata Steel IJmuiden are also considered. Combing both insights the KPI-tree in Figure 3.9 is used. This KPI tree is used to measure the 'as-is' performance of the outer-harbour 3, and also the expected change in performance while testing alternative scenario's and configurations to tackle the identified bottlenecks.

Chapter 4

Model

In this chapter the development steps associated with the discrete-event simulation model are elaborated upon. Using Figure 5.1 as a reference, this chapter discusses step 2 *Conceptual Model* and step 3 *System Dynamics model*. This chapter starts with an overview of the conceptual representation of the model, in which all the process steps to be handled by the computerized simulation model, are visualised using the flowchart method and Logic Flow method. This does not only help to provide structure in the creation of the computerized model, but also will be used in the validation process after the model is finished. What follows is a 'Process Description Language (PDL)' which is a method to write down in regular English, all the processes that the computerized model will take. Succeeding the conceptual model and PDL and based on both, is a computerized model. As elaborated upon in chapter 2, the necessary knowledge gained in that chapter is used to answer the first part of sub-research question 4. The function of this chapter is to answer the second part of this sub-research question, highlighted in bold:

- Sub-research question 4: *What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals* ***and what should this model look like in terms of its design?***

4.1 Conceptual model

The definition of a conceptual model as used in this research thesis is based on (Robinson, 2008). The authors describe a a conceptual model in their paper as a description of the assumptions, simplifications, inputs, outputs, workings and objectives of a computer simulation model and functions as a foundation for the computer code to be developed. In this section these aspects are discussed. Using the Process Flow diagram method as well as the Logic flow method, the conceptual model is made. Taking Figure 4.1, as a reference point as to where in the process this chapter is situated. In chapter 3 the system is analysed and the most important assumptions and limitations made are discussed. This results in the square 'System description'. Currently and further discussed in this chapter the model abstraction and thus the simplifications are elaborated upon such that eventually a conceptual model can be distilled.

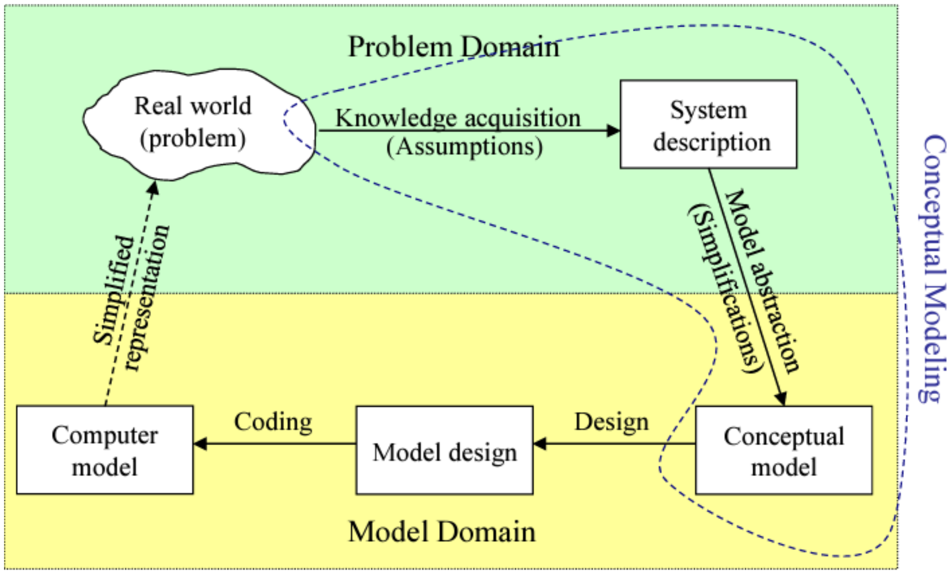


Figure 4.1: Artefacts of Conceptual Modeling (Robinson, 2011)

Input

Input for the model are empty deep sea vessels which require a certain load of coils and ETTS. Random draws from a historical data set of 75 deep sea vessels are taken as to function as the load a vessel requires. The inter-arrival time of vessels is approached using an exponential function based on historical inter-arrival times of circa 200 deep sea vessels in the last three years.

Output

The 'physical' output of the system are fully loaded deep sea. Besides the processing of vessels, the model also produces values for the KPIs that are used to measure the performance of the system. These KPIs are subsequently used to identify bottlenecks as well as to measure the theoretical increase or decrease of these KPIs during the testing of alternative scenarios and configurations.

Workings

The workings of the model are described in detail using PDL, found in Appendix C, and can also looked into in Figure 4.3, Figure 4.4 and Figure 4.5. The model is giving the aforementioned input, namely empty vessels requiring to be loaded with ETTS and coils. The vessel triggers a set of events, the supply of coils and ETTS towards the quay cranes and subsequently into the hold. Once a vessel is fully loaded it leaves the system. At the end of a simulation, (K)PIs are measured.

Objectives

The overall model objective is to mimic the operations related to stowing of deep sea vessels in the outer-harbour 3 of Tata Steel IJmuiden such to find bottlenecks in the system, if any and to test a set of scenarios and alternative configurations to eliminate these bottlenecks (partly). The model is thus built to answer the last sub-research question as provides the values to determine the increase of performance, in terms of the selected (K)PIs as a consequence of changing configurations and scenarios. Figure 4.2 shows an abstract representation of the conceptual model using a simplistic

Process Flow Diagram. Figure 4.3 shows the initialization steps that are taken by the model. This figure represents a more detailed look on the of all the processes outside the square in Figure 4.2 via use of the Logic flow diagram method. In this phase a vessel is generated and enter the system. Once the vessel in generated each of the four generators is activated. Figure 4.4 Subsequently starts where the former figure ends. On the far left side (bottom if vertical) three generators are activated and on the top (left if vertical) the other generator is activated. Figure 4.5 emphasises the operations inside the hold of the vessel. This figure continues where the former figure stops, namely after the model has checked whether a quay crane is available for loading the next colli. Once a quay crane is available the Logic flow in Figure 4.5 is initiated. After all coils and ETTS are secured the a full vessel leaves the system as can be seen in Figure 4.2.

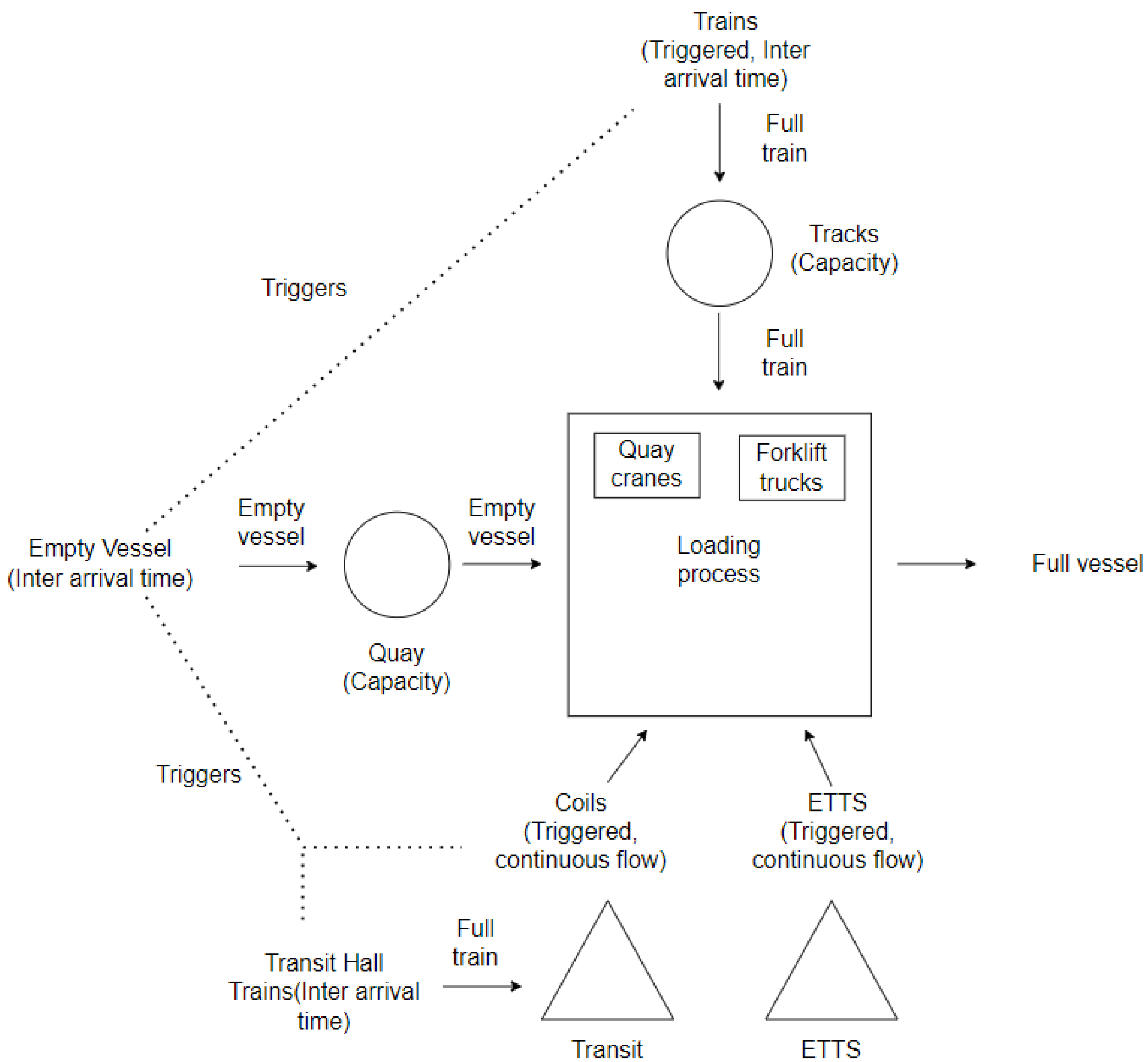


Figure 4.2: Abstract representation of the conceptual model

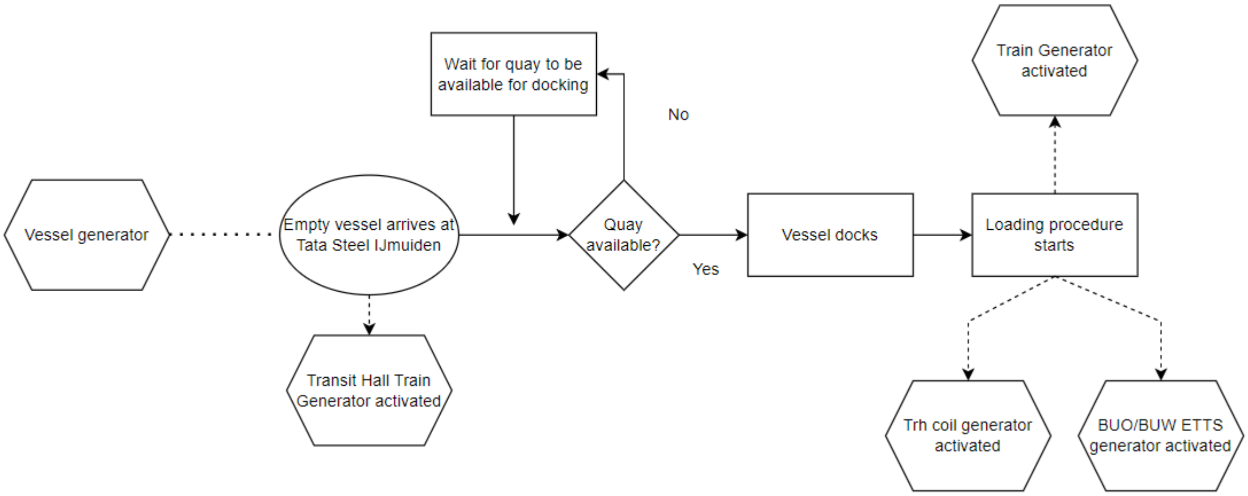
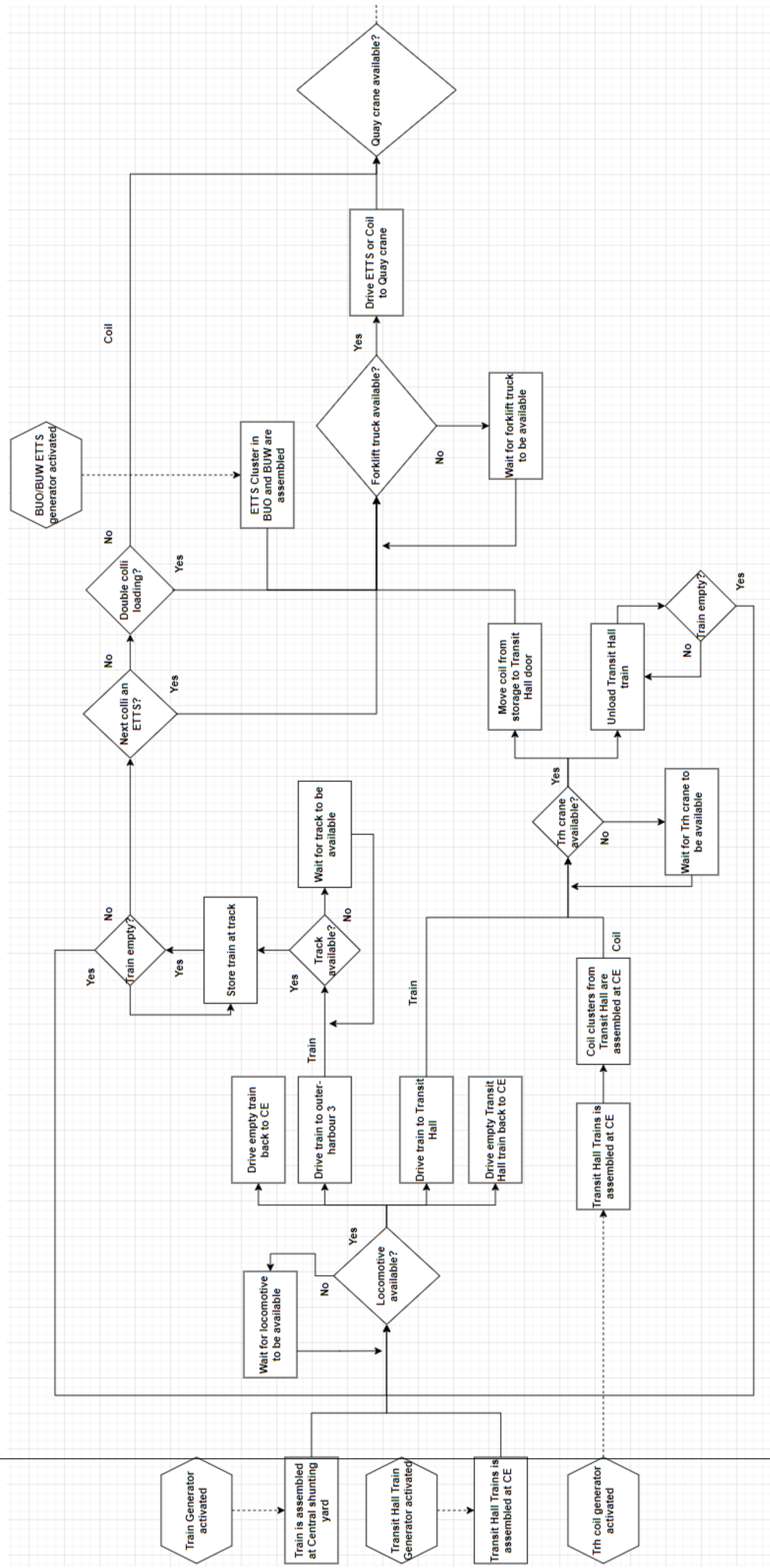


Figure 4.3: Conceptual model part 1: Initialization


Train Generator activated
Train is assembled at Central shunting yard
Transit Hall Train Generator activated
Transit Hall Trains is assembled at CE
Trh coil generator activated
Locomotive available?
Yes
No
Wait for locomotive to be available
Drive empty train back to CE
Drive train to outer-harbour 3
Drive train to Transit Hall
Drive empty Transit Hall train back to CE
Transit Hall Trains is assembled at CE
Coil clusters from Transit Hall are assembled at CE
Train
Track available?
Wait for track to be available
Store train at track
Train empty?
Next colli an ETTS?
Double colli loading?
Coil
BUO/BUW ETTS generator activated
ETTS Cluster in BUO and BUW are assembled
Forklift truck available?
Wait for forklift truck to be available
Drive ETTS or Coil to Quay crane
Quay crane available?
Trh crane available?
Wait for Trh crane to be available
Move coil from storage to Transit Hall door
Unload Transit Hall train
Train empty?

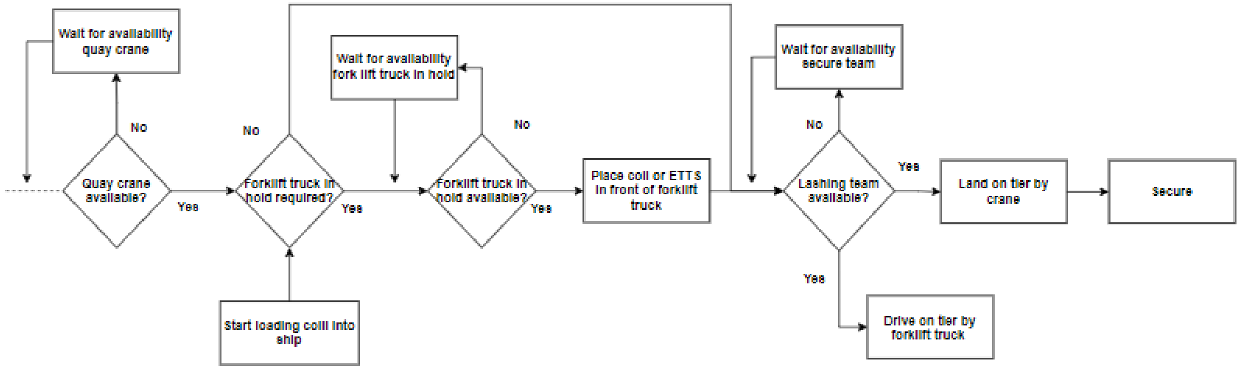


Figure 4.5: Conceptual model part 3

4.1.1 Assumptions and simplifications

In general a model is used to mimic the real life system under research. However, as George Box stated: "All models are wrong, but some are useful". This quote explains that each model includes to a more or lesser extent simplifications and assumptions in order to overcome the complexity of the real world. In this section, the simplifications and assumptions made with respect to the real life system are therefore considered in the conceptual model. In the process of constructing a conceptual model based on the system description, simplifications have to be made as can be seen in Figure 4.1. These simplifications have to be discussed. (Robinson, 2011) describes assumptions as decisions made due to the uncertainties about the real world being modeled. They are the result of limited knowledge on certain aspects of the real world. Simplifications are made such as to stimulate a quicker model development and use, and also to increase the transparency of the model to both the developer as well as the used or interested party. Using these definitions the following assumptions are made throughout this research:

Assumptions

Shifts

S&W usually uses a 3,3,2 crane operation planning, meaning that during the shift from 06:00-14:00 and from 14:00-22:00 1 Transit Hall crane and 2 quay cranes are operational. From 22:00-06:00 only one quay crane is available for operation. The model puts one of the quay cranes out of operations randomly such to mimic this planning.

Cluster and stowage sequence

First of all, the cluster sequence and stowage sequence of vessels are not considered in this research. Meaning that there is no predefined order in which coils or ETTS are loaded other than the rule of thumb used in the harbour which states that ETTS are stowed preferably first, followed by the stowage of coils. This is modelled by loading trains with ETTS first and only load additional coils if weight restriction allow for that. Once all ETTS are transported towards the quay, there will automatically be more space left for coils to be loaded onto trains Moreover, coils from the Transit Hall are only delivered after all ETTS from the ETTS storage in the harbour are already loaded. As size and weight in fact to play a role in the sequence of loading it is expected that there the model might 'load' vessels faster than would have been the case in real life.

Barges and short sea vessels

Secondly, the focus of this research paper is on the loading sequence of the largest type of ships visiting the outer-harbour 3 of Tata Steel IJmuiden, the deep sea vessels. During several interviews and conversations with operational personnel it was stated that the most complex and most time consuming processes are considered while loading deep sea vessels. It is assumed for the model that only deep sea vessels visit the port. The expected effect is that the utilisation of machines and resources will be lower in a simulated year than it would be in the real system, simply because barges and short-sea vessels are not processed by the model.

Pre,- and post stowage processes

Every vessel that arrives at the harbour of Tata Steel IJmuiden is only allowed to dock if clearance is given. Once a vessel is cleared a sequence of pre-loading processes are executed, such as the docking itself and a hatch test 'luiken test'. Once these processes are finished stowage is started. Once the stowage of the vessel is done, the hatches of the holds are closed and the vessel is undocked. These pre,- and post stowage processes take time, however in this research they are not considered. Overall this has no expected impact of the results of the model as these procedures are assumed to be the same for each ship and because the model results focus on the loading time and also are compared to the historical loading times rather than the full docking time of vessels.

Forklift truck handlings

As elaborated upon in subsection 3.4.6, there are eight forklift truck routes around the quay considered in this research. These include the routes to the two quay-cranes from the Transit Hall, the BUO, the BUW and from trains. Transporting colli from the train to the cranes is considered for all ETTS and only for those coils that are moved in pairs of two per crane movement. Loading per two coils is not possible directly from train wagons, and therefore requires a forklift truck to move the coils from the train onto the quay, within the reach of a crane. For each of these movements a constant value is considered, based on data required from using a stopwatch actual operations during stowage of deep sea vessels in the outer-harbour 3. Potential impacts of this decision are only worth considering if the forklift trucks turn out to be the bottleneck in the system. However, this is not expected to be the case as case studies such as (Kulak et al., 2013) suggest that yard trucks etc. are almost never the bottleneck in terminal environments. However if indeed the forklift truck are considered to be bottlenecks, if might be required to look at this assumption again and reconsider whether making these trips a constant is actually defensible.

Securing colli

The time it takes to secure colli in a ship are assumed to be 90 seconds for coils and 120 seconds for ETTS, due to the unavailability of data on this process. These two constants are determined in consolidation with operations expert. They admitted that the duration of this process is depending on countless factors and that they could only make educated guesses as to the duration.

Simplifications

Use of resources

Throughout the model, certain components ask for the availability of resources with limited capacity. Resources are usually linked to a sequence of tasks. For example, a forklift truck is assigned to transport coils from the Transit Hall towards one of the quay cranes. The model is made in such a way that for each of these tasks one of the available forklift trucks is used instead of a dedicated forklift truck. This simplification holds for each resource in the model, the locomotives, tracks, Transit Hall crane, quay cranes, forklift trucks in the hold as well as the securing teams.

Double stowage

During certain parts of the stowage process, the crane teams are able to move two ETTS or coils at the same time. This is possible once a certain number of collo are already loaded onto the vessel and if the proper crane handling equipment is available. If all conditions are met, the crane within the real life system will move two colli at the same time. However, within the model, each coil or ETTS is moved and processed by the quay-cranes individually. Once the conditions for double loaded are met as is described in the PDL in section 4.1.1, each colli is still processed individually, but now, the sampled handling time for that colli is divided by two as to simulate this double loading. The logic used here can be explained using the elaborating on the following two situations:

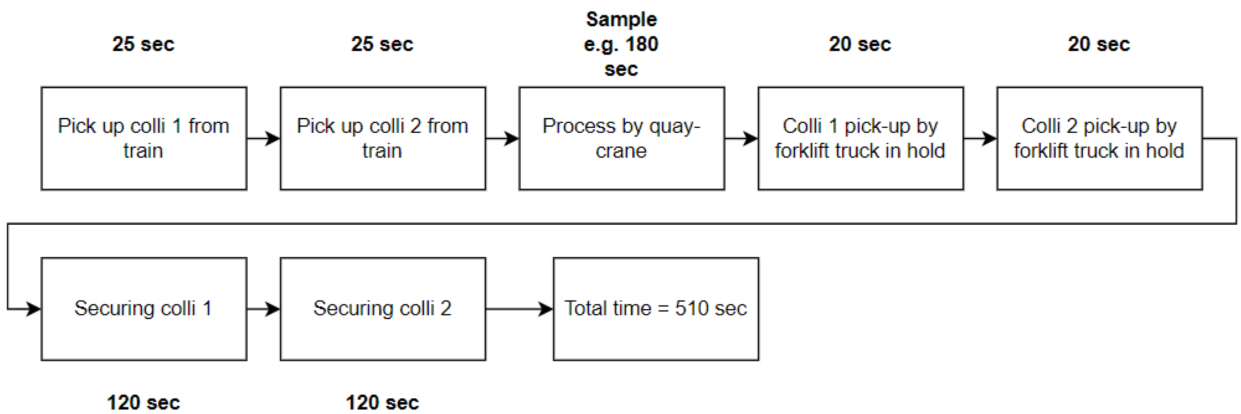


Figure 4.6: Double colli loading sequence real-life system

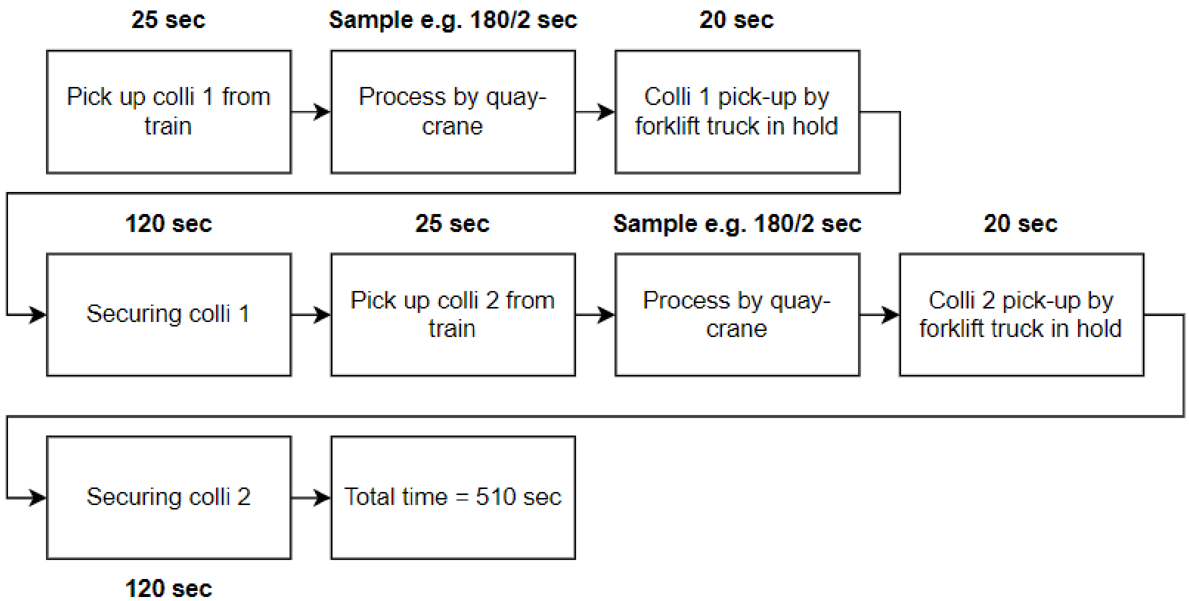


Figure 4.7: Double colli loading sequence simulation model solution

Process Description Language

As mentioned the PDL is used to go from a conceptual model towards a computerized model.The PDL is used as guidance to code the computerized model in such a way that it resembles the design indented by the developer and it also functions as a reference point for those interested in how the computerized model works, without having to deep dive into the code. The PDL can be found in Appendix C.

Model implementation

Model implementation is done using the Python programming language and specifically the Salabim Discrete-event Simulation package. The reason to use both is because both are open source software packages. Further implementation as specifically the verification is done in in a separate chapter, chapter 5 as to combine it with the model validation steps.

4.1.2 Conclusion

The intention of this chapter is to answer the second part of sub-research question 4.

- Sub-research question 4: *What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals* ***and what should this model look like in terms of its design?***

Multiple methods to design discrete-event simulation models are used. Firstly the design methodology as presented in Figure 5.1 is used as a guidance for the steps to take during the design and realisation of a simulation model. It starts with the problem definition and system thinking as done in chapter 3, followed by designing a conceptual model. This conceptual model is based on the view of (Robinson, 2011), where the significance of a well designed conceptual model is emphasised as it should clearly include the inputs, outputs, workings and objective of the model as well simplifications and assumptions made transfer a real world problem in such a way that can eventually be described using appropriate programming language. The model should include those elements that are deemed important in the processes under investigation and therefore they should be included in the conceptual and computerized model. For this research a conceptual model was successfully made and enables the author to design the PDL as can be seen in Appendix C and the computerized model for the experiments. The computerized model is written using Python with the Salabim Discrete-event Simulation package as it is software for models.

Chapter 5

Verification, validation

Validation and verification are two vital steps in designing models. These are solid methods to determine whether 'the model is right' and whether 'it is the right model'. As one can see in Figure 5.1 These are together with the sensitivity analysis part of the fourth step in the process of model design.

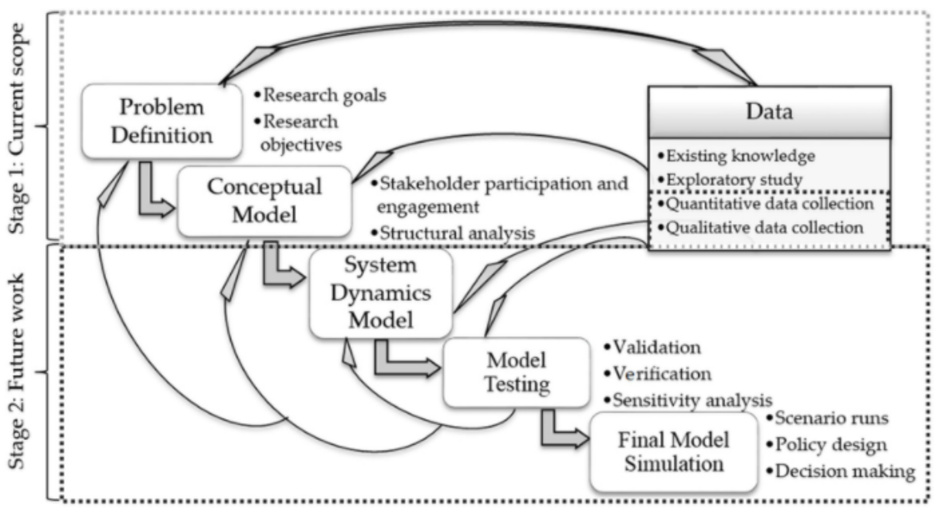


Figure 5.1: Model of the Russian Federation Construction Innovation System: An Integrated Participatory Systems Approach (Suprun et al., 2016)

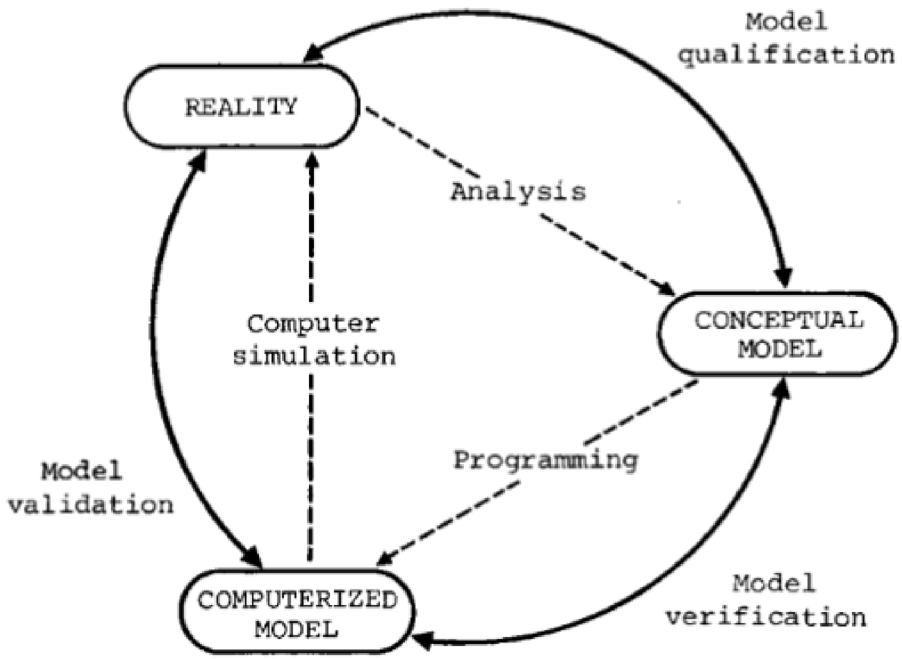


Figure 5.2: SCS report - Terminology for model credibility (Committee et al., 1979)

(Committee et al., 1979) displays how the model verification and validation are related to the real system, conceptual model and computerized model. From analysis on the real system, a conceptual model is made. Subsequently, from this conceptual model representation of the system, a computerized model representation is made through programming in which verification plays a major role as it helps in building a computerized model that fits the design. Once the model is verified, computer simulations can be executed and compared to the real life system. The outputs of both the real life system as well as the computerized model should be compared as to validate the model. it is important to understand that models are representations of the real system in which simplifications are unavoidable to make. However, if your model behaves and calculates results that are within acceptable margins on the real system, the model can be considered valid in the eyes of the user. In this chapter, both the verification and validation of the model are elaborated upon in detail. The chapter is finished by analysing the current system with the goal of setting a base value for each of the KPIs such that these can be used for comparison later with the experiments.

5.1 Verification

Verification is a significant step in the process of building a model. In order to verify a model, one must ask the question whether the model is right. This entails the fit of the model according to the planned design and specifications of the model, namely the conceptual design and Program Description Language that were designed. Verifying the computerized model in this research entails the execution of a set of verification tests both during the development of the conceptual model as well as the transition to the computerized model. Below one can see the list of verification tests that were executed. These tests are based on suggestions from (Duinkerken and Atasoy, 2019).

- Flow conservation
- Use deterministic values instead of stochastics and predict outcome

5.1.1 Flow conservation

The conservation of flow of temporarily elements entering and leaving the system is also tested. These test provide insight in whether the model processes these elements according to the intentions of the designer and developer of the model.

- ETTS load of a vessel equals train + BUO&BUW supply
- Coil load of a vessel equals train + Transit Hall supply
- Load of quay-trains and Transit Hall trains

Flow conservation of the whole system

For each of the tests discussed in this section, 10 random vessels are generated from the 75 vessels available. As these are random the numbers change throughout the tests. In the first test, seen in Table 5.1, the model is forced to supply all coils and ETTS via trains instead of using the Transit Hall or BUW storage. If build correctly, all values in column 5 and 8 should be zero, which is the case. Moreover, the 'Vessel load total' column 3 should equal the sum of the supplied colli which are stated in column 6 'ETTS load total' and column 9 'Coil load total' again this is the case.

Test: 100% coils and ETTS trains	Vessel load ETTS	Vessel load coils	Vessel load total	Train load ETTS	BUO&BUW load ETTS	ETTS load total	Train load coils	Transit Hall load coils	Coil load total
1	0	1367	1367	0	0	0	1367	0	1367
2	0	743	743	0	0	0	743	0	743
3	0	565	565	0	0	0	565	0	565
4	0	565	565	0	0	0	565	0	565
5	992	480	1472	992	0	992	480	0	480
6	0	565	565	0	0	0	565	0	565
7	315	394	709	315	0	315	394	0	394
8	0	469	469	0	0	0	469	0	469
9	1052	516	1568	1052	0	1052	516	0	516
10	136	347	483	136	0	136	347	0	347
Total	2495	6011	8506	2495	0	2495	6011	0	6011

Table 5.1: Flow conservation checks for 100 load of coils and ETTS via trains

In the second test, seen in Table 5.2, the model is forced to supply 75% of the coils and ETTS via trains and 25% using the Transit Hall or BUW storage. As this model processes individual colli, a perfect 25% is not possible as you would not get integer numbers. However, rounded the numbers again work out. According to the same comparison of columns as in with the first test.

Test:	Vessel load ETTS	Vessel load coils	Vessel load total	Train load ETTS	BUO&BUW load ETTS	ETTS load total	Train load coils	Transit Hall load coils	Coil load total
1	0	1367	1367	0	0	0	1026	341	1367
2	1067	676	1743	801	266	1067	507	169	676
3	411	774	1185	309	102	411	581	193	774
4	850	755	1605	638	212	850	567	188	755
5	1103	24	1127	828	275	1103	18	6	24
6	0	430	430	0	0	0	323	107	430
7	1188	382	1570	891	297	1188	287	95	382
8	0	1367	1367	0	0	0	1026	341	1367
9	0	839	839	0	0	0	630	209	839
10	962	646	1608	722	240	962	485	161	646
Total	5581	7260	12841	4189	1392	5581	5450	1810	7260

Table 5.2: Flow conservation checks for 75% load of coils and ETTS via trains and 25% via outer-harbour 3 storage

In the third test, seen in Table 5.3, the model is adjusted to split the ratio of supply of coils and ETTS via train and Transit Hall and BUW to 50/50. Again due to having to deal with integer numbers the outcomes are not perfectly 50% differentiated, however again the flow conservation is maintained as the columns show.

Test:	Vessel load ETTS	Vessel load coils	Vessel load total	Train load ETTS	BUO&BUW load ETTS	ETTS load total	Train load coils	Transit Hall load coils	Coil load total
1	0	1367	1367	0	0	0	684	683	1367
2	1067	676	1743	534	533	1067	338	338	676
3	0	1196	1196	0	0	0	598	598	1196
4	0	590	590	0	0	0	295	295	590
5	923	620	1543	462	461	923	310	310	620
6	7	1041	1048	4	3	7	521	520	1041
7	0	1	1	0	0	0	1	0	1
8	1052	516	1568	526	526	1052	258	258	516
9	1214	98	1312	607	607	1214	49	49	98
10	0	1367	1367	0	0	0	684	683	1367
Total	4263	7472	11735	2133	2130	4263	3738	3734	7472

Table 5.3: Flow conservation checks for 50% load of coils and ETTS via trains and 50% via outer-harbour 3 storage

In the fourth test, 25% of the products are supplied via train and the other 75% via the Transit Hall and the BUW. Again looking at the results the model is doing what it should. ETTS can be checked by summing up column 4 and 5 and compare and compare the outcomes with column 1. Coils can be checked by summing column 7 and 8 and compare it to column 2. Summing column 6 and column 9 should equal column 3.

Test:	Vessel load ETTS	Vessel load coils	Vessel load total	Train load ETTS	BUO&BUW load ETTS	ETTS load total	Train load coils	Transit Hall load coils	Coil load total
1	0	1367	1367	0	0	0	342	1025	1367
2	1067	676	1743	267	800	1067	169	507	676
3	0	266	266	0	0	0	67	199	266
4	1107	322	1429	277	830	1107	81	241	322
5	0	1	1	0	0	0	1	0	1
6	0	839	839	0	0	0	210	629	839
7	1541	0	1541	386	1155	1541	0	0	0
8	767	732	1499	192	575	767	183	549	732
9	675	716	1391	169	506	675	179	537	716
10	675	716	1391	169	506	675	179	537	716
Total	5832	5635	11467	1460	4372	5832	1411	4224	5635

Table 5.4: Flow conservation checks for 25% load of coils and ETTS via trains and 75% via outer-harbour 3 storage

Lastly and to finish this series of flow conservation tests, the model is adjusted to only supply coils and ETTS via the Transit Hall and the BUW. Outcomes are summarised in Table 5.5. Expectations are that both column 4 and 7 are zero, which they are. Moreover, comparing the other columns again shows that the total vessel load is supplied and processed by the model.

Test:	Vessel load ETTS	Vessel load coils	Vessel load total	Train load ETTS	BUO&BUW load ETTS	ETTS load total	Train load coils	Transit Hall load coils	Coil load total
1	0	1367	1367	0	0	0	0	1367	1367
2	0	469	469	0	0	0	0	469	469
3	878	570	1448	0	878	878	0	570	570
4	769	642	1411	0	769	769	0	642	642
5	136	347	483	0	136	136	0	347	347
6	0	689	689	0	0	0	0	689	689
7	0	616	616	0	0	0	0	616	616
8	0	348	348	0	0	0	0	348	348
9	1152	657	1809	0	1152	1152	0	657	657
10	0	425	425	0	0	0	0	425	425
Total	2935	6130	9065	0	2935	2935	0	6130	6130

Table 5.5: Flow conservation checks for 0% load of coils and ETTS via trains and 100% via outer-harbour 3 storage

Overall the five flow conservation tests performed show that the model is able to supply coils and ETTS according to the indented design. Also the model processes the correct amount of products which build trust that the model is doing what it should.

Flow conservation Transit Hall

The Transit Hall has a capacity of 2000 coils. During the loading procedure of vessels a percentage of the required coils is supplied via the Transit Hall rather than directly via trains. As there is inflow and outflow of the Transit Hall again flow conservation should be kept. For this test 10 simulation runs of 10 randomly generated vessels are executed. The Transit Hall is set to 2000 at the beginning of each simulation. The results of the simulation runs are summarised in Table 5.6. The model is verified for this part if the sum of column 1 and column 2 minus column 3 equals the value in column 4. As one can see, this is the case for all simulations. The model is thus verified for maintaining the correct flow of coils with respect to the Transit Hall.

Simulation:	Initial storage Transit Hall	Transit Hall input	Transit Hall output	End storage Transit Hall
1	2000	2231	2513	1718
2	2000	1820	1808	2012
3	2000	2063	2410	1653
4	2000	1028	1233	1795
5	2000	1511	1594	1917
6	2000	917	1944	973
7	2000	1924	2138	1786
8	2000	1264	1579	1685
9	2000	402	1876	526
10	2000	1814	1933	1881

Table 5.6: Flow conservation of the Transit Hall

5.1.2 Deterministic input and prediction

In order to predict how long a ship would be docked to the quay and stowed, all stochastic values used in the model are set to deterministic values. The capacities of all resources, except the locomotives and quay tracks, are set to 1, such as to mimic what would happen if all components are waiting in the same queue for the same resource, in other words all flow follows same paths where possible. Delay of operations due to rain or failure of machines is neglected. Also the quay crane that is operational, is active 24/7. The input setup for this test is as follows:
Configuration

- 1 quay crane
- 1 Transit hall crane
- 1 Forklift trucks on the quay
- 1 Forklift truck in the hold
- 1 securing team available in the hold
- 3 locomotives
- 3 quay tracks
- No rain
- No failure of machines
- No 3-3-2 quay crane operational planning

Scenario

- 1 vessel with 1965 ETTS and 412 coils
- 85% of coils from the Transit Hall or 350 coils
- 15% of coils supplied via trains 62 coils
- 34% of ETTS via BUW and BUO 668 ETTS
- 66% of ETTS supplied via trains 1297 ETTS

Performance

- Transport from BUO and BUW to quay cranes constant at 120 seconds
- Transport from the Transit Hall towards the quay cranes equals 40 seconds
- Transport from train towards the quay cranes equals 30 seconds
- Transport in hold 20 seconds
- Quay crane with a constant cycle time of 1 minute
- Transit hall crane with a constant cycle time of 1 minute
- Securing coil takes 90 seconds
- Securing ETTS takes 120 seconds
- Assembling time trains CE constant at 8 hours
- ETTS transported via trains constant at 60
- Coils transported via trains constant at 60
- Allowed weight for trains constant at 850 tonnes
- ETTS weight constant at 8 tonnes
- Coil weight constant at 20 tonnes
- Transportation of train towards the quay at 45 minutes

Output

- In total 22 trains towards the quay with 62 coils and 1297 ETTS with a total weight of 11616 tonnes (or 62*20+1297*8)
- 0 trains towards the transit hall
- Length of loading 10219.0 minutes
- 1965 ETTS loaded with a total tonnage of 16702.5 tonnes
- 412 coils loaded with a total tonnage of 8240 tonnes

It must be proven that 10219.0 minutes is a predictable value of the total loading time, given the configuration, scenario and performance data as stated above. Looking at the way the simulation model is designed. As expected firstly the ETTS from the BUW and BUO are loaded in combination with trains from CE transporting 60 ETTS with a weight of 480 tonnes and 18 coils with a weight of 360 tonnes such that the limit of 850 is not exceeding as designed as can be seen in the list of loads of these 22 trains in Table 5.7. Every 8 hours exactly a train arrives at the quay, with the last one at 10125.0. This is in line with what is expected as the first train is already loaded once the vessel docks. The train takes 45 minutes and thus arrives exactly at 45 as can be seen in Table 5.7. From minute 45, 21 more trains are generated. Thus 45 + 21*480 = 10125.0 minutes. The last train carries 37 ETTS with a total load of 296 tonnes as can also be seen in Table 5.7. Therefore these 37 ETTS take on average 10219.0 - 10125 = 2.5405 minutes which is exactly equal to the processing times before the securing team. Taking little's law into account. First, 30 seconds processing time to move the ETTS with a forklift truck from train to quay crane. Subsequently 60 seconds of processing time by the quay crane and lastly 20 seconds for the forklift truck inside the hold to place the ETTS in its final position. Thus in total 110 seconds, which is equal to an arrival rate of 60/110 or 0.5405 ETTS/minute + the additional 120 seconds for the securing it self resulting in 2.5405 minutes. Thus concluding, the train arrives at the quay at 10125.0 minutes. Each ETTS takes on average 2.5405 minutes, meaning 37 ETTS will take 94 minutes, thus 10125.0 + 94 equals 10219 minutes. This concludes that if all values are made deterministic one can predict the exactly.

Train	Arrival time at quay [min]	Total tonnage of load [kton]	Number of ETTS	Tonnage ETTS [kton]	Number of coils	Tonnage coils [kton]
1	45	840	60	480	18	360
2	525	840	60	480	18	360
3	1005	840	60	480	18	360
4	1508	640	60	480	8	160
5	1965	480	60	480	0	0
6	2445	480	60	480	0	0
7	2925	480	60	480	0	0
8	3405	480	60	480	0	0
9	3885	480	60	480	0	0
10	4365	480	60	480	0	0
11	4845	480	60	480	0	0
12	5325	480	60	480	0	0
13	5805	480	60	480	0	0
14	6285	480	60	480	0	0
15	6765	480	60	480	0	0
16	7245	480	60	480	0	0
17	7725	480	60	480	0	0
18	8205	480	60	480	0	0
19	8685	480	60	480	0	0
20	9165	480	60	480	0	0
21	9645	480	60	480	0	0
22	10125	296	37	296	0	0

Table 5.7: Train data for deterministic test

5.2 Validation

Validation of a model is asking whether the model and its associated data, accurately enough represent the real world processes one tries to model. The question to be answered is whether 'it is the right model'. Validation is the process of being certain, within a domain of applicability, that the model is able to generate results withing a satisfactory range of accuracy in the context of the intended application of the model. As much as it is desired, 100% validation does not exist as the very nature and definition of a model is that it is wrong to some extend. In this section the model built, is validated by executing a set of test in a base scenario and base configuration context. This base model mimics the 'as-is' situation of the outer-harbour 3. For each test, the results are compared with historical data. In Figure 5.3 one can see a simple representation of the validation plan.

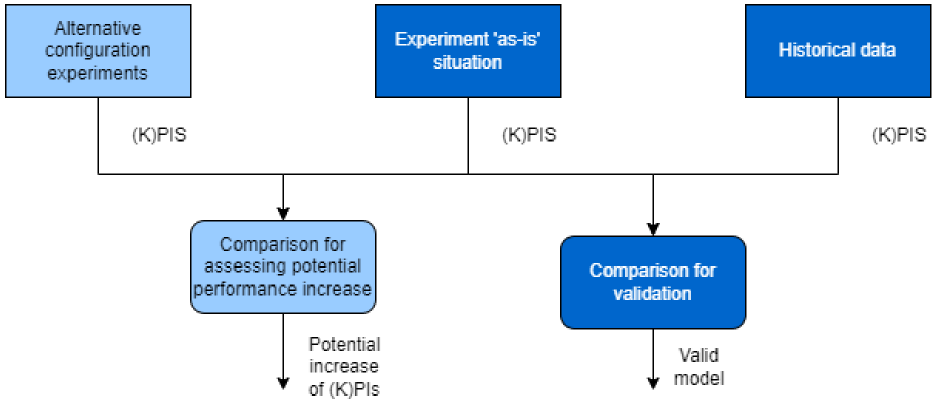


Figure 5.3: Visualised validation plan in dark blue

Not all facets of the model can be validated, however several are tested to make sure that the model is valid to a certain extent. For the DES model made to model the logistical processes around the outer-harbour 3 of Tata Steel IJmuiden the validation tests to be performed are:

- Inter-arrival time of vessel validation
- KPI calculation validation
- Quay crane operational time validation
- Quay crane rain and failure interruption validation

5.2.1 Base scenario,- and configuration

The base configuration and base scenario are discussed in chapter 3, which elaborates on the analysis of the system. A list of 74 vessels and their corresponding coils and ETTS load, that have visited IJmuiden between October 2020 and January 2022 is used as input for the model for this test. The data can be found in Table D.2 and Table D.3. The model is run for exactly 365 days. Vessels from this list are randomly generated with an inter-arrival time of 6,1 days and are subsequently processed by the model. The base configuration data includes:

- 2 quay cranes
- 2 quay forklift trucks
- 2 forklift trucks in a vessel's hold
- 2 securing teams
- 3 locomotives
- 1 Transit Hall crane

Important to mention is the fact that for the quay cranes, the quay,- and hold forklift trucks, as well as the securing teams the 3-3-2 crane operational strategy as discussed in chapter 3 applies. Lunch breaks, watch change, rain and failure/maintenance occurrences are also applicable, as discussed in chapter 3.

5.2.2 Inter Arrival Time

Firstly the inter-arrival time of vessels as calculated by the model is compared to the actual inter-arrival time of the 74 vessels. In Figure 5.5 one can see two plots. The upper plot includes a histogram of the inter-arrival times as generated by the model. In the lower plot, one can see a histogram including the inter-arrival times of historical data. The model inter-arrival times vary from 0 to 270 hours, with an average of 147,3 hours. The historical data shows inter-arrival times varying between 0 and 270 hours as well, with a mean of 149,3 hours. Based on these two figures, it can be concluded that the model generates vessels with a valid inter-arrival time.

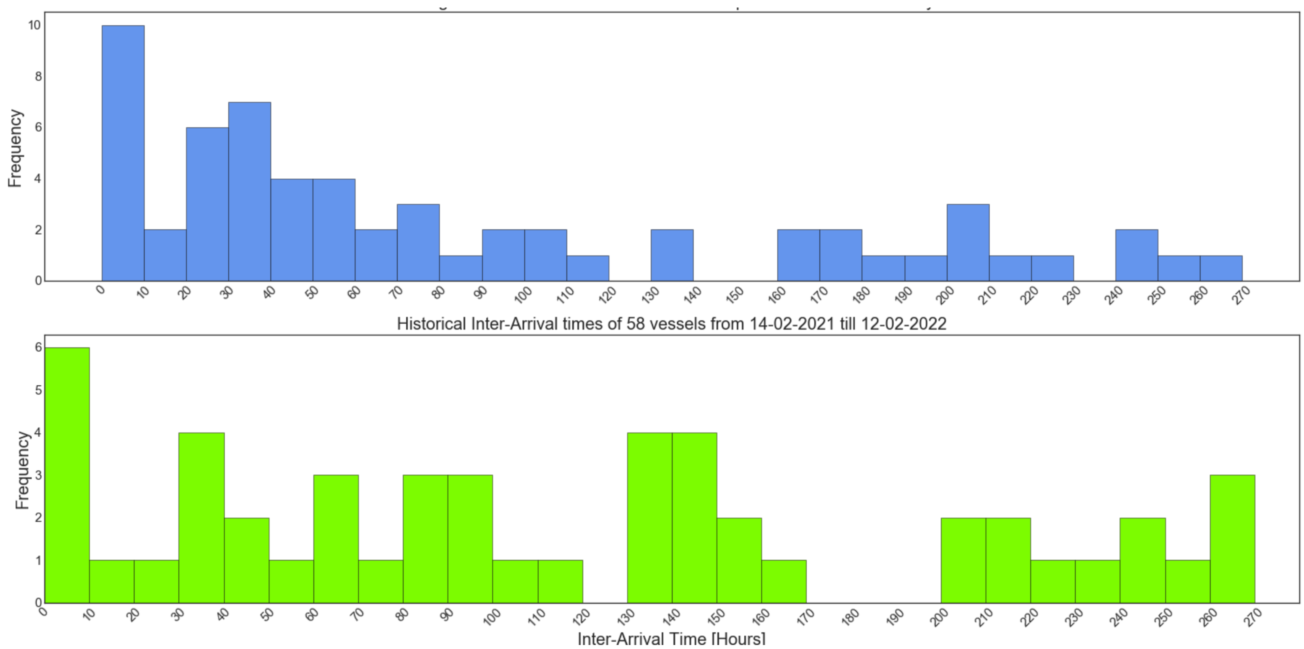


Figure 5.4: Comparison of Inter-Arrival Time of vessels generated by the model and historical data

Validation of KPIs

In this section a quantitative confidence interval validation test is executed on the simulation model outputs. For each KPI a confidence interval is built according to the validation method procedure constructed by (Petty, 2012):

1. Select the model output variable to be validated
2. Determine an appropriate sample size n.
3. Run the model n times
4. Calculate the sample mean $\bar{x}$ and sample standard deviation s
5. Based on the availability of distribution of the model output variable and the availability of the population standard deviation chose z or t distribution to calculate the confidence interval
6. Select the desired confidence level c, e.g. 95%

7. Calculate confidence interval $[L, U]$

8. If the population mean of the output variable of interest is within the confidence interval $[L, U]$, the model can be declared valid for that output variable. If not, the model is invalid for that output variable.

This method is applied to draw conclusions whether the simulation model is able to calculate the KPIs with a certain accuracy. This conclusion is thus drawn based on the fact whether the true mean value of this KPI is situated within the confidence interval. The setup of this validation test is as follows. Each simulation includes the arrival, and processing of 50 unique vessels. Vessels that arrive with an exponentially distributed inter-arrival time, with a mean of 6,2 days. The vessels and their respective ETTS and/or coil loads are not generated using a distribution, but are drawn from a dataset including vessels that have visited the outer-harbour 3 in the past. The data set can be found in Appendix F. As discussed in chapter 3, there are three reasons why this decision is made. Firstly, this way it is guaranteed that vessels are processed by the model that request realistic loads of ETTS and coils. Secondly, as each simulation run includes the same vessels and same load, comparisons can be made more easily. Lastly, this approach makes it possible to compare the values of (K)PIS with historical values of these (K)PIs. In order to fix the scenario data of the experiments, the list of vessels randomly generated for this first experiment is subsequently used as scenario data input for the other experiments elaborated upon in chapter 6. Apart from the scenario data, the configuration data includes:

- 3 Locomotives
- 1 Transit Hall crane
- 2 Forklift trucks on the quay
- 2 quay cranes
- 2 Forklift trucks in hold of vessel
- 2 securing teams

In order to generate a confidence interval and to check whether the population mean for each KPI falls within that confidence interval, the population distribution has to be generated as well as the population standard deviation. The population distribution for each KPI is assumed to be normal distributed. If the mean of each KPI is known as well as standard deviation of the population the z distribution is used. For some of the KPIs only the population mean is known, but the standard deviation is not known and therefore the t distribution will be used to construct confidence intervals for each these KPIs. The KPIs that are not validated are 'Costs' and the 'Use of resources' KPI. The former KPI is not checked as the costs of the base model are assumed to be equal to the known costs, 8.8 million euros. The model does not separately calculate costs as a function of for example of the resources operated. The latter KPI cannot be validated as there is no data available regarding historical values. Each simulation is run 30 times as to stimulate stimulate statistical accuracy (Petty, 2012). Hence the sample size $n = 30$ and the degrees of freedom equals 30 - 1 = 29. The confidence level c, is 0.95 and for 58 degrees of freedom the required the critical value of the Student t distribution t_c thus should equal 1.699 and the critical z value z_c should equal

1.96. Based on this information the confidence intervals of the population of which no standard deviation is known is calculated using:

$$\left(\bar{x} - t_c\frac{s}{\sqrt{n}}, \bar{x} + t_c\frac{s}{\sqrt{n}}\right) \tag{5.1}$$

For the KPIs of which the population standard deviation is known, the following formula is known:

$$\left(\bar{x} - z_c\frac{\sigma}{\sqrt{n}}, \bar{x} + z_c\frac{\sigma}{\sqrt{n}}\right) \tag{5.2}$$

Where $\bar{x}$ equals the sample mean, s equals the sample standard deviation, σ equals the population standard deviation and n the sample size. Using a confidence interval of 95% for each KPI the validity of the model is checked. If true mean of each KPI is within the 95% confidence interval of the sample means that the model is deemed valid (Petty, 2012). The results can be seen in Table 5.8.

n = 30 Degrees of freedom = 29 z .95 = 1,96 t .95 = 1,699	Statistical test	Population		Model		Confidence interval		Validation
KPI	**T or Z test**	**Population mean mu**	**Population Std sigma**	**Model mean X**	**Model Std dev s**	**Lower bound L**	**Upper bound U**	**Valid?**
Productivity volume	z	4477	2115	5620	511,5	4863,4	6377,1	No
Productivity quantity	z	297	112	353	29,8	243,0	323,2	Yes
Puntuality	t	21	N.A.	22	4,4	20,4	23,2	Yes
Demurrage	t	€ 484.964	N.A.	€ 476.865	€ 103.489	€ 508.967	€ 444.763	Yes
Average loading time	z	3,6	2,2	3,4	0,3	2,6	4,2	Yes

Table 5.8: Validity test Model 50 unique vessels

Table 5.8 provides a quantitative insight into the validity of the simulation model that is built. As one can see, for each of the KPIs, except the loading time, the model is deemed valid as the population means fall within the confidence intervals.

Punctuality

From the table, once can see that the population mean of the punctuality performance falls inside the calculated confidence interval of the punctuality simulation results as calculated by the model appear. Therefore the model is deemed valid for this key performance indicator.

Demurrage

Based on the simulation result, a sample mean and standard deviation of this key performance indicator is used to create a confidence interval. The population mean of the demurrage costs is inside the confidence interval and therefore the model is deemed valid for this key performance indicator.

Average loading time

The average loading time of vessels is considered as one of the KPIs that is used to assess the performance on the outer-harbour 3. Therefore it is important to validate that the model outputs of this KPI are in acceptable line with actual average loading time of deep sea vessels in the outer-harbour 3. The population mean of the average loading time equals 3.6 days. The population mean falls within the upper and lower boundary of the 95% confidence interval, thus the model is considered valid for calculating the average loading time of vessels.

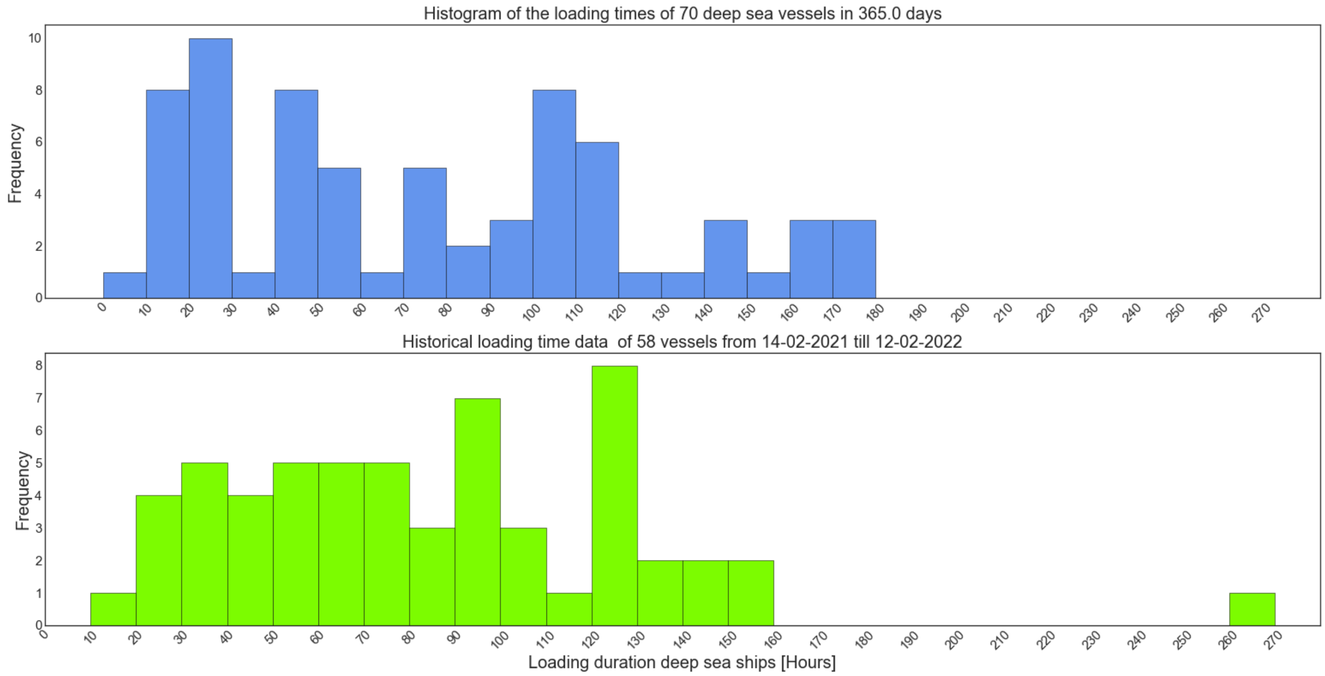


Figure 5.5: Comparison of stowage time model and historical data

Productivity volume

The productivity population mean equals 4477 tonnes/day. The lower boundary of the 95% confidence interval equals 4863 tonnes/day, thus the model is in that sense not considered valid for calculating the productivity in volume. The next step is subsequently to explain why the model calculates higher productivity volumes that the actual population mean. This is done in section 5.2.2.

Productivity quantity

Besides the productivity in volume, it is also measured in terms of number of colli loaded per day. Looking at the table, it can be seen that the population mean of 297 is within the confidence interval for the model productivity colli/day. Therefore the model is considered valid for calculating the colli/day.

Explanation

section 5.2.2 explains that the simulation model is not considered valid for calculating the volume productivity. However, in section 5.2.2 it discussed is that the model is in fact valid for calculating the productivity measured in colli/day. There seems to be a mismatch here. The model processes more volume as there is a difference of around 400 tonnes/day. This is expected to be due to the fact that the average weight of the colli is assumed to be uniform for both coils and ETTS for this research. However, it could very well be that this the mean would be more towards a lower number. However as the number of colli loaded per day is still deemed valid, there are no concerns as to the overall validity of the model.

Costs

Costs are not part of the validation process. Costs are only calculated if there are additional expenses made. The base configuration thus has additional costs of 0, which cannot be validated. The additional costs per used locomotive per 8 hours was validated by Tata Steel experts. This number is rounded 100.000 euros and is used in experiment 2.

5.2.3 Other validation tests

Apart from the validation KPI outputs of the simulation model, it is also worthwhile to validate those components of the model of which historical data is available, and thus can be used to compare model outputs with. In the coming sections some additional components of the simulation model are validated.

Operational time cranes

In the real system, the quay cranes are not operational 24 hours per day, 365 days a year. If the model would operate the quay cranes constantly, vessels would be processed much faster. Therefore model output is compared to historical data. As can be seen in Table 5.9 for a period of 220 days the cranes were not operational for about 38& of the total time. The model output is almost the same. Therefore it is concluded that the model operates the quay cranes to the same extent as would be the case in the real system.

Non-operational quay cranes	Historical data	Period	Percentage	Model output
Crane 131	121052 minutes not operational	220 days	38,2%	37,4%
Crane 132	117494 minutes not operational	220 days	37,1%	38,2%

Table 5.9: Comparison between historical non-operational times quay cranes and model output

Rain and failure

Both rain and failure interrupt the loading process and are therefore modelled as well. Looking at both Table 5.10 and Table 5.11 one can see that only the interruption time of crane 131 by rain is calculated to be less by the model than the real historical shows. However crane 132 seems to be measured properly as well as the failure for both cranes. Overall, as this is not a significant part of the model, the effects are considered valid.

Rain occurences	Historical data	Period	Percentage	Model output	Period
Crane 131	26674 minutes interrupted by rain during operations	220 days	22,0%	17,8%	365 days
Crane 132	21573 minutes interrupted by rain during operations	220 days	17,8%	17,5%	365 days

Table 5.10: Comparison between historical interruptions due to rain and the model output

Failure occurrences	Historical data	Period	Percentage	Model output	Period
Crane 131	5076 minutes interrupted by failure and maintenance	220 days	4,19%	4,48%	365 days
Crane 132	3836 minutes interrupted by failure and maintenance	220 days	3,27%	4,78%	365 days

Table 5.11: Comparison between historical interruptions due to failure and maintenance and the model output

Conclusion on verification and validation

Overall the model is verified and validated by executing multiple tests. From the validations tests is it clear that the model calculates to much volume to be processed per day. However the number of colli processed per day is still within acceptable boundaries. This higher volume is expected to be the result of the distribution of colli weights to be estimated higher that would have been the case in real life. However as this is the only invalid part of the model and the author is aware of this, the model overall is accepted and used to analyse the system further in this chapter and for the experiments done in chapter 6.

5.2.4 Calculating the bottleneck in the current system

Previous verification and validation tests proof that the model is to a large extent able to mimic the real life system and thus it is used to analyse the of the current configuration and detect the bottleneck(s). Tata Steel IJmuiden wants to obtain more valuable insights into the bottleneck or bottlenecks in the processes associated with the loading of deep sea vessels in their outer-harbour 3. As part of field research, several employees of Tata Steel were asked to shine their light on those processes that could be the bottleneck. In general either the locomotive capacity and the duration to assembly trains in the different warehouses in the hinterland were expected to be the bottlenecks. The following analysis aims to confirm or refute these thoughts by running 30 experiments with current input scenario, configuration and performance data. The goal is thus to identify bottlenecks in the current system. The results of this experiment provide insights were the bottleneck is located in the current system. Knowing where the bottleneck is located provides direction into which configuration changes are most wise to test and what the impact of those changes are on the performance of the system. In Table 5.12 small summary of the analysis setup is given.

Base configuration analysis	
Reason	Tata Steel expert insights
Setup change scenario	Scenario equals base scenario from section 5.2.2
Setup change configuration	Configuration equals base configuration from section 5.2.2
Goal	Detect bottleneck(s) in current system
Expected results	Based on interviews with Tata Steel employees the supply from the hinterland and/or the locomotive capacity are most likely to be the bottleneck(s)

Table 5.12: Base configuration analysis setup

Results

The simulation is run and the results are further analysed using two bottleneck detection methods. In recap, the first method is to identify the bottleneck based on the element with the highest occupancy. Occupancy is defined as the utilisation rate of a machine divided by its capacity. Applying this method on the results, the occupancy rates of each of the elements are ranked, from highest to lowest as can be seen in Table 5.13. The element with the highest occupancy rate is the CE and thus considered the bottleneck.

Element	Occupancy
CE	0,45
Locomotives	0,29
Transit Hall crane	0,19
lashing	0,16
Quay Cranes	0,15
Forklift trucks	0,04
Forklift trucks hold	0,02

Table 5.13: Occupancy of elements base configuration

The second method used is an adapted version of the the Critical indicator value method as discussed in chapter 2. This method requires simulation statistics on average occupancy, idle and blocking times of all elements. The Critical indicator value of the ith machine can be calculated as follows:

$$KR_i = \left(\frac{\sum_{i=1}^{n} B_i}{n} - B_i \right) + \left(I_i - \frac{\sum_{i=1}^{n} I_i}{n} \right) + \left(BI_i - \frac{\sum_{i=1}^{n} B_{Ii}}{n} \right) \tag{5.3}$$

Where:

- KR_i, the critically indicator for the i-th workplace [%]
- B_i, the average utilization rate for the i-th machine (Busy) [%]
- B_{Ii}, the average blocking rate for the i-th machine (Blocked) [%]
- I_{Ii}, the average starvation rate for the i-th machine (Idle) [%]

This method is applied to the results of 30 runs of the model using base scenario, configuration and performance data. The results are visible in Table 5.14. Elements with a negative KR_i value can be improved by adding capacity. The element with the lowest KR_i is considered the bottleneck. Elements with positive KR_i have capacity reserves and their capacity is not optimally utilised. Looking at the table the CE element has the lowest KR_i value and thus is considered the bottleneck in the system. Lowering this score can be realised by adding capacity to the element. Ideally each of the elements has a score around 0 as this indicates that their capacities are aligned with each other.

Element	KR-value
CE	-62,5
Locomotives	-38,7
lashing	-13,1
Transit Hall crane	-9,0
Quay Cranes	-7,5
Forklift trucks	41,0
Forklift trucks hold	90,0

Table 5.14: Critical Indicator Value KR of elements base configuration

Finding the bottleneck in an overloaded system

The setup up of this analysis is similar to the setup of the previous analysis in subsection 5.2.4 in terms of the configuration. However, instead of a using the exponential distribution of the IAT of vessels, the system is overloaded by setting the mean IAT of vessels to 100 minutes instead of 6.2 days, which is arbitrary, but small enough such that the model generates vessels faster than the outer-harbour 3 can be processes. In Table 5.15 the setup is shown. The objective of this experiment is to determine whether the bottleneck in the system as found in analysis in subsection 5.2.4 is also the bottleneck in a system that is overloaded with vessels. The reason is twofold. First by doing this a more realistic approach of the real system is made as in fact, there are almost constantly docked barges, short sea and deep sea vessels in the outer-harbour 3 that require the system to work around the clock and also for example prevent Transit Hall trains from being driven to the Transit Hall due to a higher request for locomotive capacity. Moreover, it could be that certain elements are not identified as bottlenecks in a system that is partly idle, but are in fact a bottleneck if they are working constantly.

Overloaded system analysis	
Reason	Author suggestion
Setup change scenario	Scenario equals base scenario from section 5.2.2, however mean vessel IAT set to 100 minutes instead of 6.2 days
Setup change configuration	Configuration equals base configuration from section 5.2.2
Goal	Detect bottleneck(s) in current system
Expected results	Based on interviews with Tata Steel employees the supply from the hinterland and/or the locomotive capacity are most likely to be the bottleneck(s)

Table 5.15: Overloaded system analysis setup

Results

The same two methods are applied to calculate the occupancy and Critical Indicator Value KR. The occupancy rates of each of the elements are calculated and ranked, from highest to lowest as can be seen in Table 5.16. The element with the highest occupancy rate is the CE and thus considered the bottleneck.

Element	Occupancy
CE	0,60
Locomotives	0,31
lashing	0,22
Quay Cranes	0,20
Transit Hall crane	0,12
Forklift trucks	0,06
Forklift trucks hold	0,03

Table 5.16: Occupancy of elements in overloaded base configuration

Calculating the Critical Indicator Value using Equation 5.3 results in Table 5.17. Using the same logic, it can be concluded that, according to this method, the CE is the main bottleneck again as its KR_i value is the lowest of all elements.

Element	Occupancy
CE	-85,3
Locomotives	-32,8
lashing	-14,8
Quay Cranes	-7,6
Transit Hall crane	13,3
Forklift trucks	35,7
Forklift trucks hold	92,1

Table 5.17: Critical Indicator Value KR of elements in overloaded base configuration

5.2.5 Conclusion

This chapter is dedicated to verifying and validation the simulation model. As the verification and validation was executed, it provided feedback for the model to be improved which resulted in an overall more confidence level of the author and the user. Verification tests includes flow conservation tests throughout the system, train rides, or lack of them if no hinterland supply of coils or ETTS is required and last but not last changing all stochastic values to deterministic values and predict the output of the system. Validation tests include the comparison of model KPI outputs and historical data of these KPIs as well as additional validation of model outputs of which historical data is available. To validate outputs of the model of which no historical data is present experts are asked for validation. Moreover the model is tested for its capabilities of calculating the KPIs to an acceptable extent. Overall the model is deemed suitable to simulate the system at an acceptable level and will therefore be used to experiment with. Apart from the productivity volume of vessels each of the KPIs is considered valid. This fault in the model is known and can therefore be taking into account while assessing the results.

Chapter 6

Experiments

This chapter is used to elaborate on the experiments executed. The model is verified and validated in the previous chapter. Now three experiments are executed to tackle the bottlenecks founds in the base model and to analyse the expected increase of the performance in terms of the same (K)PIs. A simplified experimental plan is highlighted in navy blue in Figure 6.1. In the coming sections the setup, goals and expected results of the experiments are elaborated upon.

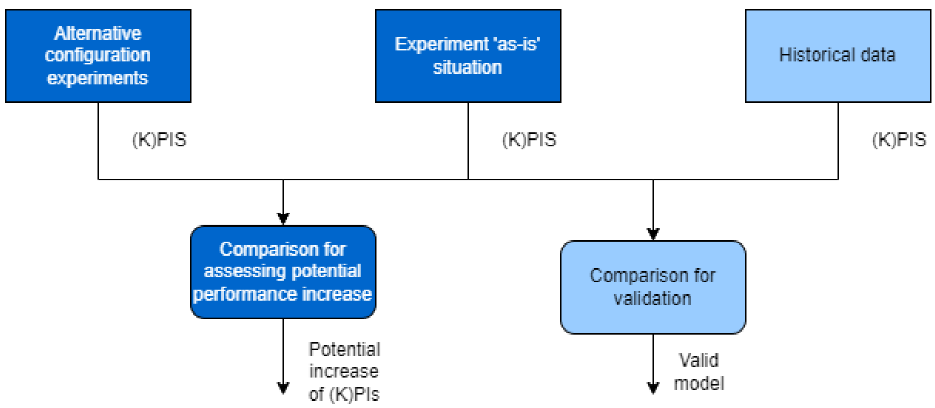


Figure 6.1: Experimental plan

6.1 Experimental plan

In this section an experimental plan is built and elaborated upon. The goal of the experiments is to find answers to a selection of the research questions set for this research thesis. In this particular case, the research question to be answered in this section is:

- Sub-research question 5: *What type of experiments, in terms of potential future terminal configuration alternatives are relevant to execute?*

6.1.1 Bottleneck elimination experiments

In subsection 5.2.4 and section 5.2.4 it is concluded that the CE is identified to be the bottleneck in this system. In addition to this observation, the availability of locomotives is also further investigated as this elements does also have bottleneck characteristics due to relatively high occupancy and low Critical Indicator value. Based on these findings three experiments are proposed. The first experiment is performed to investigate the impact of decreasing the duration of assembling trains by the CE on the performance. The second experiment includes the impact of the increasing the locomotive capacity on KPIs. The last experiment investigates the impact of loading more coils from the Transit Hall instead of via trains. The experiments are designed in consolidation with experts from Tata Steel, and supported by methods provided in the literature, as a response to the bottleneck found in chapter 5. The results of the experiments are discussed in chapter 7. The results of the three experiments are compared to the KPI values calculated in Table 5.8.

Experiment 1: Increase supply rate of CE

The current bottleneck clearly is the assembly of collo in the hinterland by the CE. The scenario input for this experiment remains the same as the input in section 5.2.2. The upper and lower bounds of the uniform distribution used to generate trains in the hinterland is decreased step-by-step from [6,10] hours until [1,1] hours. The full setup is presented in Table 6.1.

Experiment	**1**
Reason	Supply from hinterland is determined to be the main bottleneck. Based on expert experience and author initiative.
Setup	Setup in terms of vessels processed is the same. Throughout the experiments, the duration of train assemble is gradually decreased from an average of 8 hours to 1 hour
Goal	Investigate the impact of eliminating the bottleneck and the effects on the performance of the outer-harbour 3

Table 6.1: Experiment 1: Motive, setup and goal

The base configuration run is already performed for validating the model. Simulation run 2 to 8 are executed 30 times with random seeds. Therefore the sample size of each experiment equals 30 in order to observe potential statistical significance. Each time the same 50 vessels are generated by the model, with different IAT due to random seeds used such that comparisons can be made. Details with respect to these load of these vessels can be found in Appendix E

Experiment 1 Run nr.	**Upper Bound loading time CE trains**	**Lower Bound loading time CE trains**	**Average loading time CE trains**
1 (Base configuration)	10	6	8
2	9	5	7
3	8	4	6
4	7	3	5
5	6	2	4
6	5	1	3
7	3	1	2
8	1	1	1

Table 6.2: Setup experiment 1

Experiment 2: Increase locomotive capacity

Besides the observation that CE is the bottleneck, section 5.2.4 and subsection 5.2.4 show that there is room for increasing the capacity of locomotives, as the KR-value of this element is relatively low. In the following experiment the locomotive capacity is gradually increased to investigate change in performance of the KPIs. It is use full to test multiple configuration changes to spread the potential for solutions and their expected increase of decrease on the performance such that decision-making processes can be supplied with additional valuable information.

Experiment	**2**
Reason	Author initiative.
Setup	Setup in terms of vessels processed is the same. Only the initial locomotive capacity of 3 will be gradually increased to 6 locomotives, by adding 1/3 to the capacity each simulation run. This equals adding 1 additional locomotive for 8 hours, thus 1/3 of a whole 24 hour cycle.
Goal	As the locomotive capacity is the number 2 bottleneck, it is interesting to investigate the impact on the performance purely from adding more locomotives to perform transportation tasks

Table 6.3: Experiment 2: Motive, setup and goal

Experiment 2 **n = 30 for each run** **Run nr.**	**Locomotive capacity**
1 (Base configuration)	3
2	3 1/3
3	3 2/3
4	4
5	4 1/3
6	4 2/3
7	5
8	5 1/3
9	5 2/3
10	6

Table 6.4: Setup experiment 2

Experiment 3: Increase coils loaded via Transit Hall for all deep sea

An internal objective of the Stevedoring & Warehousing department is to supply 80% of the coils of a deep sea vessels via the Transit Hall. However, as analysed earlier, currently an average supply via the Transit Hall of 65% is achieved. The supply of coils via the hinterland is indeed identified as the bottleneck in the system as it is now, therefore it is worthwhile to 1, investigate how a different use of hinterland warehouse capacity could lead to the much desired 80% and 2, see what the impact of more or less coils from the Transit Hall would be on the KPIs. The scenario data of this experiment includes the same 50 vessels as processed in experiment 2. Moreover, the configuration data is the same as the base model. The performance data of assembly rate of trains bound for the Transit Hall is however changed throughout the experiments.

Experiment	3
Reason	Tata Steel experts
Setup	Setup is largely the same as the base model. However the supply rate of Transit Hall trains will change from average of 8 hours up to 1 hours.
Goal	Investigate what would theoretically be necessary in terms of transportation towards the Transit Hall to achieve higher amounts of coils to be supplied from here instead of directly via trains

Table 6.5: Experiment 3: Motive, setup and goal

Experiment 1 Run nr.	Upper Bound loading time Transit Hall trains	Lower Bound loading time Transit Hall trains	Average loading time Transit Hall trains
1 (Base configuration)	10	6	8
2	9	5	7
3	8	4	6
4	7	3	5
5	6	2	4
6	5	1	3
7	3	1	2
8	1	1	1

Table 6.6: Setup experiment 3

6.1.2 Conclusion

In this chapter sub-research question below is answered.

- Sub-research question 5: *What type of experiments, in terms of potential future terminal configuration alternatives are relevant to execute?*

From the comparison between the base model and historical data is was made clear that the bottleneck in the 'as-is' system currently is the supply of colli from the hinterland warehouses. Therefore a set of experiments is designed, in consolidation with Tata Steel experts and backed by literature to research the effect of realistic changes to the configuration to tackle the bottleneck and to measure the effect of this on the KPIs. Three experiments are executed. The first experiment aims to measure the influence of an increase of hinterland warehouse supply rates. The current duration is 10 to 6 hours. This rate is step by step decreased. The second experiment's objective is to research the influence of the percentage of coils loaded into a vessel from the Transit Hall. By changing the rate at which trains with coils destined for the Transit hall are generated, it can be seen firstly, how many transporation movements are necessary to achieve this 80% goal and secondly what the impact of such a percentage would be on the KPIs. The third experiment is designed to provide insights into the impact of available locomotive capacity. All experiments have largely the same setup as the base model, but differences are addressed in the respective subsections.

Chapter 7

Results

In this section of the results of experiments executed in chapter 6 are elaborated upon. For each experiment the results are presented in table form and in graphs with the objective of answering sub-research question 6:

- Sub-research question 6: *What will the expected performance of the terminal be, when these potential terminal configurations are tested?*

For each experiment and each run the results are plotted in a graph and shown in a table. The graph shows the sample mean of each KPI over the 30 runs. For each data point a 95% confidence interval is plotted using the t distribution as formulated in Equation 5.1. Subsequently, the results are compared to the base model outcomes using the One-sided Paired Two sample t-test. This test is used as the same set of 50 vessels, thus pairs of observations, are processed by the model with different configurations. This test is described using Equation 7.1.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{7.1}$$

Where $\bar{X}_1$ equals the sample mean of the experimental configuration, s_1 equals the sample standard deviation of the experimental configuration and n_1 the sample size of the experimental configuration. $\bar{X}_2$ equals the sample mean of the base configuration, s_2 equals the sample standard deviation of the base configuration and n_2 the sample size of the base configuration. If t is larger than the threshold value t critical T_c, the results are considered to be statistical significant. For the results of the experiments a 95% T_c is used. For a sample size of 30, this value equals 1.699.

For each of the three experiments the graphs are shown in the main text. However each graph is accompanied by a table which includes the values. These tables are all placed in Appendix E. These tables are referred to in this chapter to smoothen the storytelling.

7.1 Experiment 1:Increase hinterland supply rate

In this section, the results of experiment 1 are shown and discussed. The experiment aims to provide insights into the potential performance increase in terms of the (K)PIs from chapter 3 as a result of configuration changes to the found bottleneck in the system, namely the supply of trains from the CE.

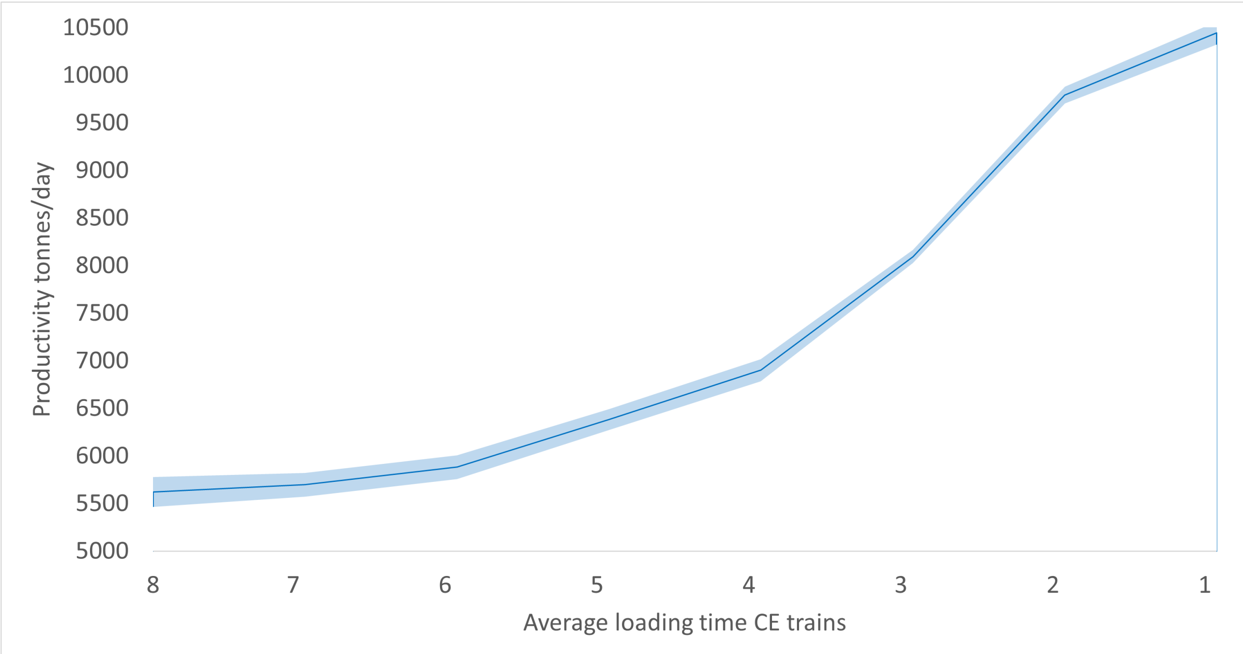


Figure 7.1: Experiment 1: Productivity volume

In Table E.1 the change in volume productivity is summarised. The sample mean and standard deviation are given for each sub-experiment. Figure 7.1 shows in light blue the confidence interval for each of the results. The confidence interval tells us that with 95% certainty it can be said that the actual expected volume productivity for each point is situated somewhere in the light blue area. The results show that overall decreasing the duration of assembling trains by the CE has a positive effect on the volume loaded on vessels per day. However, the impact on this KPI increases as the average duration decreases.For an average of 7 hours, there is only a slight increase. Evermore, this increase is not statistically significant. An average of 6 hours resulting in a sample mean of 5881 tonnes/day does result in statistically significant changes. From point 6 hours the line gets steeper until point 2 hours, when it flattens again. In chapter 1 it is elaborated upon that Tata Steel aims to increase their productivity, in terms of volume, by 20%. Looking at the results, the objective can be achieved by realising an average time between 5 and 4 hours per train.

Figure 7.2 and Table E.2 shows the KPI productivity quantity in colli loaded per day. The graph looks similar to the productivity measured in volume as expected due to the fact that the volume and number of colli loaded per day are directly related to each other. Results become statistically significant at the point of reducing the duration by 2 hours.

The course of these lines can be explained by looking at the Critical Indicator values presented in Table 5.14. The gap between the CE and the other elements is large. Therefore it requires quite some additional capacity for the CE to realise significant impact on the productivity which can be seen in Figure 7.1 and Figure 7.2. After the 6 hour point, the impact grows larger as the Critical Indicator value comes close to that of the locomotives. This implies that capacities of these two elements are closer to each other which should results in smoother operations. This is confirmed by looking at the plot in Figure 7.3. At the 6 hour point the KR value of the locomotive and CE are equal. Around the 2 hour point, the curve flattens. This is possible due to the fact that, at this point the CE by no means the bottleneck anymore and therefore improving its capacity will not result in any significant changes to the productivity.

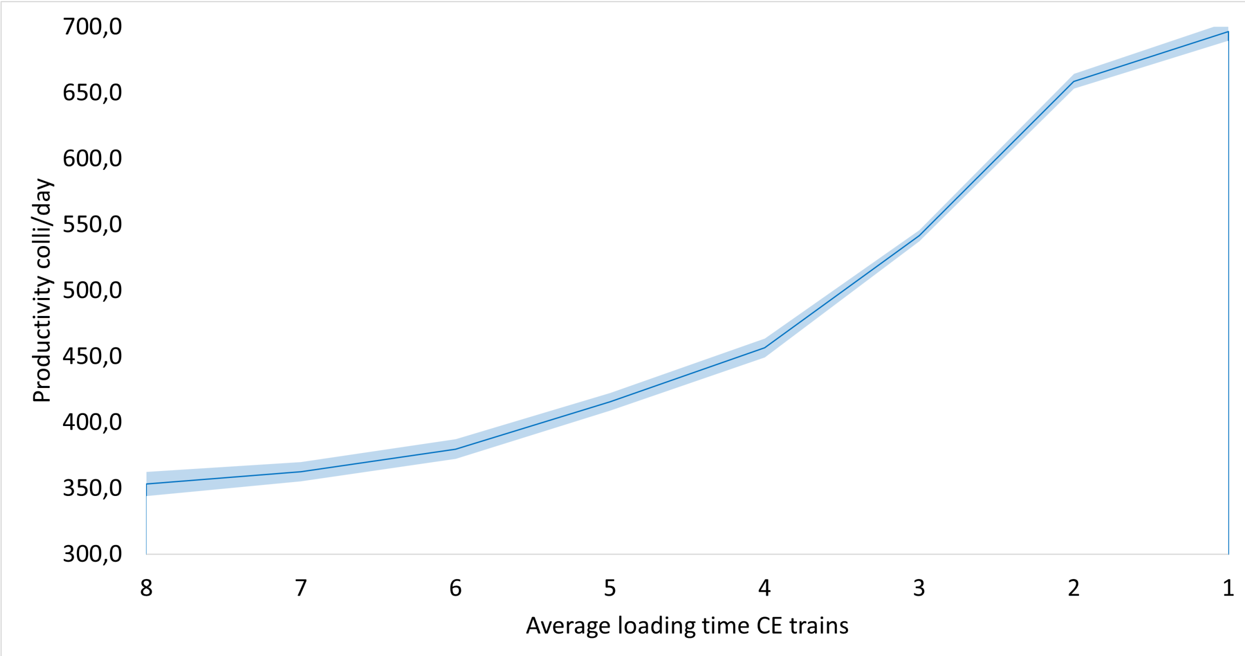


Figure 7.2: Results experiment 1: Productivity

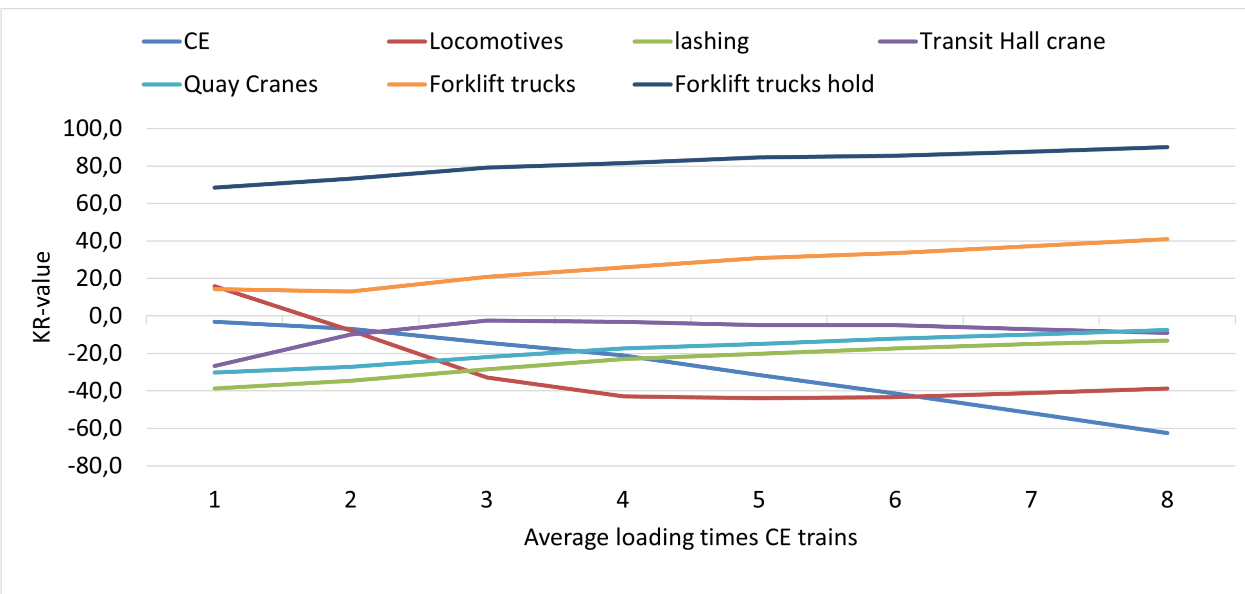


Figure 7.3: Results experiment 1: KR values

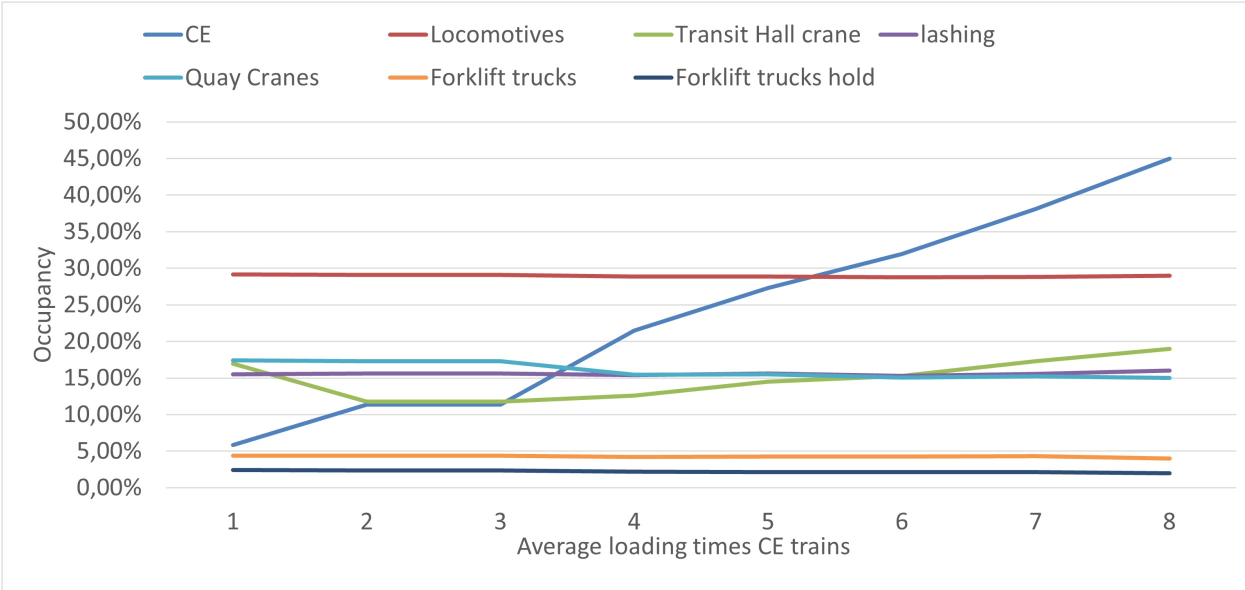


Figure 7.4: Results experiment 1: Occupancy

Loading more colli per day, should result in a decreasing average loading time per vessel. This hypothesis is confirmed as one can see in Figure 7.5 and Table 5.8. The average loading time is 3.41 days in the base configuration. For a decrease of the average train loading time by 1 hour, an increase of 10 colli/day loaded on average can be expected. Which decreases the average loading time of vessels by 0.3 days as one can see in the table and in the graph. The 7 hour point shows an average loading time of 3,13 days and is considered to be statistical significant. Overall, Table 5.8 shows that for each hour of train loading time won, 0.3 days of loading time per vessel is removed. At this point, it can be concluded that decreasing the average loading times of trains by the CE will increase the volume and quantity loaded on vessels per day. This has significant impact on the average loading time of vessels. It would be in line with expectations that the number of vessels loaded before the agreed upon deadline will increase due to these effects. The overall effect of increasing CE speed on the punctuality can be seen in Figure 7.6 and Table E.4. As in line with the expectations, the number of vessels leaving on time increases as the duration of assembling CE trains is decreased. All speed increases of the CE result in statistically significant results.

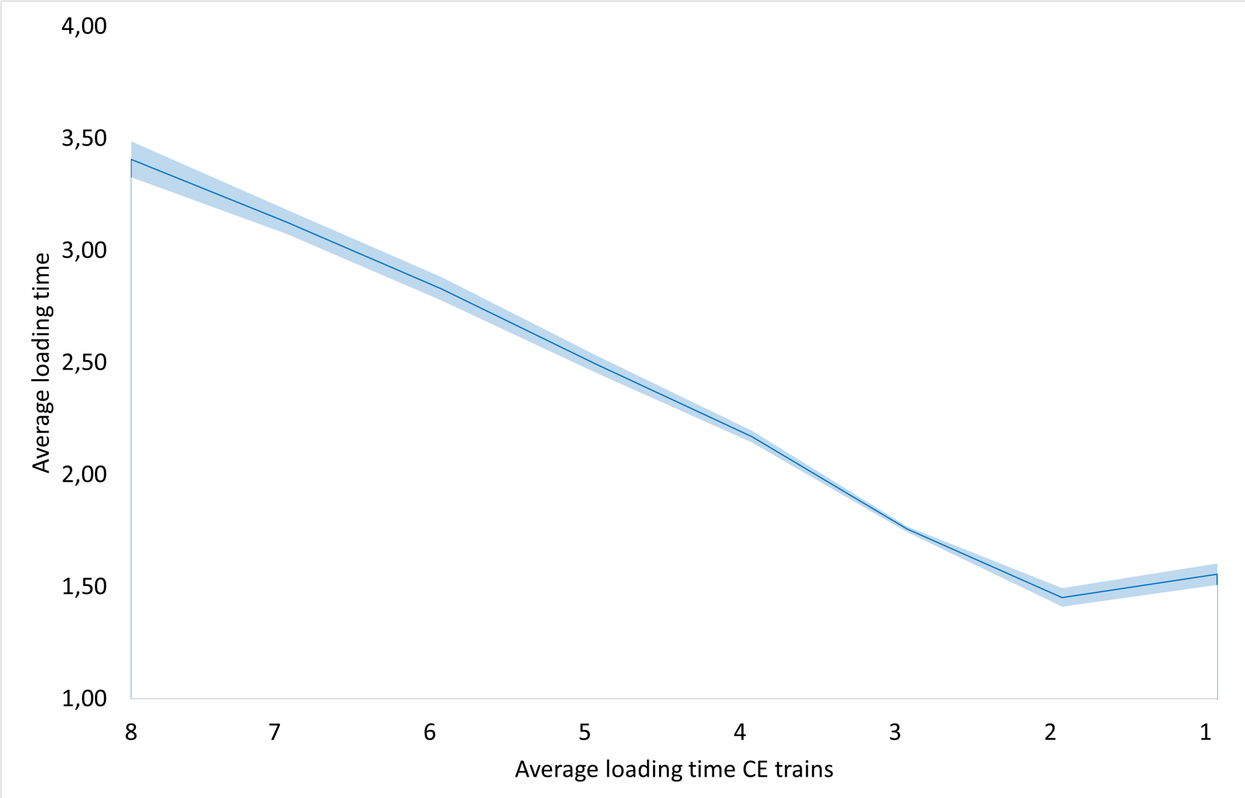


Figure 7.5: Experiment 1: Average loading times

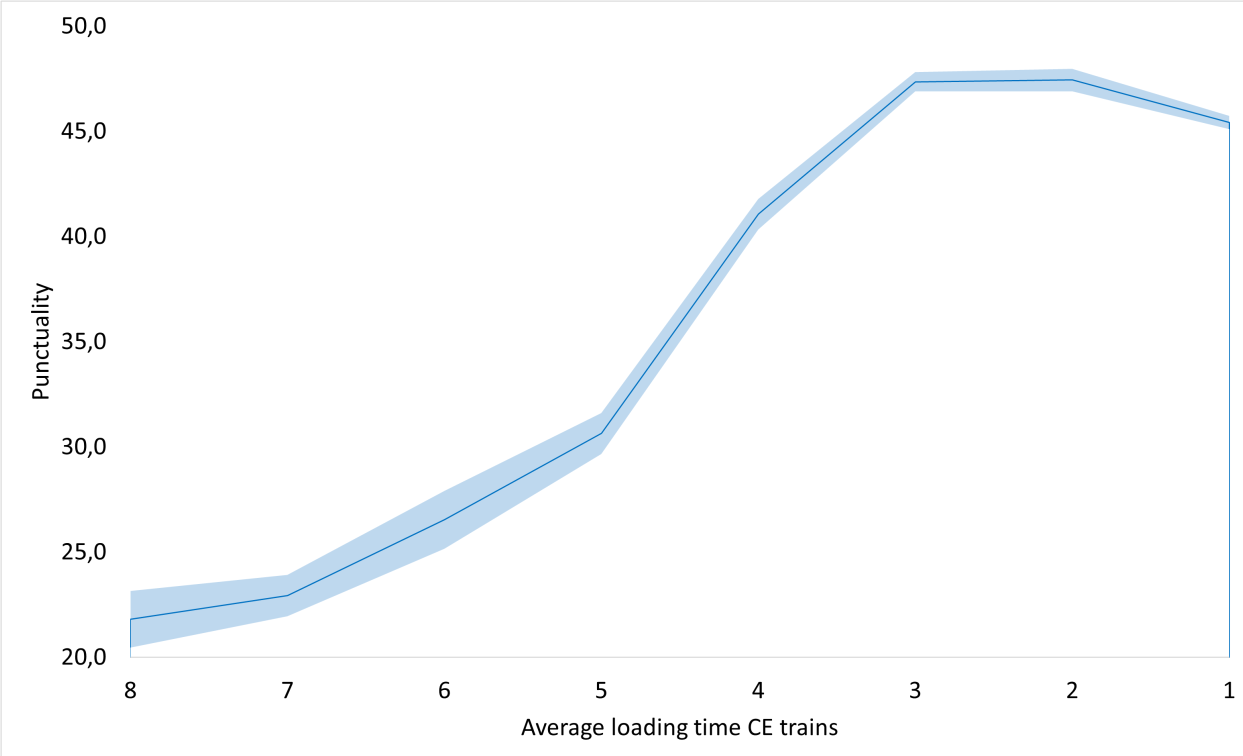


Figure 7.6: Experiment 1: Punctuality

The last KPI to assess is the demurrage. As the punctuality increases, it is expected that the demurrage costs decrease as more vessels are loaded on time. Looking at Figure 7.7 and comparing it with Figure 7.6 it is visible that the two graphs have opposite lines. The demurrage costs decreases significantly for each vessel that is loaded on time due to the faster supply from the CE. Interestingly, at the 2 hour point, an increase is noted. This is again the effect of the fact that at around this point the CE is by no means the bottleneck anymore as shown by the occupancy and KR values. Therefore the effect of adding capacity slowly reduces up to a point where a new bottleneck is realised. One can see it as if a new base configuration is created at this 2 hour point. Hence, due to the stochasticity of the model increasingly influences the results which can be seen in the relatively large confidence intervals for the 2 hour and 1 hour point.

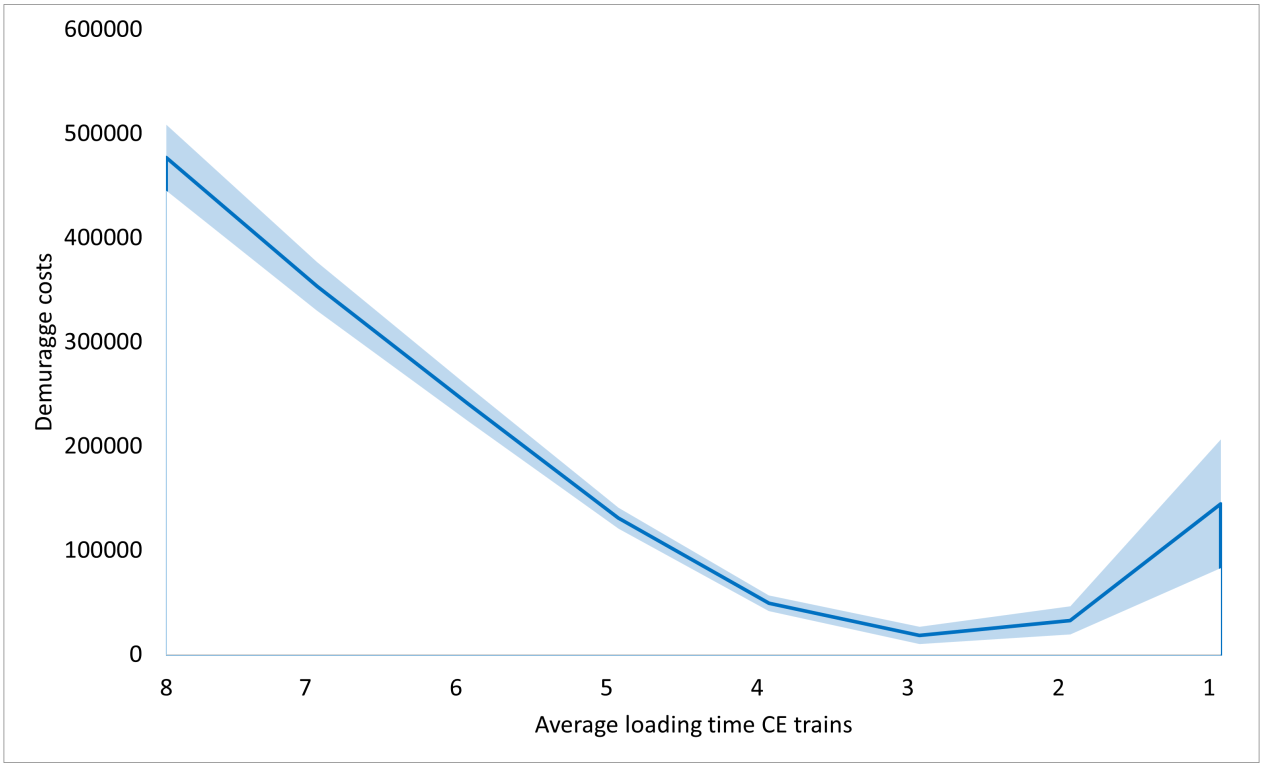


Figure 7.7: Experiment 1: Demurrage

7.2 Experiment 2: Increase locomotive capacity

In this section the results of experiment 2 are shown. This includes the experiment in which the impact of increasing locomotive capacity on the performance on the outer-harbour 3 is investigated. Table 6.3 and Table 6.4 show the experimental setup.

In Figure 7.8 and Figure 7.9 the productivity measured in volume/day and colli/day is plotted as a function of the locomotive capacity. The results are also displayed in Table E.6 and Table E.7. Immediately visible is the lack of improvement in the productivity, despite the increase of locomotive capacity. There are some fluctuations visible, however there none of the results are statistically significant. Thus it can be concluded that adding locomotive capacity does not have significant impact on the volume and quantity productivity.

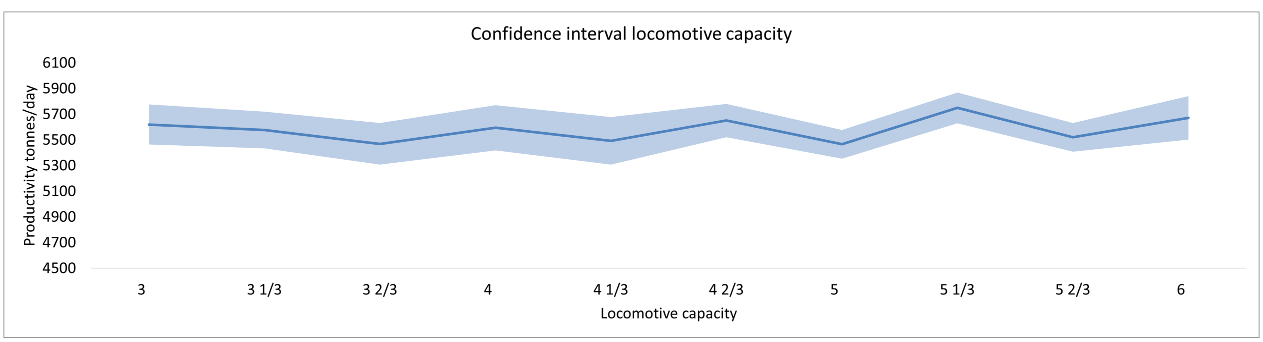


Figure 7.8: Productivity volume plot for experiment 2

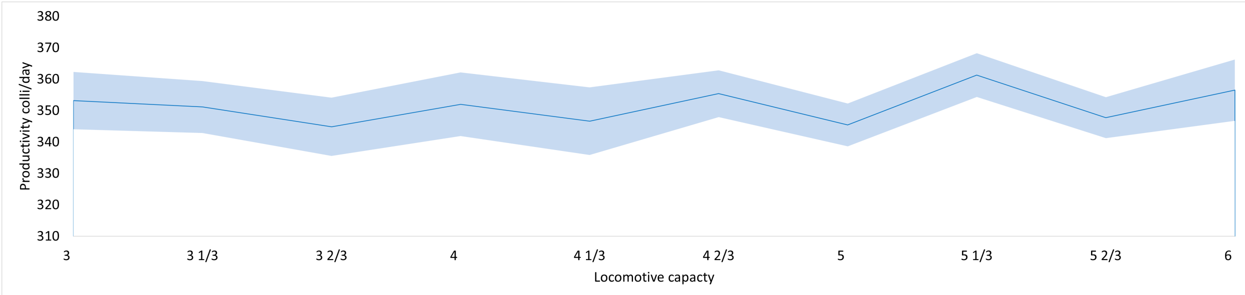


Figure 7.9: Productivity quantity plot for experiment 2

The first results of experiment 2 show that no significant changes to the productivity is to be expected if the locomotive capacity is increased. As a consequence the average loading time of vessels is not improving as well. The line in Figure 7.10 remains more or less constant. For each of the locomotive capacities tested, the sample mean remains within the confidence interval boundaries of the base configuration, which implies that for none of the configuration changes statistical differences are expected.

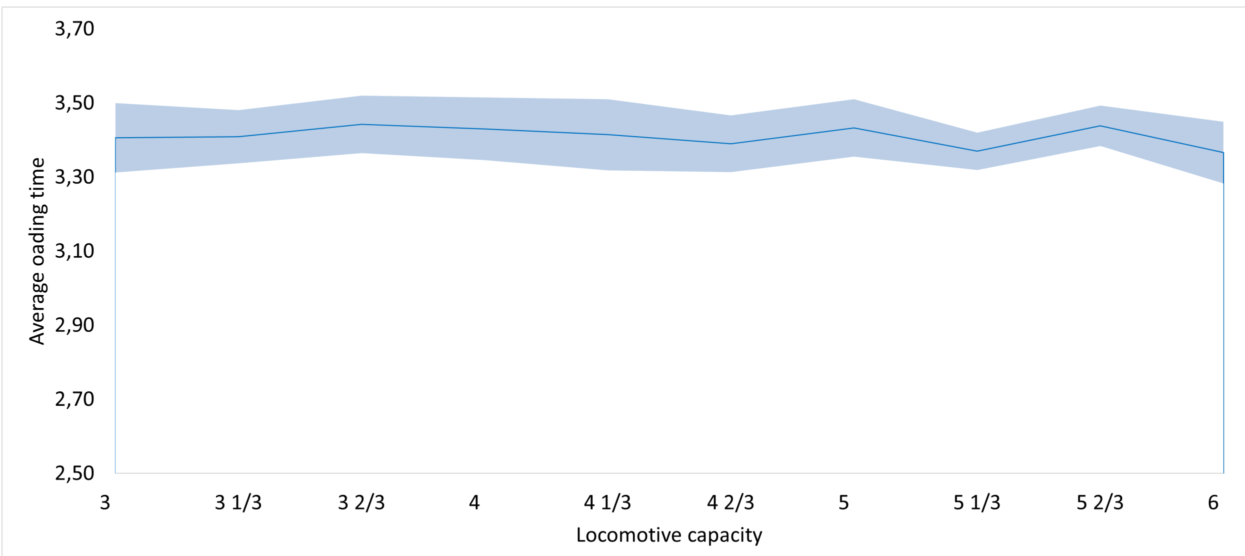


Figure 7.10: Average loading time plot for experiment 2

When looking at the lack of improvements in the productivity and average loading time of vessels, it is expected that the punctuality will neither be improved significantly. This is confirmed when Figure 7.10 and Table E.9 are inspected. The punctuality of the base configuration is rounded 22. Each of the data points remains within the confidence interval of the base configuration and therefore no statistical difference in punctuality is expected.

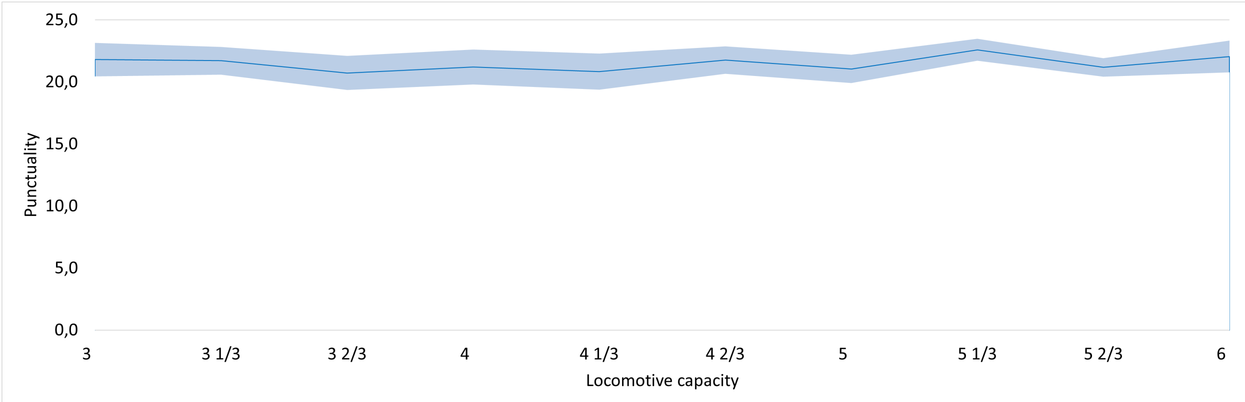


Figure 7.11: Experiment 2: Punctuality

Looking at Figure 7.12 and Table E.10 it is clear that the demurrage costs do not decrease significantly. This is in line with the other results. A lack in increasing productivity should not decrease the average loading time of vessels. The number of vessels being loaded on time will remain the same and thus the expected demurrage costs to be paid as well. In addition, having more locomotive capacity requires additional operational expenses. These increasing expenses can be seen in Figure 7.13 and Table E.11. The operational expenses increase by an average of 100.000 euros for each shift of 8 hours that an additional locomotive is operational. With a deficiency of decreasing demurrage costs and increasing operational expenses as a result of adding locomotive capacity, it can be concluded that this solution is not economically viable.

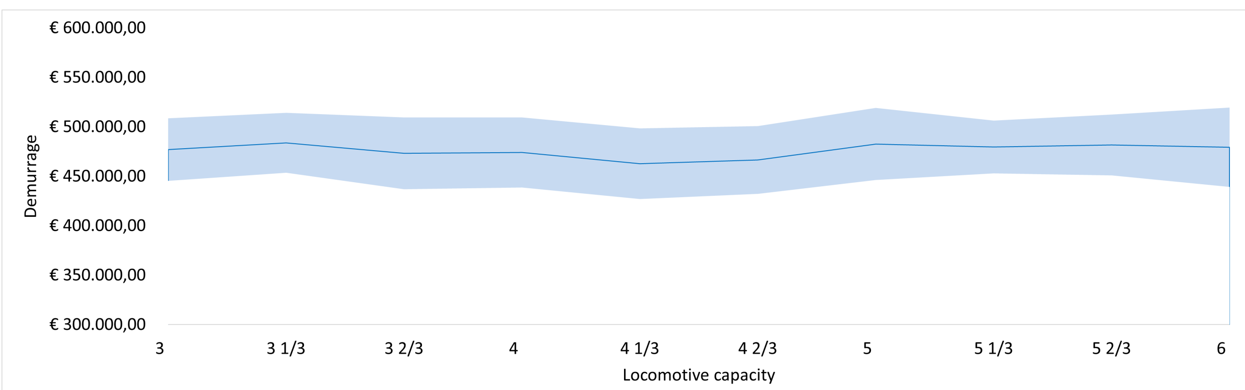


Figure 7.12: Demurrage plot for experiment 2

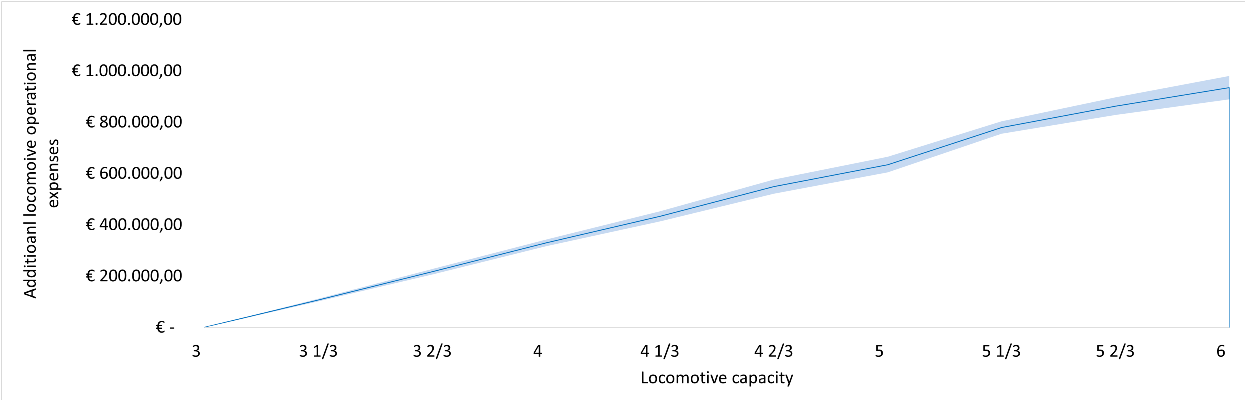


Figure 7.13: Experiment 2: Additional operational expenses

Lastly, the occupancy rates and the Critical Indicator Values for each run are discussed. As one can see in Table E.12 and in Table E.13 for all elements except the locomotive, these rates remain constant. Important to note is that the CE remains the bottleneck as expected and thus keeps slowing done the overall processes of the outer-harbour 3. This results in a lack of improvements in the system.

7.3 Experiment 3: Increase usage of Transit Hall

In this section the results of the experiment 3 are discussed. This experiment aims to increase the use of the Transit Hall by gradually increasing the speed at which trains with load for the Transit Hall are generated.

First of all, the effect of increasing the supply rate of trains towards the Transit Hall on the usage of the Transit Hall is visible in Figure 7.14 and Table E.14. The figure and graph show for gradually increasing supply speeds of Transit Hall trains that an increasing percentage of coils is loaded via this storage facility.

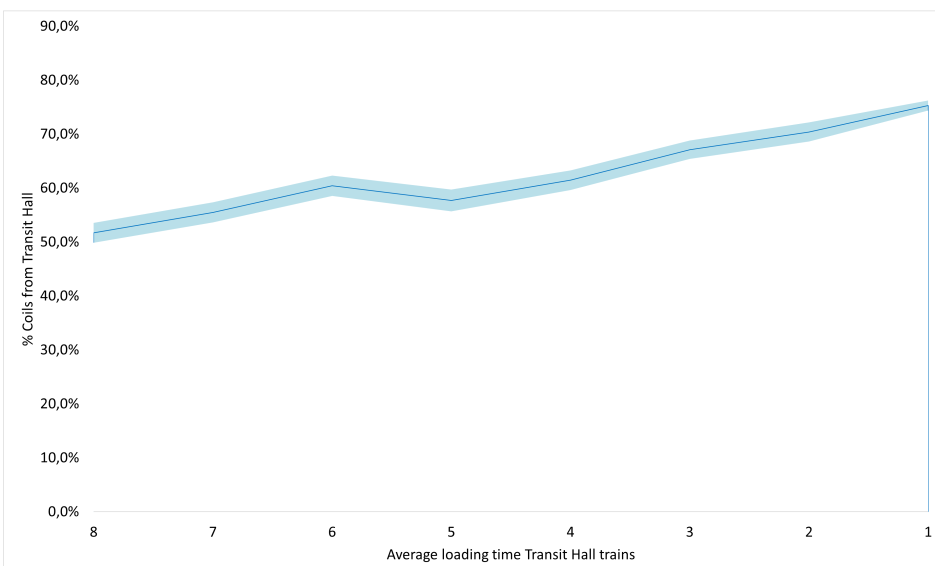


Figure 7.14: Experiment 3: Coils from Transit Hall

The volume productivity and quantity plotted in Figure 7.15 and Figure 7.16 indicate for a decrease in supply duration of Transit Hall trains by 1 hour, an expected increase of Transit Hall usage by 4.8%. This is not expected to have a significant influence on the productivity as only 3 colli or 28 tonnes are loaded on average extra per day. At the 6 hour point a little more than 60% can be supplied via the Transit Hall which does result in a statistical significant improvement of the production volume by 250 tonnes/day or around 16 colli/day. At the 5 hour point the average percentage of coils even decreases. Moreover, there is overlap in the confidence intervals of the 6, 5 and 4 hour points, indicating that between these points no relative statistical improvements or deterioration's are to be expected. A possible explanation could be that the Transit Hall crane becomes increasingly burdened with work as can be seen when looking at the occupancy and KR values in Table E.20 and Table E.21. This result in the crane to be less able to load coils towards the quay. However, what would have been expected is a further stagnation in productivity. As one can see in the graph, an increase is again measured, followed by stagnation and an increase again. This pattern is hard to explain, but is it expected that this is the result of stochasticity in the model and the setup of the experiment. The goal is to measure the effect of loading more coils from the Transit Hall. This is enforced by forcing more trains towards this storage place. Therefore, this percentage is not directly controlled and is subject to the stochasticity of the model. The objective of Tata Steel is to increase the productivity by 20%. Looking at Table E.14, this percentage can be approached when each hour a train would be ready, resulting in 75.3% of the coils to be loaded from the Transit hall.

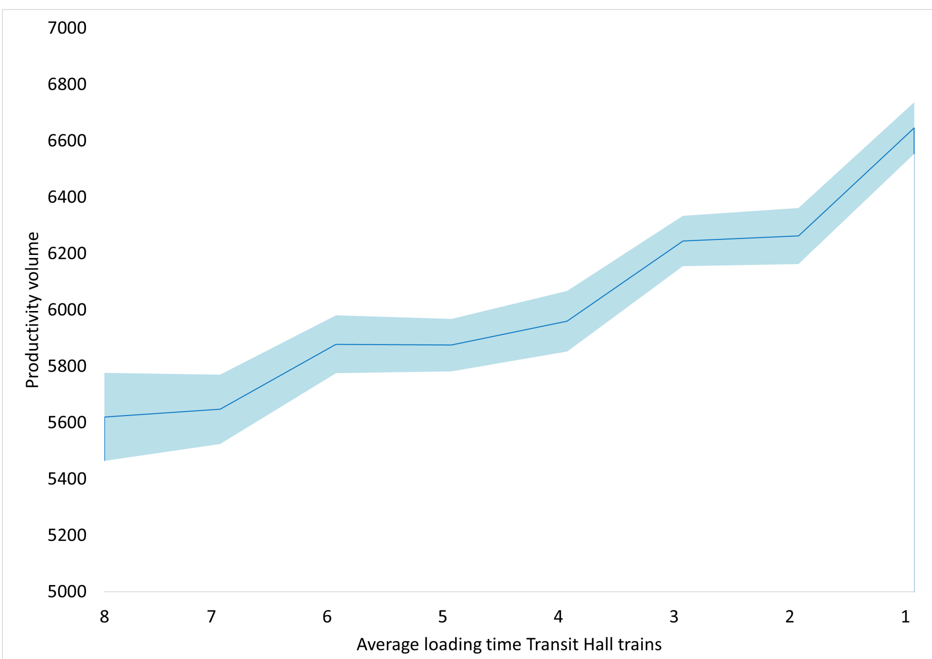


Figure 7.15: Experiment 3: Productivity volume

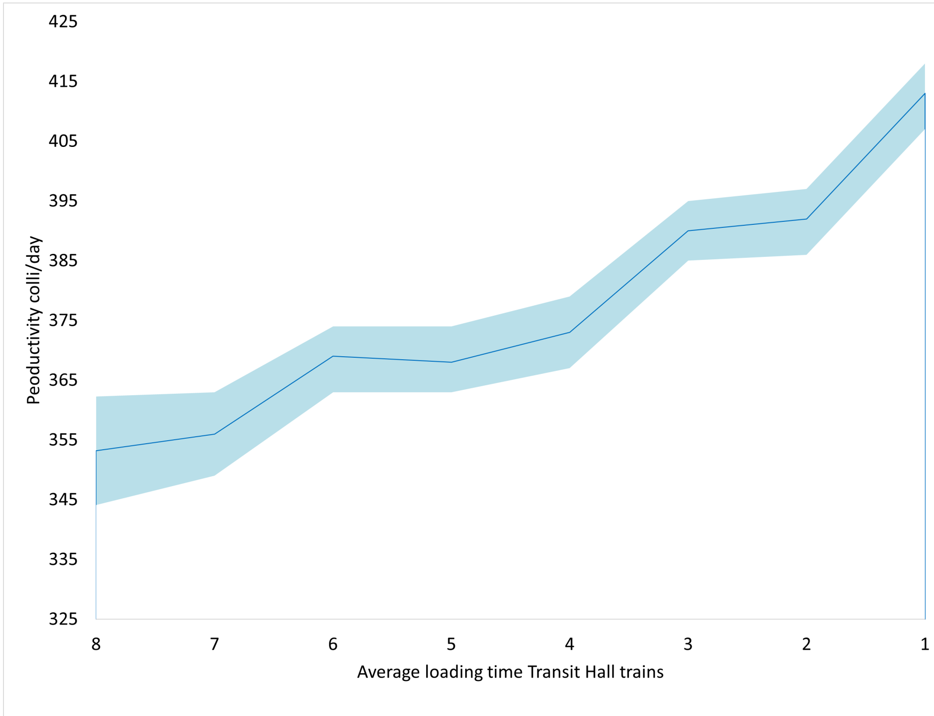


Figure 7.16: Experiment 3: Productivity quantity

The average loading time KPI shows a similar pattern to the productivity results as shown in Figure 7.17. Decreasing the supply duration of trains by 1 hour and thus an increase of 4.8% from the Transit Hall only results in a 0.03 day decrease in the average loading time of vessels as can be seen in Table E.17, which is not considered to be a statistical improvement compared to the base configuration. At the 6 hour point, when 60.4% of the coils are supplied via the Transit Hall the average loading time decreases by 0.17 days. Overall results become statistically significant from the 6 hour point.

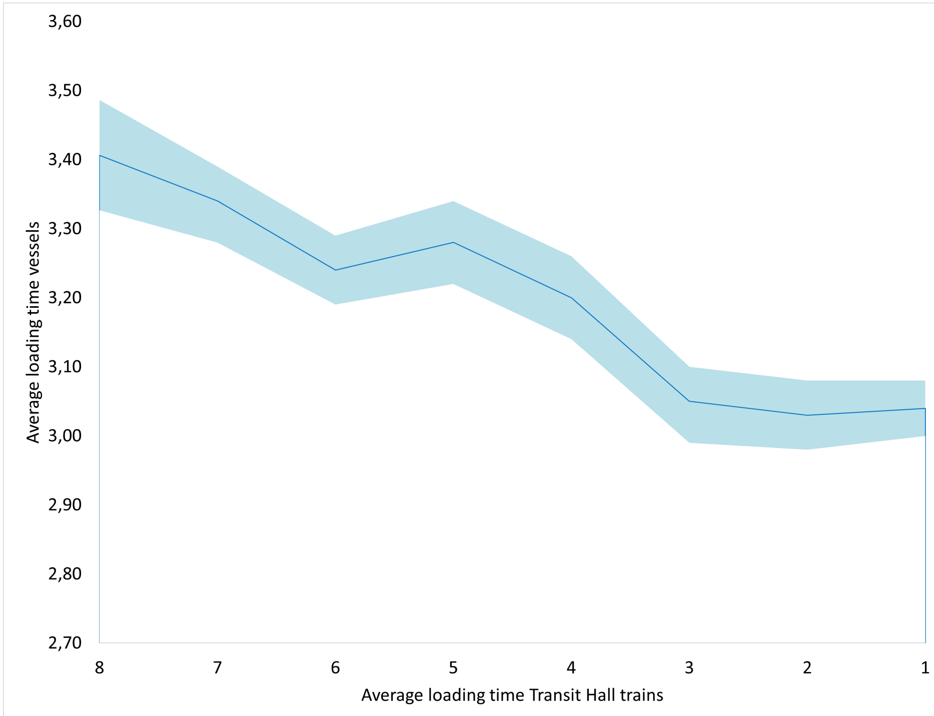


Figure 7.17: Experiment 3: Average loading time

The punctuality follows a similar pattern as the average loading time of vessels as expected. Firstly there no significant difference improvement measured. However this changes once the 6 hour point is reached. Globally for each hour, except 5 and 6 hour point and the 3 - 2 hour point, 1 additional vessel is loaded on time. Looking at the demurrage costs in Figure 7.19 and Table E.19 the 6 hour point gives significant improvements with respect to this KPI. Overall the demurrage costs are slowly, but steadily decreasing. The 1 hour point however shows an increase again as well as a larger standard deviation at this point resulting in a larger confidence interval. The lower bound overlaps with the upper bound of the 2 and 3 hour points indicating that the actual expected demurrage is somewhere in that area an not statistical difference between these points is expected. It could therefore be that this line is just the effect of the stochastic nature of the model.

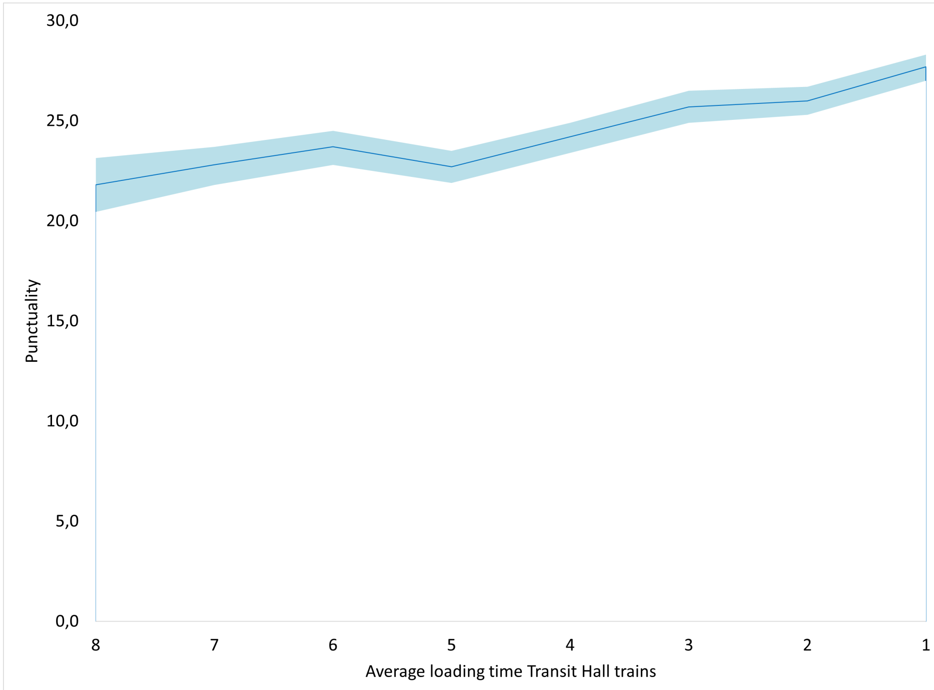


Figure 7.18: Experiment 3: Punctuality

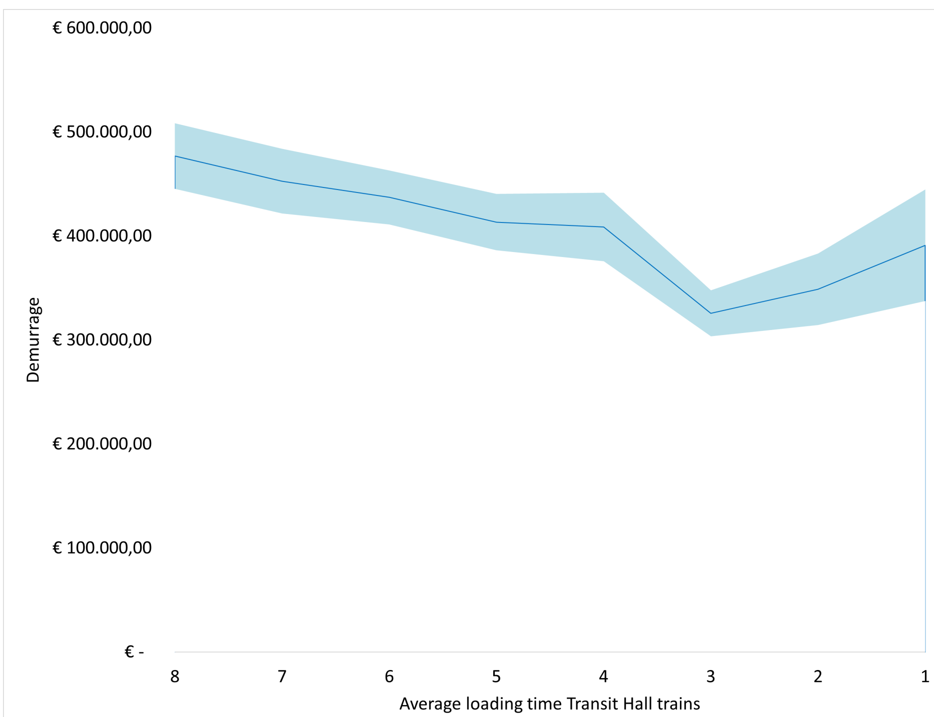


Figure 7.19: Experiment 3: Demurrage

7.3.1 Conclusion on the results

This chapter aims to provide an answer to sub-research question 6:

- Sub-research question 6: *What will the expected performance of the terminal be, when these potential terminal configurations are tested?*

Three experiments are executed to find answers to this question. The first experiment shows that the aimed increase in productivity of 20% by Tata Steel can be achieved once the CE duration of assembling trains is reduced to 4-5 hours on average. Another interesting observation is that, although the productivity does not increase significantly for an hour decrease in average train loading time by the CE, the average loading time of vessels, the punctuality and demurrage costs do. Overall an increase of all KPIs is expected for each hour that Tata Steel is able to reduce their CE supply duration with.

The second experiment shows no significant changes to ant of the KPIs. Concluded can be that for this system adding locomotive capacity does not add any value in terms of the KPIs. Evermore, the additional operational expenses make it a uninteresting configuration to realise. The bottleneck remains the CE, which keeps slowing down the whole system.

The last experiment aims to increase the performance of the system by increasing the number of coils loaded on vessels via the Transit Hall instead of via trains. In the base configuration around 50% of the coils is loaded from the Transit Hall. By increasing the supply of trains towards this storage facility the productivity, average loading time, punctuality and demurrage costs all increase gradually. The 20% increase in productivity aspired by Tata Steel can be realised by loading 75% of the coils from the Transit Hall and the other 25% via trains.

Overall it can be concludes that it is most impact to aim at improving the supply processes surrounding the CE rather than investing in additional locomotives. Small increases in productivity, as a result of faster supply via trains results in significantly shorter loading time of vessels, a higher punctuality and lower demurrage costs. Moreover, the use of the Transit Hall to a larger extent that is currently the case does also result in higher KPI values. However, it can be seen that eventually the Transit Hall crane is increasingly burdened with work due to more trains arriving. This slows down the loading process of vessels and the improvements of the KPIs are not as significant compared to the first experiment.

Chapter 8

Discussion

Concluded is that the performance of the outer-harbour 3 of Tata Steel IJmuiden can be improved most significantly by decreasing the assembly duration of trains by the CE. In this chapter the results are elaborated upon in light of both existing literature and in consolidation with the experts from Tata Steel. Moreover the limitations of this research are discussed and recommendations for future research are given as well as recommendations for Tata Steel.

8.1 Interpretation of findings

Apart from the quantitative interpretation of the results as done in chapter 7, it is also worthwhile to discuss the other findings that have been made throughout this thesis project. In this section the used methods during this thesis and their use fullness in tackling the challenges faced in this research are discussed. Firstly, Although specific KPIs for break bulk terminals were not found in the literature, this thesis proves that proposed KPIs for container terminals literature such as (Ha et al., 2019) and KPIs used in practice by Tata Steel IJmuiden can lead to KPIs that are applicable in practice. It is a good example of how the academic world and practice can supplement each other. Moreover, this research thesis shows that DES models are also applicable in break-bulk cargo contexts and that valuable insights can be gained by such models. This in line with papers found in literature that state that such logistical environments should be modelled using DES due to the lack of analytical methods to fully grasp the complexity of such systems Al-Harkan and Hariga (2007); Cimpeanu et al. (2017); Longo et al. (2013); Cartenì and de Luca; Cimpeanu et al. (2015). The Delft System approach to analyse systems for modelling as proposed by (Hans et al., 2008) has proven useful as well. The structured way of selecting elements, relationship and drawing system boundaries for the purpose of modelling shows that despite the complexity of logistical processes it is possible to built a model that proofs valuable for decision-making support. The next section will elaborate more on the limitations of this research and the model as well as recommendations for further research and for Tata Steel.

8.2 Limitations of the research thesis

The intention of this research project is to provide Tata Steel IJmuiden insights into the current workings of their deep sea loading processes in the outer-harbour 3 by applying academic methods and a critical view on these processes. The company required additional insights into the potential bottlenecks in their current system and insights into the expected increase of the performance of this system in clearly defined key performance indicators. Making large investments to increase the performance of a system without having a well formed idea where such investments could have the largest impact is a risky step to take. This situation provided an ideal context to apply discrete-event simulation methods to aid in the decision-making process of Tata Steel IJmuiden by providing useful insights into the expected performance increase of the decision at hand. However, the fate of a model is always that it is not a 100% realistic representation of the system it is mimicking. Assumptions and simplifications are always required to make the problem at hand manageable. In chapter 4 the mentioned results are important to discuss. They set the boundaries and also make clear what the limitations of this research are.

The system investigated in this research thesis is the outer-harbour 3 and than specifically during the loading of deep sea vessels. These are the largest type of vessels that are processed by Tata Steel IJmuiden. An immediate effect of this decision is that, the full utilization of each of the machines and resources used in the real system is not fully grasped. This is due to the fact that machines and resources in the real system are also used for loading short sea vessel and barges. In this light, the same element, namely the loading rate of warehouses in the hinterland, is still expected to be the bottleneck if one would have taking these ships into account. This is expected because during the loading of such smaller vessels it is highly uncommon to make use of the Transit Hall. This makes the dependency on the supply of coils to the outer-harbour 3 via trains even larger and so the bottleneck even more present. Furthermore, the exclusion of width, height and size of colli has also effects on the results that are worth mentioning. Per colli the dimensions and weights can fluctuate quite a lot. This influences the sequence in which colli have to be loaded. For example, larger colli always have to be placed on the bottom. Moreover, several other constraints with respect to these characteristics of the colli are to be taken into account while loading vessels. Interviews with several operational employees of the S&W department brought to light that it is often the case that the sequence in which the colli are loaded on trains in the hinterland warehouses do not always match the 'optimal' sequence in which the colli should be loaded onto the ship. This results in additional search work for the stowage teams during the loading of vessels. This search work was not part of this research. Consequence of this decision is that the loading time of vessels as calculated by the model is higher than it would be in real life. .

Some of the choices to use certain academic methods also deserve some additional elaboration. The average bottleneck detection methods such as the ones used in this research are of value when the system under investigation is looked at from a long term perspective. One can measure which element or elements reduce the overall performance of a system on the long term. Average bottlenecks do have their limitations as they do not fully describe the system in every state it could be in. Shifting bottleneck methods such as the Active period method developed by (Roser et al., 2002) could also be applied to the system. This method looks at the shift of a bottleneck from one machine to another while the system is active. When applying this method it is recommended to research the loading procedure of individual vessels, since this would ignore the idle times of machines when there are no ships to be loaded. Such a system would represent in a way a manufacturing chain in which a continuous flow of products goes through several processes.This method gives more real time insights into the occurrence of bottlenecks while a system is active and thus could provide real time info which a stowage team can act upon immediately. Hence the level at which a system is looked at, often the result of the questions or problems that an organization deals with, influences the methods that are most applicable to that case.

Another point of discussion is to assume the speed-of-work of cranes to be approached by a distribution which excludes to some extend the influences of certain factors on the actual speed-of-work of these cranes in real operations. Another approach for the analysis of the quay cranes and the crane inside the Transit Hall could have been to look at what factors influence the speed at which the cranes move colli. For example, the experience of the crane driver or weather conditions do in fact influence cycle speed of these cranes. However, these factors are not researched in this thesis. An approach to take these factors into account is to create a function in which weights are attached to appropriate parameters. Analysis on the importance of each parameter leads to these weights. This same approach can be used to investigate cycle times of other machines.

Chapter 9

Conclusions and recommendations

In this section the final conclusions are given on each sub-research question as well as recommendations for further research and for Tata Steel. This thesis has the objective to answer the main research question as is formulated throughout the first weeks of this research. The main research question is:

How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?.

Insights from this research can be used in the decision-making processes regarding investments in machine and resource necessary in order to realise this performance improvement. System thinking, Discrete-Event Simulation (DES) and Key performance indicator selection methods are researched and applied to the loading processes of deep sea vessels visiting the outer-harbour 3 of Tata Steel IJmuiden. In this case study a DES model is built and used to analyse the machines, resources and processes of the harbour and appropriate KPIs are selected to measure the current performance. Subsequently three 'What if' experiments are executed in which for each experiment the configuration is changed to assess the potential impact on the performance. This chapter provides concluding answers to the sub-research questions and at the end of this chapter a final conclusion is given together with the answer to the main research question.

Sub-research question 1

What logistical processes at the break-bulk sea terminals are found in literature? Break-bulk cargo terminals are often placed near large industrial manufacturers that produce this type of cargo. In order for their products to be shipped towards the customer, these plants have logistical infrastructure to enable the necessary transporation. These processes include the inter-plant transportation of (semi-) finished products between factories. Factories are accompanied by warehouses where products can be stored temporarily. Central consolidation points are used for bringing together steel products before they are send towards the sea terminal via truck of train transporation. The logistical processes in break-bulk sea terminals have a function of transferring break-bulk cargo from one mode of transporation to another. Once products arrive in the terminal there are multiple machines used to enable the loading of these products onto vessels. Forklift trucks are used for short distance transporation, whereas quay cranes are used to move the products from the quay into the ship. As break-bulk cargo is defined as cargo without an universal size, special equipment such as cables or pliers are frequently used. A not to be forgotten step is to secure the loads.

Sub-research question 2

How do these logistical processes work at Tata Steel IJmuiden? In follow-up of sub-research question 1, field research was done on the logistical processes surrounding the outer-harbour 3 of Tata Steel IJmuiden. The On-site Logistics department of Tata Steel IJmuiden is responsible for all on-site and exporting logistical processes around the steel plant. The department is split into three sub-departments. OSP is responsible for creating and maintaining planning schedules for warehouses, on-site rail transport and the arrival and processing of deep and short sea vessels and barges. The Rail department is responsible for carrying out the rail planning made by OSP. S&w oversees the execution of the planning in the warehouses and in the harbours. Once a vessels docks in the outer-harbour 3 of Tata Steel, a whole chain of processes is put into action. The delivery of steel colli to the harbour is both realised via harbour on-site temporarily storage directly from the hinterland of the steel plant using trains and locomotives. The central rail shunting yard or CE is used as the consolidation point for wagons loaded with steel products originating from warehouses on-site. Subsequently locomotives are used to transport the wagons towards the harbour. Once colli arrive in the outer-harbour 3, multiple quay cranes, forklift trucks and securing teams are working together to realise the loading of colli onto vessels.

Sub-research question 3

What defines the performance of break-bulk harbours and what methods are used to quantify bottlenecks and improvements?. A complete picture of important logistical processes is created. It is necessary to define how the performance of these processes can actually be measured. The definition of performance used by break-bulk terminals depends on its objectives. However, in general Key performance indicators used to steer sea port terminals are often related to productivity/throughput in volume or quantity per unit of time and lead times of vessels. The higher the throughput of vessels, the more vessels can be processed or otherwise the less vessels are delayed. The On-Site Logistics department of Tata Steel already uses detailed KPI trees to assess and steer their organisation. Important KPIs for this research are productivity in volume per day, as well as the operational costs. This KPI tree is assessed using academic literature and supplemented by four KPIs, productivity quantity, punctuality, vessel loading time and demurrage. This set of KPIs enables the quantification of the performance of the outer-harbour 3. Overall the performance is thus measured using five KPIs:

- Productivity
  - Volume (Tonnes/day)
  - Quantity (Colli/day)
- Costs
- Loading time vessels
- Punctuality
- Demurrage

Setting standards for KPIs help organisations to assess their performance on management level. However these KPIs are in fact influenced by the performance of many sub-processes. Performance indicators can be defined and used to measure how these sub-processes are performing and thus where bottlenecks are located. Many bottleneck detection methods are present in literature, however the degree of applicability depends on the objective of investigators. Despite the differences in these methods, machines or resources considered to be bottlenecks are always slowing down processes, resulting in under-utilisation of other machines and a sub-optimal performance of the whole system. Gathering data on idle, blocking and utilization rates of machines is crucial to detect bottlenecks, therefore these three performance indicators are measured for each of the machines investigated in this research. Two average bottleneck detection methods are used. The occupancy rate method, where the machine with the highest occupancy is considered the bottleneck, and the Critical Indicator Value method, which measured the overall machine capacity surplus or deficiency compared to the total average of the whole system. These two methods are deemed suitable for this particular research as the system under investigation is assessed during a long period of time. During the experiments 50 vessels are processed taking at least 200 days which provides the information and statistics to calculate what elements are the bottlenecks on average and thus where investments and improvements can result in the highest impact on performance.

Sub-research question 4

What type of quantitative model is a good fit to mimic and evaluate alternative configurations of break-bulk terminals and what should this model look like in terms of its design?. Answering the first three sub-research questions help to understand which processes are important to investigate and how to measure their performance. The next step is to find methods that enable the calculation of the performance, hence the formulation of the fourth sub-research question. The answer to this sub-research question is found in the literature. Break-bulk terminals can be mimicked using discrete-event simulation models as these models are most suitable for gathering statistics on complex logistical processes. This property makes it fitting for application on the outer-harbour 3 of Tata Steel IJmuiden. Moreover, DES models are well suited to provide additional information for decision-making processes of organizations by testing 'what-if' scenarios and configuration alternatives. Such models are designed by analysing the system of interest, making assumptions to create a conceptual model and subsequently make necessary simplifications to end with a computerized simulation model. Each of the steps are linked to each other by means of continuous feedback loops to guarantee as much as possible a verified and validation model. Overall, the aim is to make the model complex to an extent that it is possible to built in terms of time available, but also that is can generate insights on a system without being to generic.

Sub-research question 5

What type of experiments, in terms of potential future terminal configuration alternatives are relevant to execute?. The design criteria for the model are processed in the final design and the model is built which enables to perform experiments with it. Three experiments are executed. The input scenario data are kept the same to allow for objective comparison, but the configuration settings of each experiment differ. For experiment 1 the speed of load supply towards the quay is increased. The second experiment assess the impact of an increase of locomotive capacity on the performance. The third experiment evaluates an improved utilisation of the Transit Hall storage facility near the harbour. The results of these experiments are compared with the current configuration in terms of the KPIs discussed earlier.

Sub-research question 6

What will the expected performance of the terminal be, when these potential terminal configurations are tested? The expected performance of the terminal will be largest if current bottleneck in the system is tackled. Currently this is CE element which is elements 'responsible' for the supply of load towards the quay during loading processes. The first experiment shows that relatively small increases in the productivity volume and quantity lead to significant decreasing average loading time of vessels. This in turn leads to a higher punctuality and less vessels being delayed. Tata Steels aims to improve its productivity by 20%. This will lead to a decrease in the average loading time per vessel by 1.3 days and a decrease in demurrage costs by more than 400000 euros. This can be realised by decreasing the supply duration by 3 hours minimum. Increasing the locomotive capacity does not have significant impact on the performance. This is due to the fact that the assembly of trains by the CE is the bottleneck and therefore will nonetheless prevent any performance increase. Utilisation increase of the Transit Hall by 25% can be realised by decreasing the duration of loading for Transit Hall trains by 7 hours. This higher utilisation results in an overall expected increase of productivity in volume and quantity of around 20%. The utilisation of the Transit Hall is an indirect effect of the model. Sending more trains towards the Transit Hall increases this utilisation, but results in impractical solutions, for example 1 hour per train instead of the current 8 hours. An additional experiment could be to set the storage capacity of the Transit Hall to infinity and manually chose the percentage of coils to be loaded from the Transit Hall.

The main research question

The answers of the previous sub-research questions are used to ultimately answer the following main research question: *How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?*. The performance can be improved by firstly identify all the important elements linked to the outer-harbour 3. In this research 7 elements are identified, all of which are potential bottlenecks. Subsequently performance should be defined clearly in terms of KPIs and PIs that are in line with the aspired objectives of Tata Steel. The harbour's performance can be assessed using five KPIs. To identify the bottlenecks three PIs are used. A DES model is used to assess the performance and has proven that it can contribute to decision-making by measuring the expected increase of performance for a set of alternative configurations. Overall the largest improvements can be achieved by improving the supply rate of loads directly towards the quay. Secondly, improvements to the performance are also expected when the harbour coil storage facility, the Transit Hall, is used to a larger extent than it is used nowadays, although the expected improvements are not as large as with increasing the supply rate of loads. Adding locomotive capacity alone does not solve any of the challenged faces and at the same time even increases operational expenses. Overall it can be concluded that the insights from this research show where Tata Steel should improve their processes to maximise the improvement of the performance of their outer-harbour 3.

9.1 Recommendations for further research

Based on the discussion and conclusions, suggestions and recommendations for further research and for Tata Steel are discussed in this section The academic studies on break-bulk cargo ports are limited. Research done on such ports, using DES models, are even more scarce. In that light there are multiple directions that provide potentially interesting topics to investigate. In this research thesis the emphasis is placed on the application of bottleneck methods using average performance metrics of the system under investigation. However, valuable additional insights can be gained by applying shifting bottleneck detection method such as the Active Period method. This would provide stakeholders information on which machine or resource is or are the bottleneck(s) in the system at certain moments in time. This information enables more real-time prevention methods to be taken to eliminate bottleneck while they are appearing. Interesting directions for further research are to investigate bottleneck prediction methods in the context of break-bulk cargo ports. As organizations gather more data on all levels of their processes, it is more likely that enough data is available to apply these methods. The ANFIS model proposed by (Zhengcai et al., 2012) or the ARMA model developed by (Li et al., 2011) are such models. Overall the financial aspects considered in this thesis are limited. The focus has been on the operational improvements of the outer-harbour 3 of Tata Steel. However, more extensive research of the costs and benefits of each solution is expected to contribute even more to decision-making processes as it can be seen as detailed input for business cases.

9.2 Recommendations for Tata Steel IJmuiden

In addition to suggestions for further research, there are also some suggestions for Tata Steel to look further into. The recommendations are split into several topics and are discussed in this section.

KPIs

- **Recommendation 1: Add Quantity KPI to existing KPI-tree** One of the findings in chapter 3 was to add an average loading time (lead time) KPI and productivity quantity KPI to the current KPI-tree. The OTB department used the former KPI, however it is recommendation for the OSL department to also have more data on this performance at hand. The same hold for the measuring the productivity in quantity instead of solely in volume. The weight of collo are not a determining factor in the cycle times of machines. A lighter colli takes as much time to handle as a heavier colli. However if one would only look at the volumes it would not give the full picture of the performance that is realised. Combining quantity and volume does provide that picture.

- **Recommendation 2: KPI prioritisation for future performance optimisation** It is recommended for Tata Steel to think about which KPIs they consider most important. This research does not optimise for KPIs, however is useful for Tata Steel to rank KPIs such that further researchers can put more emphasis on improving those KPIs that are considered most important. Organising brainstorm sessions is a method to do so.

Data

- **Recommendation 3: Data differentiation** Tata Steel has large quantities of data available and they acknowledge the value of data as well. For graduate students, but also for employees of OSL it can be beneficial to differentiate in each type of vessel visiting Tata Steel and the harbour where these vessels were loaded. Understand in detail where vessels were loaded makes it easier to differentiate in measuring the performance of each harbour individually.

- **Recommendation 4: Setup and implementation of loading rate dashboard to be used by S&W** During the system analysis phase of this research thesis it became clear that the data that is currently available can also be used to track the loading operations of vessels in the harbours. Multiple plots were created to understand better how the throughput differs throughout the loading process of vessels. It is recommended to use this data to track the course of the loading processes by for example plotting the course of the loading process in terms of realised volumes loaded versus the expected volumes. An example of such a plot can be found in Figure F.1. The added value of doing this is that it enables Tata Steel to compare the performance of the operations to the norm that is set on an almost real-time operational level. Also it could help in identifying reoccurring patterns in the loading operations that would otherwise be very hard to identify. For example, it could be that the during the loading of ETTS it is harder to reach the norm of 13 colli/hour. Plotting this gives additional insights that either confirms of refutes this hypothesis. The port planner could benefit from this as it helps to understand why the executing of the planning has gone different that was planned beforehand.

Results

- **Recommendation 5: Focus on improving supply of colli by train** As concluded, the highest performance increase, in terms of the KPIs measured, can be achieved by improving the duration it takes to supply colli via trains towards the quay. It is recognised that it is easier said than done. This research quantifies what the potential performance would be once Tata Steel can realise these improvements to their supply system. Based on these results the OSL department is advised to focus their attention to improving this part of the process. Financing improvement projects can be done with money that is saved by having to pay less demurrage costs in the future as a result increasing the productivity. Currently there is sufficient capacity of forklift trucks, cranes and securing teams to improve the performance of the outer-harbour 3. No investments or changes are necessary as it would not result in performance increase. This thus indicates that from a operational performance perspective it is not worthwhile to invest in a new hydraulic crane.

- **Recommendation 6: Put more emphasis on using the Transit Hall** Reaching a 20% increase in productivity can be achieved by almost halving the supply duration of trains by the CE. The second best option achieves an increase in productivity of 18% by using the Transit Hall 25% more than it is used currently. Therefore, if decreasing train assembly time is considered too difficult at the moment, it is advised to put more emphasis on transporting more coils towards the Transit Hall instead and make that a priority.

- **Recommendation 7: Alternative deployment strategy of quay cranes** Based on the base configuration Critical Indicator Values calculated in chapter 3 one can see that the quay cranes do have a small lack of capacity overall. The gap between the KR value of the quay cranes and the CE and locomotives is quite large meaning that by reducing the capacity of the quay cranes, you would equalise these values more. Although it has to be measured in detail, it is worthwhile for Tata Steel to see whether then can go from a 3-3-2 crane configuration towards a 3-2-2 crane configuration. Expected is that the impact of the performance is not large as the quay cranes are not the bottleneck. However, using the crane less would safe money in the form of fte's which can subsequently be used elsewhere. It is thus advised to OSL to further investigate the possibility of reducing the number of operational crane-teams when the loading of deep sea vessels is considered.

Model

- **Recommendation 8: Model usage** The Python DES model is built specifically to mimic the processes related to the loading of deep sea vessels in the outer-harbour 3. Many data inputs such as processing times of machines and inter-arrival times of vessels are easily adjustable. It is more difficult to add additional components to the model as this requires more know how of the Python programming language and how the Salabim software package works. However, with knowledge sharing of the author, additional adjustments to the model can be done. For example also include barge and short-sea vessels loading in the outer-harbour 3. The model has proven its usefulness and it can provide more insights in the future for Tata Steel to help in decision-making. In order for the model to be even more accurate it is recommended to look at assumptions and limitations discussed in chapter 5. These are shortcomings in the model and do not fully mimic the actual operations and should therefore be considered or even eliminated for the results to be more realistic.

Bibliography

Are you confused about supply chain measurement and metrics? Mar 2017. doi: https://www.benchmarkingsuccess.com/are-you-confused-about-supply-chain-measurement-and-metrics/.

I. Al-Harkan and M. Hariga. A simulation optimization solution to the inventory continuous review problem with lot size dependent lead time. *Arabian Journal for Science and Engineering*, 32(2): 327, 2007.

A. E. Branch. *Elements of shipping*. Routledge, 2007.

M. Bruglieri, E. Gerzelj, A. Guenzani, R. Maja, and R. de Alvarenga Rosa. Solving the 3-d yard allocation problem for break bulk cargo via variable neighborhood search branching. *Electronic Notes in Discrete Mathematics*, 47:237–244, 2015.

A. Cartenì and S. de Luca. Analysis and modeling of container terminal handling activities.

S.-Y. Chiang, C.-T. Kuo, and S. Meerkov. Dt-bottlenecks in serial production lines: Theory and application. *Robotics and Automation, IEEE Transactions on*, 16:567 – 580, 11 2000. doi: 10.1109/70.880806.

R. Cimpeanu, M. Devine, D. Tocher, and L. Clune. Development and analysis of a port terminal loader model at rusal aughinish. *Simulation Modelling Practice and Theory*, 51:14–30, 02 2015. doi: 10.1016/j.simpat.2014.11.001.

R. Cimpeanu, M. T. Devine, and C. O'Brien. A simulation model for the management and expansion of extended port terminal operations. *Transportation Research Part E: Logistics and Transportation Review*, 98:105–131, 2017.

S. T. Committee et al. Terminology for model credibility. *Simulation*, 32(3):103–104, 1979. doi: 10.1177/003754977903200304.

S.-C. Council. Supply-chain operations referencemodel. scor overview. version 8.0, Jul 2007.

M. B. Duinkerken and B. Atasoy. Quantitative methods for logistics lecture me44206 - 06 experimenting, Oct 2019.

H. Eskandari, N. Babolmorad, and N. Farrokhnia. Bottleneck analysis in a pharmaceutical production line using simulation approach. *Simulation Series*, 45:195–202, 01 2013a.

H. Eskandari, N. Babolmorad, and N. Farrokhnia. Bottleneck analysis in a pharmaceutical production line using simulation approach. In *SummerSim*, page 12, 2013b.

G. Greeff and R. Ghoshal. *Practical E-manufacturing and supply chain management*. Elsevier, 2004. ISBN 978-0-7506-6272-7. doi: https://doi.org/10.1016/B978-075066272-7/50013-0.

A. Guenzani, E. Gerzelj, R. D. A. Rosa, K. P. Fraga, B. P. Arpini, and D. S. Silva. Mathematical model for planning the layout and stacking of granite blocks in a maritime terminal. *International Journal of Logistics Systems and Management*, 26(4):453–474, 2017.

A. Gunasekaran and B. Kobu. Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. *International Journal of Production Research*, 45:2819 – 2840, 2007.

M.-H. Ha, Z. Yang, and J. S. L. Lam. Port performance in container transport logistics: A multi-stakeholder perspective. *Transport Policy*, 73(C):25–40, 2019. doi: 10.1016/j.tranpol.2018.09.

V. Hans, O. Jaap, and L. Gabriël. *The Delft Systems Approach Analysis and design of Industrial Systems*. Springer London, 2008.

P. Joon. Data-driven transportation planning for a large manufacturing plant, 2020.

J. Koturiak and M. Gregor. Simulation in production system life cycle. *Computers in Industry*, 38: 159–172, 1999.

O. Kulak, O. Polat, R. Gujjula, and H.-O. Günther. Strategies for improving a long-established terminal's performance: a simulation study of a turkish container terminal. *Flexible Services and Manufacturing Journal*, 25(4):503–527, 2013.

M. Leporis and Z. Králová. A simulation approach to production line bottleneck analysis. 2010.

K. Li and H. Tian. Integrated optimization of finished product logistics in iron and steel industry using a multi-objective variable neighborhood search. *ISIJ International*, 55(9):1932–1941, 2015.

L. Li, Q. Chang, G. Xiao, and S. Ambani. Throughput bottleneck prediction of manufacturing systems using time series analysis. *Journal of Manufacturing Science and Engineering*, 133(2), 2011.

F. Longo, A. Huerta, and L. Nicoletti. Performance analysis of a southern mediterranean seaport via discrete-event simulation. *Journal of Mechanical Engineering*, 59(9):517–525, 2013.

P. Mack. Chapter 35 - big data, data mining, and predictive analytics and high performance computing. pages 439–454, 2014. doi: https://doi.org/10.1016/B978-0-12-407910-6.00035-1.

R. J. Meurn and C. L. Sauerbier. *Marine Cargo Operations: A Guide to Stowage*. 2004.

S. Mukherjee and A. Chatterjee. The concept of bottleneck. In *International Conference on Multi-Echelon*, pages 37–48, 2007.

J. A. Ottjes and H. P. Veeke. Process interaction modeling, Oct 2012.

S. Papavinasam. Chapter 14 - management. pages 841–918, 2014. doi: https://doi.org/10.1016/B978-0-12-397022-0.00014-5.

M. D. Petty. Calculating and using confidence intervals for model validation. In *Proceedings of the Fall 2012 Simulation Interoperability Workshop*, pages 10–14, 2012.

R. Poveda-Bautista, D. Baptista, and M. García-Melón. Setting competitiveness indicators using bsc and anp. *International Journal of Production Research - INT J PROD RES*, 50:1–15, 09 2012. doi: 10.1080/00207543.2012.657964.

S. Robinson. Conceptual modelling for simulation part i: definition and requirements. *Journal of the operational research society*, 59(3):278–290, 2008.

S. Robinson. Choosing the right model: Conceptual modeling for simulation. In *Proceedings of the 2011 Winter Simulation Conference (WSC)*, pages 1423–1435. IEEE, 2011.

C. Roser, M. Nakano, and M. Tanaka. Shifting bottleneck detection. In *Proceedings of the Winter Simulation Conference*, volume 2, pages 1079–1086. IEEE, 2002.

C. Roser, M. Nakano, and M. Tanaka. Comparison of bottleneck detection methods for agv systems. In *Winter Simulation Conference*, volume 2, pages 1192–1198, 2003.

S. Saurí, P. Morales Fusco, E. Martín, and P. Benítez. Comparing manned and automated horizontal handling equipment at container terminals. *Transportation Research Record: Journal of the Transportation Research Board*, 2409:40–48, 12 2014. doi: 10.3141/2409-06.

H. Schoenmaker. Generating stowage plans in the steel industry (master thesis), 2016.

D. L. Schott and M. van den Hoed. Break bulk and bulk terminals. *Encyclopedia of Maritime and Offshore Engineering*, pages 1–10, 2017.

S. Shaw, D. Grant, and J. Mangan. Developing environmental supply chain performance measures. *Benchmarking: An International Journal*, 17:320–339, 06 2010. doi: 10.1108/14635771080001424.

J. Sterman. Business dynamics, system thinking and modeling for a complex world. *http://lst-iiep.iiep-unesco.org/cgi-bin/wwwi32.exe/[in=epidoc1.in]/?t2000=013598/(100)*, 19, 01 2000.

E. Suprun, O. Sahin, R. Stewart, and K. Panuwatwanich. Model of the russian federation construction innovation system: An integrated participatory systems approach. *Systems*, 4:29, 08 2016. doi: 10.3390/systems4030029.

C. Surie and M. Wagner. *Supply Chain Analysis*. Springer, 2008.

H. Tian, Z. Liu, and X. Deng. General cargo yard storage allocation optimization based on layout. In *2018 Chinese Control And Decision Conference (CCDC)*, pages 5271–5276. IEEE, 2018.

W. Urban and P. Rogowska. Engineering management in production and services methodology for bottleneck identification in a production system when implementing toc. *Engineering Management in Production and Services*, 12, 07 2020. doi: 10.2478/emj-2020-0012.

C. Zhengcai, D. Jijie, L. Min, and W. Yongji. Bottleneck prediction method based on improved adaptive network-based fuzzy inference system (anfis) in semiconductor manufacturing system. *Chinese Journal of Chemical Engineering*, 20(6):1081–1088, 2012.

Appendix A

Scientific paper

Analysis and Simulation of a Break Bulk Terminal in the steel industry

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Abstract—Break bulk terminal operators are constantly in search for improving the performance of their operations. The logistical processes associated with these operations are complex and identifying where improvements have the largest impact on performance therefore is as well. In this paper a combination of system thinking and discrete-event-simulation methods is used to analyse and mimic the loading procedure of deep-sea vessels in the harbour of a large steel manufacturer. A set of alternative resource and machine configurations is tested with a built simulation model to measure the potential performance increase compared to their current operations performance. Results provide insights for the decision-making process in which the manufacturer has to decide what investments have to be made in the future.

Keywords—Break Bulk terminal operations, Discrete-Event Simulation, System-Thinking, Decision-making

I. INTRODUCTION

To standardise cargo handling equipment the container was introduced in the previous century. However, some types of cargo cannot be transported in containers due to their size or weight for example. Such cargo is often handled in individual pieces. This cargo is referred to as break-bulk cargo. The total percentage of cargo that is categorised as break-bulk is shrinking as more and more cargo is transported in containers. However, in absolute tonnage break-bulk cargo is still growing [1]. Break-bulk cargo still currently accounts for a considerable amount of the maritime trade. In 2005, the total break-bulk fleet size in dead weight tonnage equalled 11% depending on the exact definition of break-bulk cargo used [2]. Break bulk thus differs from other cargo is the fact that these type of goods are processed per piece instead of bulk or containers for example. despite this difference, the operations and processes associated with break bulk terminals are very similar to dry bulk or container terminals [1]. Products are transferred (transshipped) from one mode of transportation, for example vessel, barge, truck or train to another. In order to do so, terminals are provided with shore cargo handling equipment. Five major break-bulk product groups that will still be considered break-bulk in the future [1] being:

- Bags
- Bananas
- Project cargo
- Roll-on roll off
- Timber & steel

Specially interesting for this research is steel break-bulk cargo. Due to the nature of steel break-bulk cargo, processing these goods will in general take more time as the steps in the process are less standardised compared to handling containers. The function of these break-bulk terminals can be described as the temporarily on-site storage of general cargo and the realisation of the transfer of this cargo to and from storage or from one mode of transportation to another. In order to do so, equipment handling machines such as forklift trucks, trains, trucks and quay cranes are needed. The costs associated with the storage, handling and transportation of (semi) finished products are significant cost items for steel manufacturers[3]. Before vessels have even berthed the quay of a terminal, a series of processes are put into action to transport steel coils towards the harbour. Once a vessel arrives, the required machines, resources and workers work together to execute the loading as efficient as possible. Delays in the departure of loaded vessels can result in major fines to be paid. In this research specific focus is placed on providing insights into the decision-making processes in which break-bulk cargo handlers in the steel industry often find themselves in. Which of the existing processes should be improved first in order to achieve overall performance increase. This paper elaborates on the research done on this topic in the context of the logical processed of one of the export harbours of Tata Steel IJmuiden. The On-Site Logistics department and more specifically the Stevedoring & Warehousing sub-department are responsible for the operations associated to the loading of large ocean going vessels in this harbour. The main question answered by this research is stated as follows: *How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?*. By analysis the current system and its performance the bottlenecks are identified. Subsequently a set of experiments is performed to assess the potential performance increase for alternative use of machines and resources compared to the current configuration. This results in objective insights that can be valuable in complex decision-making processes that the organisation faces. This paper is structured as follows. In chapter section II relevant literature is discussed. In section III the research methodology is elaborated upon. Moreover in this section the system at hand is analysed and based a DES model is proposed. In section IV the built DES model is applied to a case study and the results are discussed. The paper is finalised with section V in which the final conclusions and recommendations for future research are discussed.

II. Literature research

Simulation modelling and bottleneck detection

The function of break-bulk terminals is similar to that of container terminals. The operators of these terminals are responsible for transferring break-bulk cargo from one mode of transportation to another by using specialised material handling equipment. Looking specifically at the steel industry, the costs associated with these storage, handling and transportation of (semi) finished products are significant cost items for steel manufacturers. Being able to decrease these costs can increase profit margins of steel coils even more than applying technical improvements to the production processes as these are limited due to technical limitations [3]. Bottlenecks in the processes result in organisations not being able to fully use the potential of their resources which results in less efficiency and thus lower performance. What defines a bottleneck however is not set in stone. For each production or logistical process, the description of the bottleneck could mean something different. However, many researchers have tried to do so. [4] defines a bottleneck in a production or logistical process as a point in the process where congestion occurs. This happens when the arrival rate of workload for one of the production or logistical processes is larger than the that particular process is able to handle. Due to these bottlenecks the output of a system of process is smaller than the theoretical maximum. Bottleneck do not only have a location, but also a magnitude. If a machine is defined as a bottleneck in a certain logistical process, but its impact is very small, it might not be worth to invest time and money in improving its capacity [5]. The literature provides a multitude of models that can aid in identifying bottlenecks in systems based on statistics. In general their are two categories of methods.

- Analytical methods
- Simulation methods.

The first category of methods is based on the fact that systems can be described using statistics [6, 7]. Analytical methods are useful to predict the bottleneck on the long term. A disadvantage however is that usually the system under investigation is complex to such an extend that it is near to impossible to apply these methods. The second category, simulation models, provide a solution to this problem as these models are able to simulate complex, dynamical and often stochastic processes. A disadvantage of such simulation methods however is the time spend on developing such models to an extent that they are useful for providing insights.

1. Simulation modelling

Many papers found in the literature aim to optimise operations of container terminals. Apart from a few studies aiming to solve optimisation and planning challenges for break-bulk cargo [8, 9, 3] there are no studies found on applying discrete-event simulation modelling techniques on break-bulk terminal operations. Simulation models are capable of capturing the time-dependent behaviour of logistical systems where stochastic behaviour is exhibited by a large number of elements that mostly have a multitude of interrelations with each other thus resulting in complex systems [10]. The advantage of such models is that they allow to perform experiments on these systems as if they were operational without having to make high risk and high cost investments. The application of such models in other logistical contexts are plentifully and have proven to be insightful in contexts in which decision-making is difficult as the complex nature of the logistical processes makes is hard to predict the impact of investments. DES models are useful tools to design, operate, identify bottlenecks and assess alternative configurations and scenarios to improve logical processes compared to other methods such as analytical methods [7, 11]. DES models have been applied to a multitude of topics related to logistics and port logistics [12, 13, 14, 15]. Simulation techniques have proven to be ideal tools to identify the bottlenecks in a system and to test and measure countermeasures to tackle these bottlenecks. [7] and [13] both elaborate on the advantage of simulation based model compared to analytical models to mimic complex logistical systems and to find bottlenecks in the system and argue that discrete-event simulation models are a preferred model for their study of the process of bulk carrier loading and discharge. They choose to do so, due to a large number of variables and a degree stochastics that would generate an analytically uncontrollable system.

2. Bottleneck detection

Simulation models can calculate, if properly build, the necessary statistics themselves. The statistics can subsequently be used as input for several bottleneck calculation methods. The simulation methods can be split even further in [16]:

- Momentary bottleneck detection
- Average bottleneck detection

Momentary bottleneck detection methods are used to detect which machines or resources are at a given point in time the bottleneck. They are particularly useful when an organisation wants to act relatively quickly if once a bottleneck occurs in their operations. Average bottleneck detection methods are used to measure what machines or resources in a system or the bottleneck on the long term. So given a relatively long period of time, what resources have the largest negative impact of the performance of the whole system. In [17, 18] several bottleneck detection methods are tested and studies concluded that of those methods, the critical indicator value method was proven to generate the best result. This method is suitable for usage in combination with simulation models as the required inputs of average utilization, idle, blocking and waiting times of the resources/machines can be calculated by these models. For each machine in the system, these rates are used to calculate the critical indicator of a machine and compare it to the average critical indicator value of the whole system. This gives insight into the machines or resources that require capacity expansion as well as those machines or resources that have capacity reserves and thus could be utilized better. The Critical indicator value of the *ith* machine can be calculated as follows:

$$KR_i = \left(\frac{\sum_{i=1}^{n} B_i}{n} - B_i\right) + \left(I_i - \frac{\sum_{i=1}^{n} I_i}{n}\right) + \left(BI_i - \frac{\sum_{i=1}^{n} B_{Ii}}{n}\right) + \left(Li - \frac{\sum_{i=1}^{n} L_i}{n}\right) \quad (1)$$

Where:

- KR_i, the critically indicator for the i-th workplace [%]
- B_i, the average utilization rate for the i-th machine (Busy) [%]
- B_{Ii}, the average blocking rate for the i-th machine (Blocked) [%]
- I_{Ii}, the average starvation rate for the i-th machine (Idle) [%
- L_i, the average waiting rate for labor for the i-th machine (Labor) [%]

Besides this method another often used average bottleneck detection is the utilisation method in which the machine or resource with the highest overall utilisation is considered the bottleneck in the system.

Key performance indicators

The definition of key performance indicators (KPIs) and performance indicators (PIs) is not universally defined and so are their functions. Suggestions for definitions are however plentiful in literature. [19] suggests that KPIs should be used by organisations to

- Manage performance
- Enable sustainable business improvement
- Drive change

Other literature also suggests that KPIs should above all help businesses in the decision-making processes they face [20] and enable them to compare the performance of management and technical processes to norms [21]. Overall the choice for which KPIs to use depends on the decision-making level, strategic, tactical or operational at which businesses want to inform, control and steer their organisation [22]. In the past KPIs were mostly financially focused, however non-financial KPI are more widely used as well [23].

As the literature suggests, KPIs should be selected such that they provide to right information regarding the managerial and technical performance and whether that performance is in line with a chosen strategy. This research focuses on the performance of a break-bulk terminal in the steel industry and operations in such terminals are quite similar to those of container terminals. [24] proposes a measurement instrument for port performance indicators in the container terminal industry. The authors combine the perspective of different stakeholders, terminal operators, customers and municipalities into a selection of the most widely used KPIs. Specifically related to the core activity of terminals which is to transfer containers between modes of transportation the authors state that the performance indicators can be split into two categories. Firstly the productivity in terms of occupancy of berths and the utilization of machines and resources, and secondly the lead time of vessels, trucks and cargo due to the similarities between containers and break-bulk terminals these KPIs can be expected to the effective for the latter as well.

III. Methodology

To the best knowledge of the author, system thinking methods and DES models have never been combined and researched in the context of the steel break-bulk industry. This despite the fact that this type of cargo still being a significant part of total amount of goods traded world wide. By combining the Delft System Approach [10] to identify the relevant elements and processes and set system boundaries and using these results to mimic the system with use of a DES model knowledge to topic is added. The conceptual modelling approach proposed by [25] is followed in a case study involving the loading procedures of deep sea vessels in the outer-harbour 3 of Tata Steel IJmuiden.

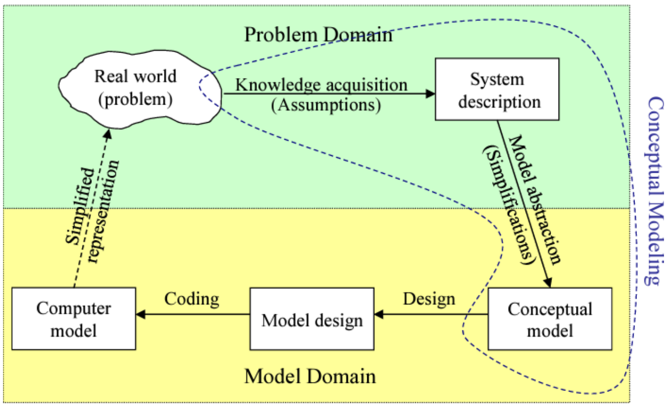

Fig. 1: Artefacts of Conceptual Modeling [25]

First the real world system is translated into a system description using the principles of analysing systems in a structured way as proposed by [10]. By means of this method a system boundary is drawn and machines and resources referred from here on by 'elements', are identified that could be potential causes of non-optimal functioning of the harbour of Tata Steel. By doing so a set of assumptions are required as decisions made due to the uncertainties about the real world being modeled are unavoidable [25]. The system description is used as guide to make a conceptual model version of the system. Necessary simplifications are made to enable faster model development and use. Two conceptual model versions are built. The first one is a combination of the Process Flow diagram method and the Logic flow method which combined represent the flow of material through the system and the elements that process the materials. Secondly a Program Description Language conceptual model representation is built to simplify the step between the more tangible representation of the system and the highly abstract representation of the system in the form of a computerised model. The computerised model is built using the Python programming language in combination with the Salabim Discrete-event simulation software package. With this model the performance of the current system is measured, bottlenecks are identified using the *utilisation method* and a slightly changed *critical indicator value method* where the 'average waiting rate I_{Ii}' is not taking into account as the model does not calculate this metric. Accordingly alternative configurations are tested and the results are compared to the performance of the current system.

System Analysis

Based on the system thinking method discussed in section III the system at hand is analysed. A set of temporarily, permanent and environmental elements is identified, some of which are potential causers for non-optimal performance of the system. In total 15 elements are identified, five temporarily, nine permanent and one environmental element. Of these 15, eight listen below are considered to be potential bottlenecks in the system.

- Temporarily elements
  - Locomotives
  - Trains
- Permanent elements
  - Transit Hall Crane
  - Quay forklift trucks
  - Hold forklift trucks
  - Quay cranes
  - Secure teams
- Environmental elements
  - CE

Each of these element's statistics are calculated by the simulation model to determine whether or not they are considered to be a bottleneck and to what extent they cause the system not to operate to its potential. Two types of products are researched. The first product type is the coil and the second the 'Eye To The Sky' (ETTS). Both types are referred to in this paper by collo and colli in plural. The CE represents operations required for loading of trains with the two collo the hinterland of the Tata Steel manufacturing site. The locomotives are subsequently needed to transport the trains towards the quay of outer-harbour 3 or the Transit Hall. The latter is a temporarily storage facility of coils to function where coils can be stored before vessels arrive to be less dependent on the supply via trains during loading of vessels. This Transit Hall has a crane which is used to unload trains and load coils towards the quay. Forklift trucks are used to execute transportation tasks between the Transit Hall and the quay cranes as well as from trains on the quay and the quay cranes. In the hold of vessels forklift trucks are also used to put ETTS and coils into their final position. For each product loaded the secure teams are responsible for securing the load.

In addition to the elements, the system's performance has to be measured using an appropriate set of KPIs. Based on literature discussed and KPIs used by Tata Steel five KPIs are used in this case study to measure performance:

- Productivity, split in tonnage/day and colli/day
- Demurrage
- Costs (Additional operational costs)
- Punctuality
- Average vessel loading time

Modelling

After the analysis of the system and the selection of KPIs to measure its performance the conceptual model representations are made. In Figure 2 the Process Flow Diagram of the system is seen. An empty vessel enters arrives at the harbour, thus enters the system. Before the vessels docks the quay it triggers Transit Hall trains to be loaded with coils only in the CE and go towards the Transit Hall, where the Transit Hall crane unloads the coils and puts them into temporarily storage. Once the vessel is docked, trains are now being loaded with both coils and ETTS and er not transported towards the Transit hall anymore, but directly towards the quay where they are unloaded by the quay cranes and forklift trucks. In parallel, the Transit Hall crane also moves coils from the temporarily storage towards its doors from where forklift trucks transport the coils towards the quay cranes. Apart from rail supply of ETTS, these products are also transported by forklift trucks from the a storage point in the outer-harbour 3, the BUO-BUW, towards the quay cranes. Once all coils and ETTS are loaded onto a vessel no more trains are generated and no more coils and ETTS are loaded from temporarily storage until a new vessel arrives at the harbour.

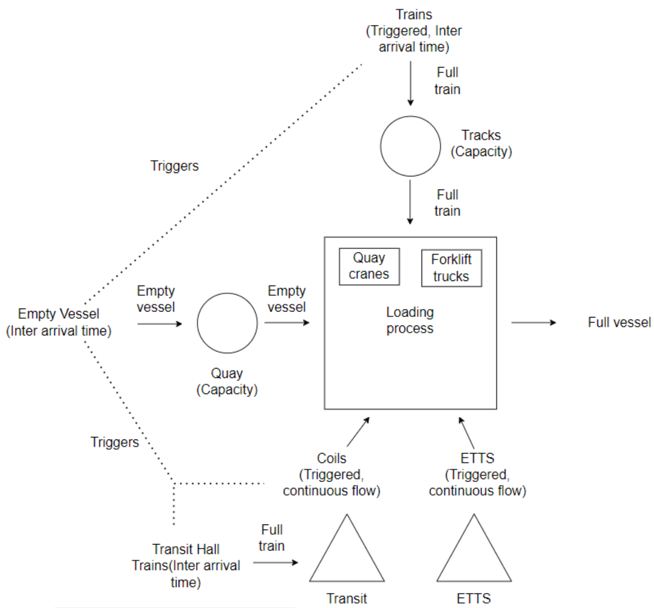

Fig. 2: Abstract representation of the conceptual model

1. Assumptions

The conceptual model is used as a description of the assumptions, simplifications, input, output, workings and objectives that the to be built computerised model should contain [26]. Assumptions are made due to uncertainties about the real life system. The most important ones are discussed. shortly. In the real outer-harbour 3 barges and short sea vessels also have to be loaded with a variety of ETTS and coils. In this research however, only deep see vessels are processed due to the loading processes associated with these vessels being most complex. This results in the overall utilisation of machines to be lower than you would measure based observing the harbour in real life. Moreover, it is assumed that the transportation time of forklift trucks on the quay and in the hold of vessels is constant. These constants are measured using a stopwatch. The same holds for securing coils and ETTS inside the hold of vessels. Due to the many, often shift specific ways of workings that the shift crews have adopted throughout the years it was failed to approach this process by a distribution. Lastly, in the real system coils and ETTS are transported to the harbour in clusters based on their size and shape such that a stowage can be performed in a sequence. This sequence has to be followed, but it takes time. This is ignored in this research which results in slightly faster overall loading of vessels compared to the loading time of vessels in the real system.

2. Simplifications

Simplifications are used to simplify the step computerising the conceptual model. Firstly, some elements have more than 1 machine at their disposal, for example there are two quay forklift trucks available. The model is made in such a way that for each of these tasks one of the available forklift trucks is used instead of a dedicated forklift truck. This simplification holds for each resource in the model, the locomotives, tracks, Transit Hall crane, quay cranes, forklift trucks in the hold as well as the securing teams. The second simplification has to do with double stowage. If all conditions are met, the crane within the real life system will move two colli at the same time. However, within the model, each coil or ETTS is moved and processed by the quay-cranes individually. Instead of processes two colli at the same time, the model handles each colli twice as fast, resulting overall in the same effect.

3. Input

Input for the model are empty deep sea vessels. Random draws from a historical data set of 50 deep sea vessels are taken as to function as the load a vessel requires. The inter-arrival time of vessels is approached using an exponential function based on historical inter-arrival times of circa 200 deep sea vessels in the last three years.

4. Output

The 'physical' output of the system are fully loaded deep sea. Besides the processing of vessels, the model also produces values for the KPIs that are used to measure the performance of the system. These KPIs are subsequently used to identify bottlenecks as well as to measure the theoretical increase or decrease of these KPIs during the testing of alternative scenarios and configurations.

5. Workings

The model is giving the aforementioned input, namely empty vessels requiring to be loaded with ETTS and coils. The vessel triggers a set of events, the supply of coils and ETTS towards the quay cranes and subsequently into the hold as visible in Figure 2. Once a vessel is fully loaded it leaves the system. At the end of a simulation the (K)PIs discussed in section III are measured.

6. Objectives

The overall model objective is to mimic the operations related to stowing of deep sea vessels in the outer-harbour 3 of Tata Steel IJmuiden such to find bottlenecks in the system, if any and to test a set of scenarios and alternative configurations to eliminate these bottlenecks (partly). The model thus functions as a tool to measure the impact of changes to the system on the performance of the system without having to execute these changes in the real harbour.

7. Computerised model

Based on the conceptual models, the computerised model is build. The Python programming language is used in combination with the Salabim Discrete-Event Simulation modelling software package.

IV. CASE STUDY

The build Discrete-Event Simulation model is used to assess the current performance of the system. The outcomes of the assessment are used as a reference for the experiments performed. 50 vessels and their required loads are drawn from available historical data and are used as input for the simulations. The vessels arrive according to exponentially distributed Inter Arrival Times which are calculated using the historical arrival times of almost 200 deep sea vessels. The configuration of the machines and resources is summarised in Table 1.

Element	Capacity
Locomotives	3
Transit Hall crane	1
Quay forklift trucks	2
Quay cranes	2
Hold forklift trucks	2
Secure teams	2

TABLE 1: CONFIGURATION OF OUTER-HARBOUR 3

The configuration is visualised in Figure 3. The simulation is run for 30 times to reach statistically meaningful results. From the 30 simulation runs statistics on are collected required to apply the *utilisation method* and *critical indicator value method*. Occupancy is defined as the utilisation rate of a machine divided by its capacity. Applying this method on the results, the occupancy rates of each of the elements are ranked, from highest to lowest as can be seen in Table 2. The element with the highest occupancy rate is the CE and thus considered the bottleneck.

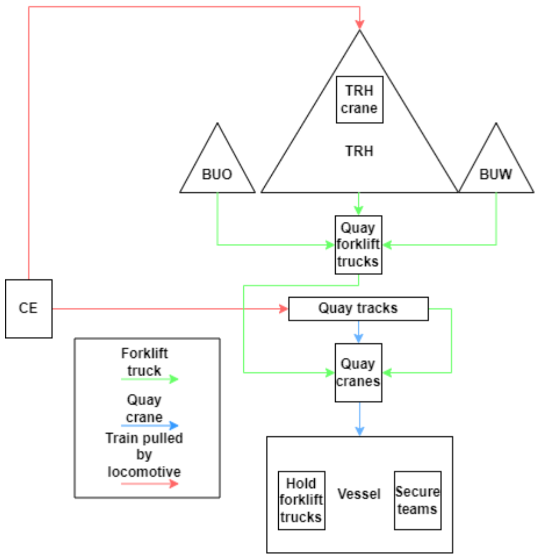

Fig. 3: Simplistic overview of outer-harbour 3

Element	Occupancy
CE	0,45
Locomotives	0,29
Transit Hall crane	0,19
lashing	0,16
Quay Cranes	0,15
Forklift trucks	0,04
Forklift trucks hold	0,02

TABLE 2: OCCUPANCY OF ELEMENTS BASE CONFIGURATION

The Critical indicator value method requires simulation statistics on average occupancy, idle and blocking times of all elements. The results are visible in Table 3. Elements with a negative KR_i value can be improved by adding capacity. The element with the lowest KR_i is considered the bottleneck. Elements with positive KR_i have capacity reserves and their capacity is not optimally utilised. Looking at the table the CE element has the lowest KR_i value and thus is considered the bottleneck in the system.

Element	KR-value
CE	-62,5
Locomotives	-38,7
lashing	-13,1
Transit Hall crane	-9,0
Quay Cranes	-7,5
Forklift trucks	41,0
Forklift trucks hold	90,0

TABLE 3: CRITICAL INDICATOR VALUE KR OF ELEMENTS BASE CONFIGURATION

Experiments and results

Based on the analysis elaborated upon in section IV it is concluded that the CE elements is the main bottleneck. Three experiments are executed to assess the potential increase of performance by changing the configuration. The scenario data remains the same apart from the Inter Arrival Time of vessels, which is still randomly drawn from the same exponential distribution. Thus the same 50 vessels with the same load visit the harbour and also in the same sequence. The results with respect to the volume/day productivity and the average loading time of vessels is discussed in this paper as these results are most outstanding.

1. Experiment 1: Increase supply rate CE

In the first experiment the supply rate of train assembly by the CE is decreased by one hour each time from the initial 8 hours on average up till and including 1 hour. As the CE is considered the bottleneck adding capacity is hypothesised to have an positive impact on the volume/day loaded onto vessels which is confirmed as can be seen in Figure 4. As the simulation is subject to stochasticity in arrival times and processing times fluctuations throughout the 30 simulations is observed. In order to take this uncertainty into account a 95% confidence interval is made for each simulation. Looking at the graph it can be concluded that the productivity increases for each hour that the average loading time of trains is reduced, thus reducing the supply duration has a positive impact on the workings of the performance of the outer-harbour 3. Tata Steel aims to improve its volume/day performance by 20% which is reached around the 4 hour point. In addition to the productivity the average loading time of vessels is also measured for each simulation. The results are visible in Figure 5. As in line with increasing productivity, the average loading time of vessels is reducing. Roughly speaking for each hour reduced, the average loading time is decreasing by 0.3 days.

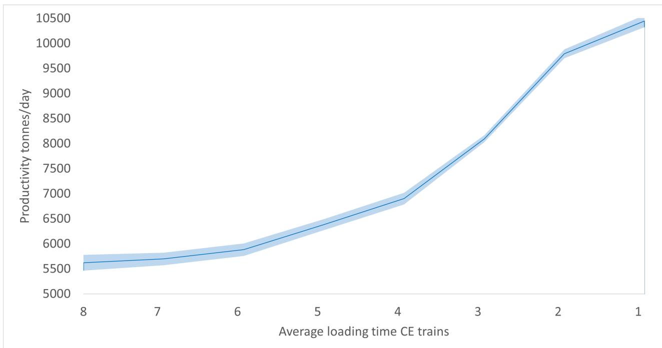

Fig. 4: Experiment 1: Productivity volume (Tonnes/day)

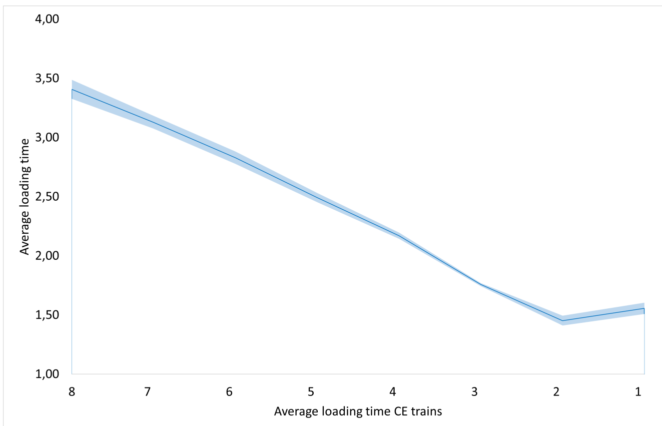

Fig. 5: Experiment 1: Average loading times (Days)

2. Experiment 2: Increase locomotive capacity

In the second experiment the locomotive capacity is increased gradually. The initial configuration contains three locomotives that are operational 24 hours per day. Each day is made up of 3 shifts of 8 hours and each shift either 1, 2 or 3 additional locomotives are added. To clarify, a locomotive capacity of 3 1/3 thus means that 3 locomotives are always operational and 1 out of the 3 eight hour shifts an additional locomotive is added etc. Again for each simulation 95% confidence intervals are calculated. What stands out when looking at Figure 6 is that the productivity does not increase if additional locomotives are put into operation. The line remains more or less horizontal and taking the confidence intervals into account to significant change is performance is measured. Looking at Figure 7 the same can be said regarding the average loading times. As in line with the absence of an increase in, vessels will not significantly be loaded faster compared to the base configuration when 3 locomotives are used. Although not displayed in this paper, no significant impact on the other KPIs is observed.

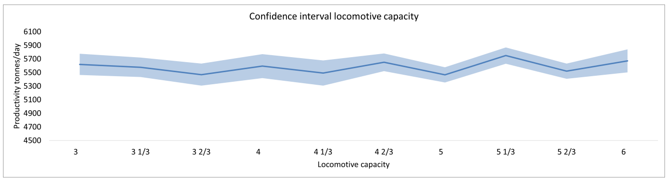

Fig. 6: Experiment 2: Productivity volume (Tonnes/day)

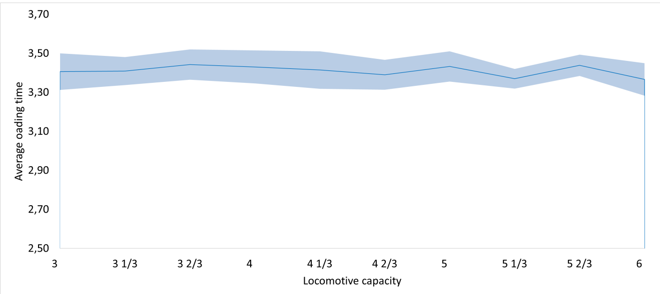

Fig. 7: Experiment 2: Average loading times (Days)

3. Experiment 3: Increase use of the Transit Hall

In the third and final experiment the impact of loading more coils from the Transit Hall into vessels on the performance is measured. In order to do so, the loading duration of trains bound for the Transit Hall is decreased from an initial average duration of 8 hours to 1 hour only. By doing so, more trains are forced to go towards the Transit Hall instead of towards the quay, potentially resulting in more coils available for loading once vessels are docked. Looking at Figure 9 the productivity is gradually increasing when the duration of loading of trains towards the Transit Hall decreases. This results in an increase in the total percentage of coils being loaded from the Transit Hall rather than from trains as can be seen in Figure 8. At the start 50% can be loaded from the Transit Hall, but the faster trains are assembled, the more can be supplied via this storage point towards vessels. At the 1 hour point around 75% is supplied via the Transit hall resulting in around 6600 tonnes/day to be loaded onto vessels on average. Looking at Figure 10 this results in an overall decrease in the loading time of vessels of 0.4 days or 10 hours.

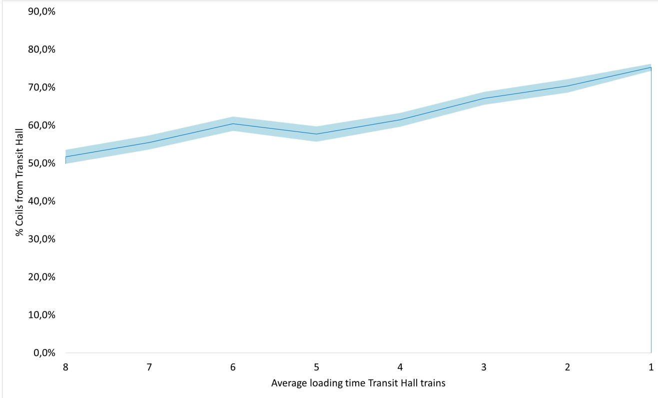

Fig. 8: Experiment 3: Percentage of coils loaded from the Transit Hall

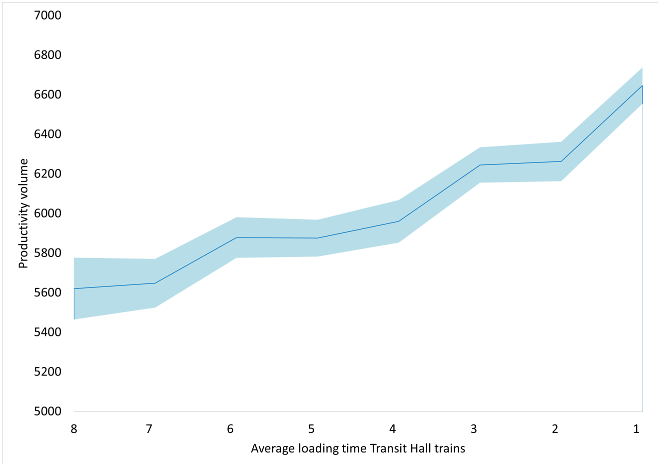

Fig. 9: Experiment 3: Productivity volume (Tonnes/day)

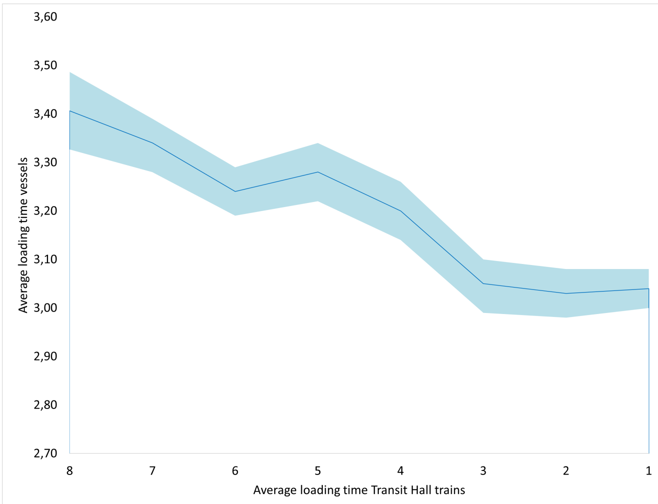

Fig. 10: Experiment 3: Average loading times (Days)

V. CONCLUSION & RECOMMENDATIONS

Overall the aim of this research was to answer the main research question *How can the performance of the outer-harbour 3 of Tata Steel IJmuiden be improved?*. In order to answer this question academic methods are applied to the case study of the outer-harbour 3 of Tata Steel IJmuiden. The performance can be improved by firstly identify all the important elements linked to the outer-harbour 3. In this research 7 elements are identified, all of which are potential bottlenecks. Subsequently performance should be defined clearly in terms of KPIs and PIs that are in line with the aspired objectives of Tata Steel. The harbour's performance can be assessed using five KPIs. To identify the bottlenecks three PIs are used. A Discrete-event simulation model has proven useful and is used to assess the performance and has proven that it can contribute to decision-making by measuring the expected increase of performance for a set of alternative configurations. Overall the largest improvements can be achieved by improving the supply of loads towards the outer-harbour 3. To a lesser extent it helps to increase the use of the Transit Hall. Adding locomotive capacity alone does not solve any of the challenges faced and at the same time even increases operational expenses. Overall it can be concluded that the insights from this research show where Tata Steel should improve their processes to maximise the improvement of the performance of their outer-harbour 3. With respect to further research it is recommended to apply more other type of bottleneck detection methods to similar case studies. This research shows the added value of average bottleneck detection methods. However as bottlenecks tend to shift throughout time shifting bottleneck methods such as the Active Period method can be useful to measure the bottleneck in systems at certain periods in time. In addition, in a time in which organisations gather more and more data, methods aiming to predict bottlenecks are developed. The ANFIS model proposed by zhengcai2012bottleneck or the ARMA model developed by li2011throughput are such models.

REFERENCES

[1] D. L. Schott and M. van den Hoed, "Break bulk and bulk terminals," *Encyclopedia of Maritime and Offshore Engineering*, pp. 1–10, 2017.

[2] A. E. Branch, *Elements of shipping*. Routledge, 2007.

[3] K. Li and H. Tian, "Integrated optimization of finished product logistics in iron and steel industry using a multi-objective variable neighborhood search," *ISIJ International*, vol. 55, no. 9, pp. 1932–1941, 2015.

[4] W. Urban and P. Rogowska, "Engineering management in production and services methodology for bottleneck identification in a production system when implementing toc," *Engineering Management in Production and Services*, vol. 12, 07 2020.

[5] S.-Y. Chiang, C.-T. Kuo, and S. Meerkov, "Dt-bottlenecks in serial production lines: Theory and application," *Robotics and Automation, IEEE Transactions on*, vol. 16, pp. 567 – 580, 11 2000.

[6] H. Eskandari, N. Babolmorad, and N. Farrokhnia, "Bottleneck analysis in a pharmaceutical production line using simulation approach." in *SummerSim*, 2013, p. 12.

[7] I. Al-Harkan and M. Hariga, "A simulation optimization solution to the inventory continuous review problem with lot size dependent lead time," *Arabian Journal for Science and Engineering*, vol. 32, no. 2, p. 327, 2007.

[8] M. Bruglieri, E. Gerzelj, A. Guenzani, R. Maja, and R. de Alvarenga Rosa, "Solving the 3-d yard allocation problem for break bulk cargo via variable neighborhood search branching," *Electronic Notes in Discrete Mathematics*, vol. 47, pp. 237–244, 2015.

[9] H. Tian, Z. Liu, and X. Deng, "General cargo yard storage allocation optimization based on layout," in *2018 Chinese Control And Decision Conference (CCDC)*. IEEE, 2018, pp. 5271–5276.

[10] V. Hans, O. Jaap, and L. Gabriel, *The Delft Systems Approach Analysis and design of Industrial Systems*. Springer London, 2008.

[11] F. Longo, A. Huerta, and L. Nicoletti, "Performance analysis of a southern mediterranean seaport via discrete-event simulation," *Journal of Mechanical Engineering*, vol. 59, no. 9, pp. 517–525, 2013.

[12] J. Koturiak and M. Gregor, "Simulation in production system life cycle," *Computers in Industry*, vol. 38, pp. 159–172, 1999.

[13] R. Cimpeanu, M. T. Devine, and C. O'Brien, "A simulation model for the management and expansion of extended port terminal operations," *Transportation Research Part E: Logistics and Transportation Review*, vol. 98, pp. 105–131, 2017.

[14] A. Cartenì and S. de Luca, "Analysis and modeling of container terminal handling activities."

[15] R. Cimpeanu, M. Devine, D. Tocher, and L. Clune, "Development and analysis of a port terminal loader model at rusal aughinish," *Simulation Modelling Practice and Theory*, vol. 51, pp. 14–30, 02 2015.

[16] C. Roser, M. Nakano, and M. Tanaka, "Shifting bottleneck detection," in *Proceedings of the Winter Simulation Conference*, vol. 2. IEEE, 2002, pp. 1079–1086.

[17] M. Leporis and Z. Králová, "A simulation approach to production line bottleneck analysis," 2010.

[18] H. Eskandari, N. Babolmorad, and N. Farrokhnia, "Bottleneck analysis in a pharmaceutical production line using simulation approach," *Simulation Series*, vol. 45, pp. 195–202, 01 2013.

[19] "10 - production data collection and performance analysis," pp. 270–307, 2004. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780750662727500130

[20] S. Papavinasam, "Chapter 14 - management," pp. 841–918, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780123970220000145

[21] P. Mack, "Chapter 35 - big data, data mining, and predictive analytics and high performance computing," pp. 439–454, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780124079106000351

[22] A. Gunasekaran and B. Kobu, "Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications," *International Journal of Production Research*, vol. 45, pp. 2819 – 2840, 2007.

[23] R. Poveda-Bautista, D. Baptista, and M. García-Melón, "Setting competitiveness indicators using bsc and anp," *International Journal of Production Research - INT J PROD RES*, vol. 50, pp. 1–15, 09 2012.

[24] M.-H. Ha, Z. Yang, and J. S. L. Lam, "Port performance in container transport logistics: A multi-stakeholder perspective," *Transport Policy*, vol. 73, no. C, pp. 25–40, 2019. [Online]. Available: https://ideas.repec.org/a/eee/trapol/v73y2019icp25-40.html

[25] S. Robinson, "Choosing the right model: Conceptual modeling for simulation," in *Proceedings of the 2011 Winter Simulation Conference (WSC)*. IEEE, 2011, pp. 1423–1435.

[26] Robinson, "Conceptual modelling for simulation part i: definition and requirements," *Journal of the operational research society*, vol. 59, no. 3, pp. 278–290, 2008.

Appendix B

Appendix System Analysis

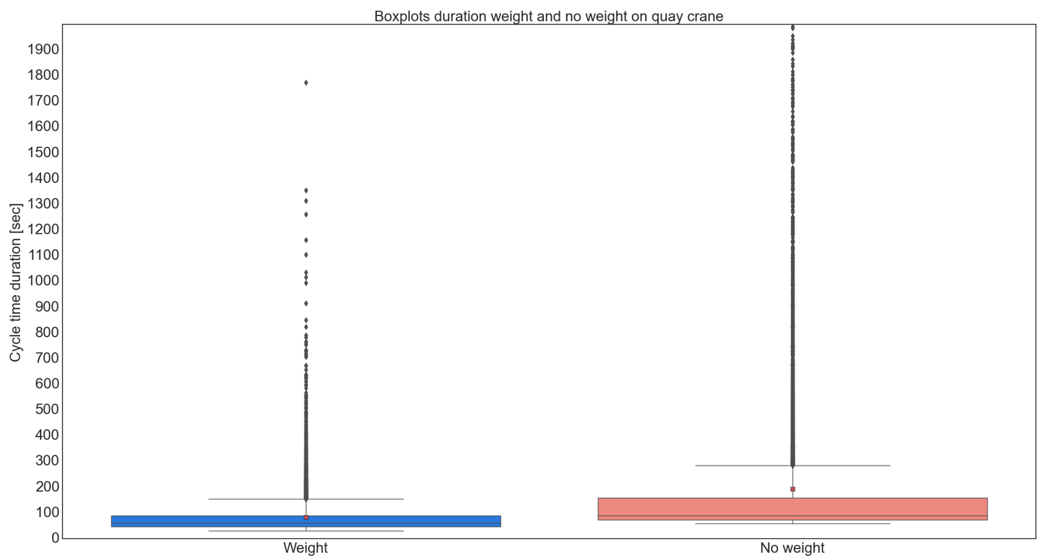

Figure B.1: Boxplots quay cranes work rate

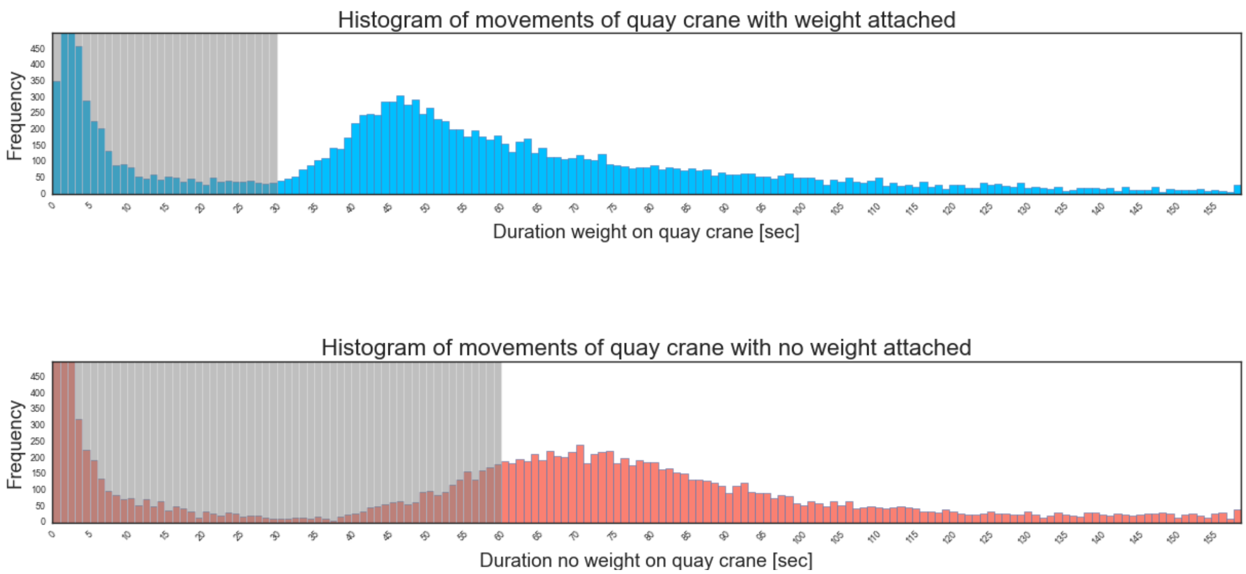

Figure B.2: Histogram of quay crane movements with in grey the signals that are excluded

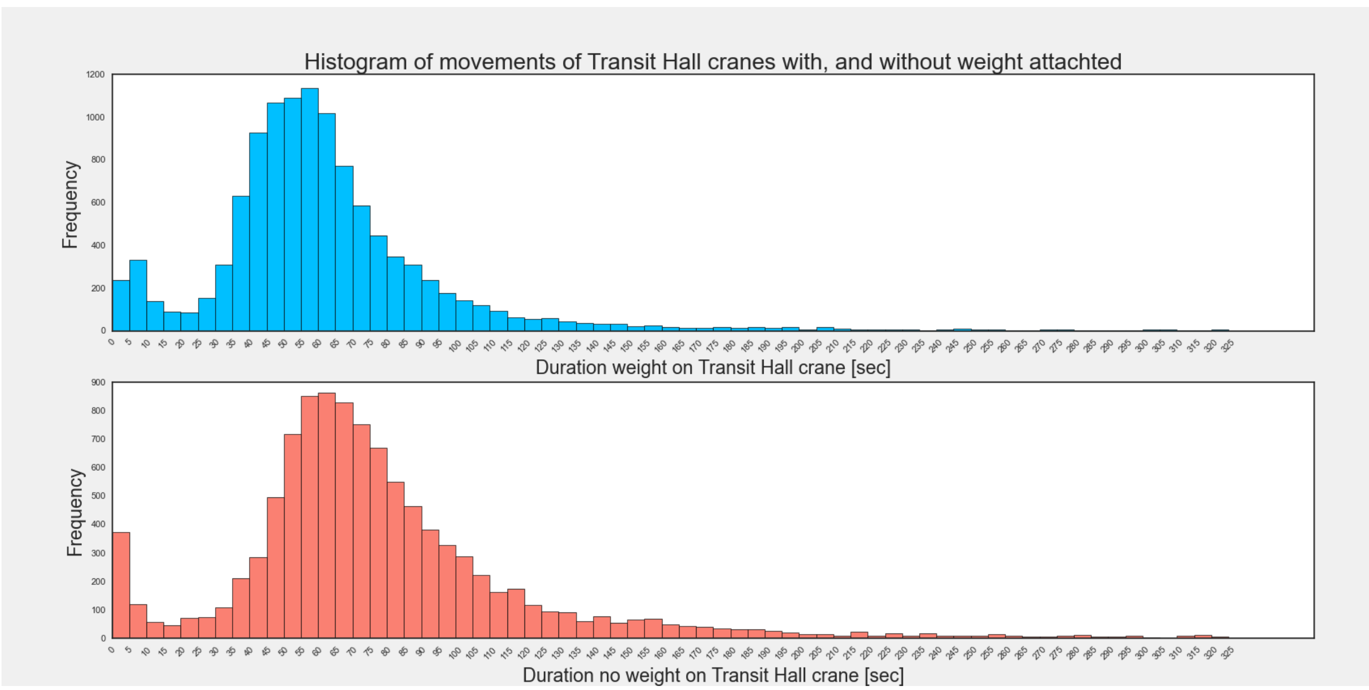

Figure B.3: Histogram of movements of Transit Hall cranes with, and without weight attached

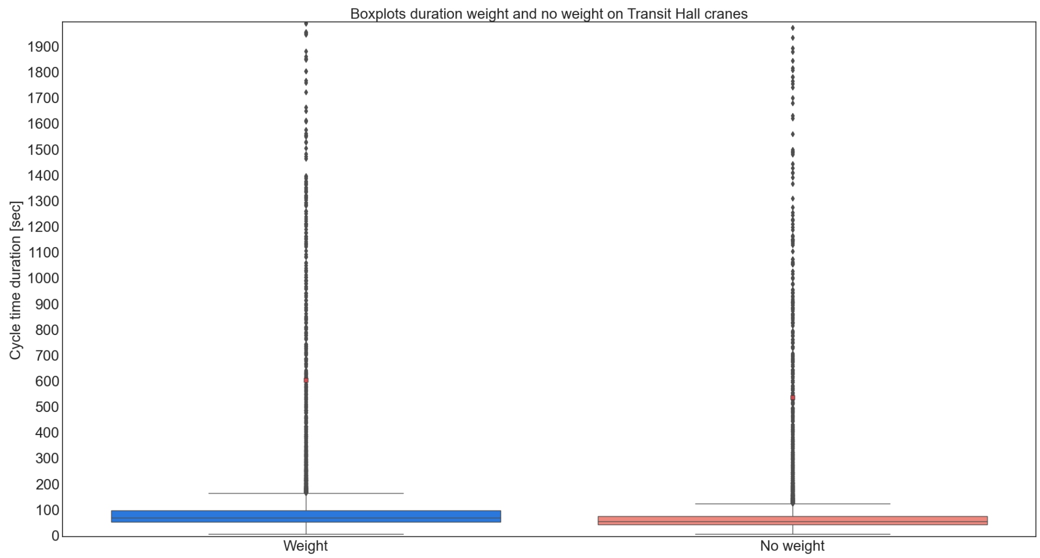

Figure B.4: Boxplots Transit hall crane work rate

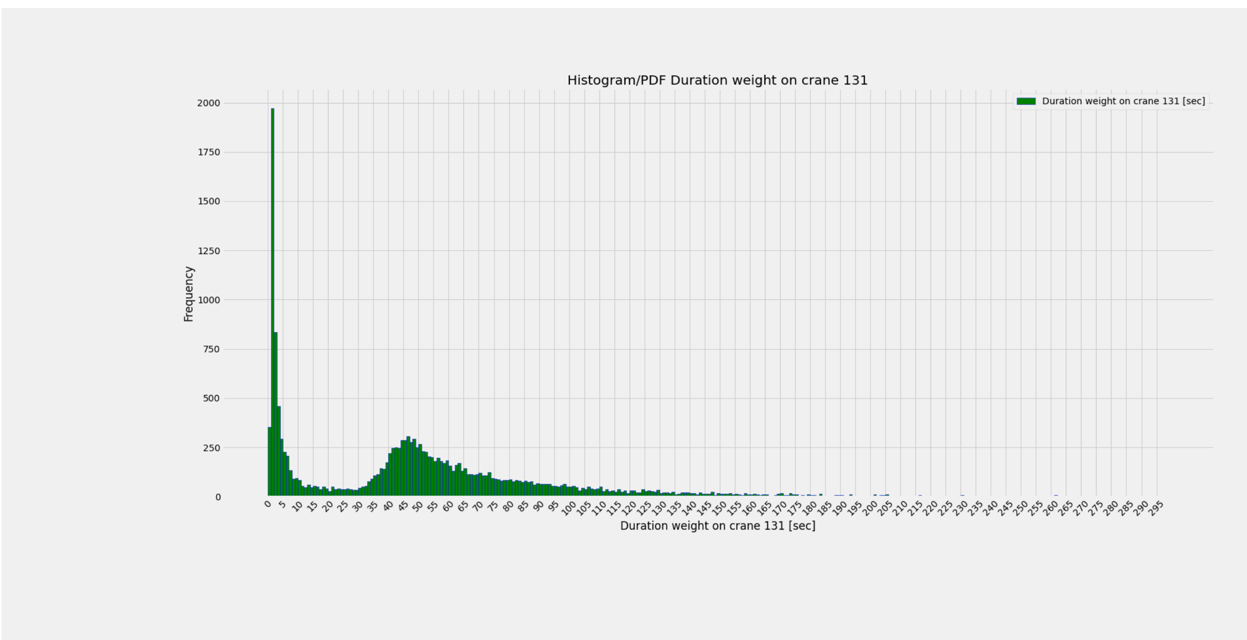

Figure B.5: Histogram of duration 'weight on crane 131'

Observation [seconds]	**BUW to crane 131**	**BUW to crane132**	**BUO to crane 131**	**BUO to crane 132**	**TRH to crane 131 & 132**	**Train to crane 131 &132**
1	89	134	99	66	38	12
2	69	104	96	64	52	16
3	54	81	149	99	39	40
4	118	177	116	77	38	38
5	89	134	195	130	37	15
6	89	134	155	103	35	18
7	46	69	140	93	43	28
8	64	96	95	63	40	43
9	75	113	99	66	48	17
10	113	170	156	104	45	34
Average	81	121	130	87	42	26
Value used for model	80	120	120	80	40	25

Table B.1: Quay forklift transportation duration observations

Appendix C

Appendix Process Description Language

ShipGenerator

Attributes

- InterArrivalTimeShip = ExponentialDistribution
- ShipETTSLoad = Sample from historical data
- ShipCoilLoad = Sample from historical data
- NumberofShipsToGenerate = Constant

Process

- *Repeat for NumberofShipsToGenerate*
  - Wait InterArrivalTimeShip.sample
  - newShip = Newship.nr
  - newShip.ShipETTSLoad = ShipETTSLoad.sample
  - newShip.ShipCoilLoad = ShipCoilLoad.sample

Ship

Attributes

- ShipETTSLoad = Sample from historical data
- ShipCoilLoad = Sample from historical data
- ShipRemainingETTSLoad = ShipETTSLoad
- ShipRemainingCoilLoad = ShipCoilLoad
- ShipTotalshipLoad = ShipRemainingETTSLoad + ShipRemainingCoilLoad
- ShipETTSLoaded = 0

- ShipCoilsLoaded = 0
- TrainETTSLoad = TriangularDistribution
- TrainCoilLoad = TriangularDistribution
- create TrainsQueue
- create TrhQueue
- create BuwQueue
- create TransittrainQueue
- enter ships_in_systemQueue

Process

- request QuayResource until honoured
- if request honoured
  - enter QuayQueue
  - activate TrainGenerator
  - activate BuwGenerator
  - activate TrainTransitHallGenerator
  - check number of coils in Transit Hall. Max 80% from Transit Hall if available, otherwise take what is stored
  - check for availability of one of the quay cranes
    - if available, ship activate available crane
    - start loading procedure
  - if not available
    - passivate Ship
    - if available

TrainGenerator

Attributes

- Train.ship = ship, trains with load are connected to the ship currently docked
- TrainETTSLoad = TriangularDistribution
- TrainCoilLoad = TriangularDistribution
- InterArrivalTimeTrain = UniformDistribution

Process

- *repeat while TrainRemainingETTSLoad + TrainRemainingCoilLoad   0*
- TrainRemainingETTSLoad = ShipETTSLoad * %ETTSviaTrain

- TrainRemainingCoilLoad = ShipCoilLoad * %CoilsviaTrain
- TrainETTSLoad = Min(TrainRemainingETTSLoad, TrainETTSLoad.sample())
- TrainCoilLoad = Min(TrainRemainingCoilLoad, TrainCoilLoad.sample())
- TrainRemainingETTSLoad = TrainRemainingETTSLoad - TrainETTSLoad
- TrainRemainingCoilLoad = TrainRemainingCoilLoad - TrainCoilLoad
- Trainname = Train.ship.number
- wait InterArrivalTimeTrain.sample()

Train

Attributes

- TrainETTSLoad = Sample from TrainGenerator
- TrainCoilLoad = Sample from TrainGenerator
- Train.ship = ship, trains with load are connected to the ship currently docked
- enter ship.trainQueue
- enter trains_in_systemQueue

Process

- check locomotive availability until honoured
- if request honoured
  - hold 1 locomotive for train transporttime_locomotives
  - release locomotive
- check tracks availability until honoured
- if request honoured
  - park on available track
- check quay crane availability until honoured
- if request honoured
  - activate available quay crane
- if TrainETTSLoad and TrainCoilLoad = 0
  - release tracks.Resource
  - leave ship.trainQueue
  - leave trains_in_systemQueue
  - release quay_crane

TrhGenerator

Attributes

- Trh.ship = ship, Trh components are connected to the ship currently docked
- InterArrivalTimeTRHCoil = LogNormalDistribtion

Process

- *repeat while TrhRemainingCoilLoad > 0*
- TrhRemainingCoilLoad = ShipCoilLoad * %CoilviaTrh
- TrhRemainingCoilLoad = TrhRemainingCoilLoad - TrhCoilLoad
- Trhname = Trh.ship.number
- wait InterArrivalTimeTRHCoil.sample()

Trh

Attributes

- TrhETTSLoad = 1
- TrhCoilLoad = 0
- Trh.ship = ship, Trh components are connected to the ship currently docked
- enter trhs_in_systemQueue

Process

- check Transit Hall crane availability until honoured
- if request honoured
  - Trh activate Transit Hall crane
- release Transit Hall crane
- leave trhs_in_systemQueue
- Trh in_operation = False
- check quay forklift truck availability until honoured
- if request honoured
  - Trh activate quay_forklift_truck
- release quay forklift truck
- enter trh.ship.trhs.Queue
- check quay cranes availability until honoured

- if request honoured
  - Trh activate one quay crane
- leave trh.ship.trhs.Queue
- release quay crane

BuwGenerator

Attributes

- Trh.ship = ship, Trh components are connected to the ship currently docked
- InterArrivalTimeBUW = 1 minute

Process

- BuwRemainingETTSLoad = ShipETTSLoad * %ETTSviaBuw
- while BuwRemainingETTSLoad > 0

  TrhETTSLoad = 1

  TrhCoilLoad = 0

  BuwRemainingETTSLoad = BuwRemainingETTSLoad - TrhETTSLoad

  Buwname = Buw.ship.number

  wait InterArrivalTimeBUW

BUW

Attributes

- BuwETTSLoad = 1
- BuwCoilLoad = 0
- Buw.ship = ship, Buw components are connected to the ship currently docked
- enter buws_in_systemQueue

Process

- check quay forklift truck availability until honoured
- if request honoured
  - BUW activate quay_forklift_truck
- release quay forklift truck
- enter buw.ship.buws.Queue
- check quay cranes availability until honoured
- if request honoured

  - BUW activate one quay crane
- leave buw.ship.buws.Queue
- leave buws_in_system
- release quay crane

Quay Crane

Attributes

- Cycle_time_quay_to_ship = LognormalDistribution
- Cycle_time_ship_to_quay = LognormalDistribution

Process

- *repeat while True*
- if Quay Crane is activated
- Check if there are quay cranes requester
- if True
  - Quay Crane enter cranes_working.Queue
- if ETTS and is loaded from a Train
  - for all Train.Load_ETTS
    * if Ship.cargo_loaded $\geq$ 300 and Double_ETTS_Cage is availability
      · speed_coefficient = 0.5
    * speed_coefficient = 1
    * hold Quay Crane for Cycle_time_quay_to_ship.sample * speed_coefficient
    * activate ETTS
    * hold Quay Crane for Cycle_time_ship_to_quay.sample * speed_coefficient
- else if ETTS and is loaded from BUW
  - if Ship.cargo_loaded $\geq$ 300 and Double_ETTS_Cage is availability
    * speed_coefficient = 0.5
  - speed_coefficient = 1
  - hold Quay Crane for Cycle_time_quay_to_ship.sample * speed_coefficient
  - activate ETTS
  - hold Quay Crane for Cycle_time_ship_to_quay.sample * speed_coefficient
- if Coil and is loaded from a Train
  - for all Train.Load_Coil
    * if Ship.cargo_loaded $\geq$ 300
      · speed_coefficient = 0.5

        * speed_coefficient = 1
        * hold Quay Crane for Cycle_time_quay_to_ship.sample * speed_coefficient
        * activate Coil
        * hold Quay Crane for Cycle_time_ship_to_quay.sample * speed_coefficient

- else if Coil and is loaded from TRH
    - if Ship.cargo_loaded $\geq$ 300
        * speed_coefficient = 0.5
    - speed_coefficient = 1
    - hold Quay Crane for Cycle_time_quay_to_ship.sample * speed_coefficient
    - activate Coil
    - hold Quay Crane for Cycle_time_ship_to_quay.sample * speed_coefficient

TrainTransitHallGenerator

Attributes

- TrainTransitHall.ship = ship, TrainTransitHall with load are connected to the ship currently docked
- InterArrivalTimeTransitHallTrain = UniformDistribution

Process

- TransitHallRemainingETTSLoad = capacity_trh_storage - coil_in_storage_trh
- while coil_in_storage_trh < capacity_trh_storage and TrainTransitHall.ship is not docked

    TrainTransitHallCoilLoad = Min(TransitHallRemainingETTSLoad, TrainTransitHallCoilLoad.sample())

    TrainTransitHallname = TrainTransitHall.ship.number

    wait InterArrivalTimeTransitHallTrain.sample()

TrainTransitHall

Attributes

- TrainTransitHallCoilLoad = Sample from TrainTransitHallGenerator
- TrainTransitHall.inoperation = False
- TrainTransitHall.ship = ship, TrainTransitHall with load are connected to the ship currently docked
- enter ship.TrainTransitHallQueue
- enter trh_trains_in_systemQueue

Process

- check locomotive availability until honoured

- if request honoured
  - hold 1 locomotive for train transporttime_locomotives
  - release locomotive
- check Transit Hall crane availability until honoured
- if request honoured
  - Trh activate Transit Hall crane
- if TrainTransitHallCoilLoad
  - leave ship.TrainTransitHallQueue
  - leave trh_trains_in_systemQueue
  - release Transit Hall crane

Trhcrane

Attributes

- Cycle_time_hall_to_door = LognormalDistribution
- Cycle_time_door_to_hall = LognormalDistribution

Process

- *repeat while True*
- if Transit Hall Crane is activated
- Check if there is Transit Hall cranes requester
- if True
  - Transit Hall Crane enter trhcranes_working.Queue
- if requester is TrainTransitHall
  - for allTrainTransitHallCoilLoad
    - hold transit hall for Cycle_time_hall_to_door.sample()
    - hold transit hall for Cycle_time_door_to_hall.sample()
- if requester is Coil
  - hold transit hall for Cycle_time_hall_to_door.sample()
  - hold transit hall for Cycle_time_door_to_hall.sample()
- if no requester
  - Crane leaves trhcranes_working.Queue

Forklift

- Time_forklift_truck_train = constant
- Time_forklift_truck_buw = RandomChoice[BUW,BUO]
- Time_forklift_truck_trh = constant

Process

- *repeat while True*
- if Forklift is activated
- check if there are quay cranes requester
- if True
  - Forklift enter cranes_working.Queue
- if ETTS and is loaded from a Train
  - hold Time_forklift_truck_train
- else if ETTS from BUW
  - hold Time_forklift_truck_buw.sample()
- else if Coil and is loaded from a Train and Ship.cargo_loaded $\geq$ 300
  - hold Time_forklift_truck_train
- else if Coil and from TRH
  - hold Time_forklift_truck_trh

Forklift_hold

- Time_forklift_truck_hold = constant

Process

- *repeat while True*
- if Forklift is activated
- check if there are quay cranes requester
- if True
  - hold Time_forklift_truck_hold

Team

Attributes

- Time_team_secure_ETTS = constant
- Time_team_secure_Coil = constant

Process

- *repeat while True*
- if Quay Crane is activated
- Check if there are quay cranes requester
- if True
  - Quay Crane enter cranes_working.Queue
- if ETTS
  - hold Time_team_secure_ETTS
  - ShipETTSLoaded + 1
- if Coil
  - Time_team_secure_Coil
  - ShipCoilsLoaded + 1
- if ShipETTSLoaded + ShipCoilsLoaded = ShipTotalshipLoad. Ship is fully loaded
- Ship leave ships_in_systemQueue

Coil

Attributes

- BuwETTSLoad = 0
- BuwCoilLoad = 1

Process

- if Ship.cargo_loaded $\geq$ 300
  - check hold forklift truck availability until honoured
  - if request honoured
    - Coil activate hold_forklift_truck
  - release hold forklift truck
- check team availability until honoured
- if request honoured
  - Coil activate team
- release team

ETTS

Attributes

- BuwETTSLoad = 1
- BuwCoilLoad = 0

Process

- check hold forklift truck availability until honoured
- if request honoured
  - ETTS activate hold_forklift_truck
- release hold forklift truck
- check team availability until honoured
- if request honoured
  - ETTS activate team
- release team

Rain

Process

- *repeat while True*
  - time_between_rain = UniformDistribution.sample()
  - time_of_rain = UniformDistribution.sample()
  - hold Rain for time_between_rain - time_of_rain
  - interrupt all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams
  - hold time_of_rain
  - release all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams

FailureCrane131

Process

- *repeat while True*
  - time_between_failure = UniformDistribution.sample()
  - time_of_failure = UniformDistribution.sample()
  - hold FailureCrane131 for time_between_failure - time_of_failure
  - interrupt Crane131
  - hold time_of_failure
  - release Crane131

FailureCrane131

Process

- *repeat while True*
  - time_between_failure = UniformDistribution.sample()
  - time_of_failure = UniformDistribution.sample()
  - hold FailureCrane132 for time_between_failure - time_of_failure
  - interrupt Crane132
  - hold time_of_failure
  - release Crane132

FailureCrane031

Process

- *repeat while True*
  - time_between_failure = UniformDistribution.sample()
  - time_of_failure = UniformDistribution.sample()
  - hold FailureTrhcrane031 for time_between_failure - time_of_failure
  - interrupt Trhcrane031
  - hold time_of_failure
  - release Trhcrane031

FailureCrane032

Process

- *repeat while True*
  - time_between_failure = UniformDistribution.sample()
  - time_of_failure = UniformDistribution.sample()
  - hold FailureTrhcrane032 for time_between_failure - time_of_failure
  - interrupt Trhcrane032
  - hold time_of_failure
  - release Trhcrane032

Wachtwissel

Process

- *repeat while True*
  - hold self 435 min
  - interrupt all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams
  - hold self 45 min
  - release all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams

Shaft

Process

- *repeat while True*
  - hold self 120 min
  - interrupt all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams
  - hold self 45 min
  - release all cranes, trhcranes, quay forklift trucks, hold forklift trucks, teams
  - hold self 315 min

Kraanbedrijf

Process

- *repeat while True*
  - hold self 960 min
  - interrupt RandomChoice[Crane131, Crane132]
  - hold self 480 min
  - release Crane131 or Crane132

Lococlaimer

Process

- *repeat while True*
  - time_between_claim = UniformDistribution.sample()
  - time_to_claim = UniformDistribution.sample()
  - hold self for time_between_claim - time_to_claim
  - claim locomotive
  - hold time_to_claim
  - release locomotive

Initialize

- initialize all classes
- set simulation duration
- start ShipGenerator

Appendix D

Appendix Experiments

Vessels for experiments	ETTS	Coils	Loading_rate	ton/day	Historical Forecast DEM in €	DEM rate/ HD	Demurrage	Total_loading_time_historical	Colli_per_day_historical
1	0	378	4500	3241	7467	3750	4375	1,5	251
2	878	570	5000	3648	18287	6300	8291	5,3	274
3	769	642	5000	3895	17949	7425	5365	5,3	266
4	0	469	4500	3524	2804	4500	1772	1,8	263
5	850	755	5000	4750	17724	7200	11229	4,6	350
6	0	317	3500	4265	2982	4000	2694	1,2	262
7	0	733	6000	2657	73081	20500	0	6,2	118
8	1336	498	5000	1950	82889	7200	63204	11,2	163
9	0	707	5000	5253	15913	8500	3039	2,7	259
10	0	1	6000	5	129324	20500	0	6,2	0
11	1245	617	5000	4175	7536	7425	1527	5,4	347
12	0	798	6000	5797	82903	24600	0	3,3	245
13	0	347	4500	6831	4615	4500	0	0,9	387
14	0	419	4500	4503	18955	4000	0	1,3	324
15	992	480	5000	4642	3336	7200	0	4,1	355
16	923	620	5000	7513	0	7425	0	2,8	560
17	0	316	3500	0	0	3250	0	inf	0
18	756	0	4000	3430	7716	11250	0	2,4	311
19	962	646	5000	5769	902	7200	0	3,8	426
20	1152	657	5000	2402	53099	7425	25890	9,6	189
21	0	266	3500	5345	0	4000	0	0,7	370
22	1035	591	5000	5342	0	7425	0	3,9	421
23	0	573	3500	3360	17115	4500	13516	2,4	241
24	136	347	6000	7731	21961	11475	16789	1,1	433
25	1052	516	5000	3882	13352	7425	0	5,4	291
26	0	325	3500	4263	8979	4750	6944	1,1	302
27	0	474	4000	3717	5850	4000	0	2,7	178
28	93	1144	5000	3214	26443	7425	8353	6,5	192
29	1077	526	5000	5850	2419	7425	14231	3,5	456
30	1395	369	5000	3848	74190	7200	46936	5,6	313
31	1107	322	5000	5244	0	6300	0	3,6	397
32	315	394	6000	3639	28942	11475	23736	3,0	236
33	0	565	4500	3890	32037	7500	0	2,1	267
34	0	348	3500	4482	6631	4750	2444	1,0	348
35	675	716	5000	4685	10417	7425	0	4,4	315
36	7	1041	5000	7532	0	6300	0	2,6	410
37	774	16	4000	4276	11391	11250	8473	1,7	456
38	0	590	4500	4263	8060	7000	0	2,1	283
39	1188	382	5000	3801	10448	7200	0	5,4	293
40	0	839	4500	2340	27151	6000	18981	4,3	196
41	34	1073	5000	5123	0	7425	1799	4,0	276
42	0	583	4500	3992	41150	8500	30641	2,1	278
43	767	732	5000	5698	38333	7200	24969	3,8	390
44	411	774	6000	7011	0	11475	0	3,0	391
45	615	478	5000	4398	62923	7200	40699	3,7	294
46	0	477	6000	13731	0	34440	0	1,0	485
47	0	614	4500	3448	8692	5000	0	2,5	247
48	0	545	4500	1359	89686	13000	71392	6,6	82
49	0	1367	6000	5996	33306	11700	21952	4,0	341
50	0	425	3500	4149	0	4850	5723	1,4	300

Table D.1: Vessel input experiments

TRNR	ETTS	Coils
10022	0	378
10405	878	570
13367	769	642
14896	0	469
16019	850	755
19398	0	317
20551	0	733
20966	1336	498
22867	0	707
23777	0	1
25694	1245	617
26981	0	798
27234	0	347
30139	0	419
30391	992	480
32251	923	620
33704	0	316
34484	756	0
35121	962	646
36318	1152	657
36408	0	266
37642	1035	591
38493	0	573
39108	136	347
39919	1052	516
41477	0	325
41660	0	474
41688	93	1144
41977	1077	526
43058	1395	369
43806	1107	322
44740	315	394
44793	0	565
44963	0	348
45415	675	716
46304	7	1041
46629	774	16

Table D.2: Vessel input data part 1

TRNR	ETTS	Coils
46703	0	590
47962	1188	382
48502	0	839
49279	34	1073
49517	0	583
50856	767	732
51738	411	774
52026	615	478
52590	0	477
52885	0	614
53220	0	545
53520	0	1367
54273	0	425
54774	0	1196
56162	0	1298
56627	206	826
56954	0	710
57891	0	404
58169	1541	0
58207	1965	412
58227	0	317
59072	0	604
59233	0	616
60183	0	689
60805	0	430
61683	1677	203
62681	0	634
63152	1214	98
64417	208	897
66178	0	521
69386	0	743
71125	801	700
72987	0	738
73335	1103	24
75404	1067	676
75987	0	482
78685	0	944

Table D.3: Vessel input data part 2

Appendix E

Appendix Results

The three experiments run in this research thesis required a significant number of simulation runs to be performed in order to receive statistical meaningful results. Due to the high number of simulation runs (more than 750) it was decided to only show the average and confidence intervals in the appendix rather than all results. This was decided to keep the appendix clear and not too overwhelming with all results.

KPI Productivity volume **n = 30** **Degrees of freedom = 58** **z .95 = 1,96** **t58,0.95 = 1,673 = 1,699**	**8 (Base configuration)**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	**5620**	**5697**	**5881**	**6381**	**6902**	**8079**	**9793**	10489
Sample std	**511,5**	**408**	**411**	**358**	**380**	**224**	**289**	387
CI 95%	**[5464,5776]**	**[5573,5822]**	**[5756,6007]**	**[6272,6491]**	**[6785,7018]**	**[8010,8147]**	**[9704,9881]**	[10371,10608]
Statistical significance $t_{58,0.95}$	X	No	Yes	Yes	Yes	Yes	Yes	Yes

Table E.1: 95% Confidence intervals and statistical significance volume productivity KPI

KPI Productivity quantity **n = 30** **Degrees of freedom = 58** **z .95 = 1,96** **t58,0.95 = 1,673 = 1,699**	**8 (Base configuration)**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	**353**	**363**	**380**	**416**	**456**	**542**	**659**	697
Sample std	**30**	**24**	**25**	**22**	**24**	**14**	**18**	23
CI 95%	**[344,1,362,3]**	**[355,4,369,9]**	**372,2,387,3**	**[409,0,422,1]**	**[449,3,463,7]**	**[537,3,545,8]**	**[653,1,664,3]**	689,4,703,7
Statistical significance t_{58,0.95}	**X**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Yes

Table E.2: 95% Confidence intervals and statistical significance quantity productivity KPI

KPI Loading rate **n = 30** **Degrees of freedom = 58** **z .95 = 1,96** **t58,0.95 = 1,673 = 1,699**	**8 (Base configuration)**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	**3,41**	**3,13**	**2,83**	**2,49**	**2,17**	**1,76**	**1,45**	1,56
Sample std	**0,26**	**0,18**	**0,17**	**0,13**	**0,09**	**0,04**	**0,13**	0,16
CI 95%	[3.33,3.49]	[3.07,3.18]	[2.78,2.88]	[2.45,2.53]	[2.14,2.20]	[1.74,1.77]	[1.41,1.49]	[1.51,1.60]
Statistical significance t_{58,0.95}	**X**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Yes

Table E.3: Experiment 1: Average loading time vessels

KPI Loading rate n = 30 Degrees of freedom = 58 z .95 = 1,96 t58,0.95 = 1,673 = 1,699	8 (Base configuration)	7	6	5	4	3	2	1
Sample mean	**21,8**	**22,9**	**26,5**	**30,6**	**41,1**	**47,4**	**47,4**	45,4
Sample std	**4,4**	**3,2**	**4,5**	**3,2**	**2,4**	**1,5**	**1,8**	1,0
CI 95%	**[20.5,23.1]**	[22.0,23.9]	[[25.2,27.9]]	[29.7,31.6]	[40.3,41.8]	[46.9,47.8]	**46.9,48.0**	[45.1,45.7]
Statistical significance t_{58,0.95}	**X**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Yes

Table E.4: Experiment 1: Punctuality

KPI Loading rate n = 30 Degrees of freedom = 58 z .95 = 1,96 t58,0.95 = 1,673 = 1,699	8 (Base configuration)	7	6	5	4	3	2	1
Sample mean	**476865**	**353558**	**241174**	**130897**	**49121**	**18276**	**32720**	144736
Sample std	**103489**	**76587**	**55207**	**33113**	**24244**	**27611**	**44066**	201744
CI 95%	[445254,508475]	[330165,376951]	[224311,258037]	[120783,141011]	[41715,56526]	[9842,26710]	[10260,46180]	[83114,206358]
Statistical significance t_{58,0.95}	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Yes

Table E.5: Experiment 1: Demurrage

KPI Productivity volume **n = 30** **Degrees of freedom = 58** **z 0.95 = 1,96** **t58,0.95 = 1,673**	**Locomotive capacity available**									
	3	3 1/3	3 2/3	4	4 1/3	4 2/3	5	5 1/3	5 2/3	6
Sample mean	5620	5577	5469	5595	5493	5651	5466	5750	5521	5672
Sample std	511	399	452	492	519	362	312	336	312	471
CI 95%	[5464,5776]	[5435,5720]	[5307,5631]	[5419,5771]	[5307,5679]	[5522,5781]	[,55785355]	[5629,5870]	[5409,5632]	[5504,5840]
t value sample	0	-0,36	-1,21	-0,19	-0,96	0,27	-1,41	1,16	-0,91	0,41
Statistical significance	X	No	No	No	No	No	No	No	No	No

Table E.6: Experiment 2: Productivity volume

KPI Productivity quantity **n = 30** **Degrees of freedom = 58** **t58,0.95 = 1,673**										
Locomotive capacity available	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Sample mean	353	351	345	352	347	355	345	361	348	357
Sample std	30	23	26	28	30	21	19	19	18	27
CI 95%	[344,362]	[343,359]	[336,354]	[342,362]	[336,357]	[348,362]	[339,352]	[354,368]	[341,354]	[347,366]
t value sample	0	-0,30	-1,16	-0,16	-0,85	0,33	-1,20	1,25	-0,85	0,45
Statistical significance	X	No	No	No	No	No	No	No	No	No

Table E.7: Experiment 2: Productivity quantity

KPI Average loading time **n = 30** **Degrees of freedom = 58** **t58,0.95 = 1,673**										
Locomotive capacity available	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Sample mean	3,41	351	345	352	347	355	345	361	348	357
Sample std	0,26	23	26	28	30	21	19	19	18	27
CI 95%	[3.31,3.50]	[3.34,3.48]	[3.36,3.52]	[3.35,3.51]	[3.32,3.51]	[3.31,3.47]	[3.35,3.51]	[3.32,3.42]	[3.28,3.49]	[3.28,3.45]
t value sample	0	-0,30	-1,16	-0,16	-0,85	0,33	-1,20	1,25	-0,85	0,45
Statistical significance	X	No	No	No	No	No	No	No	No	No

Table E.8: Experiment 2: Average loading time

KPI Punctuality n = 30 Degrees of freedom = 58 t58,0.95 = 1,673										
Locomotive capacity available	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Sample mean	21,8	21,7	20,7	21,2	20,8	21,8	21,1	22,6	21,2	22,1
Sample std	4,4	3,1	3,8	3,9	4,1	3,1	3,2	2,5	2,1	3,6
CI 95%	[20.5,23.1]	[20.6,22.8]	[19.4,22.1]	[19.8,22.6]	[19.4,22.3]	[20.7,22.9]	[19.9,22.2]	[21.7,23.5]	[20.4,21.9]	[20.8,23,3]
t value sample	0	0,09	1,01	0,56	0,89	0,04	0,75	-0,86	0,70	-0,24
Statistical significance	X	No	No	No	No	No	No	No	No	No

Table E.9: Experiment 2: Punctuality quantity

KPI Demurrage n = 30 Degrees of freedom = 58 t58,0.95 = 1,673										
Locomotive capacity available	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Sample mean	€ 476.865	€ 483.847	€ 473.227	€ 473.972	€ 462.606	€ 466.508	€ 482.577	€ 479.545	€ 481.633,52	€ 479.345,49
Sample std	€ 103.489	€ 84.272	€ 101.437	€ 99.124	€ 99.876	€ 95.881	€ 101.908	€ 74.734	€ 85.941,38	€ 112.007,74
CI 95%	[445.254,508.475]	[456.876,510.819]	[440.762,505.692]	[442.247,505697]	[430.641,494.572]	[435.821,497.196]	[449.961,515.193]	[455.626,503.464]	[454.127,509.139]	[443.497,515.193]
t value sample	0	-0,29	0,14	0,11	0,54	0,40	-0,22	-0,11	-0,19	-0,09
Statistical significance	X	No	No	No	No	No	No	No	No	No

Table E.10: Experiment 2: Demurrage

Additional operational expenses										
Locomotive capacity available	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Sample mean	€ -	€ 106.637,77	€ 216.500,38	€ 329.448,00	€ 432.929,24	€ 548.825,85	€ 634.531,58	€ 779.220,19	€ 862.511,98	€ 934.132,50
Sample std	€ -	€ 15.054,21	€ 33.309,69	€ 41.510,24	€ 60.980,17	€ 86.366,52	€ 95.913,41	€ 74.575,63	€ 107.688,68	€ 142.575,26
CI 95%	X	[101.819,111.455]	[205.839,227.161]	[316.162,342.733]	[413.412,452.466]	[521.184,576.467]	[603.834,665.229]	[755.352,803.088]	[828.056,896.978]	[888.500,979.764]

Table E.11: Experiment 2: Additional locomotive operational expenses

Occupancy elements										
Locomotive capacity	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Quay Cranes	0,15	0,15	0,15	0,15	0,15	0,16	0,17	0,15	0,14	0,16
Forklift trucks	0,04	0,04	0,04	0,04	0,04	0,05	0,05	0,04	0,04	0,05
Forklift trucks hold	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
lashing	0,16	0,15	0,16	0,15	0,16	0,17	0,17	0,16	0,15	0,17
Transit Hall crane	0,19	0,18	0,18	0,18	0,19	0,21	0,21	0,19	0,17	0,21
Locomotives	0,29	0,26	0,24	0,21	0,20	0,19	0,18	0,16	0,15	0,15
CE	0,45	0,42	0,43	0,42	0,45	0,47	0,48	0,43	0,42	0,47

Table E.12: Experiment 2: Occupancy

KR values elements										
Locomotive capacity	**3**	**3 1/3**	**3 2/3**	**4**	**4 1/3**	**4 2/3**	**5**	**5 1/3**	**5 2/3**	**6**
Quay Cranes	-7,5	-8,1	-8,6	-8,8	-9,3	-9,3	-9,7	-10,5	-11,2	-10,6
Forklift trucks	41	38,8	38,9	38,9	39,6	40,7	40,9	39,3	36,0	39,6
Forklift trucks hold	90	87,9	88,2	87,8	88,7	89,4	89,3	87,6	86,3	88,0
lashing	-13,1	-13,2	-13,8	-14,2	-14,7	-14,8	-15,1	-16,0	-16,2	-15,9
Transit Hall crane	-9	-7,7	-8,0	-10,0	-9,6	-12,0	-12,6	-12,5	-9,3	-13,7
Locomotives	-38,7	-35,6	-30,5	-26,9	-23,1	-19,3	-16,0	-16,9	-16,5	-11,5
CE	-62,5	-62,1	-66,2	-66,7	-71,7	-74,7	-76,9	-71,0	-69,1	-75,9

Table E.13: Experiment 2: Kr Value

Perc. coils from Transit Hall n = 30 Degrees of freedom = 58 t58,095 = 1,673								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	51,7%	55,5%	60,4%	57,7%	61,5%	67,1%	70,4%	75,3%
Sample STD	6,0%	6,1%	6,2%	6,6%	5,9%	5,6%	5,8%	3,1%
CI 95%	[49.9,53.5]	[53.6,57.4]	[58.5,62.3]	[55.7,59.7]	[59.6,63.3]	[65.4,68.8]	[68.6,72.2]	[74.4,76.3]
t value sample	0	2,44	5,54	3,70	6,36	10,30	12,26	19,24
Statistical significance	X	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table E.14: Experiment 3: Coils from Transit Hall

KPI Productivity volume n = 30 Degrees of freedom = 58 t58,095 = 1,673								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	5620	5648	5878	5876	5960	6244	6263	6645
Sample STD	511,5	403	335	304	352	292	326	300
CI 95%	[5464,5776]	[5525,5771]	[5776,5980]	[5783,5969]	[5852,6067]	[6155,6334]	[6163,6362]	[6554,6737]]
t value sample	0	0,23	2,31	2,35	3,00	5,80	5,80	9,47
Statistical significance	X	No	Yes	Yes	Yes	Yes	Yes	Yes

Table E.15: Experiment 3: Productivity volume

KPI Productivity quantity n = 30 Degrees of freedom = 58 t58,095 = 1,673								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	353	356	369	368	373	390	392	413
Sample STD	30	24	19	18	20	17	18	17
CI 95%	[344,362]	[349,363]	[363,374]	[363,374]	[367,379]	[385,395]	[386,397]	[407,418]
t value sample	0	0,40	2,45	2,33	3,03	5,88	6,11	9,56
Statistical significance	X	No	Yes	Yes	Yes	Yes	Yes	Yes

Table E.16: Experiment 3: Productivity quantity

KPI Average loading time n = 30 Degrees of freedom = 58 t58,095 = 1,673								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	3,41	3,34	3,24	3,28	3,2	3,05	3,03	3,04
Sample STD	0,26	0,19	0,16	0,19	0,19	0,17	0,16	0,12
CI 95%	[3.33,3.49]	[3.28,3.39]	[3.19,3.29]	[3.22,3.34]	[3.14,3.26]	3.00,3.10	[2.98,3.08]	[3.00,3.08]
t value sample	0	1,13	2,97	2,14	3,50	6,26	6,72	6,97
Statistical significance	X	No	Yes	Yes	Yes	Yes	Yes	Yes

Table E.17: Experiment 3: Average loading time

KPI Punctuality **n = 30** **Degrees of freedom = 58** **t58,095 = 1,673**								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	21,8	22,8	23,7	22,7	24,2	25,7	26	27,7
Sample STD	4,4	3,1	2,7	2,6	2,5	2,7	2,4	2,2
CI 95%	[20.5,23.1]	[21.8,23.7]	[22.8,24.5]	[21.9,23.5]	[23.4,24.9]	[24.9,26.5]	[25.3,26.7]	[27.0,28.3]
t value sample	0	1,02	2,02	0,96	2,60	4,14	4,59	6,57
Statistical significance	X	No	Yes	Yes	Yes	Yes	Yes	Yes

Table E.18: Experiment 3: Punctuality

KPI Demurrage **n = 30** **Degrees of freedom = 58** **t58,095 = 1,673**								
Average loading time Transit Hall trains	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Sample mean	€476.864,91	€452.676,00	€437.096,00	€413.376,00	€408.820,00	€325.641,00	€348.750,00	€391.064,00
Sample STD	€103.489,22	€101.628,00	€85.330,00	€89.023,00	€ 107.860,00	€2.595,00	€112.771,00	€175.429,00
CI 95%	[445.254,508465]	[412.634,483.718]	[411.032,463.160]	[386.184,440567]	[375.875,441.766]	[303.468,347.815]	[314.304,383.196]	[337.480,444.648]
t value sample	0	0,91	1,62	2,55	2,49	6,55	4,58	2,31
Statistical significance	X	No	No	Yes	Yes	Yes	Yes	Yes

Table E.19: Experiment 3: Demurrage

Occupancy elements **Average loading Time Transit Hall trains**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Quay Cranes	0,15	0,15	0,16	0,15	0,15	0,16	0,15	0,15
Forklift trucks	0,04	0,05	0,05	0,04	0,04	0,05	0,05	0,05
Forklift trucks hold	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
lashing	0,16	0,16	0,16	0,16	0,15	0,16	0,16	0,16
Transit Hall crane	0,19	0,20	0,22	0,20	0,21	0,24	0,26	0,28
Locomotives	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29
CE	0,45	0,41	0,40	0,34	0,29	0,25	0,19	0,10

Table E.20: Experiment 3: Occupancy

KR value elements Average loading Time Transit Hall trains	8	7	6	5	4	3	2	1
Quay Cranes	-7,5	-8,2	-9,0	-9,8	-10,7	-11,6	-12,7	-14,3
Forklift trucks	41,0	40,5	42,3	39,2	38,4	39,6	39,5	38,3
Forklift trucks hold	90,0	88,6	89,2	86,3	84,0	83,9	81,0	78,3
lashing	-13,1	-13,7	-14,3	-15,7	-16,4	-17,7	-19,0	-20,5
Transit Hall crane	-9,0	-11,5	-15,6	-14,3	-17,5	-24,3	-29,5	-35,1
Locomotives	-38,7	-39,5	-39,4	-41,9	-43,2	-43,1	-44,9	-47,2
CE	-62,5	-56,2	-53,1	-43,9	-34,6	-26,9	-14,5	0,4

Table E.21: Experiment 3: KR value

Appendix F

Appendix other

Vessel nr.	Vessel coil load	Coils from Transit Hall	% coils from Transit Hall	Coils from CE	% coils from CE
1	1367	1093	79,96%	274	20,04%
2	369	295	79,95%	74	20,05%
3	583	466	79,93%	117	20,07%
4	203	162	79,80%	41	20,20%
5	732	585	79,92%	147	20,08%
6	266	212	79,70%	54	20,30%
7	798	220	27,57%	578	72,43%
8	1073	513	47,81%	560	52,19%
9	642	0	0,00%	642	100,00%
10	419	182	43,44%	237	56,56%
11	590	0	0,00%	590	100,00%
12	316	252	79,75%	64	20,25%
13	565	371	65,66%	194	34,34%
14	16	0	0,00%	16	100,00%
15	826	386	46,73%	440	53,27%
16	716	493	68,85%	223	31,15%
17	203	162	79,80%	41	20,20%
18	707	565	79,92%	142	20,08%
19	256	204	79,69%	52	20,31%
20	710	568	80,00%	142	20,00%
21	710	568	80,00%	142	20,00%
22	590	328	55,59%	262	44,41%
23	617	0	0,00%	617	100,00%
24	1196	956	79,93%	240	20,07%
25	526	420	79,85%	106	20,15%
26	382	305	79,84%	77	20,16%
27	774	612	79,07%	162	20,93%
28	570	0	0,00%	570	100,00%
29	347	277	79,83%	70	20,17%
30	516	128	24,81%	388	75,19%
31	16	12	75,00%	4	25,00%
32	774	291	37,60%	483	62,40%
33	1196	956	79,93%	240	20,07%
34	348	278	79,89%	70	20,11%
35	477	250	52,41%	227	47,59%
36	642	282	43,93%	360	56,07%
37	634	507	79,97%	127	20,03%
38	590	131	22,20%	459	77,80%
39	583	70	12,01%	513	87,99%
40	347	0	0,00%	347	100,00%
41	203	0	0,00%	203	100,00%
42	583	466	79,93%	117	20,07%
43	369	295	79,95%	74	20,05%
44	526	420	79,85%	106	20,15%
45	616	11	1,79%	605	98,21%
46	614	491	79,97%	123	20,03%
47	1196	956	79,93%	240	20,07%
48	378	302	79,89%	76	20,11%
49	1196	956	79,93%	240	20,07%
50	1073	858	79,96%	215	20,04%
51	256	204	79,69%	52	20,31%
52	1	0	0,00%	1	100,00%
53	620	496	80,00%	124	20,00%
54	590	472	80,00%	118	20,00%
55	325	260	80,00%	65	20,00%
56	469	375	79,96%	94	20,04%
57	203	162	79,80%	41	20,20%
58	676	540	79,88%	136	20,12%
59	733	586	79,95%	147	20,05%
60	480	185	38,54%	295	61,46%
61	689	91	13,21%	598	86,79%
62	469	0	0,00%	469	100,00%
63	733	191	26,06%	542	73,94%
64	521	130	24,95%	391	75,05%
65	325	0	0,00%	325	100,00%
66	382	0	0,00%	382	100,00%
67	348	0	0,00%	348	100,00%
68	404	281	69,55%	123	30,45%
69	620	73	11,77%	547	88,23%
70	1367	458	33,50%	909	66,50%

Table F.1: Validation tests for coils from the CE and Transit Hall

Vessel nr.	Vessel ETTS load	ETTS from BUO & BUW	% ETTS from BUO & BUW	ETTS from CE	% ETTS from CE
1	0	0	0,00%	0	0,00%
2	1395	474	33,98%	921	66,02%
3	0	0	0,00%	0	0,00%
4	1677	570	33,99%	1107	66,01%
5	767	260	33,90%	507	66,10%
6	0	0	0,00%	0	0,00%
7	0	0	0,00%	0	0,00%
8	34	11	32,35%	23	67,65%
9	769	261	33,94%	508	66,06%
10	0	0	0,00%	0	0,00%
11	0	0	0,00%	0	0,00%
12	0	0	0,00%	0	0,00%
13	0	0	0,00%	0	0,00%
14	774	263	33,98%	511	66,02%
15	206	70	33,98%	136	66,02%
16	675	229	33,93%	446	66,07%
17	1677	570	33,99%	1107	66,01%
18	0	0	0,00%	0	0,00%
19	1860	632	33,98%	1228	66,02%
20	0	0	0,00%	0	0,00%
21	0	0	0,00%	0	0,00%
22	0	0	0,00%	0	0,00%
23	1245	423	33,98%	822	66,02%
24	0	0	0,00%	0	0,00%
25	1077	366	33,98%	711	66,02%
26	1188	403	33,92%	785	66,08%
27	411	139	33,82%	272	66,18%
28	878	298	33,94%	580	66,06%
29	136	46	33,82%	90	66,18%
30	1052	357	33,94%	695	66,06%
31	774	263	33,98%	511	66,02%
32	411	139	33,82%	272	66,18%
33	0	0	0,00%	0	0,00%
34	0	0	0,00%	0	0,00%
35	0	0	0,00%	0	0,00%
36	769	261	33,94%	508	66,06%
37	0	0	0,00%	0	0,00%
38	0	0	0,00%	0	0,00%
39	0	0	0,00%	0	0,00%
40	136	46	33,82%	90	66,18%
41	1677	570	33,99%	1107	66,01%
42	0	0	0,00%	0	0,00%
43	1395	474	33,98%	921	66,02%
44	1077	366	33,98%	711	66,02%
45	0	0	0,00%	0	0,00%
46	0	0	0,00%	0	0,00%
47	0	0	0,00%	0	0,00%
48	0	0	0,00%	0	0,00%
49	0	0	0,00%	0	0,00%
50	34	11	32,35%	23	67,65%
51	1860	632	33,98%	1228	66,02%
52	0	0	0,00%	0	0,00%
53	923	313	33,91%	610	66,09%
54	0	0	0,00%	0	0,00%
55	0	0	0,00%	0	0,00%
56	0	0	0,00%	0	0,00%
57	1677	570	33,99%	1107	66,01%
58	1067	362	33,93%	705	66,07%
59	0	0	0,00%	0	0,00%
60	992	337	33,97%	655	66,03%
61	0	0	0,00%	0	0,00%
62	0	0	0,00%	0	0,00%
63	0	0	0,00%	0	0,00%
64	0	0	0,00%	0	0,00%
65	0	0	0,00%	0	0,00%
66	1188	403	33,92%	785	66,08%
67	0	0	0,00%	0	0,00%
68	0	0	0,00%	0	0,00%
69	923	313	33,91%	610	66,09%
70	0	0	0,00%	0	0,00%

Table F.2: Validation tests for ETTS from the CE and BUO-BUW

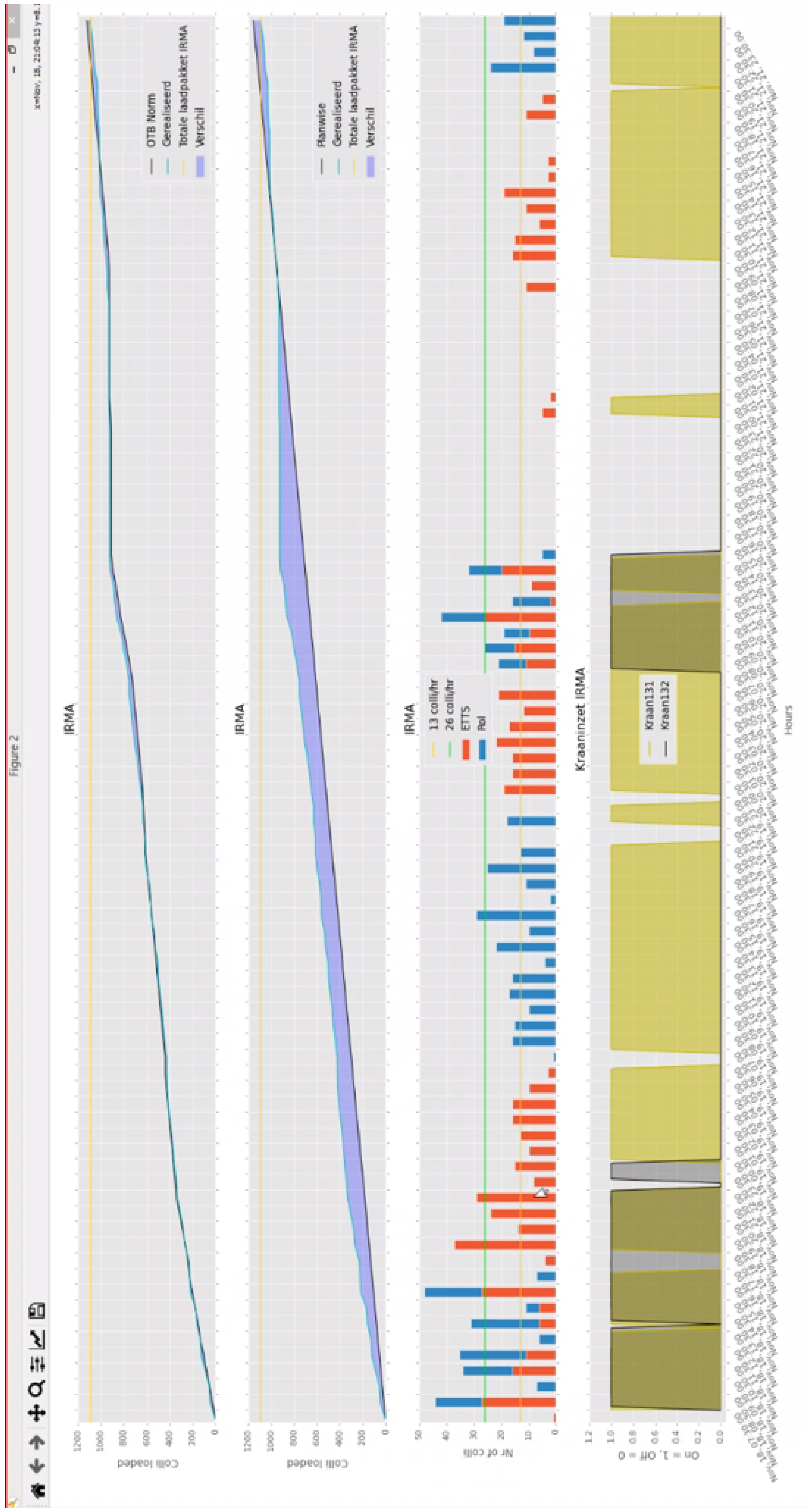

Figure F.1: Example of recommendation to plot course of loading process of vessels