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Introducing service differentiation in barge handling at a container terminal

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Introducing Service Differentiation in Barge Handling at a Container Terminal

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It should be noted that some numbers mentioned in this thesis are fictitious due to confidentiality reasons.

Preface

This report concludes my master thesis project, which I conducted at Europe Container Terminals (ECT) in Rotterdam. The project is the final stage of my Master in Operations Management & Logistics at the Eindhoven University of Technology. More importantly, this report is the final stage of an amazing student life.

I would like to thank several people who helped me during the thesis project. First of all, I would like to express my gratitude to Albert Veenstra, my first supervisor from the Eindhoven University of Technology. You helped me by finding a company to write this thesis and gave me the opportunity to conduct research in the Port of Rotterdam. Besides, your knowledge on the subject and feedback provided me with enough direction to form this thesis. Also my second supervisor, Luuk Veelenturf, was important for this project. Your critical feedback helped me to structure the thesis in an academic way and to reflect on my own analysis. Thank you both for your effort and time.

Next, I would like to thank my ECT supervisors. My first supervisor at ECT, Marco Meerman. Marco, from day one you gave me full responsibility on the project and supported me in important decisions I made regarding the scope and direction of the project. I really enjoyed our meetings, as we spent many hours talking about the terminal operations as well as personal stuff. At the end of most meetings, we concluded that the barge handling environment is highly-complex and no standalone approach will solve the existing issues. Furthermore, I would like to thank my second supervisor at ECT, Bart van Riessen. Bart, your academic and critical opinion has provided me with very useful feedback, especially in the simulation phase and in making the results more concrete. Besides, I would like to thank Arno van Rijn and other colleagues for their enthusiasm in this project.

Special thanks go out to Ben van Rooy from Brabant Intermodal, who helped me understanding the barging market. Furthermore, I would like to thank all other barge operators for their input.

I also want to thank my family and my parents in particular for supporting me during my entire study and life. Especially, I want to thank Floor who encouraged me throughout the project and my entire student life. I am very grateful for your love and I am really looking forward to our trip.

Finally, I would like to thank my friends who have made it a wonderful student life: the l'Eon Dix guys, the IRP Bazen and participants, Old Times, De Raad der Stokken, #hog, the people I met during the Race of the Classics and my exchange semester in New Jersey, and all others, thank you for everything.

Henk Snepvangers

Management Summary

This thesis presents the results of our study to introduce service differentiation in barge handling at a container terminal. As a case study, the operational department of Europe Container Terminals (ECT) was used. Currently, the barge handling is a complex issue for both ECT and the barge operators. Barge operators need to make multiple appointments with terminal operators, which results in a high workload for the barge planners of ECT. The barge planners have to ensure a reliable and real-time planning of the barge handling (i.e., the berth plan) for the upcoming day(s). The berth plan is key as input for related operational (planning) activities at the terminal, since efficient utilization of resources (e.g., cranes and crew) and operational planning (e. g., vessel and stack planning) depend on it.

Problem Statement

Nowadays, the collaboration between the terminal and barge operators regarding the barge handling is problematic. Recent research (e.g., Douma, 2008; Douma, Schutten & Schuur, 2011; Fazi, 2014) studied possible strategies to solve the collaboration problem. However, none of these studies analyzed the introduction of service differentiation in barge handling, while the urgency for more service-oriented business strategies in ports is known for many years (Van Nunen & Veenstra, 2005). Therefore, this research focuses on the operational design of service differentiation between barges in order to solve the problems and to improve the berth plan reliability. This differentiation establishes opportunities for more specific service towards the barge operators. Therefore, the research question of this thesis is formulated as:

What is the berth plan reliability performance of introducing service differentiation in barge handling at a container terminal?

One of the key issues is the reliability of the berth plan within the operational department of ECT, which is the focus of this study. The reliability of the barge berth plan depends on one hand on the terminal operator due to barge capacity allocation and operational disturbances. On the other hand, the reliability is also affected by the lack of reliability of the appointments made with the barge operators. Barge operators try to ensure capacity at the terminal operator. They can freely cancel an appointment or make adjustments to their original announcement information without consequences. Therefore, these appointments are often unreliable which affects the reliability of the berth plan.

Through a series of interviews, we found multiple underlying factors which cause the unreliability in the process of making appointments. The most important findings were:

- The high probability of infeasible barge trips, as barges have many appointments in the port;
- The high pressure to make an appointment between the terminal and barge operator, due to disturbances throughout the supply chain and the pressure on the final delivery of the transported products;
- A mismatch between the available information and the announcement deadline at ECT, as the barging market is highly dynamic and barge transport orders rapidly change in time.

The underlying cause of the research problem is that ECT does not handle barges based on their specific characteristics and reliability. Therefore, ECT does not take the strategic behavior of the barge operators into account in the appointment making process. We argued that a more customized barge handling process comes with an improved behavior of the barge operators. This includes more reliable appointments and thus a more reliable berth plan.

Redesign

The service differentiation comes with a division of barges in groups and this results in a separated barge planning, as the groups have their own announcement deadline and are thus planned at separated time points. This strategy comes with decisions related to the capacity allocation to groups, in order to deal with the possible spreading in service levels between clusters. This brings forth decisions that are related to the integration of this redesign in the current process, and can be divided into these three design decisions:

1. Clustering decision: the assignment of barges to groups;
2. Planning horizon decision: the (new) planning horizon per group;
3. Resource decision: the allocation of (reserved) berth capacity to groups.

Clustering is the task of grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups. We argued for three groups and assigned barges to these clusters based on the cluster analysis guidelines as presented by Mooi and Sarstedt (2011). In this analysis, the clustering variables were based on cancellation data and represented the reliability of the made appointments per barge.

Figure 1 graphically shows the clustering result in a scatter plot; note that the three colors each represent a cluster. The big blue rectangle on the bottom left side of Figure 1 represents all barges with zero cancellations and thus have no variable values. These are clustered in group X.

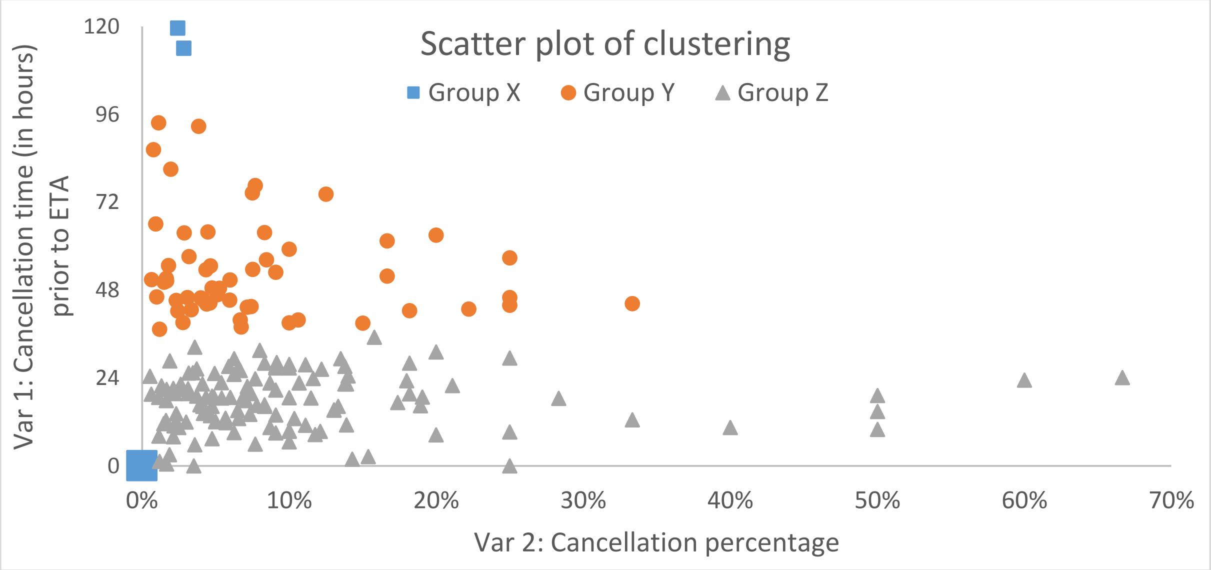

Figure 1: Scatter plot of clustering with barge memberships per group

The clustering resulted in three groups of barges and separated the reliable barges with the unreliable ones. For example, the average historical cancellation percentage of group X is 0,2% and the percentage of group Z is 6,6%. Based on these group characteristics, we separated and customized the barge planning per group.

The service levels between groups may differ, as arrivals of barges of different groups are planned at different moments, while the same barge capacity is available for these three groups. Therefore, we analyzed berth capacity allocation rules in order to evaluate the impact of the redesign on the service level per group. Three different types of strategies were analyzed:

1. *Fixed cluster capacity:* there is a fixed barge capacity reserved per cluster;
2. *Flexible cluster capacity:* a part of the barge capacity is reserved, while the other capacity can be used by all clusters;
3. *Free cluster capacity:* there is no capacity reserved and all capacity can be used by all clusters.

Figure 2 shows an example overview of the redesign. As can be seen, the planning horizons differ between the cluster groups; the horizons are 48, 24 and 12 hours for respectively group X, Y and Z.

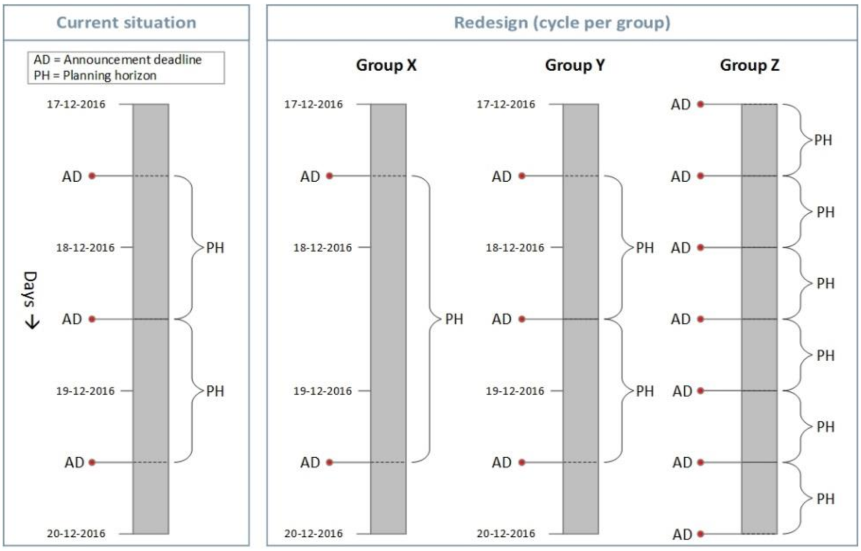

Figure 2: Overview of the redesign with per group the announcement deadlines (AD) and planning horizons (PH)

Simulation Study

We designed a discrete-event simulation model to evaluate the performance of the redesign. This simulation processes the complex barge handling system in an ordered sequence of defined events. We analyzed the performance of the planning system based on the barge waiting times, reliability of the berth plan and the workload of the barge planner. In order to give realistic insights, we used in-company data of ECT as simulation input for our experiments. We expect behavioral improvement of the barge operators as the barge handling is more customized for different barge groups. Therefore, we introduced two degrees that represent the behavior of the barge operators in order to assess the flexibility of the redesign.

Results

Based on the simulation experiments, we found interesting insights concerning the performance of the approach. The most striking finding was that the redesign resulted in the desired service differentiation. In other words, the differentiated barge handling comes with better service levels towards more reliable barges. This finding is an opportunity for both the terminal and the barge operator to focus more on collaboration and reliable services. Specially, the 'free cluster capacity' allocation strategy is flexible in different scenarios and provides the opportunity for service differentiation.

Furthermore, the reliability of the berth plan improved. The redesign leads towards a minimum reduction of approximately 30% in re-plan movements, which is a measurement for the barge planners workload. A further reason to conclude the increased reliability is the fact that a significant number of cancellations and change requests is 'surpassed' because of the lower planning horizons. In contradiction, the reduction in movements causes the berth plan (in the simulation model) to be less flexible than in the current situation. However, in practice this could be solved by introducing extra re-optimization moments.

Based on these findings, it can be concluded that there are ways to improve parts of the barge planning process. However, the implementation in practice should be based on a careful weighing of the performance indicators of both the terminal and barge operator. We found that improving parts of the barge handling process may also cause a loss of flexibility or performance in other parts. Next to that, it could decrease service towards barge operators who make unreliable appointments. To avoid this, careful implementation is necessary.

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1. Introduction

This chapter contains an introduction of the research project and a description of Europe Container Terminals (ECT), the company where this thesis was conducted. Furthermore, we introduce the berth plan of the barge handling at the container terminal, as barge handling is the thesis' main topic.

1.1. Research Introduction

The port of Rotterdam is the largest container transshipment hub in Europe and it is ideally located in the heart of Europe's largest consumer markets. Through the port of Rotterdam, goods are transshipped to locations in Europe by train, truck and barge. According to the Port of Rotterdam Authority (2015) a throughput of more than 12,3 million TEU (i.e., Twenty feet Equivalent Unit; a common way for the measurement of containers) was achieved in 2015.

Regarding the transportation and handling operations of shipping containers, certain companies became specialized operators of both transportation and transshipment. These companies gain prominence as economies became globalized and trade between distant regions grew. The best examples of such companies are the shipping liners who operate container vessels, as well as container terminal operators who operate the cargo and container handling and transshipment infrastructure at ports. Most of the containers handled in the port of Rotterdam have a destination in its hinterland, and thus need further transportation. Due to its unique location, in the delta of the rivers Rhine and Meuse, the port of Rotterdam has access to well-developed waterways; this makes container shipping an attractive mode of hinterland transportation. In 2015, about 65% of the containers which passed through the Port of Rotterdam had a hinterland origin or destination (Port of Rotterdam Authority, 2015). The port authority aims that the modal split between the modes truck/barge/rail changes from 47/40/13 in 2009 to 35/45/20 in 2035, in the interest of fulfilling governmental demands to reduce trucking (Port of Rotterdam Authority, 2015).

The use of hinterland shipping seems to be an effective way of transporting large numbers of containers without burdening the already stressed road infrastructure and the environment; however, the current barge handling proves to be extremely difficult (Snepvangers, 2015). As a result, terminal capacity is often underused and waiting times at terminals are high. Here, the waiting time is defined as the time a barge operator has to wait until the vessel can visit the terminal, i.e. the difference between the demanded visit time and the time planned by the terminal operator.

The role of the barge operator is to organize hinterland container transportation by barge and the acquisition of containers is an important task for a barge operator. Most barge operators contract barge owners (i.e. persons or companies who have command of barge ships) to sail fixed round trips between Rotterdam and the hinterland. To be competitive with other modalities it is important for a barge operator to offer frequent and reliable services with enough capacity and at low cost.

From the terminal operators perspective, the complex hinterland transportation network and problems related to developments and issues in the barging market result in resource planning difficulties. In particular, the behavior of barge operators have a huge impact on the complexity of the barge planning. Hence, this master thesis focuses on the impact of barge operator behavior on the terminal operators reliability of the berth plan and was conducted at ECT.

1.2. Company Description

ECT is the leading container terminal operator in Europe and it operates two deep-sea terminals at the port of Rotterdam at the Maasvlakte directly on the North Sea. ECT's core business is the fast, efficient and safe discharge, temporary storage and loading of containers. In 2013, ECT handled more than 7,4 million TEU, which represented more than 60% of the container volume which passes through this port and 19% of the total container volume of the Hamburg-Le Havre range. In addition, ECT operates hinterland terminals in The Netherlands, Germany and Belgium and coordinates a wide network of transportation services between the deep-sea ports and the hinterland terminals via its European Gateway Services (ECT, 2014). ECT's competitors up to 2014 consisted of the APM terminal, located at the Maasvlakte. However, for 2016 two large container terminals are scheduled to begin operations at the Maasvlakte 2. Therefore, in order to compete with competitors, fulfil demands, optimize processes and minimize costs, ECT needs to develop and come up with innovative solutions.

1.3. Barge Berth Plan

The berth plan of the terminal operator can be described as the overview of all appointments with vessel operators and thus includes the berth location and time assignment (defined as ETA: Estimated Time of Arrival) of all upcoming vessel arrivals. The berth location indicates the physical location the vessel is assigned to and illustrates the assigned crane(s) that will be used during the handling of the vessel. The vessel operators notifies an upcoming vessel arrival by entering an announcement in the port communicating system, including the published time of arrival (PTA) and the number of loading and unloading containers (i.e., the call size). Berth planning consists of performing all activities related to the appointment making process between the terminal and vessel operator. The berth plan is constructed by three different operators: the barge, feeder and deep-sea planner. This threefold division is based on the distinctive need in planning and handling, as high-volume and long distance transportation vessels need more terminal capacity and a longer planning horizon than low-volume short-distance barge transportation.

The barge planning is performed within the operations department and is responsible for all planning, controlling and managing processes in order to provide smooth operations at the waterside and landside of the terminal. On the basis of the berth plan, working staff is assigned and equipment, handling and transport is scheduled. Therefore, the berth plan is a crucial part of the terminal performance as all other operational planning depend on it.

Figure 3 provides a schematic example of a berth plan. Appointments are represented as rectangles and have a specific appointment time (vertical axis) and berth location (horizontal axis). Furthermore, the rectangle gives information about the number of containers to (un)load as the longer (the vertical length of) the rectangle the more time is planned to handle the vessel. The width of the rectangle provides information about the length of the vessel, and thus the berth capacity which is required. In this overview, the three vessels types (barge, feeder and deep-sea) are depicted with different colors (respectively blue, grey and black). For example, the black rectangles represent deep-sea vessels and need more capacity than the other vessels. Furthermore, the assigned capacity can be expressed in the number of cranes allocated per vessel and depends on the assigned berth location. The more cranes per berth location, the higher the production rate in loading/unloading containers per hour. The left side of the berth plan is a dedicated barge berth, as there is one crane available at that berth location and only barges can be planned at that location.

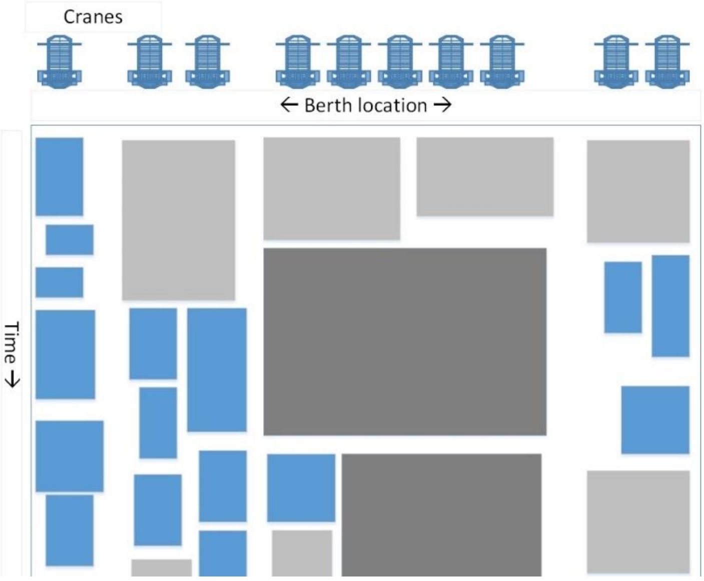

Figure 3: Schematic overview of a berth plan with time on the vertical axis and the berth location on the horizontal axis.

The barge planner is responsible for the administrative handling and planning of the barge announcements, since the main task is to compose an on-time berth plan of all announcements. The barge planner releases the announcements circa 24 hours before their arrival on a First Come First Served (FCFS) basis into the terminal planning system and plans the appointment with the barges. Furthermore, the barge planner communicates (mostly per phone or e-mail) with barge operators and, if required, re-plans appointments because an appointment was cancelled or changed. Also, re-planning can be necessary in case of other (terminal) disturbances (e.g., crane failures, capacity reduction or weather conditions). In case of re-planning within eight hours of a vessel arrival, the resources planner anticipates and updates operational schedules.

While planning and managing the berth plan, the barge planner needs to take into account different factors and norms, such as the equipment performance, number of cranes per object, disturbances, connections with other vessels, internal transportation, and breaks and switching of staff. All these factors are unpredictable and therefore norms are set for the berth production in containers per hour per object. Furthermore, the terminal strategy influences the decision making process of the planner. Overall, the barge planner ensures a logical, reliable and efficient berth plan, taking into account capacity restrictions (e.g., transportation, equipment, staff and stack) and interests of the terminal operator and the customers.

2. Research Design

In this chapter, we state the initial problem statement from the perspective of the company. A literature review on this subject is given to support the importance of solving the problem. Furthermore, the barging market is described briefly. We outline the research outline as objectives and research questions are presented, and the scope of the research project is defined. Finally, we provide the thesis structure.

2.1. Initial Problem Description

2.1.1. Company Problem Statement

As mentioned in the introduction, the current barge handling and related resource planning is a complex issue for terminal operators and especially for ECT. ECT handles a large number of the containers which pass through the port of Rotterdam (60% of the total hinterland volume), and thus a high volume of containers is delivered and picked-up by barge transport. This high-volume of barge-related containers comes with multiple appointments with barge operators. This result in a high workload for the barge planners, who have to ensure a reliable and real-time planning of the barge handling for the upcoming day(s). The berth plan is key as input for related operational (planning) activities at the terminal, since efficient utilization of resources (e.g., cranes and crew) and operational planning (e. g., vessel and stack planning) depend on it. Therefore, a reliable berth plan is of high importance, as there are cost involved with rescheduling and idleness of resources.

The reliability of the barge berth plan depends on the one hand on the terminal operator due to barge capacity allocation and operational disturbances, but on the other hand on the reliability of the appointments with the barge operators. Barge operators can freely cancel an appointment or make adjustments to their original announcement information, which causes a decrease in reliability of the appointments. The barge operators behavior furthermore depends on the extent to which they include slack time on the basis of previous experiences at the terminal. Because of that, the barge planner has to deal with uncertainty due to strategic planning of barge operators. In other words, an appointment could be made in order to reserve a part of the berth capacity for any of his barges. On the workplace, these announcements are named “ghost-announcements”: the published time of arrival of the barge is not based on their real estimated time of arrival but on the expected planned time at the terminal and the demand of other barge operators. In this way, the barge operator tries to ensure a spot at the berth at the terminal. Therefore, ECT has to anticipate on the strategic behavior of the barge operators, which enhances miscommunication, frustration and distrust between both parties. This is further analyzed in Chapter 3.

From the perspective of ECT, unreliable appointments can result in unproductiveness of resources, though most risk of idleness is involved with late communication of cancellations and changes in time of arrival. Moreover, the initial company problem can be stated as the high number of cancellations and change requests. Over the last two years, the percentage of cancellations is around 6% (based on company data). However, Portbase, the Port community system, keeps track of all barge operator changes and their data show a cancellation percentage of 12,4% in 2015, as depicted in Figure 4.

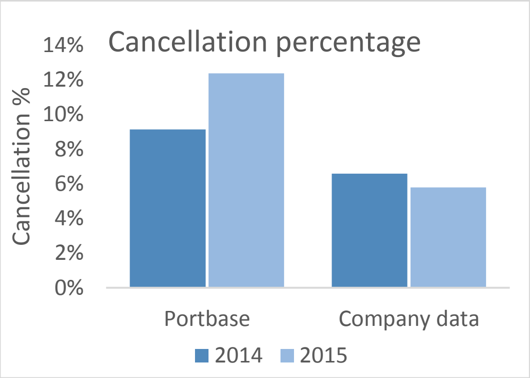

Figure 4: Percentage of cancelled announcements at the ECT, based on both company and Portbase data

2.1.2. Literature Supporting the Company Problem

Although barge transport is not a fast mode of transport, barges can operate according to regular shipping schedules. However, currently the time spent in the port of Rotterdam before sailing to a hinterland destination is on average 22,5 hours, of which only 7,5 hours are used for loading and unloading - the remaining time is spent sailing and waiting (Douma, Schutten & Schuur, 2009). This is caused by the fact that barge operators have to make appointments with, on average, eight different terminal operators and the expectation is that this number will increase due to the extra terminals at the Maasvlakte 2 (Konings, 2009). Hence, it may be expected that the barge alignment problem, which is reviewed in this section, becomes more urgent in the next years.

The barge alignment problem is defined as all problems related to the collaboration issues between the terminal and barge operators. The barge handling alignment issues can be explained by the fact that the terminal operator gives the lowest priority to the handling of barges, in comparison with the handling of large sea vessels (i.e., feeders and deep-sea vessels). Barges are handled at the terminals waterside, using the same transshipment capacity (i.e. cranes and berth capacity) as large sea vessels; as a results of this, pressure is put on the barge berth plan. The problematic alignment between the terminal and barge operators impacts the terminal operations significantly. Improving the barge handling will increase the quay utilization and will furthermore decrease delays and reduce frustration (Kim & Lee, 2015).

Barges usually visit several terminals and this creates dependencies between the activities performed at the terminals. In this way, a disruption at one terminal could quickly propagate through the port and disturb the operations of other barge and terminal operators. The consequence is that barge operators face uncertain waiting and handling times at terminals, and terminals deal with uncertain arrival times of barges. The uncertainty in the alignment process leads to several undesirable effects, as described by Douma (2008). For example, some barges try to influence their processing times at terminals by exhibiting strategic behavior. They reserve berth capacity and cancel appointments and announce wrong numbers of containers in order to obtain a convenient appointment for handling. In queueing literature, this phenomenon is described as reneging: “A customer first choose to join a queue, but gradually lose their patience and eventually leave the queue before receiving service in case of intolerable waiting” (Wang, et al., 2014). In this case, the barge operator makes the appointment while later on he may cancel it due to the long waiting time, as this high waiting time makes the barge trip infeasible. However, here strategic behavior also influences the behavior of the ‘customer’, as appointments are used to reserve berth capacity. Hence, there is no real waiting line as the barges waiting time is based on the published arrival and planned time in the berth plan.

It is possible that the terminal as well build in slack time based on previous experiences of late arrivals and deviations from the scheduled number of moves. Therefore, it is not surprising that - due to unreliable announcements, intentional slack and lack of co-ordination - some shipping schedules are infeasible from the start (Douma, 2008). The barge planners often receive limited or fuzzy information that are hard to combine or compare with other information; planners rely on rules of thumb to counter this (Bruggeling & Menno, 2011).

The problematic alignment between barge and terminal operators, the so-called barge handling problem, is considered to be the most urgent problem in hinterland barge container transportation by the Port of Rotterdam (Douma, 2009; Van Staalduinen, 2014). In operations research literature, the berth allocation problem has not been studied extensively, but these papers study this problem with a given set of vessels to be processed, and without considering strategic behavior of barge operator (Douma et al. 2009). Douma (2009) constructed a multi-agent system that represented the business network in the port of Rotterdam and introduced waiting profiles in the appointment making process. This research concluded that waiting profiles approach reduces the average waiting time with almost 80%. In a comparable study, Douma, Schuur and Jagerman (2011) constructed a simulation model in order to study the behavior of the terminal operator in terms of cooperativeness. However, in both studies the models did not evaluated the behavior of the barge operators and the reliability of the berth plan.

2.1.2.1. Causes of the Alignment Problem

De Langen and Van der Horst (2004) analyzed the coordination problems in hinterland chains of seaports in detail, as did Douma et al. (2009). Below, the most important factors found in both studies are enumerated:

- The unequal distribution of costs and benefits of coordination (Van der Horst & De Langen, 2008);
- Each terminal and barge operator wants to stay autonomous;
- There are no contractual relationships between barge and terminal operators;
- Limited information sharing between parties regarding performances, delays and schedules;
- A highly dynamic environment, since countless numbers of events, disturbances and contact moments between actors are present in this business;
- Risk-averse behavior and a short-term focus of firms in hinterland chains.

Digging deeper into the above presented alignment problem, Melis (2003) found the most frequent causes of the troubled collaboration between the terminal and barge operator and came up with the following causes:

- Delays during barge handling due to:
  - Lack of available transshipment capacity (e.g., cranes and staff);
  - Problems with documentation, exemptions and (un)loading lists.
- Arrival delays due to:
  - Delays at previous terminals (domino effect);
  - External factors such as equipment failure on board and the weather.
- Unreliable schedules due to:
  - Unreliable announcements regarding the number of containers to be loaded and unloaded;
  - Lack of co-ordination between the various terminal schedules;
  - Schedule ‘slack’ created intentionally by barge and terminal operators;
  - Different deadlines applied by terminal operators for the submission of announcements.

Information Availability in Container Transportation

According to Kim and Lee (2015), one of the crucial conditions for the development of efficient networks is the availability of reliable information on containers (e.g., arrival and departure times, content, and modes of internal transport). Terminal operators mostly only have estimated arrival and departure times, while more exact information can be used to better stack containers, to minimize internal travel time to the proper pick up points, and to avoid lateness or earliness of loading and unloading different modes of transport (Gharehgozli et al., 2014). Furthermore, terminal operators typically do not know the final destination of the container, and only gets informed relatively late by the hinterland transporter about collection of the container. This leads to queueing of barges at the terminal and simultaneously drops in efficiency in the sea terminal (Fransoo & Lee, 2013).

In the research of Melis et al. (2003), it was concluded that the lack of transparency of information and availability of terminal capacity creates inefficient routing of barges in the port and causes much frustration between the actors. Based on current literature and expert opinions, we concluded that over a ten year time frame nothing improved in the collaboration between the container terminal and their main partners, such as the barge operators (Kim & Lee, 2015). Activities that can improve the collaboration are increasing the information sharing, improving data accuracy, integrating scheduling, and devising economic measures for the collaboration (Kim & Lee, 2015).

Contractual Agreements

Probably the most important cause of the alignment problem is that most terminal operators do not have contractual arrangements with barge operators (Douma A. , 2008). Currently, the barge operator makes an appointment to visit the terminal operator with a specific barge, but do not makes any further agreements (other than a time and place). In contradiction, the barge and terminal operators have contractual agreements with deep sea carriers who are their only paying customer. Because of that, terminal operators prioritize the handling of sea vessels above barges while allocating terminal capacity. However, this construction leads to delays in processing the barges and this has a negative impact on the service level of ECT. In the summer of 2014, delays of barges were as big as seven days which caused negative attention for ECT.

2.1.2.2. Barging market

Three hinterland markets for container barge transport through the Port of Rotterdam can be distinguished: the Rhine river market, the Rotterdam-Antwerp market and the domestic market. This classification is based on organizational and operational differences and although these services areas use the same mode of transport, different parties are active within these service areas (Konings, 2009; Van Staalduinen, 2014). On the Rhine River and Rotterdam-Antwerp trade some barge operators cooperate by sharing barge capacity. In this way they can offer frequent services with enough capacity.

In total, there are about twenty container terminals suitable for container barge handling located throughout the Netherlands and approximately 75 barge operators serve the container terminals. The active barges on the Dutch waterways have a capacity between the 32 and 500 TEU. Aside of these elaborated difficulties, there are prevalent external challenges. Van Staalduinen (2014) investigated the barging market and presented opportunities and threats that will influence developments, these opportunities and threats can be seen in the table below.

Table 1: Opportunities and threats for barge operators in the Netherlands (Van Staalduinen, 2014)

Opportunities	Threats
Opening of Maasvlakte II	Barge handling problems
Modal shift ambitions of Rotterdam PA	Increasing involvement of deep sea actors
Increasing containerization (reefers)	Increasing vessel size in maritime sector
Congestion in road transport	Price pressure in road transport
Cooperation	New terminal initiatives
New logistics concepts	Image of container barge transport
Depot function for deep sea carriers	Disappointing economic growth
Professionalization	JIT-deliveries (focus on speed)
Increasing focus on sustainability	Other modalities innovate faster

An important task of the barge operator, which is relevant in our study, is the alignment of barge operations with inland and deep-sea terminals. Shippers (i.e. the customers) generate demand for hinterland transport and are therefore key in the container barging market. Because a reliable and in-time delivery is crucial for the continuity of a shipper, a shipper prefers to control the hinterland transport chain (Van der Horst and De Langen (2008). A shipper is not involved in the organization of container barge transport, but contracts a transportation orchestrator who is responsible for this. The transportation orchestrator, which can be a shipping line, expediter, freight forwarder or the shipper itself, arranges all or a part of the door-to-door transport activities. Transportation orchestrators are continuously looking to offer the best and cheapest transportation solutions. Usually, these companies contract a hinterland orchestrator who is responsible for the hinterland transportation and thus for the final delivery. However, the way the whole transportation chain is designed differs for every customer, which makes the behavior and interests of barge operators difficult to assess.

In Figure 5, the basic relations within the hinterland transportation chain are depicted. Note that parties can be involved in multiple parts of this chain. For instance, the customer can directly contract a hinterland orchestrator or an inland terminal. All actors are attempting to gain more control over the hinterland transport chain of container barging (Fransoo & Lee, 2013). This dynamic might be the basis of the earlier described problems; the actors operate independently of the transportation orchestrator, which makes the coordination and barge handling at the terminal operator complex.

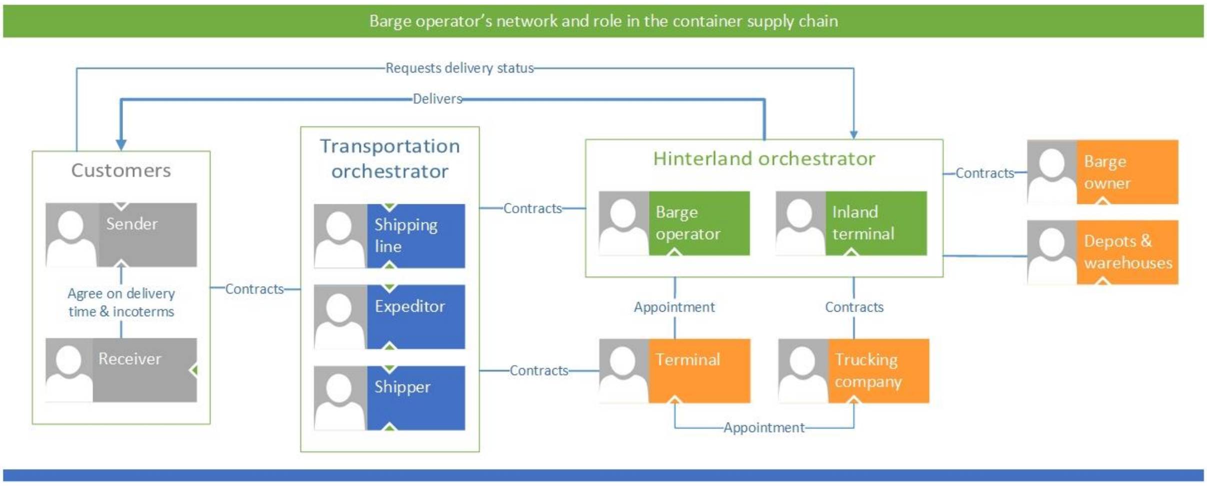

Figure 5: The actors and mutual relations in the container (hinterland) supply chain, partly elaborated from Van der Horst & De Langen (2008)

2.1.2.3. Conclusion

The barge and terminal operator alignment problem is dynamic and intertwined interests and strategic behavior influence the performance of the barge handling processes at ECT. The literature review addressed potential underlying causes and supports the stated company problem. Therefore, the initial problem -that is the basis of this research- can be stated as the unreliability of the appointments between the terminal and barge operators and thus the unreliability of the barge berth plan. Furthermore, the company suggested to take into account the thoughts and needs of the barge operators, since nowadays the collaboration is far from optimal; moreover, this came to the surface in literature as well.

2.1.3. Service Differentiation

The unreliable berth plan is partly due to the strategic behavior of barge operators and therefore, obviously, the strategic behavior of the barge operators needs to be diminished. To address this behavior it is required to differentiate between announcements, as not all appointments are unreliable. As discussed earlier, the barge arrivals differ in their origin, frequency of visiting the terminal in information availability at the time of communicating the announcement. From the terminal operators perspective, the combination of varying barge characteristics and behavior calls for differentiation in barge handling. Service differentiation in port business is not unknown, as the barge, feeder and deep-sea threefold division is a well-known separation in vessel handling from the terminal operators perspective. Currently, limited research has been conducted regarding the differentiation in handling within barges. However, the urgency for more service-oriented business strategies in ports exists for many years (Van Nunen & Veenstra, 2005). The research problem is of high interest for both the terminal and barge operator and therefore it would be a completion on current literature to further analyze the introduction of operational dispersion in barge handling. In section 2.1.2, the problems are found to be market-wide problems. However, the incentive of this research comes from ECT. Thus, it is possible to evaluate the differentiation strategy based on an in-company analysis and a simulation study based on real data. Furthermore, both the literature and the company statement described the collaboration issues between the barge and terminal operator, hence the later suggested redesign needs to be tuned with the market. Therefore, multiple interviews and feedback moments have been conducted in order to involve both the terminal and barge operators in this thesis.

2.2. Research Outline

2.2.1. Objective and Research Questions

As indicated in the previous section, the barge handling problem is complex and it is clear that the barge planning is in need of improvement, especially in times of tough competition and the opening of the Maasvlakte 2. Poor alignment between barge and terminal operators comes with negative effects related to the planning reliability of ECT and is partly due to the fact that ECT does not differentiate in barge handling. Therefore, this research focuses on the operational design of service differentiation between barges in order to improve the berth plan reliability. This differentiation establishes opportunities for more specific service towards the barge operators, as a more reliable announcement possibly deserves a better service level. This research analyzes an approach to introduce service differentiation in barge handling. Therefore, objective is formulated as:

The objective of this study is to redesign the barge handling process by introducing service differentiation with the aim of increasing the reliability of the barge berth plan.

The berth plan reliability is rooted in the performance of the entire terminal operation. Thus, in this thesis the main objective is improving the reliability of appointments with barge operators. This thesis' main objective is accomplished by realizing the following objectives:

Increase the reliability of the barge berth plan:

- Decrease the number of barge cancellations;
- Decrease the number of change requests.

A more reliable berth plan results in a lower workload for the terminal barge planners, as the number of re-plan movements decreases if the number of cancellations and change requests decreases. Based on the defined objectives, the research question can be stated as:

What is the berth plan reliability performance of introducing service differentiation in barge handling at a container terminal?

We hypothesize that separated barge handling increases the barge planning performance. This hypothesis was tested by first analysing the current planning process, the redesign was then elaborated and then a simulation study compared the current situation with the redesign. This structure of the report comes with sub questions that will answer the research question:

I. *What is the root cause of the research problem?*
The underlying cause(s) of the research problem is elaborated in Chapter 3, of which interviews with barge operators are the basis of the fishbone analysis. The underlying cause of the problem is given based on this analysis and an-in company data analysis.

II. *How can the current barge planning process be redesigned in order to introduce differentiation in barge handling?*
Based on the root-cause analysis a redesign is defined in order to operationalize the new barge handling strategy (Chapter 4).

III. *What is the performance improvement of the redesign in comparison with the current situation?*
First, the simulation model is discussed and validated (Chapter 5) and simulation results are then presented (Chapter 6).

2.2.2. Scope

In this research, the focus is on how to deal with the influence of the typical behavior of the barge operators on the reliability of the berth plan. The planning process was studied with the aid of a simulation model which represents the current planning process at ECT. ECT is divided in multiple practical independent terminals; in this thesis, the terminal with the highest barge demand has been chosen to act as case study.

In order to evaluate the potential performance improvement of the redesign in this complex environment, scoping decisions were made as many aspects can influence the berth plan. Therefore, we only included the required components of the terminal operators processes which represent and can measure the performance of the current handling process, as this reduces the complexity of the analysis.

In Figure 6, an abstract overview of the barge handling process is depicted; for the sake of clarity, only the overarching aspects are shown in the overview. The blue-colored rectangles represent modules which are not considered in this research, as the activities related to these modules do not directly affect the berth planning processes of the barge handling.

First of all, the resource planning and resource restrictions for all resources (i.e., equipment, personnel and capital), except the berth capacity, are out of scope. This decision isolates the research focus on the capacity allocation problem, as this topic is the base of the redesign. Hence, no variability in the availability of other resources can influence the simulation study.

Aside of the barge handling, other terminal activities influence the performance of the cranes as for example the performance of internal transport, container handling and other terminal equipment. However, all these activities and related performance issues are left out of scope. Furthermore, the terminal operations have highly cost involved and this comes with cost-related decisions, as for example the internal transportation of containers. These cost-driven decisions are left out of scope. The berth plan can furthermore be influenced by different factors outside of the barge planner's responsibility. These factors are related to organizational policies and agreements with customers (i.e., the terminal operators strategy); however, these decisions are out of scope as well.

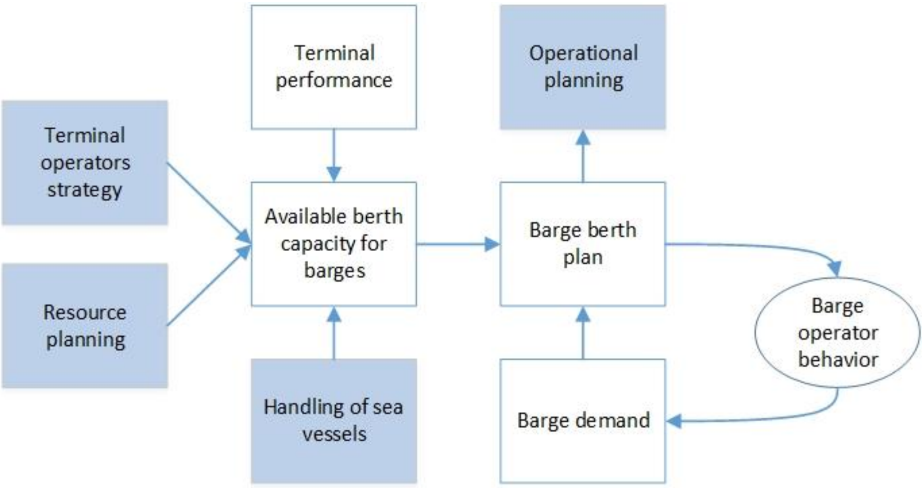

Figure 6: Abstract overview of the barge handling process and the thesis' scope (i.e., blue-colored rectangles means out-of-scope)

The operational management of barge handling at the terminal is enclosed in a complex process. That is in particular due to the fact that the barge planning has a low priority in the berth schedule of a terminal in comparison with the more capacity-demanding feeder and deep-sea vessels; therefore, a flexible capacity allocation strategy for barges is a complex research as well. Mostly, barges get capacity allocated based on the demand of feeders and deep-sea vessels and thus allocating capacity for barges based on their required capacity is not realistic. Because of this complexity, the long- and short-term capacity allocation problems are divided and in this research the focus is on the long-term capacity planning. The research focus is the long-term berth capacity allocation in barge planning, as the short-term capacity and demand fluctuations will not be studied.

In addition to the discussed scoping decisions, model assumptions were made regarding resources, terminal specific operations and the behavior of the barge operators and these are further specified in Chapter 5.

2.3. Thesis Structure

The remainder of this thesis is structured in five chapters. In Chapter 3, the current planning process is analyzed using root-cause analysis which is based on in-company data and interviews with barge operators. Chapter 4 consists of the barge handling redesign, of which a clustering is the basis. After that, in Chapter 5 the simulation model is discussed and validated and in Chapter 6 the hypotheses are tested and results are presented. In Chapter 7 the research conclusion is provided.

3. Problem Analysis

In this chapter, we describe the analysis of the barge alignment problem using root-cause analysis. First, in Section 3.1 we qualitatively analyze the problem using a fishbone diagram based on a series of interviews with barge operators. Second, we evaluate the current operational performance and analyze in-company data regarding the underlying causes of the research problem in Section 3.2. These analysis steps are found to be functional tools to analyze the root cause of a problem (Yuniarto, 2012).

3.1. Qualitative Analysis

A fishbone diagram describes potential root causes in a cross-functional setting (Yuniarto, 2012). In this case, the appointment making process between the terminal and barge operators can be seen as a cross-functional setting. Normally, the causes are found using brainstorm-sessions with involved actors. However, in this context with frustration and distrust between the actors (as mentioned in Section 2.1), face-to-face semi-structured interviews were conducted with five barge operators. From the perspective of the terminal operator potential causes were analyzed based on observations of barge planners. These both techniques were executed following the guidelines of qualitative research as keynoted by Van Aken (2007).

Barge operators can differ in terms of routings, covering distances and barge destinations. Therefore, five diverse barge operators were selected purposively in order to receive information that represents the barging market. The purpose of the interviews was to find the underlying causes of the typical strategic behavior of the barge operators, which is one of the main causes of the unreliable berth plan.

The input received from the barge operators together with the in-company observations are mapped in a cause and effect diagram and can be found in Appendix A. Note that this diagram is made specific and is focused on the alignment problem; therefore, not all terminal and port related factors were taking into account. This diagram forms the basis of the fishbone diagram, which is based on the most probable underlying causes and can be found in Appendix B. In the fishbone diagram, four main causes are presented which lead to the unreliable barge planning at the terminal. The most important findings are:

- *Infeasibility of barge trips:* Barge operators seek to maximize their volume throughput per day at the lowest possible costs. However, the barge operators needs to take into account several restrictions and factors while scheduling barge trips. The found influential factors are:
  - The current location of barge ships;
  - The capacity of the barges and the weight positions of containers;
  - Sailing times between terminals and other destinations;
  - Minimum call sizes at deep-sea terminals (e.g., a minimum call size of 10 TEU);
  - Availability of containers at the terminals (e.g., arrivals of sea vessels and terminal operations);
  - Pick-up and delivery time restrictions set by terminal operators;
  - Fixed appointment with deep-sea terminals (i.e., not all terminals allow cancellations and changes in announcements without consequences);
  - Delivery deadline of the end-customer;
  - Uncertain hinterland destination (e.g., late warehouse location decision by end-customer);
  - Demurrage and detention deadlines for the rent of containers (Fazi, 2014);
  - Uncertainty in terminal handling, sailing and due to other disturbances (e.g., weather conditions).

All these factors together cause a highly uncertain planning of a barge trip. Especially external factors, such as the terminal performance has uncertainty involved and might result in the infeasibility of an appointment. Furthermore, this uncertainty can be seen as the underlying cause of the strategic behavior, as the barge operators has to make appointments with terminal operators in a highly uncertain environment.

- *Pressure on the appointment between the terminal and barge operator:* An appointment at the terminal is triggered by the end-customer who orders the transportation. Here, the delivery deadline for the end-customers plays a huge role and because of disturbances in the whole chain, pressure is put on the barge transport. Also, the barge operators compete with each other to reserve capacity at the berth, especially in times of high waiting times.
- *Mismatch between information availability and time of announcement:* From the perspective of the terminal operator, the announcement information (i.e., the PTA and call size) needs to be reliable. However, because of the highly fluctuating environment of barge transportation, the announcement information changes over time. At ECT, a fixed deadline is ensured to announce a barge arrival, while for (a part of) the barge operators a later deadline is required to make an appointment based on more reliable information. Because of the fact that all barges have the same deadline, currently, the barge operator speculates in the appointment making process, as not all information is available to make a feasible barge trip.

Through a series of interviews, we found multiple underlying factors that cause the unreliability in the appointment making process. From the perspective of the barge operator, there is a strong possibility that the strategic appointment making behavior arises due to the uncertainty in the appointment making process as well as the limited insight in the terminal barge capacity, terminal disturbances and arrivals of sea vessels. At the moment of a new announcement, there is still information missing what in the end results in change requests or cancellations. Moreover, we concluded that announcements all have unique specifications (e.g., specific time pressure, origin, end-customer and call size) and therefore all have a specific reliability profile. This understanding supports the earlier mentioned call for service differentiation. Therefore, the hypothesis that announcements all have a specific reliability profile is analyzed in the next section.

3.2. Root-cause Data Analysis

In this section we analyze the problem context and evaluate the defined hypothesis that all announcements have a unique reliability profile. We collected data by using MySQL, which allowed the construction of data sets using the company data warehouse. The data used are related to the years 2014 and 2015, as these years can be seen as regular operational years. The obtained raw data was corrected by removing outliers and data points with missing relevant information. Unfortunately, no information was available related to the change requests.

3.2.1. Problem Context

Barge Demand

Barge demand depends on the number of barge arrivals per time unit as well as on the average call size of these arrivals. Both these characteristics are the main factors in the barge handling process as it depicts the utilization of the system: the more barges arrive on a day and the higher the average call size, the more capacity is required and the longer the berth is occupied. However, note that the real utilization of the system is influenced by the number of cancelled barges, as the number of announcements differ from the number of barges handled.

The call size (in TEU) can be approximated by a gamma distribution (as the call size is non-negative and positively skewed) with $\alpha = \frac{\mu^2}{\sigma^2}$ and $\beta = \frac{\sigma^2}{\mu}$, as these general estimation formulas for the parameters fit the distribution of the historical data of the cancellations. In order to determine the real arrival rate, the arrival rate of handled barges is corrected by adding a number of arrivals which represent (future) cancellations.

Note that the call size can fluctuate significantly throughout the year as depicted in Figure 7. Hence, there is a high variability involved with call sizes as the coefficient of variation is 0,78. The fluctuation of call sizes impacts the berth planning processes in case of a more or less constant arrival rate, as the higher the call sizes the more barge capacity is required. This relation can be found by combining Figure 7 and Figure 8, as for example the high demand of December 2015 was caused by a tremendously growth in the number of arrivals while the call size slightly dropped.

Figure 8 on the next page shows that there is little fluctuation in the total demand in TEU. However, the monthly demand can differ within and between years, as can be seen by the demand difference between 2014 and 2015. Furthermore, the barge handling process needs to deal with up- and downturns in terms of demand as shown by the peaks in the graph of Figure 8. However, the variability in demand over time in 2015 was low as the coefficient of variations were 0,18 and 0,14 for respectively the monthly and weekly demand in TEU. Thus, the required barge capacity is fairly constant in the long-run.

We also note that the demand in the period between May and August of 2014 was low in comparison with all other months in 2014 and 2015, as depicted in Figure 8. This finding is interesting as the average waiting time in this period was significantly higher than usual, as mentioned in Chapter 1. Thus, the service towards the barge operators was at the lowest point in two years during the period with the lowest demand. This may be explained by either a low terminal performance (i.e., berth production) or significantly low allocated barge capacity. These both terminal disturbances are further specified in the later of this section.

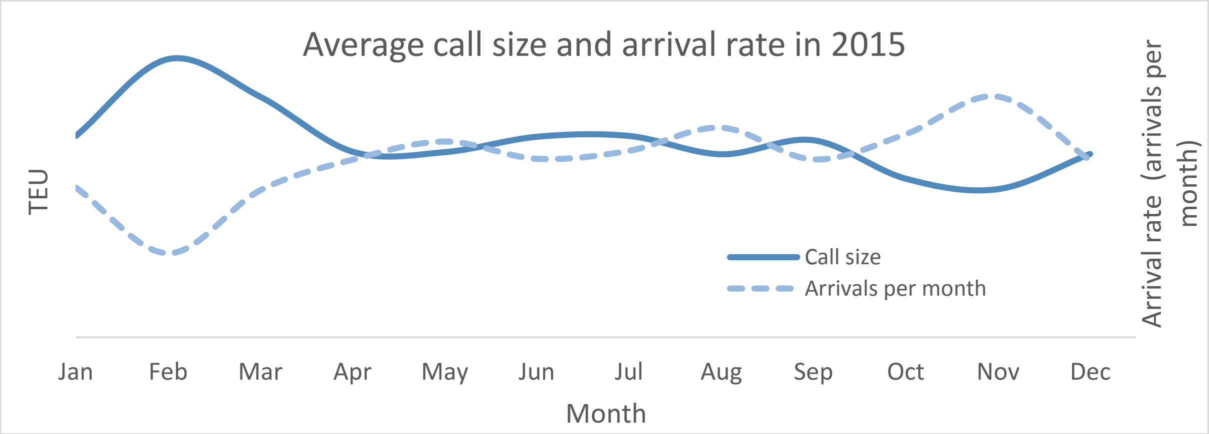

Figure 7: Average call size and number of arrivals in 2015 depicted per month (note that the axis values are not shown for confidentiality reasons)

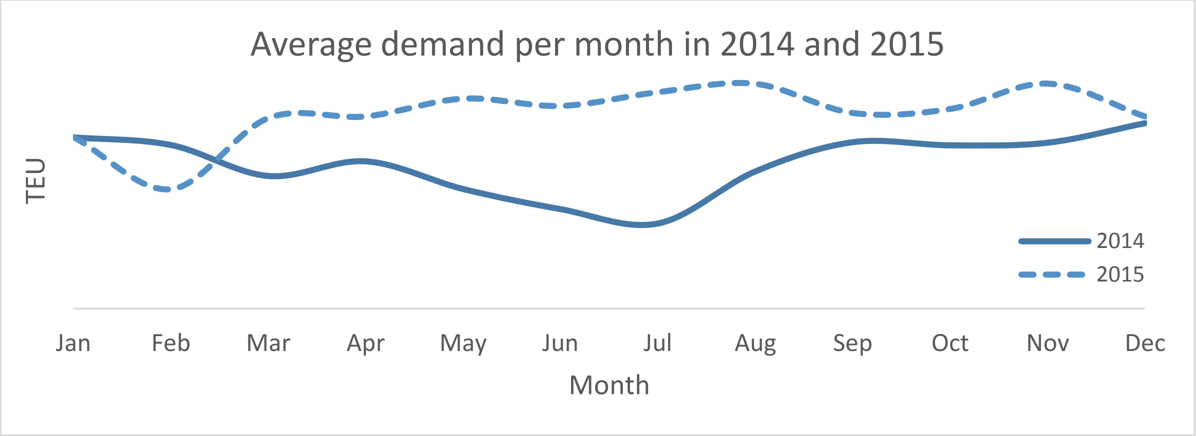

Figure 8: Average demand in 2014 and 2015 depicted per month (note that the axis values are not shown for confidentiality reasons)

Cancellations

As presented in Chapter 1, the overall cancellation percentage is minimal 5,8%, which is equal to 3.859 cancelled appointments in 2014 and 2015 together. From the barge planners perspective, the more cancellations the higher the workload due to re-plan decisions and communication involved. Furthermore, the closer the time of cancellation prior to the ETA of the appointment, the more difficult and time-consuming the re-planning of the berth plan. In the current barge planning design, the average cancellation time prior to ETA was 29,01 hours with a standard deviation of 23,89 hours. The cancellation time prior to the ETA can be approximated by a (positively skewed) gamma distribution. Moreover, apart from this characteristics, more essential are the cancellations communicated within eight hours prior to the ETA of the barge. These cancellations might possibly cause berth re-plan problems and thus have a higher probability of resource idleness involved. In the remainder, these cancellations are defined as ‘last-minute cancellations’.

Figure 9 shows the last-minute cancellations as well as cancellations communicated between the 8 and 16, 16 and 24, and more than 24 hours. In 2014 and 2015 together, 635 cancellations were communicated within the eight-hour range. This is equal to approximately 15,5% of the total number of cancellations; approximately one cancellation per day might possibly cause idleness of terminal resources. Note that cancellations communicated earlier than eight hours prior to the ETA also can cause idleness, though the barge planners have more time to reschedule the berth plan.

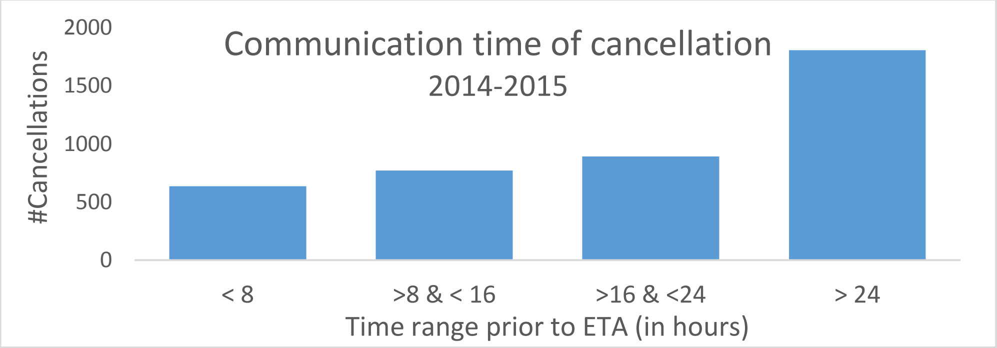

Figure 9: Number of cancellations in 2014-2015 specified per time range (in hours)

As said before, barge handling is complex and the changing behaviour of barge operator makes it even more difficult. As demonstrated in Figure 10, there is a high variance in the number of cancellations per month, which makes it hard to predict and even harder to act on. Furthermore, in Figure 10 the average waiting time per month is depicted and this shows that it is plausibly be concluded that there is a relation between the number of cancellations and the waiting times of barges. Obviously, in periods with longer waiting times the appointments are on average for a longer time period in the berth plan. This understanding supports the found relationship, since the number of cancellations increases if the waiting time increases. This could be explained by the earlier mentioned reneging phenomenon as barge operators pursue the shortest waiting time possible. In times of insufficient barge capacity, the barge operators behaviour is more strategic and less reliable. At the end, this behaviour result in an unreliable berth plan.

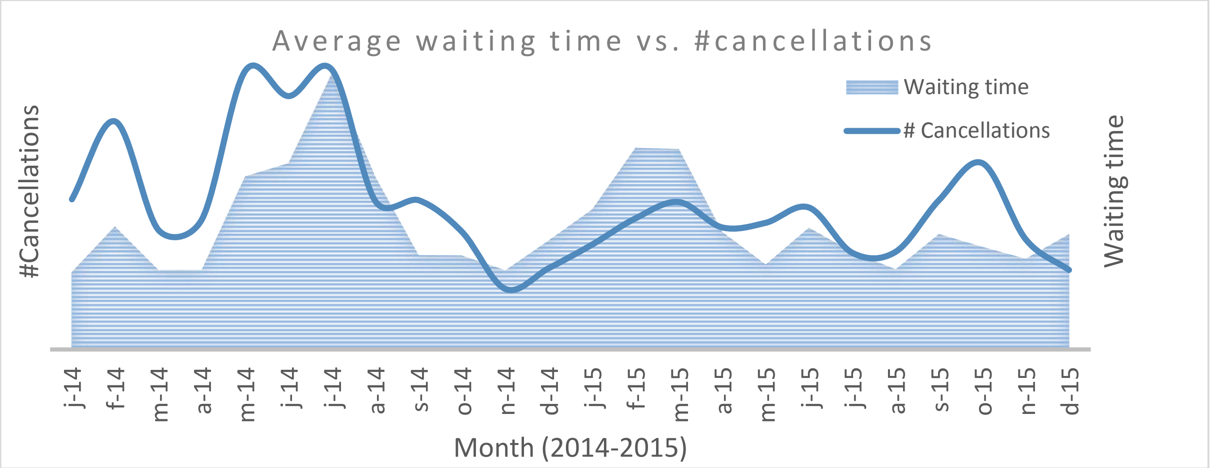

Figure 10: Number of cancellations and average waiting time in 2014-2015 specified per month (note that the axis values are not shown for confidentiality reasons)

Change Requests

A change request of an appointment is communicated by the barge operator and consists among others of a new arrival time for the specific barge. As mentioned earlier, change requests impact the berth plan as re-planning is required. Unfortunately, no data was available concerning the change requests, while these requests are important measures of the behavior of the barge operator. Therefore, the occurrence of change requests is estimated based on expertise and the cancellation data. Hence, both cancellations and change requests are subjected to the same influences. Therefore, in this research it is assumed that change requests follow the same ‘prior to ETA’ time distribution as cancellations. However, based on experience, the probability of the occurrence of a change request is assumed to be twice as high as the occurrence of a cancellation. Thus, it is assumed that the change request percentage is 11,6%.

3.2.1.2. Terminal Performance

As stated in the previous section, the terminal performance is based on both the berth production and the allocated barge capacity. A low terminal performance influences the service towards barge operators; longer processing times or little barge capacity available reduces the berth throughput and increases the waiting times. The barge berth plan is influenced by the performance of the terminal, as the berth plan is based on the average berth production rate. This rate is defined as the number of TEU handled per hour per crane. The berth production rate can be determined based on historical data regarding the handling time of the barges, as the call size and start and end time of handling all barges are known. However, this is including delays and thus is adjusted based on the estimated downtime (per hour) of a crane. Obviously, this berth production is an average and may be influenced by either crane failures or barge capacity issues.

Crane Failures

A crane failure may occur due to system errors, equipment failures or human mistakes. The number of failures and the repair time per failure are known for the years 2014 and 2015. However, no information was available about the average mean time between failures, and therefore in the remainder it is assumed that the disturbance is known at the start time of handling the specific barge. The probability that a disturbance occurs is determined based on the number of historical failures and is found to be 0,3197. The concrete impact on the berth plan is that the processing time of the barge increases. Therefore, each barge specific disturbance had extra handling time (i.e., repair time) involved. In the end, the daily average crane downtime results in a lower real barge capacity. The repair times of all crane failures are known and are depicted in Figure 11. The time to repair can be approximated by a negative exponential distribution.

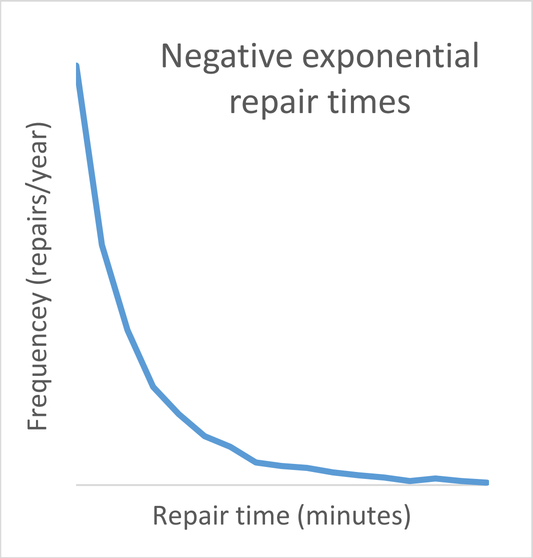

Figure 11: Repair time distribution line (note that the axis values are not shown for confidentiality reasons)

Barge Capacity Reduction

The barge capacity allocation decision is influenced by the sea vessel demand; the barge demand barely influences this decision due to the fact that barges have the lowest priority. As mentioned before, from the perspective of the barge handling, the reduction of barge capacity can be seen as a terminal disturbance. Therefore, we analyzed data concerning the handling of sea vessels, as the delays associated with the handling of these vessels have impact on the barge capacity. Here, only failures with a repair time of more than 15 minutes were included, as small disturbances in the handling of sea vessels do not impact the barge capacity. These repair times can as well be approximated by a negative exponential distribution, here with a probability of a barge capacity reduction of 0,3782 per berth per day.

3.2.2. Reliability Profiles

As it is not practical and useful to assess every announcement individually, here we analyze the reliability on barge and barge operator level. This means comparing barge operators on their reliability profile as well as comparing barges which were handled at ECT. Logically, the reliability profiles are based on both the cancellations and change requests communicated by the barge operator or related barge; however, it was not possible to retrieve in-company data related to change requests. The reliability profiles are based on two variables related to cancellations, namely:

1. The percentage of cancellations of the total number of announcements.
2. The average communication time of a cancellation prior to the ETA, measured in hours.

Note that both variables are mandatory to obtain a complete representation of the reliability of a barge or barge operator. Reasoning based on the value of variable 1 may be fallacious, as for example the cancellation percentage can be very high while all cancellations were, on average, communicated a few days prior to ETA.

Barge Operator Level

In 2014 and 2015 together, ECT served 42 barge operators and, on average, the total volume of the cancelled announcements was 10.147 TEU per year. Though, there is quite some variance in terms of reliability between the barge operators.

The scatter plot in Figure 12 shows the values of the two defined reliability variables per barge operator. Note that there were five barge operators who cancelled none of their barge appointments in the years 2014 and 2015; these barge operators are depicted as the (big) red dot. As can be seen in the plot, there is a moderate relation between the percentage of cancellations per barge operator and the average time the cancellation is communicated; the higher the percentage of cancellations, the slightly later the cancellations are communicated. However, the two barge operators with the highest cancellation percentage (i.e., the two most right dots in the scatter plot) do not support this relation. Beside of these two outliers, it may be concluded that the relationship is probable and therefore we argued that there is difference in reliability between barge operators.

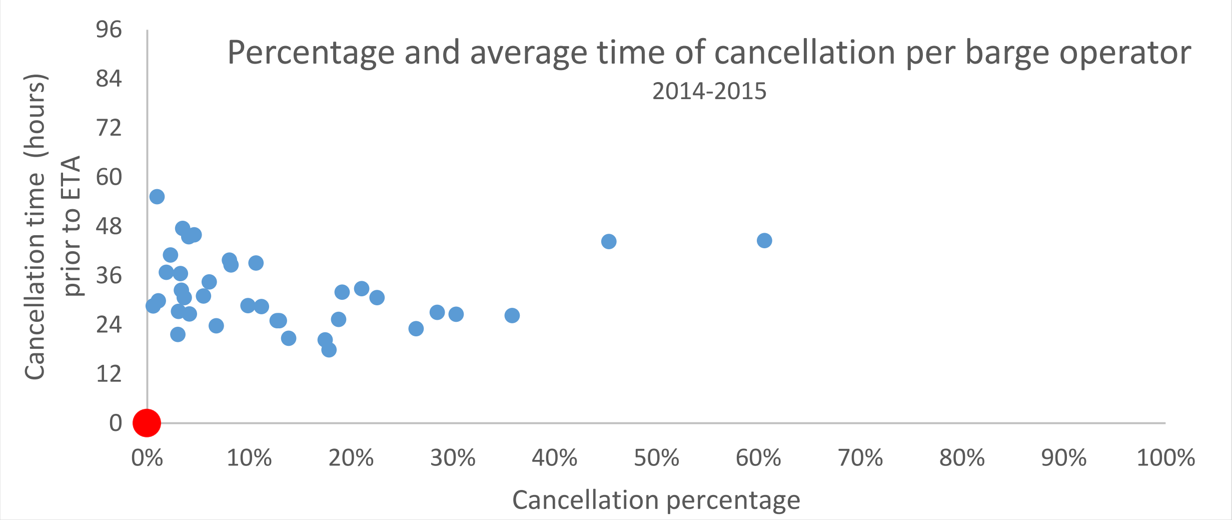

Figure 12: Average time of cancellations prior to ETA and average cancellation percentage per barge operator in 2014-2015

Barge Level

In the previous section, it is showed that there is a clear separation in reliability on barge operator level. However, due to the afore mentioned specific characteristics per announcement and the fact that barge operators operate different barges, it is possible that there is a higher variance in reliability between barges in comparison to barge operators. In total, 593 barges were served and thereof 273 barges did not cancelled an appointment in 2014 and 2015.

In Figure 13 a similar graph as with the barge operators can be found in order to compare the reliability profiles of both levels. Note that the twelve dots at the right-hand side of the graph cancelled all their appointments and thus were not handled at ECT in 2014 and 2015. As can be seen, the dispersion of values is higher as well there is more variance between the barges, compared to the barge operators reliability profile values. Especially the cancellation percentage shows considerably more variance per barge than per barge operator. Thus, we argued that the barges significantly differ in terms of reliability and that there is more variability on barge level in comparison with the barge operator level.

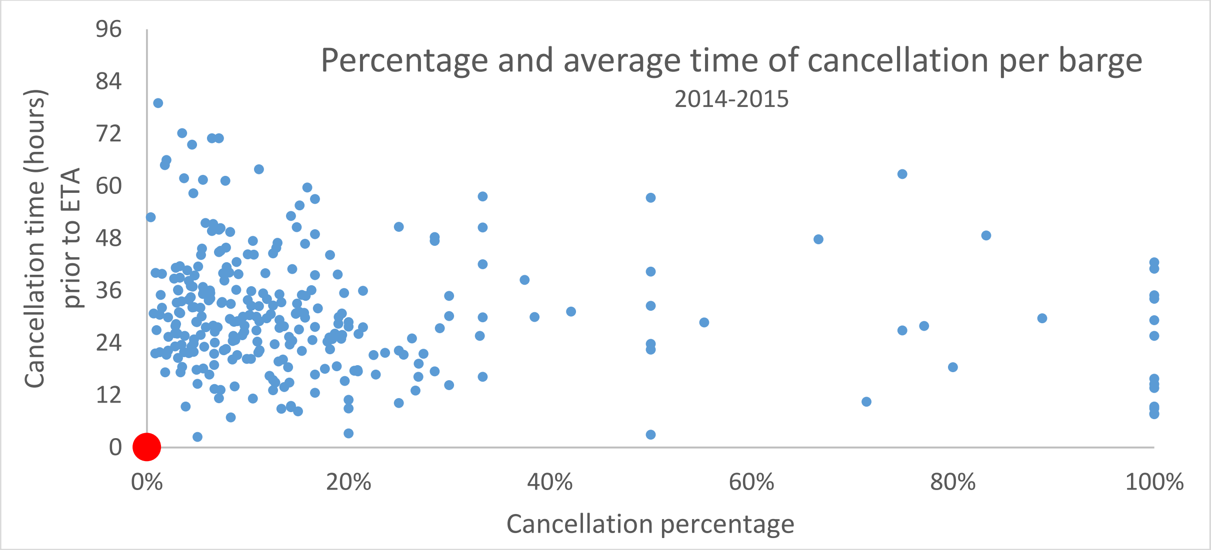

Figure 13: Average time of cancellations prior to ETA and average cancellation percentage per barge in 2014-2015

3.3. Conclusion

What is the root cause of the research problem?

The hypothesis formed in the qualitative analysis of Section 3.1 was validated in Section 3.2. We showed the variation in reliability per barge operator and per barge. Based on both qualitative and quantitative analysis, we argued that appointments significantly differ in terms of reliability, since some appointments are less reliable if a particular barge or barge operator is involved. Currently, the barge handling process does not take into account these reliability differences and therefore we concluded that the service differentiation may improve the barge handling at ECT.

Thus, the underlying cause of the research problem is that ECT does not handle barges based on their specific characteristics and reliability, and therefore does not take the strategic behavior of the barge operators into account in the appointment making process. There is more deviation in reliability on barge level in comparison with the barge operator level. In order to address issues regarding the berth reliability, we argued that differentiation between barges may solve the stated problems. In Chapter 4, the barge planning redesign is presented.

4. Redesign

In this chapter, we discuss the redesign of the barge handling process. In Section 4.1, we keynote the components of the proposed strategy and in Section 4.2 we discuss the methodology and results of the involved cluster analysis. Then, we argue for the redesign of different components of the barge handling process. Furthermore in this chapter the hypotheses are outlined and performance is defined.

4.1. Cluster-Based Planning Strategy

In this section, the service differentiation approach is translated into an operational concept, which is defined as the 'cluster-based planning strategy'. Concrete, this approach clusters barges in groups based on reliability profiles in order to implement a more specific handling of barges. The dispersion comes with a redesign of the current process, as each group of barges need terminal capacity and a specific planning horizon. From the perspective of the terminal operator, the hypothesis is that the reliability of appointments increases, and therefore the berth plan reliability increases and the workload of the barge planner decreases. This expectation is based on previous findings, as for example the found issues regarding the information availability of barge operators. In case of a shorter planning horizon (i.e., a later announcement deadline), barge transport with highly uncertain order information have more time to collect their transportation orders. Furthermore, this strategy comes with consequences for barge operators in case of unreliable behavior, as less reliable operators receive a lower service level. Note that, in the port, other terminal operators accomplish this by introducing penalty costs. In addition to this effect, this strategy divides the planning of barges and provides ECT therefore with the opportunity to vary the service levels towards barge operators. This contributes to the expectation of improved barge operator behavior as the barge operators pursue the best service possible. Furthermore, both the terminal and the barge operators are in for more collaboration, as indicated in the interviews.

As mentioned, this division of barges in groups result in a separated barge planning, since the groups have their own announcement deadline and are thus planned at separated time points. This further means that ECT has to anticipate on the capacity allocation for barges, in order to deal with the possible spreading in service levels between clusters. This comes with decisions which are related to the integration of the redesign in the current process, and can be divided into the following three design decisions:

1. Clustering decision (Section 4.2):
    - The number of clusters;
    - The assignment of barges to groups.
2. Planning horizon decision (Section 4.3):
    - The (new) planning horizon per group.
3. Resource decision (Section 4.4):
    - The allocation of (reserved) berth capacity to groups.

4.2. Cluster Analysis

Clustering is the task of grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups. In this section, we argue for the number of clusters and the assignment of barges to these clusters.

Cluster analysis is a familiar procedure in statistics and therefore widely elaborated in literature. Here, the cluster analysis is based on guidelines presented by Mooi and Sarstedt (2011). As stated in this market research handbook, one of the most important clustering characteristics is that the clustering variables provide a clear-cut differentiation between groups. Therefore, it is important to consider the level of clustering. As seen before, a typical barge operator operates different services and serves multiple customers. This leads to highly differentiated behavior and best comes forward at the barge level (Section 3.2).

The current planning strategy only differentiates barges based on call sizes. Here, the purpose is to increase the berth plan reliability by using barge clusters and thus the variables have to represent the barge reliability profiles. There is no available data of change requests and thus the clustering was performed based on the available cancellation data. Here, the variables related to cancellations and presented in Chapter 3 are used as the clustering variables. Different from the reliability profile analysis in section 3.2.2, here only the data regarding the cancellations of 2015 is used, as in the simulation study the model reproduces the year 2015.

There are different approaches and methods that can be used to determine the clusters. Hence, a combination of both the hierarchical and the k-means cluster procedure is used (Mooi & Sarstedt, 2011). The hierarchical procedure seeks for the number of clusters and the k-means procedure assigns barges to these clusters. In total, 428 barges had at least one appointment at ECT in 2015. There were twelve barges which were not handled as they had a cancellation percentage of 100% and are thus identified as outliers. The value of the two clustering variables were determined per barge and based on that, the clustering analysis is performed using the software package SPSS Statistics 23. The number of clusters is determined based on the Euclidean distances, i.e. the square root of the sum of the squared differences in the variables' values. A scree plot has been made based on the distances for all the number of cases (N=428) and the graph is plotted below. As can be seen, after case 425 the distinctive break occurs (i.e., the "elbow", made red in the graph) and thus we argued that the number of clusters is 3 (428 minus 425). Normally, the number of clusters can be validated using the variance ratio criterion; however, in this case it cannot be used as it is not possible to test for two clusters (Mooi & Sarstedt, 2011).

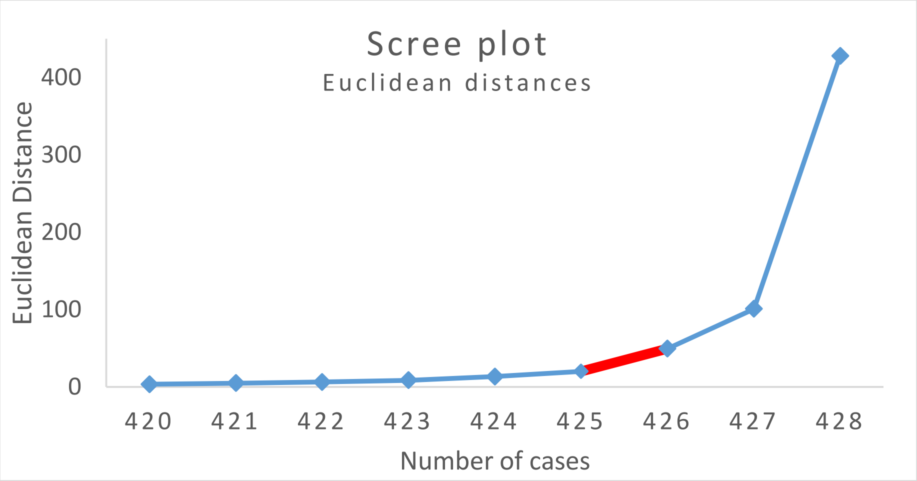

Figure 14: Scree plot of the Euclidean distances of the variables' values (N=428)

Ward's method was used as the clustering algorithm, as this is the preferred method according to Mooi and Sarstedt (2011) in situations of rather equal sized clusters in which the within-cluster variance must be minimized. This method merges barges if the merger minimizes the increase in overall within-cluster variance in comparison with the other two clusters. Note that the other clustering algorithms, as for example the centroid and average-linkage methods, showed roughly the same clustering.

4.2.1. Group Characteristics

Figure 15 graphically shows the clustering result in a scatter plot; note that the three colors each represent a cluster. The big blue rectangle on the bottom left side of Figure 15 represents the 243 barges with zero cancellations, and therefore have no variable values and are clustered in group X.

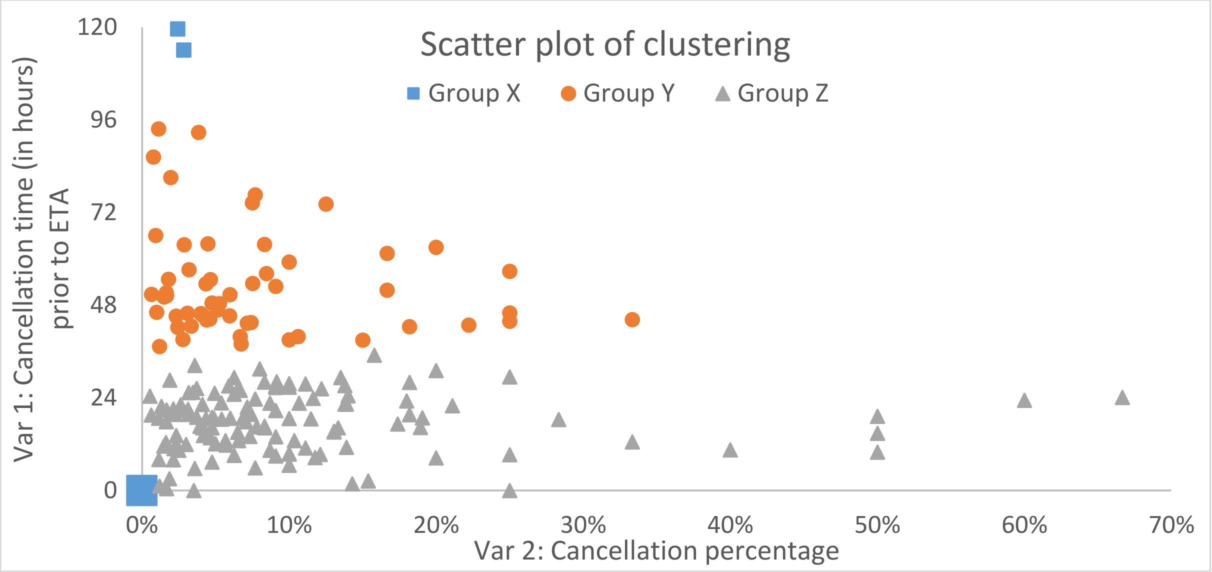

Figure 15: Scatter plot of clustering with barge memberships per group

All barges are assigned to a cluster and with this knowledge, the cluster characteristics can be determined and are depicted in the Table 2 (note that some characteristics are not presented due to confidentiality reasons). As can be seen, group X has the most 'members' and has the lowest cancellation percentage, as well as the highest average cancellation time prior to ETA. However, the total share in volume is low in comparison with the other two groups; this is explained due to the low arrival rate per barge. Group Z has the highest share in volume, the highest cancellation percentage per announcement and the lowest cancellation time prior to ETA. Furthermore, Group Y has the highest average call size.

Table 2: Output of the cluster analysis in terms of cluster characteristics

Group	#Barges	Arrivals per day*	Share of total volume (%)	Cancellation Percentage (%)	Average cancellation time prior to ETA (hours)
X	245	5,1	24,6	0,2	95,5
Y	55	4,5	32,1	4,6	48,4
Z	128	10,4	43,3	6,6	19,4

Based on the volume distribution that was the result of the clustering and the total daily volume of 2015, the average daily demand per group can be determined. The share in the total volume in 2015 per group depends on the number of visits of the barges assigned to every group: the higher the call size and the number of arrivals per day, the higher the total share in volume*. The arrival rate showed in Table 2 are adjusted based on the cancellation percentage, as explained in Chapter 3. Based on the above figures, it can be calculated that group X is responsible for approximately 1 %, group Y for 23% and group Z for 75% of all cancellations, while group three consists of 30% of all barges.

In the redesign, the groups are handled separately and thus have their own distributions related to call sizes, arrival rate and behavior characteristics (i.e., for the cancellations and change requests). The cancellation time prior to the ETA can, per group, be approximated by a (positively skewed) gamma distribution. The distribution of the cancellation times can be graphed per group, as for example can be seen for group 3 in Figure 17. The call size is as well approximated by a gamma distribution, as depicted in Figure 16.

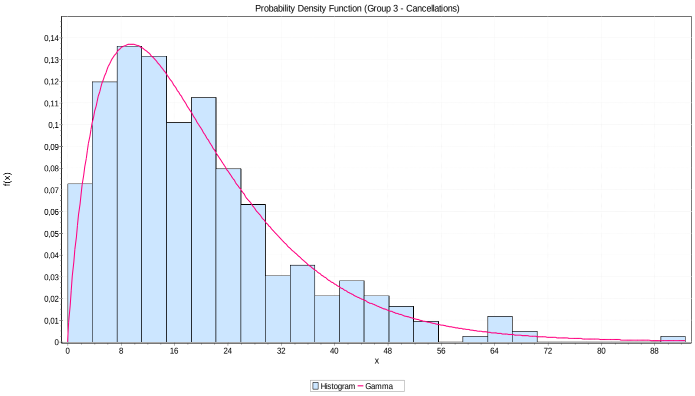

Figure 17: Cancellation time prior to ETA gamma distribution fit for group 3

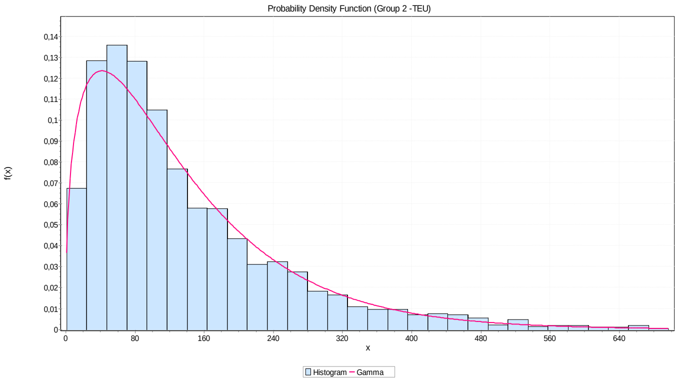

Figure 16: Call size gamma distribution fit for group 3

As stated in Chapter 3, the change request percentage is assumed to be twice as high as the number cancellation percentage and the time prior to ETA follows the same distribution as that of the cancellations. Thus, the change request characteristics per group as presented in Table 3 are used in the remainder of this research.

Table 3: Change requests group characteristics

Group	**Change request %**	**Time prior to ETA (hours)**	
		Avg.	S.d.
X	0,4	95,5	15,6
Y	9,2	48,4	21,3
Z	13,2	19,4	14,3

4.3. Planning Horizon

As explained, the planning horizon of the barge planner needs to be customized for each barge cluster. Shorten the planning horizon for barge members of cluster Z is profitable for both the terminal and the barge operator. The terminal operator benefits as the unreliable appointments will be in the berth plan for a shorter time period, which decreases the possibility of cancellations and change request. From the barge operators perspective, the barges with distinctly different reliability profiles are divided, which reduces the competition. Furthermore, the barge operators have less pressure on the appointment with ECT, as there is more time to gather the essential order information for the barge transport. Obviously, for barges clustered in group X there is no need to shorten the planning horizon, since appointments with these barges are reliable. Briefly said, the higher the uncertainty of the barges per cluster, the shorter the planning horizon for that cluster. Based on the characteristics of the groups, the following planning horizon adjustments are desired:

Group X: Retain current horizon or extend
Group Y: Retain current horizon or shorten
Group Z: Shorten the horizon

However, some aspects need to be considered before deciding on the new planning horizons:

1. Market restrictions:
    - In contrast to ECT, most barge operators have restricted opening hours. This means that there is a workable minimum in terms of planning horizon, as an announcement deadline in the middle of the night is impossible for most barge operators.
2. Operational restrictions:
    - At ECT, there is a daily cycle of three eight-hour shifts for the barge planners and currently, the planning horizon is 24 hours. The renewed planning horizons need to be synchronized with each other, since there need to be clear and workable daily planning moments. This means that the planning horizons need to be a multiplier of each other and have clear standard planning moments per shift which do not change throughout time.
    - Before the actual arrival of a barge, ECT needs approximately a minimum of 6 hours to prepare the barge handling. For example, time is necessary for custom documentation, operations planning and gate administration.

Based on the desired planning horizons and the above restrictions, two design (PH-1 and PH-2) are considered in this thesis and are provided in Table 4. These both designs differ as PH-1 is a more spread design and PH-2 is a denser and shorter planning design. For example, in the PH-1 scenario every 48 hour the announcements of group X are planned, while in the PH-2 scenario the announcements are planned every 24 hour.

Table 4: Planning horizon redesigns PH-1 and PH-2, in which per group the planning horizon is given in hours.

Scenario	Group	Planning horizon (hours)
PH-1	X	48
	Y	24
	Z	12
PH-2	X	24
	Y	12
	Z	6

In the current situation, the announcement deadline is secured for every 24 hours and applies for all barge announcements. On a fixed time per day, all announcements with a PTA within the time range of the next 24 and 48 hours (i.e., the planning horizon) are taken into account in the berth plan.

Figure 18 shows an overview of the PH-1 scenario. As can be seen, the planning horizons differ between the cluster groups; the planning horizon of group 1 (48 hours) ensures less planning moments and more appointments per berth plan for that particular group. The planning process for group 2 (24 hours) does not differ from the current situation; however, the available capacity is reduced as group 1 was planned earlier. The same situation counts for group 3 (12 hours), as group 1 and 2 are planned earlier.

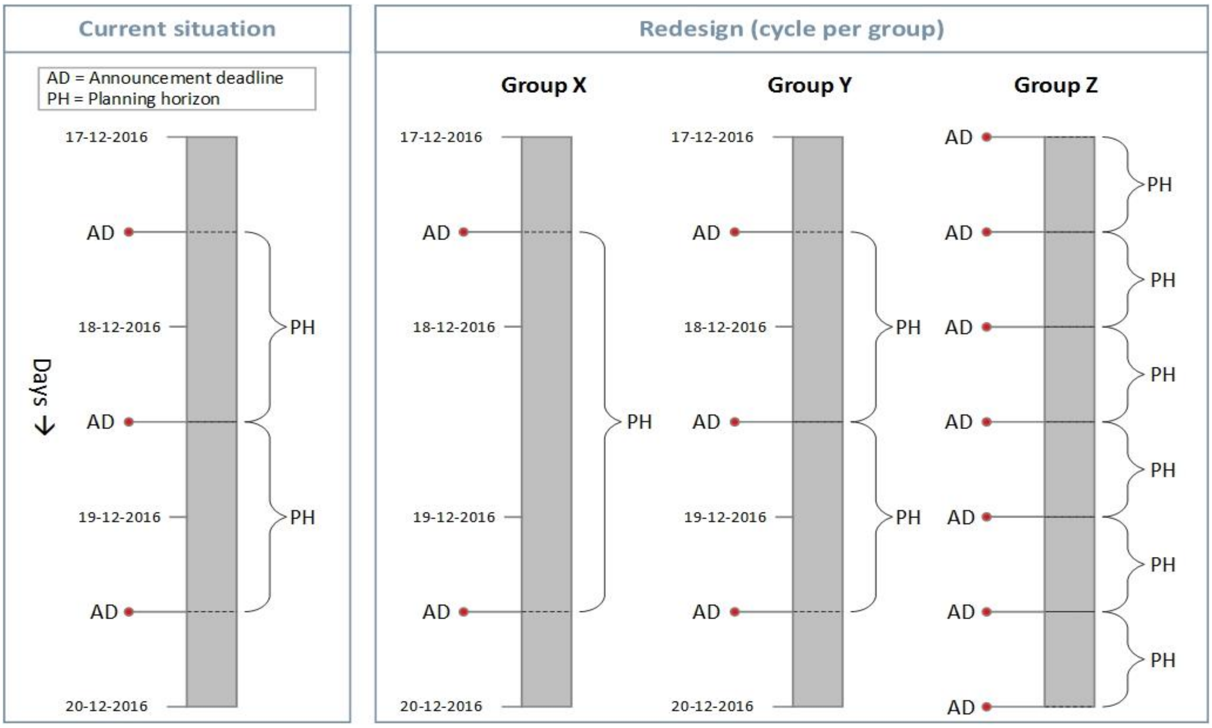

Figure 18: Overview of the redesign with per group the announcement deadlines (AD) and planning horizons (PH)

4.4. Resource Allocation

As explained earlier in this chapter, varying planning horizons for groups comes with a redesign of the allocation of berth capacity. This is due to the fact that all barges are handled at the same berths and in the current situation, were planned at the same moment in time. However, introducing different planning horizons brings forth that announcements from a group with a longer planning horizon are planned first and therefore can 'reserve' berth capacity. This means that those announcements are served with a higher service, especially in times of capacity shortage. In order to analyze the impact on the service level per group, we analyzed different berth capacity allocation strategies.

A more detailed description of the barge capacity is given in Chapter 5, however it is known that the current barge capacity consists of three available berths of which one berth is partly available. Introducing rules for allocating capacity to different barge groups has not been researched in previous literature; therefore, we introduced three different types of strategies that can be separated:

1. *Fixed cluster capacity:* there is a fixed barge capacity reserved per cluster;
2. *Free cluster capacity:* there is no capacity reserved and all capacity can be used by all clusters;
3. *Flexible cluster capacity:* a part of the barge capacity is reserved, while the other capacity can be used by all clusters;

Allocation rules need to specify what part of the barge capacity can be used by announcements of group 1 and 2. Note that group 3 is planned as last and thus no capacity allocation restrictions are needed. Based on the three types of allocation strategies, we considered six different allocation rules:

1. Fixed cluster capacity:
   - A. *Strict allocation*: there is a fixed and specific barge capacity reserved per cluster. In other words, all three clusters have their 'own' capacity available determined based on the cluster's demand share;
   - B. *Low-strict allocation:* variant of rule A as there is added 10% of extra available capacity. Note that capacity is overlapping;
   - C. *High-strict allocation:* variant of rule A as there is added 25% of extra available capacity;
2. Free cluster capacity:
   - D. *Free capacity allocation*
3. Flexible cluster capacity:
   - E. *Low-reserved allocation:* variant of rule D, as 10% of the total allocated capacity for group Z is not available for the other groups, and 10% of the total capacity for group Y is not available for group X;
   - F. *High-reserved allocation:* variant of rule D, as 25% of the total capacity for group Z is not available for the other groups, and 25% of the total capacity for group Y is not available for group X.

Based on the average daily demand per cluster and the barge capacity setting, the fixed daily capacity plan can be constructed. This is done in Chapter 6, as first the barge capacity needs to be determined. At the end of that chapter, the allocation strategies are tested and we selected the best performing rules per allocation strategy as design scenarios for the simulation study.

4.5. Simulation Study

This research is comparable with the studies of Douma (2009) and Douma, Schuur and Jagerman (2011) as in these studies the behavior of the terminal operator is studied in a likewise context as in this research. In both studies, the proposed approaches were examined in experiments modeled with discrete-event simulations. For this reason, this thesis studies the proposed strategy with the help of a discrete-event simulation. The strategy is chosen to overcome the appointment reliability, and therefore the "communication" between the terminal and barge operators needs to be included in the simulation. The simulation design is discussed in detail in the next chapter, however in the remainder of this chapter the simulation context is elaborated. As the cluster strategy is assumed to come with a behavioral improvement of the barge operators, this needs to be addressed in the simulation model. Furthermore, the precision of the clustering needs to be included in this study as well. At the end of this section, the hypotheses are stated.

4.5.1. Degree of Behavioral Improvement

The introduction of the cluster-based planning strategy expects to positively influence the behavior of the barge operator. With improved behavior we mean the reliability improvement of the appointments, as the percentage of cancellations and change requests decreases. This research does not predict the behavioral change of the barge operators, nonetheless it would be interesting to analyze this with for example game theory. From an implementation perspective, it is interesting to test to what extent improved behavior would positively influence the performance of the redesign, and thus the barge handling process. To do so, we introduce the concept of 'degree of behavioral improvement', which is based on the research of Douma (2011) in which the degree of terminal cooperativeness was evaluated. Here, we consider three degrees of behavioral improvement:

I. No behavioral improvement (BI-1): the announcement reliability does not change;
II. Low behavioral improvement (BI-2): the announcement reliability improves with 25%;
III. High behavioral improvement (BI-3): the announcement reliability improves with 50%.

Note that a reliability improvement means a reduction for both the number of cancellations and the number of change requests with the specified percentage.

4.5.2. Degree of Cluster Strictness

Another uncertain issue influencing the performance of the redesign can be defined as the clustering strictness. With clustering strictness we mean the degree in which barges might switch from one cluster to another. In practice, ECT can decide to fix the cluster members but on the other hand can decide to make it the barge operators decision. A barge operator possibly has a preference for a specific group and this preference might change in time. Therefore, ECT can accommodate this need of the barge operators by reducing the clustering strictness.

Thus, similar to Section 4.3.1, here different scenarios are included in the simulation study. The 'degree of cluster strictness' is indicated with the interchange rate, which is defined as the probability that an announcement related to a specific group switches to another group. For example, an interchange rate of 0,1 means that approximately 10% of the announcements clustered as group 1 are now announced as group 2 and another 10% is announced as group 2. In that case, approximately 20% of the announcements were changed between groups. We consider three degrees of cluster strictness:

I. High cluster strictness (STR-1): no interchanges between groups;
II. Moderate cluster strictness (STR-2): an interchange rate of 0,1 between groups;
III. Low cluster strictness (STR-3): an interchange rate of 0,2 between groups.

As the behavioral improvement degree, simulating these degrees as scenarios are in need of additional data settings and is further explained in Chapter 5.

4.5.3. Hypotheses

In this chapter, the redesign of the barge handling process is presented and in the remainder this redesign is abbreviated as the to-be-1 design. The current barge handling process is abbreviated as the as-is situation. We analyze the redesign with the help of a simulation study. As a basis for this, hypotheses were delineated in order to come up with structured conclusions. Here, the hypotheses are given:

Hypothesis 1: *The redesign is workload efficient and results in a more reliable berth plan.*

Hypothesis 2: *The redesign generates higher service levels towards the barge operators in terms of waiting time.*

Hypothesis 3: *Behavioral improvement of the barge operators result in a higher service level compared to the as-is situation and furthermore further reduces the workload.*

Hypothesis 4: *A lower cluster strictness results in higher waiting times and a higher workload.*

Hypothesis 5: *A shorter planning horizon leads towards a better overall performance of the redesign in comparison with the as-is situation.*

As the redesign comes with different scenarios related to the barge operator reliability and clustering strictness, different simulation input is used in the simulation study. Furthermore, there are scenarios for the new planning horizons per group. Concerning the hypotheses, the simulation study needs to show results regarding to these scenarios. We have created 54 different scenarios varying along the dimensions presented in Table 5. Note that the three different values (i.e., allocation rules) for the dimension 'allocation rule' are selected in Section 5.5.3.

Table 5: Dimensions varied in the experiments

Dimension	Value
Planning horizon	PH-1 and PH-2
Degree of behavioral improvement	BI-1, BI-2 and BI-3
Degree of cluster strictness	STR-1, STR -2 and STR -3
Allocation rule	Fixed, Free and Flexible

4.5.4. Other Strategies

To evaluate the effectiveness of the cluster-based strategy, the performance of two other strategies is measured as well. For both strategies a hypothesis is formed.

Queueing (to-be-2)

It is interesting to know how the planning system responds in case no appointments are made and the barges are handled based on a queue. In this case, no communication with the barge operators takes place. From the perspective of the terminal operator, this strategy is difficult to implement since there is a minimum of preparation time needed before handling. However, the performance of this strategy measures the impact of the behavior of the barge operators on the performance of the barge handling system.

Hypothesis 6: *A queueing strategy results in lower waiting times as well as less re-plan movements.*

Rescheduling Rules (to-be-3)

The re-planning of appointments in the berth plan comes with decisions related to the sequence of handling. These decisions can be based on different rules and therefore we analyzed two alternative rules. In the current situation, the explained FCFS-rule is used. Brown (2014) analyzed the performance of dispatching rules in a scheduling model and argued for rules that are based on the operational planning time. Therefore, the following two rules are analyzed:

I. Longest Processing Time (LPT): order the announcement in the berth plan based on their processing time: start with the barge with the largest handling time and seek whether there is an opportunity to reschedule, and end with the barge with the lowest handling time.
II. Shortest Processing Time (SPT): same construction as the LPT-rule but here the sequence is the other way around.

Hypothesis 7: *The SPT and LPT rescheduling rules do not improve the performance of the current situation.*

4.6. Performance Measures

In order to analyze the performance of the redesign in comparison to the current barge planning process, we assess the waiting time, reliability of the berth plan and workload of the barge planner. Therefore we develop three key performance indicators (KPIs) to analyze performance in barge planning. Moreover, we discuss the utilization of the system.

Waiting Time

In transportation, on-time delivery is probably the most important factor and this holds for container barging. However, from the terminal operators perspective, information about the customer's due date is missing; only the barge operators published time of arrival is known. Therefore, the performance indicator from the customer's perspective is the lateness, which is the difference between the PTA, p_i, and the realized completion of the barge (ATA), t_i. Assumed is that barges arrive on-time according to their last updated ETA. Therefore, the performance measure can best be formulated as the average waiting time of a barge, which is equal to the tardiness (i.e., the maximum of the lateness and zero) of a barge. Thus, the average waiting time of all barges handled (N_H), $\overline{w}$, can be calculated as follows:

$$\overline{w} = \frac{1}{N_H}\sum_{i=1}^{N_H} p_i - t_i$$

More important are the average waiting times of the three groups since this thesis focuses on service differentiation. These waiting times per group reflect the service levels and are parameterized as $\overline{w}_X$, $\overline{w}_Y$ and $\overline{w}_Z$ for respectively the average waiting time of group X, Y and Z. Note that these averages are determined in the same way as the overall average waiting time.

Reliability

The reliability of the berth plan relies on the reliability of the appointments with the barges; thus, the number of cancellations and time requests is a measure for the planning reliability. Therefore, the system shows the number of cancellations (N_C) and time requests (N_R). With that information the cancellation ($C_{\%}$) and time requests ($R_{\%}$) percentages can be calculated, as can be seen in the below formulas. Furthermore, the N_C and N_R specified per time range (as seen in Chapter 3) are important performance measures, as the cancellations and change requests within for example eight hours prior to the ETA have a significant impact on the terminal planning.

$$N_C = \sum_{i=1}^{N_A} C_i \,, N_R = \sum_{i=1}^{N_A} R_i$$

$$C_{\%} = \frac{N_C}{N_H + N_C} * 100 \,, R_{\%} = \frac{N_R}{N_H + N_C} * 100$$

Re-plan Movements

The cancellations and requests are the cause of rescheduling and thus impact the workload of the scheduler. The higher the number of re-plan movements, the higher the workload of the scheduler. This is due to the fact that with every movement decisions are involved, in which the scheduler has to take into account multiple factors and has to tune his decision with colleagues in the company. Furthermore, every cancellation or time request comes with one or more contact moments with the related barge operator. Also, re-planning another barge to an earlier point in time comes with the need to contact the barge operator. Therefore, from the perspective of the barge planner, the number of re-plan movements (N_M) will be measured. Moreover, this KPI represents the stability of the berth plan, as zero re-plan movements means that the berth plan remains unchanged.

Utilization

From the terminal perspective, optimal use of capacity is an important indicator to choose the proper new strategy. In this case, where multiple berths are involved and different capacity allocation strategies are evaluated, it is possible that some allocation strategy leads toward varying utilization between berths. However, the overall utilization, $\bar{u}$, will be equal under fixed barge capacity and equal demand. Therefore, the performance of the planning system depends on the capacity usage. Here, the degree of optimal filling of 'gaps' in the berth plan result in the related performance in terms of waiting time. Note that the utilization levels of the three berths are depicted as $\bar{u}_1$, $\bar{u}_2$ and $\bar{u}_3$ in the remainder.

4.7. Conclusion

In this chapter, we introduced the redesign of the barge handling process and is based on the conducted cluster analysis. All barges handled at ECT are assigned to one of the clusters X, Y or Z; the presented clustering and related cluster characteristics are used throughout the remainder of this research. However, because of the fact that there are different clustering techniques, the proposed clustering must not be taken for granted in implementation. Furthermore, two other strategies and the simulation study were introduced, as the redesign can be compared with these two strategies based on the defined performance measures.

How can the current barge planning process be redesigned in order to introduce differentiation in barge handling?

The redesign mainly consists of adjusting the planning horizons and related resource strategy. We introduced six allocation rules which are related to three types of allocation strategies, namely the 'Free', 'Flexible' and 'Fixed' capacity allocation strategies. Both design components are briefly discussed, as well as the uncertain future behavior of the design, i.e. the cluster strictness and the behavioral improvement of the barge operators. The introduction of service differentiation in barge handling is hypothesized to overcome the research problem. At the end of this chapter, hypotheses were stated in order to find the overall performance of the redesign in comparison with the current situation. The overall performance is tested by simulating the as-is situation as well as the redesign of the barge handling process.

5. Simulation Model

In this chapter, we integrate the current planning system and the redesign in a simulation model in order to study the performance of the redesign in comparison with the current situation. First, the design of the simulation model is presented and the model assumptions are given. The simulation was then validated and the settings are presented that are the basis of the simulation runs. Finally, a conclusion on this chapter is given.

5.1. Simulation Model Requirements

The simulation model does not need to be divided into separate modules due to the fact that there are no different units in the scope that pursue own goals and thus make 'individual' decisions. In this model, all decisions are related to allocation of capacity to barges and therefore the system as a whole adequately needs to operate according to the following requirements:

R1: Minimize waiting times;
R2: All announcements are planned;
R3: All barge operator cancellations and requests are taken into account;
R4: Operate 24 hours a day.

The working week for ECT is 7 days, 24 hours runtime per day. Regarding the optimal use of resources (i.e., berth capacity), there is no need to set a requirement to optimize the capacity utilization, as the fixed capacity ensures a specific average utilization level due to R2. Taking into account the scoping decisions, the mentioned requirements need to be met and can be controlled by the following simulation model design parameters:

DP1: Release of announcements to the barge planner;
DP2: Assignment of barges to berths;
DP3: Rescheduling of appointments due to a barge operator cancellation;
DP4: Rescheduling of appointments due to a barge operator change request;
DP5: Rescheduling of appointments due to a crane failure;
DP6: Rescheduling of appointments due to a barge capacity reduction.

The rules for the design parameters need to represent reality and are integrated in the simulation model; though, first the constraints and assumptions are stated under which the planning system is designed.

5.2. Model Assumptions

In order to simplify the planning system, assumptions are made and are listed in Table 6. These decisions have been made on purpose in order to keep control of the complexity of the model and as well for the convenience in order to come up with a reliable simulation study. Definitely, the model decisions need to be considered while making reliable statements in the conclusion phase of this research. The assumptions are separated in the following categories: berth, resources, terminal operations, barge demand and barge operator behavior.

Table 6: List of simulation model assumptions

Category	Assumption
Berth	A berth has one operational crane and therefore can serve one barge at a time.
	The berth capacity consists of two dedicated barge berths and of one berth that is partly available (capacity settings is done based on the historical waiting time in Section 5.4).
	The berth location lengths are long enough to serve all barges (i.e. to serve all ship lengths).
	A berth can serve all barges, except berth three which has a restricted daily capacity. Therefore, barges with a requested handling time cannot be served on berth 3 if that handling time exceeds the daily capacity of berth 3.
	Once a barge is handled, the barge leaves the berth directly.
Resources	All resources (i.e., personnel, equipment and capital) are sufficiently available to serve the handling of barges in the berth plan.
	There is no initial berth plan, as this situation occurs in practice as well (e.g. at the first of January). The KPIs are determined based on the period after the simulation warm-up period, as is described in Section 5.4.
Terminal operations	The berth production is deterministic and based on the historical performance.
	The processing time of a barge can be influenced by crane failures and barge capacity reductions due to for example system failures and sea vessel handling delays (see Section 5.3).
	The stacking (and all other relevant) operations do not influence the berth production, as containers are on-time available for the crane to operate.
	The terminal operates on a continuous base.
	The mooring time (i.e., the time needed before handling) of a barge is neglected.
	There is no operation time lost due to switching cranes.
	The process of handling of loading and unloading containers is identical.
	All barges are handled with identical priority.
Demand	Barges arrive according to their latest communicated time of arrival, which means that barges arrive on-time according to the information known by the terminal.
	Demand is collected at announcement deadline which is related to the planning horizon, as it does not matter at what time the barge operator communicated the announcement.
	Announcements are received on a continuous base, as the barge operators do not have any restrictions according to their barge arrivals.
	The announcement needs to have a demand of minimal one TEU.
	Barges are assigned to berths according to the FCFS rule.
	All information required to handle a barge is known at the time of arrival.
Barge Operator Behavior	In case of a cancellation within two hours of the planned time, the idle capacity is not rescheduled as there is not enough time to reschedule all operational activities.
	In case of a change request within two hours of the ETA, the newly available capacity is not rescheduled due to the high probability of berth idleness. However, the particular barge is rescheduled to the earliest possible time.
	An announcement can only have one change request involved.
	An announcement can have a change request and a cancellation involved; however, the change requests is earlier than the cancellation.
	A change request consist of a new PTA and is later in time; thus, there are no change requests which include TEU changes or an earlier requested PTA.

The assumption that a change request can only consist of a later PTA request is in contradiction with the real situation. There, the PTA can be earlier than specified in the announcement and can include changes to the requested number of TEU. Due to the complexity of the simulation model these features were chosen to be out of scope. However, because of the relatively high average waiting time, requesting an earlier planned time will not have a huge impact on the berth plan in the simulation model. In practice, an earlier requested PTA can only be embedded if another appointment is further delayed, as there is no earlier capacity available (otherwise the waiting time would be lower). Here, no priority rules are included and therefore no decisions are made in the model related to priority and change requests with an earlier PTA. Furthermore, there was no data available regarding the change requests, which makes it difficult to estimate for example the distribution of positive and negative change requests regarding the number of TEU.

5.3. Simulation Model Description

As explained in Section 4.5, this research suits a discrete-event simulation study. The barge planning model is produced in Visual Basic for Applications (VBA), an event-driven programming language and is built into Excel. The simulation study is based on real company data from the year 2015, as historical arrivals are used and the run length is one year.

In order to construct an accurate model, the simulation needs to run on a continuous base. It is not sufficient to determine for example the optimal planning based on a linear programming problem, as the planned time and the “communication” (i.e., the cancellations and requests) between the terminal and barge operators is of key importance. Depending on the time the announcements are planned, the cancellation or request will or will not take place. Therefore, the simulation will be ‘event based’, e.g. the time a communication takes place is updated once the barge has a new planned time. We introduce the following variables which are at the basis of the event based simulation:

- t_D, t_X, t_Y, t_Z: With t_D the time new announcements are released to the barge planner in the as-is situation and the release of announcements related to group X (t_X), Y (t_Y) or Z (t_Z) in the to-be-1 design, as all three groups have their own planning moments;
- t_{T_C}, t_{T_U}: The time on which a terminal disturbances takes place on either a crane (t_{T_C}) or as a capacity reduction (t_{T_U}), i.e., as the unavailable capacity increases;
- t_{B_C}, t_{B_R}: The time on which the barge operator of a specific barge in the berth plan communicates either a cancellation (t_{B_C}) or a time request (t_{B_R}).

The minimum of these time variables indicates the time of the next event. Looking at the simulation from a high level, three major paths can be determined. Either the next event is one which produces a new berth plan or the next event impacts the berth plan due to terminal disturbances or due to barge operator behavior. Both the last two events cause rescheduling to take place.

Appendix C provides a schematic overview of the integration of the DPs in the model. The three ‘swimming lanes’ correspond to the three major paths in the simulation. Rectangles represent processes and calculations, while diamonds represent decisions and checks. Note that for readability, some paths are left out and processes are aggregated. The simulation overview presented the decisions related to the handling of the announcements and is separated in three parts. From a modelling perspective, the system consists of three different phases and are here enumerated with their most important functions:

I. Pre-processing:
    - Obviously, the pre-processing part of the simulation is input for the processing part of the simulation. All input data needs to be known and the (initial) values and parameters need to be set. For example, the planning horizon is fixed and therefore all planning moments are predefined. Furthermore, also the event times of capacity reduction disturbances can be calculated, as the unavailable capacity blocks are fixed and the reductions (i.e. non-crane disturbances) are known upfront (from the simulation perspective).

II. Processing:
    - Determine event times;
    - Process events (DPs)
        1. Release appointments (*redesign:* release time differs between groups);
        2. (Re-)Plan appointments due to barge operator behavior or terminal disturbances, taken into account the capacity and announcement specifications;
        3. Continuously update the berth capacity.

III. Post-processing:
    - Determine performance (KPIs).

In the simulation model, the DPs are incorporated as described in Appendix D. However, in addition to the described rules, here the procedures concerning the determination of the event times are clarified. Note that the event times for t_D and t_{T_U} are pre-calculated, as these times do not depend on the berth plan.

Determination of Event Times

After (re-)planning, for all announcements with a new t_i the possible cancellation, change request and crane failure times are adjusted due to the data construction (i.e., the time variable 'prior to ETA'). The event time calculation is based on the 'prior to ETA'-variables, here declared as t_{i_c} and t_{i_r} for respectively a cancellation and change request. Thus, for all planned announcements $(t_i > 0)$ who have a future cancellation, change request or crane failure involved, the event times are determined after every event and is based on their (new) ETA:

$$Cancellation\ time\ of\ announcement\ i = \max(t, t_i - t_{i_c})$$
$$Change\ request\ time\ of\ announcement\ i = \max(t, t_i - t_{i_r})$$
$$Crane\ failure\ while\ processing\ announcement\ i = t_i$$

Possibility of Surpassing

Because of the above explained procedure of determining the event times of the events t_{B_C} and t_{B_R} it is possible to surpass these events. As it does not make sense if, for one of these events, the recalculated event time is earlier than time t. For example, if the recalculated cancellation time is earlier than t, the cancellation of that barge is known and is therefore not planned, i.e. "do not plan an announcement if the cancellation is already received". Therefore, if a cancellation or change request is known before or at time t, this information can be included in the berth plan at that moment. This means that it is possible to surpass a cancellation or change requests, as no future movements are needed to handle with this communication with the barge operator. In case of a change request, this means that the PTA of the announcement is adjusted before the rescheduling of the appointment.

5.4. Simulation Validation

Validation of the simulation model is required in order to obtain a model which represents the barge handling process. The model is constructed based on the listed assumptions to simplify the complex processes at ECT. The data collection is conducted with an expert at ECT, however some data was corrected. Here, the warm-up period is determined and the model is then validated using the average waiting time of 2015.

5.4.1.1. Warm-up Period

The simulation run length is one year and reproduces the year 2015. The warm-up period of the simulation is detected based on Welch's Method, which is a graphical method and evaluated by Mahajan and Ingalls (2004). Four runs generated the performance of the system, all with a simulation length of 720 days and equal capacity. Based on the moving averages of both the waiting time and utilization, the warm-up period is chosen to be 120 days, as can be seen in Figure 19 as the moment in time both the moving average of the waiting time and utilization converges.

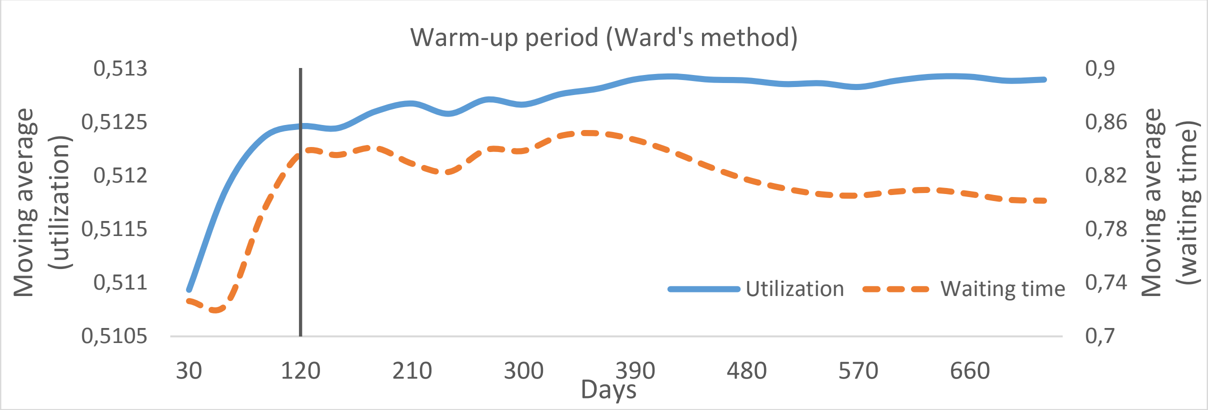

Figure 19: The moving average of the utilization of the system and the average waiting time (Ward's method)

5.4.1.2. Model Validation

The historical demand of 2015 is the input of the simulation study. However, the clustering of barges resulted in a slight deviation between the input demand in comparison with the historical demand. As can be seen in Figure 20, there is more variability over time in the input data than in the actual demand, which is due to the fact that the generated demand is based on the yearly average and does not adjust per time unit (e.g., per week). Therefore, the input data does not take into account the fluctuating call size, while it does takes into account the fluctuating arrival rate. This causes some more variability in barge demand in the simulation study; however, this is an opportunity to evaluate the redesign in a little bit more varying environment, which might be reality in the upcoming years.

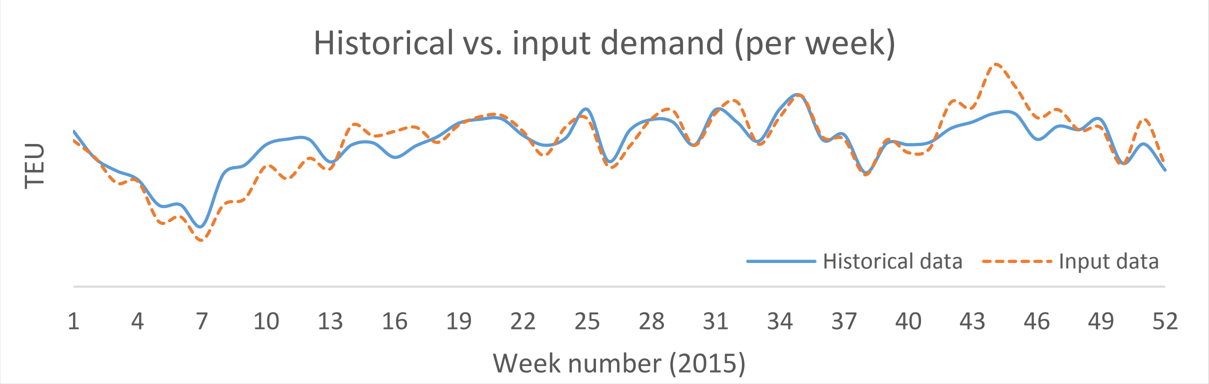

Figure 20: The historical demand of 2015 compared to the simulation input (note that the axis values are not shown for confidentiality reasons)

The historical average waiting time is the average of the waiting times in 2015, minus the waiting time of barges which were processed during the warm-up period. The average waiting time of a barge during the last eight months of 2015 is known. Before the validation of the system as a whole, the berth capacity for berth 3 was set experimentally on 20,5 hours of barge capacity per day.

In order to validate the simulation model, according to Van der Aalst (1995), if 30 or more sub runs are performed the average mean of the sub runs is approximately normally distributed. As can be seen in Figure 21, the histogram and related normal distribution curve shows clearly that the mean of the average waiting time of the simulation model follows the normal distribution.

Furthermore, the system is validated by comparing the simulation average with the confidence interval of the average waiting time. The 95% confidence intervals is determined based on the average waiting time and standard deviation of the handled barges. The lower bound is 11,98 hours and the upper bound is 12,69 hours. As shown in Figure 21, the mean of the 32 simulation runs is a waiting time of 12,13 hours. Therefore, based on both validation tests, we concluded that the behavior of the simulation is stable.

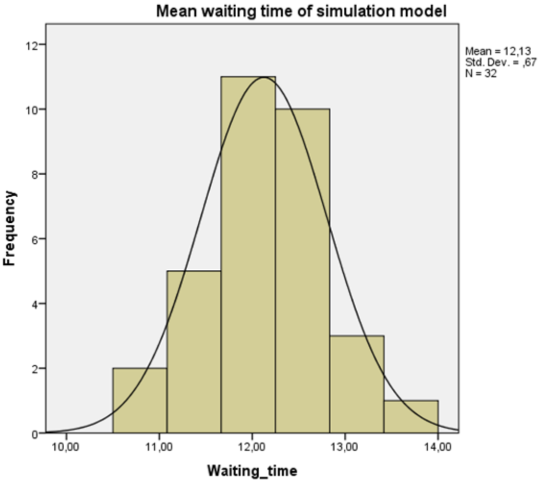

Figure 21: Normally distributed mean of average waiting time of the simulation runs

5.5. Simulation Settings

All scenarios have a run length of one year and per scenario three runs are simulated, decided based on the consideration of output quality and time restrictions. Furthermore, note that the average utilization degree is constant in the model, as the (historical) demand as well as the barge capacity are equal in all scenarios. Note that the barge operator behavior and terminal operator disturbances input is not varied between simulation runs of different scenarios; in other words, there are three generated data sets (as there are three simulation runs) which are used to simulate the different scenarios.

5.5.1. Degree of Behavioral Improvement

As discussed in Chapter 4, three scenarios in regard to the reliability of the barge operators are considered: no behavioral change (BI-1), a 25% reliability (BI-2) or 50% reliability improvement (BI-3). The simulation of these scenarios comes with the modification of input data, as the number of cancellations and change requests reduces in scenario BI-2 and BI-3. Note that the data input for the BI-1 scenario per simulation replication is identical, as the same input is used to vary the scenarios. The data modification related to the barge operator behavior scenarios is done by randomly reducing the number of cancellations and change requests both by 25 and 50% (i.e., there is a 25 or 50% probability that the cancellation or change requests was deleted). Note that the data structure is constructed in a matter that the retained cancellations and change requests are associated with the same announcements in all scenarios.

This data modification led to the data input numbers as presented in Table 7. Here the following numbers are showed: N_A is the number of announcements, N_C the number of input cancellations and N_R the number of input change requests. Notice that the number of arrivals between replications differ for the BI-2 and BI-3 scenarios, this can be explained by the fact that eliminated cancellations were deleted as announcement. Furthermore, the number of change requests and cancellations differ between the replications and BI-scenarios. This can be explained by the fact that data points were randomly deleted with probability of 25% per event (BI-2), and after that with another 25% (BI-3).

Table 7: Simulation settings regarding the BI-scenarios

Replication	BI-scenario	N_A	N_C	N_R
1	1	6972	306	538
	2	6886	220	383
	3	6819	153	267
2	1	6972	294	561
	2	6890	218	518
	3	6842	169	409
3	1	6972	293	534
	2	6894	215	488
	3	6829	150	381

5.5.2. Degree of Cluster Strictness

Similar to the previous section, the data needed to be adjusted in order to study the impact of the degree of cluster strictness. Recall the three scenarios: no interchange between groups (STR-1), an interchange rate of 0,1 between groups (STR-2) and an interchange rate of 0,2 between groups (STR-2). Here, a proportion of the announcements belonging to a specific group is randomly replaced into another group. Note that this means that for all three replications, per data input set related to three BI-scenarios, the data is modified to construct the STR-1, STR-2 and STR-3 scenarios. Therefore, per replication run there are nine different sets of input data. For example, in Table 8 the number of interchanges is given for the BI-2 scenario of replication two. As can be seen, on average 19,6% of new announcements were initiated per group in scenario STR-2. This procedure causes group 3 to decrease in number of announcements, as this group was larger than the other two groups. However, changing group sizes could be expected in practice as well.

Table 8: Simulation settings for the BI-2 scenario regarding the STR-scenarios

		STR-1	**STR-2**	**STR-3**
Total change within group (%)		N.A.	19,6 %	40,3 %
Number of interchanges		N.A.	1348	2774
Number of announcements per group	***X***	1667	1837	2002
	Y	1736	1864	2066
	Z	3483	3138	2818

5.5.3. Selection of Allocation Rules

In this section we select three allocation rules as not all rules are used in the experiments. First, based on the availably barge capacity (20,5 hours at berth 3), the six different allocation rules are applied to the capacity as for all three groups the share of the daily volume is known. And thus, for all six rules the capacity (rounded in hours) allocated for all three groups can be calculated and are shown in the table on the next page. Note that the maximum capacity per day is 68,5 hours.

Table 9: Number of hours allocated to the groups per allocation rule

Hours allocated per rule	**X**	**Y**	**Z**	**Total (hours)**
A	17	22	29,5	**68,5**
B	19	24	33	**76**
C	21	27	37	**85**
D	68,5	68,5	68,5	**205,5**
E	55	62	68,5	**185,5**
F	39	51	68,5	**158,5**

The capacity is logically assigned, as the capacity reserved per group is as much as possible allocated at one berth and in sequence, e.g. no unnecessary gaps between allocated capacity are made. This assignment of capacity and a graphical depicted berth overview can both be found in Appendix E.

Only three of the described rules are selected as parameters for the simulation runs, as not all (and possible alternatives to these) rules can be simulated due to time restrictions. From the perspective of ECT, the performance of a ‘Fixed’, ‘Free’ and ‘Flexible’ allocation rule is interesting to compare, since these three types could have different performance behaviors. Therefore, rule D is automatically selected as that is the only defined ‘Free’ allocation rule. Furthermore, one allocation rule is selected of the rules A, B and C (the ‘Fixed’ allocation rules) and on rule is selected of the rules E and F (the ‘Flexible’ allocation rules). As can be seen in the output in Table 10, the number of cancellations and requests do not significantly differ between the rules and is not used as a KPI to select the best rules. Thus, the ‘Fixed’ and ‘Flexible’ allocation rules are selected based on the waiting time performance. As can be seen in the results, rule C and rule F perform best and are thus selected as the fixed and flexible allocation rules. Rule C, D and F can furthermore be named as respectively the ‘fixed’, ‘free’ and ‘flexible’ allocation rule. In Appendix E (Table 17) all simulation output can be found regarding the six rules.

Table 10: KPI output for the 6 allocation rules

			A	**B**	**C**	**D**	**E**	**F**
Number of movements		n_m	3088	2244	2227	2155	2225	2328
Waiting time	**Group X**	$\bar{w}_X$	13,6	4,7	4,3	3,5	3,8	3,6
	Group Y	$\bar{w}_Y$	16,2	17,7	17,7	13,8	14,7	16,2
	Group Z	$\bar{w}_Z$	14,1	15,8	15,2	19,9	19,3	17,6
	Overall	$\bar{w}$	14,5	13,6	13,1	14,4	14,3	13,8

Changes in Simulation Model

The simulation model is extended in order that the redesign can be simulated as well; hence, the design parameters DP1 and DP2 are adjusted. DP1 is adjusted so that the release of announcements is specified per group based on the planning horizon. The assignment of barges to berths (DP2) has a new restriction involved which ensures that an announcement can only be planned at a specific berth and time if this capacity is available for the specific group of the announcement. Note that the other DPs are not adjusted. Thus, the allocation rules are only related to the initial berth plan and do not apply for re-planning.

5.6. Conclusion

In this chapter, the simulation model is presented and validated. Furthermore, the simulation scenarios and the related data modifications were discussed, as the simulation runs were based on adjusted data sets. At the end, two extra redesign were briefly introduced. In the next chapter, the simulation results are presented and the hypotheses are tested.

6. Simulation Results

In this chapter, the hypotheses are tested. Here, the performance of the redesigns are compared with the performance of the as-is situation based on the KPIs values for multiple scenarios. First, the results of the baseline are presented as well as the influence of the terminal performance on the baseline results. The hypotheses are then tested and a conclusion on the performance of the redesign is given. As mentioned, the output results per scenario settings are the average results of three replications.

6.1. Baseline Results

Table 11 shows the results found in the as-is situation of the berth plan. This result was used as the baseline throughout the analysis of the results, thus these KPI values are used to compare the redesigns with the as-is situation. Here, interesting is the fact that the average waiting time of announcements of group 2 is significantly higher than the averages of groups 1 and 3. This may be explained by the fact that the average call size of the announcements of group 2 is significantly higher, which results in less opportunities for rescheduling as the appointments need more berth capacity.

Table 11: Baseline output

Base	**Waiting times**				**Movements**	**Reliability**		**Utilization**			
	$\bar{w}$	$\bar{w}_X$	$\bar{w}_Y$	$\bar{w}_Z$	N_M	$C\%$	$R\%$	$\bar{u}$	$\bar{u}_1$	$\bar{u}_2$	$\bar{u}_3$
	12,61	12,38	14,05	12,02	3269,7	3,35	5,79	84,6	85,1	85,1	83,6

The KPIs related to the barge operator behavior can be separated based on the time prior to ETA, as frequently seen in this report. In the figure below, the cancellations and change requests are split per time range (in hours). In terms of berth plan reliability, these figures need to be reduced. Note that there were cancellations and change requests with a time of more than 24 hours prior to ETA; however, these are less interesting due to their low impact on the berth plan reliability.

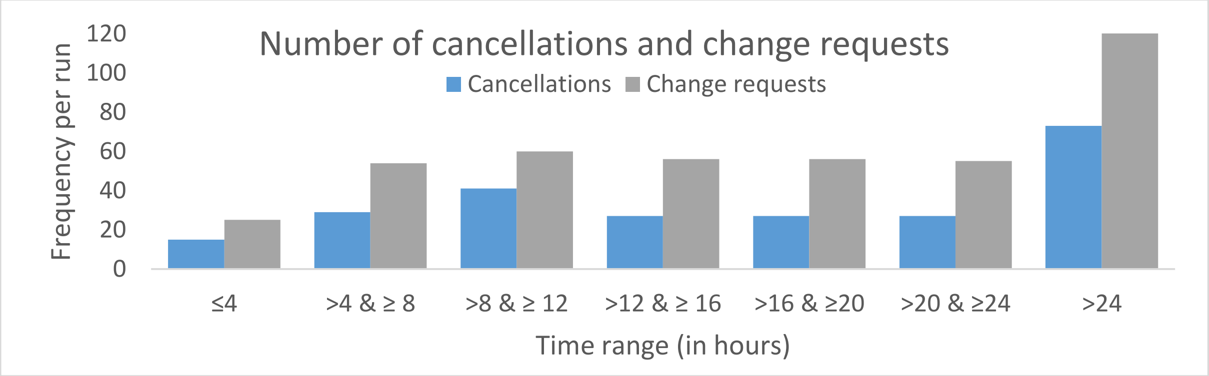

Figure 22: Simulation output regarding the plan reliability in the as-is situation

6.2. Effect of Terminal Disturbances

Table 12 provides results regarding the influence of the terminal performance on the system, i.e. simulation runs without terminal disturbances; hence, for indicating the waiting time caused by using too little resources. As can be seen, the simulations without terminal disturbances result in a 1% lower utilization. Thus, the terminal disturbances influence the simulation by reducing the capacity with 1%; due to that, the average waiting time is 12,69% higher than without terminal disturbances.

Furthermore, the performance of the planning system is influenced by modeling decisions. In the simulation study, there is no flexibility related to the use of capacity. As for example no practical features were implemented in order to reduce the waiting times, since these features offend restrictions related to the announcement characteristics. In practice, it is possible that appointments are made with an appointment time earlier than the PTA of the announcement. Furthermore, some barges receive priority which could result in a more optimal completion of the barge capacity. However, these considerations were not included in this simulation study. In this research, the simulation model for both the as-is and the to-be designs are constructed based on the same model assumptions and no model modifications were made which possibly influence the evaluation of the redesign. In contrast, we argued that the implementation of practical features is in favor of the redesign, since the new strategy has to deal with more capacity restrictions.

Table 12: Simulation output without terminal disturbances

No terminal disturbances	**Waiting times**				**Movements**	**Reliability**		**Utilization**			
	$\bar{w}$	$\bar{w}_X$	$\bar{w}_Y$	$\bar{w}_Z$	N_M	$C\%$	$R\%$	$\bar{u}$	$\bar{u}_1$	$\bar{u}_2$	$\bar{u}_3$
	11,19	10,95	12,51	10,67	3172,3	3,36	5,81	83,6	83,9	84,2	82,7

6.3. Hypotheses Results

The complete set of results of the simulation are presented in Appendix F. Note that the utilization varied between 84 and 85 percent as the barge capacity was impacted different between replications due to varying terminal disturbances.

6.3.1. To-be 1: Cluster-Based Planning Strategy

Hypothesis 1: *The redesign is workload efficient and results in a more reliable berth plan.*

Here, in order to test the hypothesis we analyzed the redesign without behavioral improvement (BI-1) and no interchanges between groups (STR-1), as the influence of these degrees are analyzed in other hypotheses. For the three allocation rules, it is found that the efficiency of the planner increases as the number of re-plan movements drops with on average 31,6%. Rule D, the 'free' allocation rule, results in the highest movements reduction with 34,1% less re-plan movements in comparison with the as-is situation.

The reliability of the berth plan slightly improved as can be seen in Figure 23, as the number of cancellations and change requests did significantly decreased in the time range of 24 hours or earlier. The other categories, i.e. the categories with more impact on the berth plan, had a lower reduction of cancellations and change requests. This is explained by the fact that in this case, with no behavioral improvement, the only berth plan reliability improvement is due to the fact that unreliable appointments are a shorter time in the berth plan. This result in surpassed cancellations and change requests within 24 hours prior to the ETA in times of sufficiently available barge capacity. Furthermore, there is no significant difference between the allocation rules. Thus, based on these findings we cannot reject hypothesis 1.

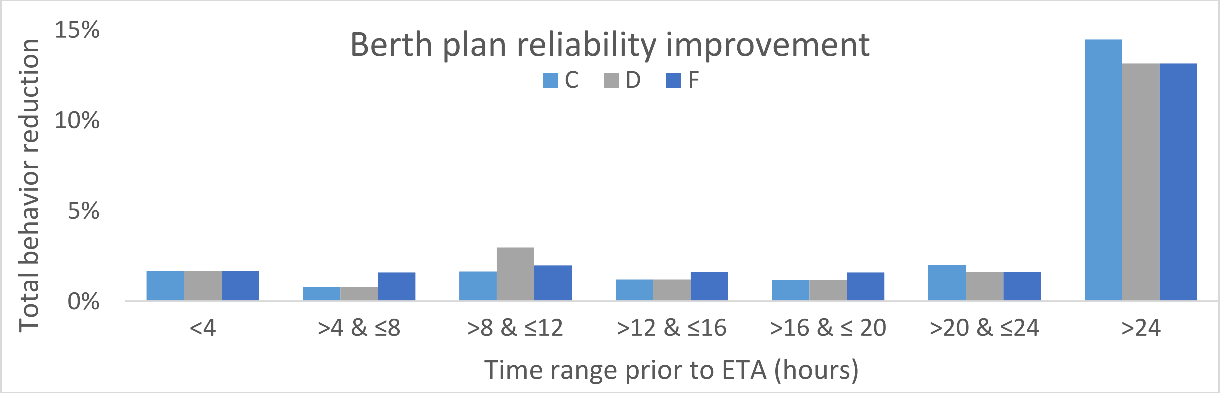

Figure 23: Berth plan reliability improvement per allocation rule, depicted as the reduction in total number of behavioral input per time range (in hours). Scenario: PH-1 / BI-1 / STR-1

Hypothesis 2: *The redesign generates higher service levels towards barge operators in terms of waiting time.*

Here, the same scenarios are compared as in the previous hypothesis. Both the overall average waiting time and the average waiting time per group is depicted in Figure 24. As shown, the average overall waiting time in the redesign is slightly worse than in the as-is situation under all allocation rules. The to-be design with allocation rule C, the 'fixed' allocation strategy, performs bests in comparison with the others, with a fairly low increase of 4,16% in waiting time in comparison with rules D (14,15%) and F (9,81%).

Furthermore, the graph shows a high deviation in waiting times between groups, as group X had a significantly lower waiting time than the other two groups. This is explained by the fact that this group is planned first; hence, all three allocation rules comes with a handling priority while introducing the planning horizons. Based on the differentiated results as depicted in Figure 24, we concluded that we cannot reject the hypothesis for group X, as the waiting time significantly reduces. On the other hand, the hypothesis is rejected for the other two groups.

Another interesting observation is the fact that the 'fixed' allocation rule (C) comes with a higher waiting time for group Y in comparison with group Z, while this is reversed for the other two rules. This may be explained by the fact that group Y has a higher average call size and is explained in Section 3.1. From a service point of view, a better service level is desired for barges who are more reliable. The 'free' (D) and 'flexible' (F) rules deliver fair waiting times to the different groups. Thus, we argued that rule C is not favorable in the redesign of the barge handling process and therefore in the next hypotheses the focus is on rule D and F.

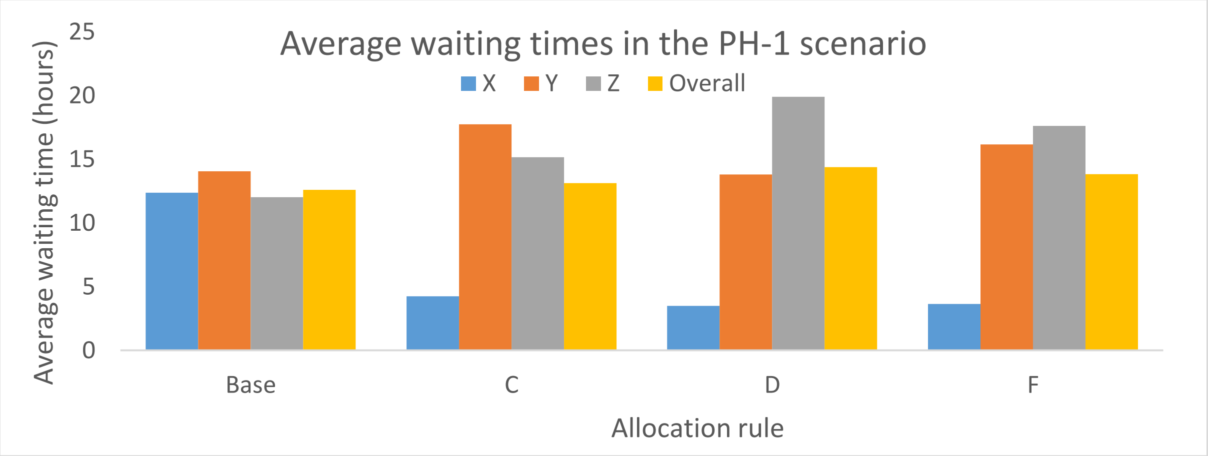

Figure 24: Average waiting times of the redesign in comparison with the as-is situation, depicted per allocation rule. Scenario: PH-1 / BI-1 / STR-1

Hypothesis 3*: Behavioral improvement of the barge operators result in a higher service level compared to the as-is situation and furthermore further reduces the workload.*

As can be seen in Figure 25, the workload further decreases as the reliability of the barge operators improves. This is obvious, as less behavioral events results in less re-plan movements.

For both allocation rules (D and F), the overall average waiting time does not improve as can be found in Figure 26; hence, there is even a slight deterioration. This can be explained by the fact that less cancellations of appointments do not impact the utilization of the system and therefore it is expected that the appointments have slightly the same waiting time, as in all three scenarios the berth plan is optimized. The higher overall waiting time is due to the increased average waiting time for group Z. Apparently, the reduced number of re-planning moments comes with a less optimal filled berth plan of the appointments of group X and Y, which results in less opportunities for group Z. On the other hand, the average waiting time for barges in group X further reduced. Therefore, we argued that for the reliable group X the hypothesis cannot be rejected. Note that rule C behaves similar in all three behavioral scenarios (see Figure 35 in Appendix G.3).

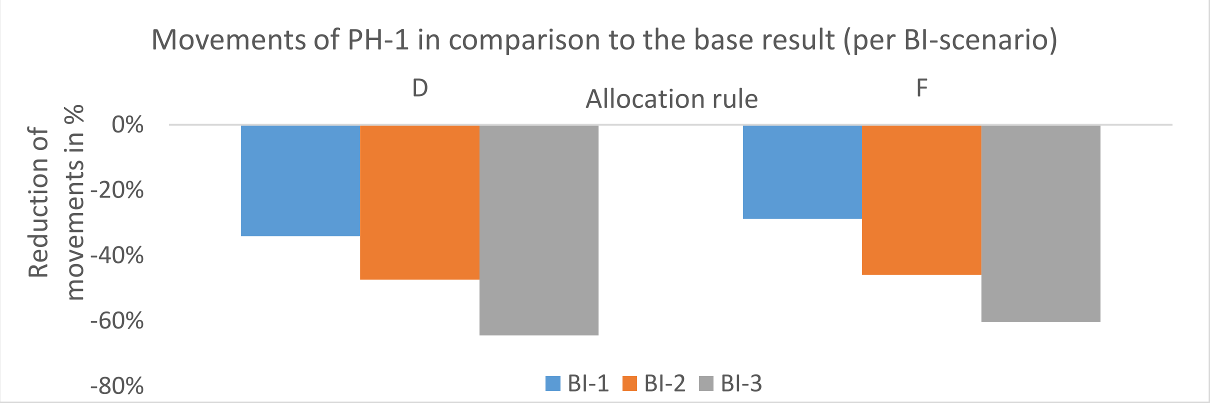

Figure 25: Reduction in workload per allocation rule due to behavioral improvement. Scenario: PH-1 / STR-1

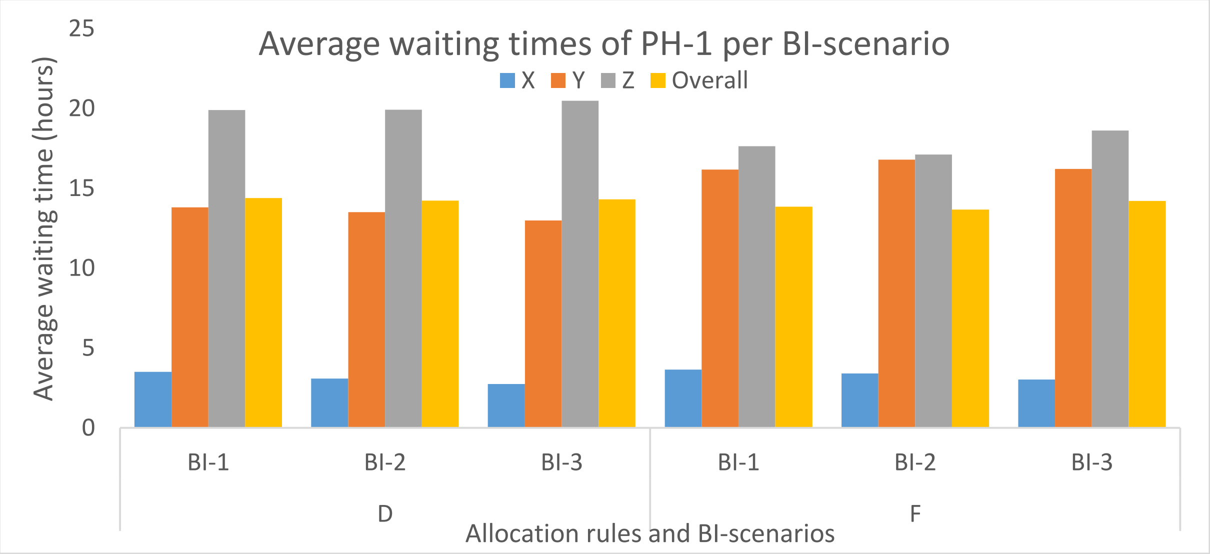

Figure 26: Average waiting times per allocation rule specified per BI-scenario. Scenario: PH-1 / STR-1

Hypothesis 4: *A lower cluster strictness results in higher waiting times and a higher workload.*
Here, we analyzed all strictness and behavioral scenarios combined with the PH-1 design of the planning horizon. As can be seen in the Figure 27, it could be concluded that the workload of the barge planner increases as the cluster strictness was lowered in case of allocation rule F. This relation is also the case for rule C as depicted in Appendix G.4. On the other hand, the 'free' allocation rule D showed more stability in terms of re-plan movements. Therefore, we argued that a lower cluster strictness does not result in a higher workload when using rule D in the redesign. These findings are be explained by the fact that the 'fixed' and 'flexible' rules have capacity restrictions involved which are based on the initial group characteristics. In case of low cluster strictness, the required capacity per group changes due to the changes group demand, while the capacity restrictions are based on the demand in the case with no announcement interchanges between groups (STR-1).

In Figures 28 and 29 we depicted, for respectively rule D and F, the changes in average waiting times caused by the different scenarios in comparison with the scenario of no interchanges between groups (STR-1). The average overall waiting time slightly increased in most strictness scenarios. The results of both allocation rules show a drop in the service level towards group X. This is possibly caused by the fact that more unreliable barges were part of group X and Y. As mentioned above, the interchanging between groups resulted in capacity restrictions that do not fit with the group demands.

Especially for rule D the waiting time of group X increases significantly. Overall, rule F comes with more stable average waiting times in case the cluster strictness is adjusted. Therefore, we argued that rule F best can be used if the cluster strictness is lowered and the goal is to provide the best service possible towards group X.

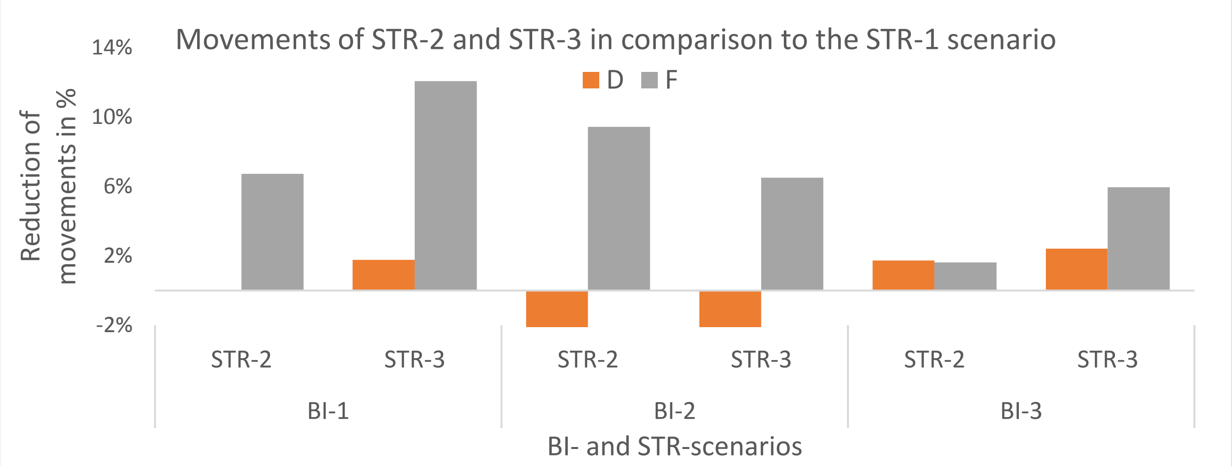

Figure 27: Movements per strictness and behavioral scenario for allocation rule D and F. Scenario: PH-1

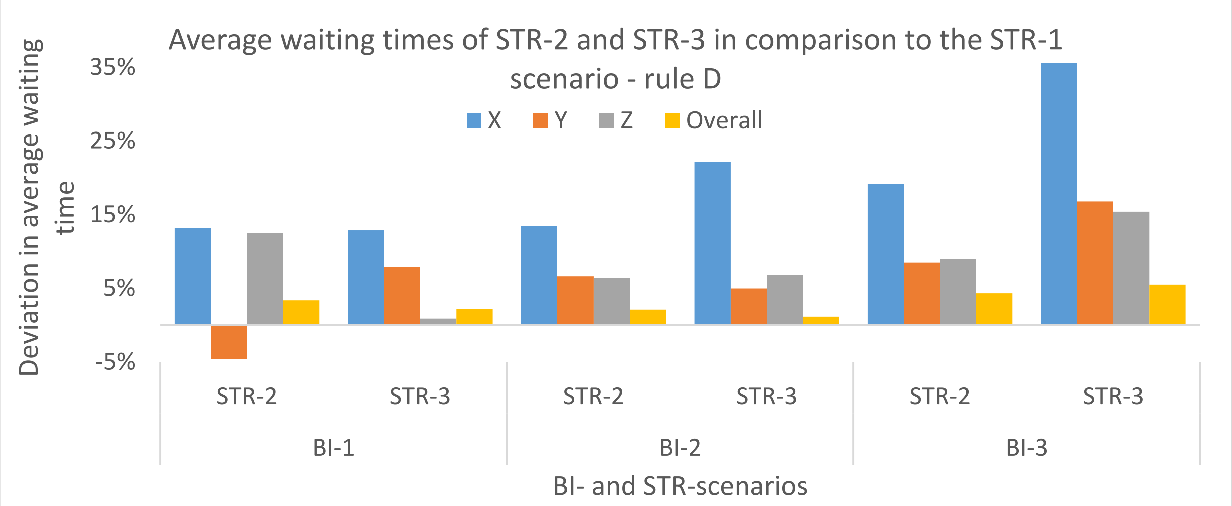

Figure 28: Average waiting time per strictness and behavioral scenario for allocation rule D. Scenario: PH-1

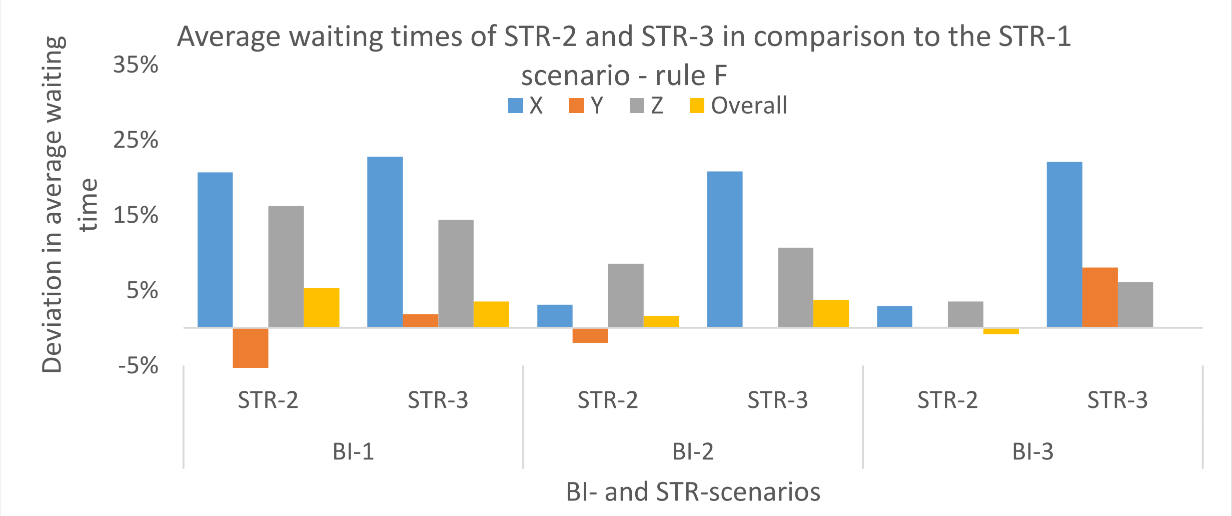

Figure 29: Average waiting time per strictness and behavioral scenario for allocation rule F. Scenario: PH-1

Hypothesis 5: *A shorter planning horizon leads towards a better overall performance of the redesign in comparison with the as-is situation.*

Here, the overall performance consists of the re-plan movements, the number of cancellations and change requests and the average waiting times. The planning horizon decision is based on the behavior of both the PH-1 and PH-2 planning horizon settings under all possible (cluster strictness and behavioral) scenarios, as these two designs could perform differently under changing circumstances.

As can be seen in Figures 38 and 39 in Appendix G.5, the number of re-plan movements as well the number of cancellations and change requests decreases in the scenario PH-2 in comparison with PH-1. No significant differences were found between the performance of the rules, as for example the reduction in re-plan movements is between the 20% and 30% for all scenarios. In case of shorter planning horizons, on average, the total time appointments are planned in the berth plan is low and the probability to surpass (see Section 5.3) events is higher. Because of that, the behavioral impact in the PH-2 scenario is lower than PH-1. Obviously, less cancellations and change requests result in less re-planning moves for the barge planner.

Figure 30 shows the deviation of the average waiting times in the PH-2 scenarios in comparison to the PH-1 scenarios in case of allocation rule D. Especially interesting is the fact that the waiting times of group X significantly increases, while the average waiting time of group Z decreases. This finding could be explained due to the fact that there is less capacity available per berth plan. In this design, group Z has more opportunities for earlier appointments because of the fact that the berth plan is constructed for a shorter time period and therefore more capacity is available for announcements of group Z. These findings are as well found in case of using the C and F allocation rules (see Figures 40 and 41 in Appendix G.5). Furthermore, the overall average waiting time is fairly constant. Thus, a short planning horizon comes with less deviation in the service levels between groups. Therefore, we cannot reject the hypothesis for the overall performance; however, from a service perspective, the hypothesis is rejected due to the fact that the waiting times of group X significantly increased.

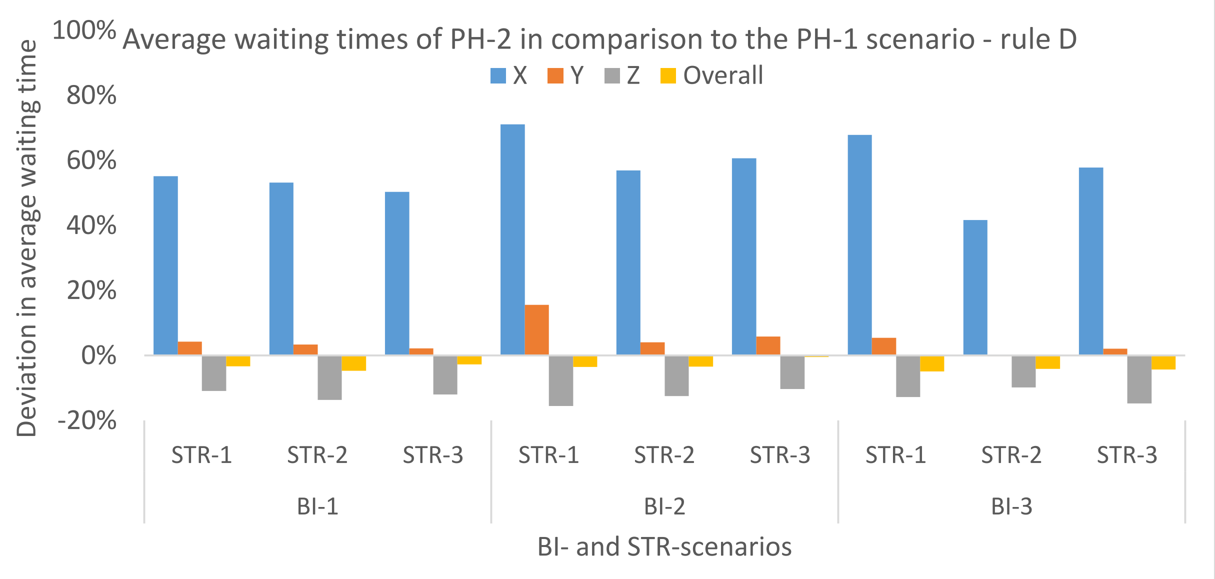

Figure 30: Average waiting time per strictness and behavioral scenario for allocation rule D. Scenario: PH-2

6.3.2. To-be 2: Queueing

***Hypothesis 6:** A queueing strategy results in lower waiting times as well as less re-plan movements.*

Handling the barges as a queue based on their PTAs, without constructing a berth plan, is an interesting strategy as then the barges are handled based on the real arrivals. Then, the barge handling processes are not influenced by the behavior of the barge operators. Thus, in this case no cancellations and change requests are communicated. Furthermore, barges are handled as early as possible and this reduces the waiting times as can be seen Table 13. The queueing strategy results in a reduction of approximately 9% in average waiting time for all groups. This reduction might be explained by the fact that here the handling of barges is always done in sequence (i.e., following the FCFS-rule) as no barge operator input influences the berth plan. We cannot reject hypothesis 6 and thus we concluded that there is room for improvement in the current barge handling process as the reliability of the berth plan can be increased.

However, note that the queueing strategy is difficult to implement from the perspective from both the terminal and barges operator. The terminal needs approximately six hours to prepare the handling of a barge and on the other hand the barge operators will have more uncertainty involved, as there routing depends on appointments with the deep-sea terminals.

Table 13: Waiting time output of the queueing strategy (note that the other KPIs do not have values as no berth plan was constructed)

	Waiting times			
	$\overline{w}$	$\overline{w}_X$	$\overline{w}_Y$	$\overline{w}_Z$
Base	12,61	12,38	14,05	12,02
Queue	11,61	11,36	12,34	11,38

6.3.3. To-be 3: Rescheduling Rules

***Hypothesis 7:** The SPT and LPT rescheduling rules do not improve the performance of the as-is situation.*

The results of the system per rescheduling rule used are depicted in the table below. Note that the FCFS-rule performs better in terms of waiting time; however, the other two rules have less re-plan movements involved. The LPT-rule does not significantly differ in terms of waiting time and this may be explained by the fact that announcements with a highly call size have more re-planning opportunities. Apparently, this results in an average waiting time that is almost equal to the performance of the FCFS-rule. Furthermore, there is no service improvement involved for group X and thus these rescheduling rules do not focus on service differentiation. Therefore, we argued that both strategies are no potential alternatives for the presented redesign.

Table 14: Overall averages of rescheduling rules

	Waiting times				Movements	Reliability	
	$\overline{w}$	$\overline{w}_X$	$\overline{w}_Y$	$\overline{w}_Z$	n_m	$C\%$	$R\%$
FCFS (Base)	12,61	12,38	14,05	12,02	3269,7	3,35	5,79
SPT	15,28	15,08	16,89	14,61	1705,3	3,35	5,88
LPT	12,84	12,74	13,80	12,42	1979,0	3,35	5,87

6.4. Conclusion

What is the performance improvement of the redesign in comparison with the current situation?

In this chapter, we presented the results of our simulation study and tested the redesign hypotheses. Furthermore, we discussed the redesign decisions and the best redesign per KPI is depicted in Table 15, as the performance of different KPIs depend on the design decisions. These designs are based on the performance as can be found in Appendix H. Note that design with the focus on service differentiation is the redesign with the best service level towards group X, while the service towards group Y is better than group Z*. The best designs are based on the average output of the behavioral scenarios, as this scenario is still uncertain. Furthermore, rule C is not included in the redesign as argued in the analysis of hypothesis 2.

As argued in Section 6.3, the redesign is workload efficient since the number of re-plan movements decreases with approximately 30% in comparison to the current situation. In addition, the number of movements further reduces in case of more reliable barge operator behavior; hence, there is a negatively linear relationship between the number of cancellations and change requests communicated and the number of re-planning moves. Furthermore, the redesign leads to a more stable berth plan as the behavior of the barge operator improves. However, the drop in cancellations and change requests within a short time range prior to the ETA is relatively low. Thus, we concluded that the redesign does not directly solve the issue of 'last-minute' cancellations, since this depends on the behavioral improvement of the barge operators.

From the barge operators perspective, none of the allocation rules had a waiting time reduction involved; hence, there was even a slightly rise in average waiting time found. This can be explained by the fact that the redesign reduces the flexibility of the system, as there are more capacity restrictions involved in the initial assignment of barges to berths. Due to less re-plan movements, the system less frequently re-optimizes the berth plan and this causes the slightly higher average waiting times. However, in practice this could be solved by introducing extra re-optimization moments. Furthermore, here the service differentiation is most important and thus the service towards group X needs to be low and the average waiting time of group Y needs to be lower than group Z. We argued that rule C does not meet these restrictions and therefore the fixed allocation strategy is undesired.

Furthermore, the redesign performance was evaluated in different experimental settings. It was concluded that allocation rule D (the 'free' allocation rule) can best be used if the focus is on the reliability of the berth plan. Also, rule D performs best under different levels of barge operator behavior, which makes this a highly flexible rule. Overall, we argued that the degree of cluster strictness negatively influences the average waiting time of the redesign, and the degree of behavioral improvement does not.

The redesign furthermore has decisions involved regarding the planning horizons per group. As seen in this chapter, the number of re-plan movement decreases while the average waiting time increases in case the planning horizon is shortened for all groups. Again, this is possibly due to the further tempered flexibility of the system. On the other hand, shorten the planning horizons comes with the opportunity to provide slightly more equal service levels to the different groups.

Table 15: Redesign decisions related to the performance of specific KPIs

KPI Focus		**Waiting times**		**Berth plan reliability**	**Re-plan movements**
		Average	*Service differentiation**		
Design setting	**PH**	PH-2	PH-1	PH-2	PH-2
	Rule	D	D	D	D
	STR	STR-1	STR-1	STR-1	STR-1

7. Conclusions and Recommendations

In this chapter we conclude this thesis by answering the research question. Moreover, we make recommendations for ECT considering the decisions regarding the redesign of the barge handling process. We conclude this chapter with possible future research directions.

7.1. Research Conclusions

In this research we focused on the barge handling at ECT, who has to plan the arrival of barges in a dynamical environment. One of the main challenges for the terminal operator is to make appointments with barge operators who only have limited knowledge about their upcoming visits. The terminal operator has to deal with this uncertainty as well and has to operate with an unreliable berth plan, as this uncertainty further increases due to the typical strategic behavior of the barge operators. These problems are known as the barge alignment problem in literature. This research analyzed the approach of introducing service differentiation in barge handling in order to solve the barge alignment problem. Therefore, the research question was stated as:

What is the berth plan reliability performance of introducing service differentiation in barge handling at a container terminal?

In Chapter 2 we stated three sub questions in order to obtain an integral answer to this main research question. Here, we reiterate these questions and summarize our results.

1. *What is the root cause of the research problem?*

In Chapter 3 we showed that there is variation in reliability per barge operator and per barge. Based on both qualitative and quantitative analysis, we argued that appointments significantly differ in terms of reliability, as some appointments are less reliable if a particular barge or barge operator is involved. Currently, the barge handling process does not take into account these reliability differences and therefore we concluded that handling differentiation may improve the barge handling at ECT. Thus, the underlying cause of the research problem is that ECT does not handle barges based on their specific characteristics and reliability, and therefore does not take the strategic behavior of the barge operators into account in the appointment making process. There is more deviation in reliability on barge level in comparison with the barge operator level. In order to address issues regarding the berth reliability, we argued that differentiation of handling between barges may solve the research problem.

2. *How can the current barge planning process be redesigned in order to introduce differentiation in barge handling?*

The redesign involves multiple design decisions, as (I) barges needed to be separated in distinguishing groups, (II) customized planning horizons were introduced and this resulted in the inquiry to introduce (III) group specific berth allocation. Thus, the redesign mainly consists of adjusting the planning horizons and related resource strategy. We introduced six allocation rules which are related to three types of allocation strategies, namely the ‘Free’, ‘Flexible’ and ‘Fixed’ capacity allocation strategies. The reason that we considered this approach, is that we expect behavioral improvement of the barge operators as the barge handling is more customized for the different barge groups. Therefore, we introduced the ‘degree of cluster strictness’ and the ‘degree of behavioral improvement’ in order to assess the flexibility of the redesign. The scenario setting of these two degrees reproduced the unpredictable behavior of the barge operators in the simulation experiments. Furthermore, for the purpose of evaluating the possibilities for implementation, we analyzed the performance of three allocation rules in the simulation study.

3. What is the performance improvement of the redesign in comparison with the current situation?
We designed a discrete-event simulation model to evaluate the performance of the redesign. In order to give realistic insights, we used in-company data of ECT as simulation input for our experiments. Based on the simulation experiments, we found interesting insights concerning the performance of the approach.

We concluded that the redesign comes with slightly higher average waiting times, because of the fact that the flexibility of the planning process reduces. However, more important, the redesign results in the desired service differentiation. Both the use of the free and flexible allocation rule results in a significant lower average waiting time for the most reliable group of barges (group X). The fixed allocation rule comes with an unfair distribution of the average waiting times, since the most unreliable group does not receive the lowest service. Furthermore, as seen in Chapter 6, a shorter planning horizon for all groups results in an increase in the average waiting time for group X. In general, we concluded that the free allocation rule performs best under different scenarios. However, we argued that the degree of cluster strictness negatively influences the average waiting time of the redesign, and the degree of behavioral improvement does not.

The reliability of the berth plan improves as variety in barge handling is introduced. The redesign leads towards at least a reduction of approximately 30% in number of re-plan movements, which is a measurement for the barge planners workload. A further reason to conclude the increased reliability is the fact that a significant number of cancellations and change requests is ‘surpassed’ because of the customized planning horizon. On the other hand, this reduction in movements causes the berth plan in the simulation model to be less flexible than the current situation. However, in practice this could be solved by introducing extra re-optimization moments.

Based on these findings, it can be concluded that this study showed that there are ways to improve parts of the barge planning process. Improving these will result in a loss of flexibility or performance in other parts of the barge handling process and in a drop in service towards a part of the customers. Implementation in practice should therefore be based on a careful weighing of the performance indicators of both the terminal and barge operator.

Note that these results are based on a simulation study in which assumptions and simulation design choices have been made which influence the behavior of the simulation. Here, a constant berth capacity was determined, while in practice the barge capacity fluctuates depending on the overall terminal performance. This is further influenced by the assumption that all resources are sufficiently available. Thus, in practice the performance of the system (e.g., the waiting time) varies more in time than in the simulation study.

Furthermore, in practice, the terminal strategy and customer agreements influence the decision-making of the barge planner as some barge arrivals receive priority in handling. However, the simulation study was focused on the long-term usage of the berth resources and therefore it was not required to fully recreate reality. Hence, it could be said that the assumptions in the redesign model do not have a significant influence on the comparison between the performance of the redesign and the current situation. As for example the average waiting time does not differ if priority rules are implemented, this only influences the average waiting time of the individual barges or barge operators.

7.2. Recommendations

The results indicate that the cluster-based planning strategy is an interesting approach for the barge handling process at ECT as the focus is on berth plan stability and service differentiation. However, as concluded in Chapter 6, the waiting time should be considered in making a decision as the service levels will differ between groups. Thus, from the perspective of ECT, the redesign should be implemented as the focus is on service differentiation. However, first a more detailed analysis concerning the redesign decisions is required in order to determine the specifications of the redesign.

Therefore, ECT needs to specify their most important goals, since this influences the design decisions of this approach.

Moreover, the clustering impacts the provision of service levels as different groups will have different service levels. In the result analysis part, we found that the group with the longest planning horizon has the lowest average waiting time. The decision on what capacity allocation rule to use influences the opportunities to influence the service level behavior of the approach. Hence, more capacity can be reserved for a particular group if that service level needs to be improved. In practice, this can be accomplished by fine-tuning the capacity reservations in either the fixed or the flexible cluster capacity strategy. The strategy without reserved capacity can best be implemented if the focus is on maximizing the reliability of the berth plan and the service towards the most reliable customers.

Another point of attention is the clustering of barges or barge operators. In this thesis, the clustering was done based on the barge level of the announcement reliability; however, this can also be done based on barge operator level. This comes with a less clear-cut differentiation between the groups, as seen in Chapter 4. On the other hand, this decision will lead to a more ease-to-use planning strategy from the perspective of the barge planner. Furthermore, there are many different clustering techniques, thus the proposed clustering method must not be taken for granted in implementation. In addition to that, the clustering in this research was done without data about the historical change requests, while this information can be collected in collaboration with Portbase. Therefore, it is advised to use that data as well in order to come up with a more clear differentiation in cluster characteristics.

Furthermore, note that the possible implementation of this redesign needs to be done in collaboration with the barge operators. In the problem analysis part of this research it is elaborated that the collaboration is far from optimal, as especially the strategic behavior of the barge operators came to the surface in literature. A way to improve the trust in the network is to design the cluster management together with the barge operators, as in practice they want to switch between groups. However, in the results it was illustrated that a lower cluster strictness has a significantly negative impact on the performance of the redesign. Therefore, ECT needs to decide whether the company seeks for more optimal processes or a better collaboration with the barge operators.

7.3. Further Research

This research was focused on the long-term strategy of the berth capacity usage and was the first step in the introduction of service differentiation in barge handling at a container terminal. Further research needs to be conducted concerning the implementation of the strategy. In practice, there is uncertainty involved due to the variability in demand and terminal disturbances. Therefore, additions to the proposed solution need to be designed in order to handle with the short-term capacity challenges. This furthermore comes with the alignment of the new berth plan strategy with the short-term planning of equipment and personnel.

Another interesting topic for further research is the behavior of the barge operators. In this research, scenarios were tested regarding to the possible improvement in behavior. However, using game theory applications the behavioral change can be determined. Hence, the degree of performance improvement of the redesign can be measured more specific. As the behavior of the barge operator influences the berth plan, also the behavior of the barge planner has an impact on the barge handling process. Thus the behavior of both actors should be further explored.

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9. Abbreviations

ATA : Actual Time of Arrival
BI : Behavior Improvement
DP : Design Parameter
ECT : Europe Container Terminals
ETA : Estimated Time of Arrival (i.e., planned time)
FCFS : First-Come-First-Served
LPT : Longest Processing Time
PTA : Published Time of Arrival
R : Requirement
SPT : Shortest Processing Time
STR : Strictness
TEU : Twenty feet Equivalent Unit (standardized metal container)

10. Variables

π	Planning horizon
π_g	Planning horizon of group g, with g $\{1, 2, 3\}$
c_i	Call size of announcement i (in TEU)
C	Indicator that represents the percentage of cancellations
C_i	Binary variable indicating whether announcement i has been cancelled
D_i	Binary variable indicating whether the handling of announcement i has been disturbed because of a crane disturbance
N_A	Number of announcements
N_C	Number of cancellations
N_H	Number of handled barges
N_R	Number of requests
h_{run}	Runtime of the system in hours per day
p_c	Productivity rate of a single crane (in TEU/hour)
p_i	Published time of arrival (PTA) of announcement i
R	Indicator that represents the percentage of requests
R_i	Binary variable indicating whether a request for adjusting the t_i of announcement i has been made
$\bar{T}$	The average tardiness
t_{b_L}	Lower bound of unavailable capacity block specified in hours on berth b
t_{b_U}	Upper bound of unavailable capacity block specified in hours on berth b
t_{B_R}	The time on which the next change request is communicated
t_{B_C}	The time on which the next cancellation is communicated
t_c	Capacity reduction length in hours per specific block
t_D	Time of the next order release, with t_{D1}, t_{D2}, t_{D3} related to the groups X, Y and Z
t_i	Planned time of arrival (ETA) of announcement i
T_i	Tardiness of announcement i
t_{i_c}	Time of cancellation of announcement i prior to t_i
$t_{i,new}$	Rescheduled planned time of arrival (ETA) of announcement i
t_{i_r}	Time of request of announcement i prior to t_i
t_{T_C}	The time on which the next crane failure takes place
t_{T_U}	The time on which the next capacity reduction takes place
$t_{x_{g_U}}$	The upper bound (i.e. end time) of the gap at berth x with numerator g
$t_{x_{g_L}}$	The lower bound (i.e. start time) of the gap at berth x with numerator g, with $g = \{1, .., N\}$
x_g	Numerator that specifies the gap number at berth x, with $x = \{1, 2, 3\}$ and $g = \{1, .., N\}$
x_i	Berth location of announcement i, with $x = \{1, 2, 3\}$
$\bar{u}$	Utilization of the system, with $\bar{u}_1$, $\bar{u}_2$ and $\bar{u}_3$ the utilization of berths 1, 2 and 3
$\bar{w}$	Average waiting time of handled announcements, with $\bar{w}_X$, $\bar{w}_Y$, $\bar{w}_Z$ the waiting time related to the groups

11. Appendix

11.1. Appendix A: Cause and Effect Diagram

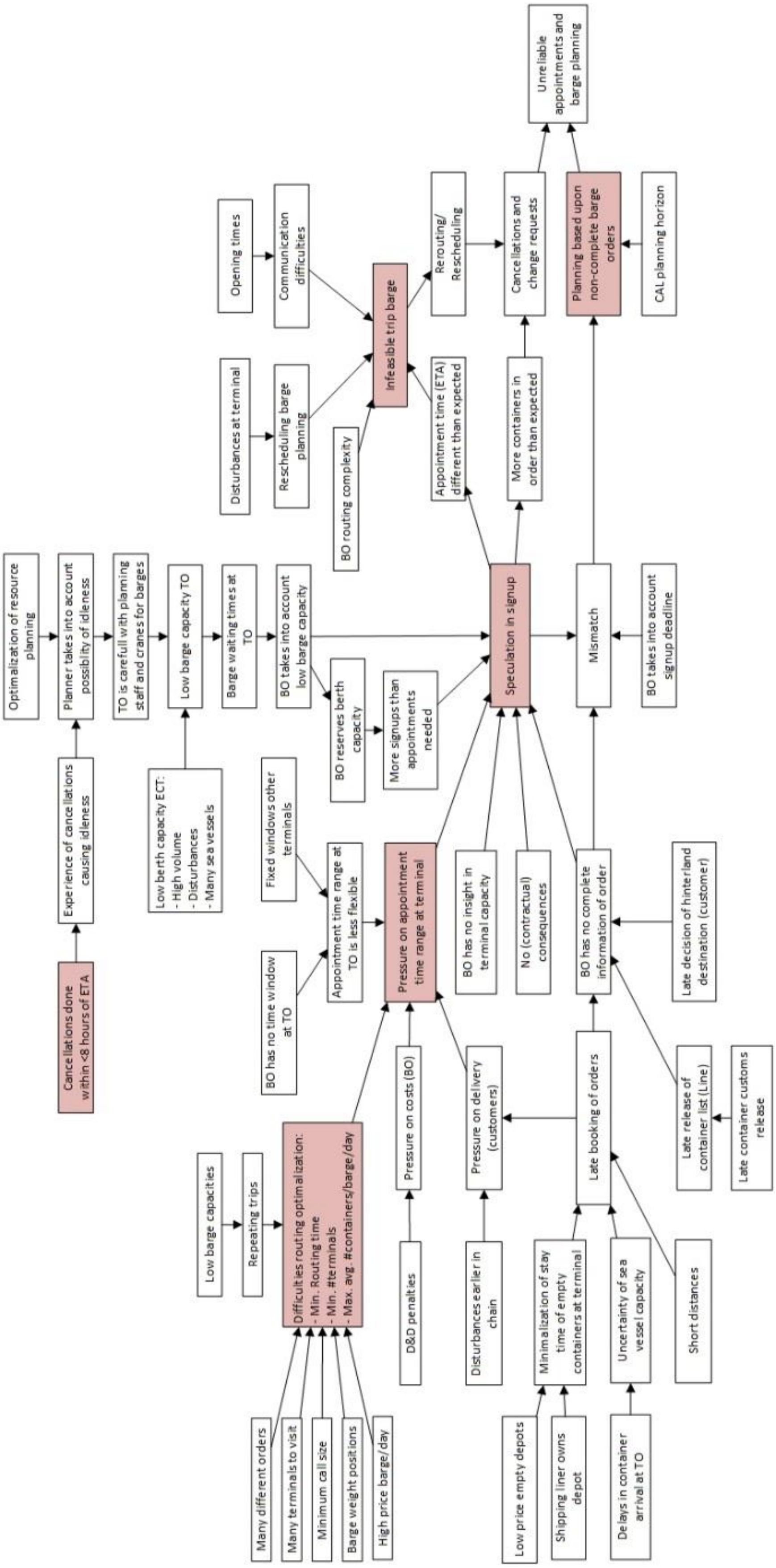

Figure 31: Cause and effect diagram

11.2. Appendix B: Fishbone Diagram

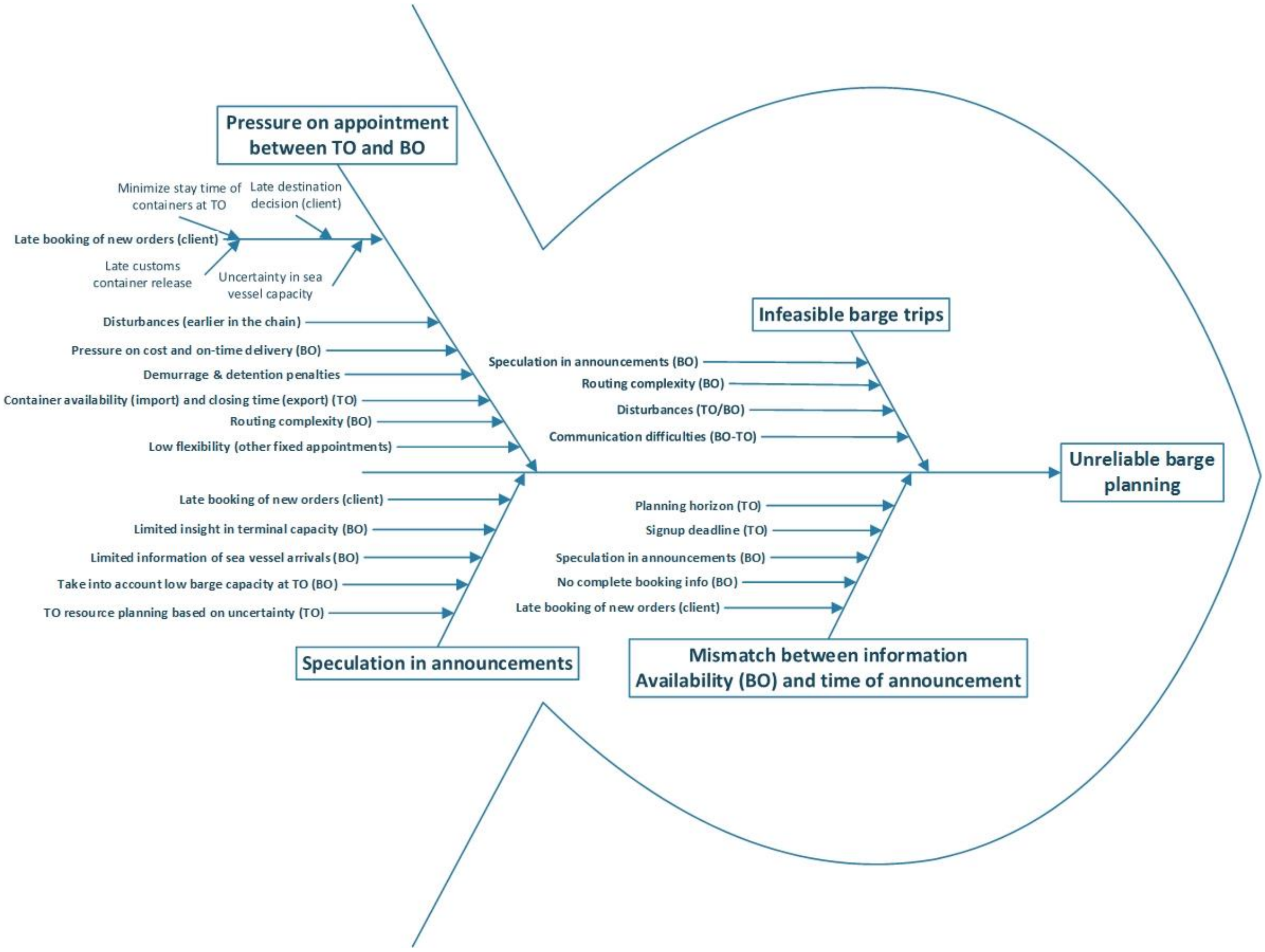

Figure 32: Fishbone diagram

11.3. Appendix C: Simulation Overview

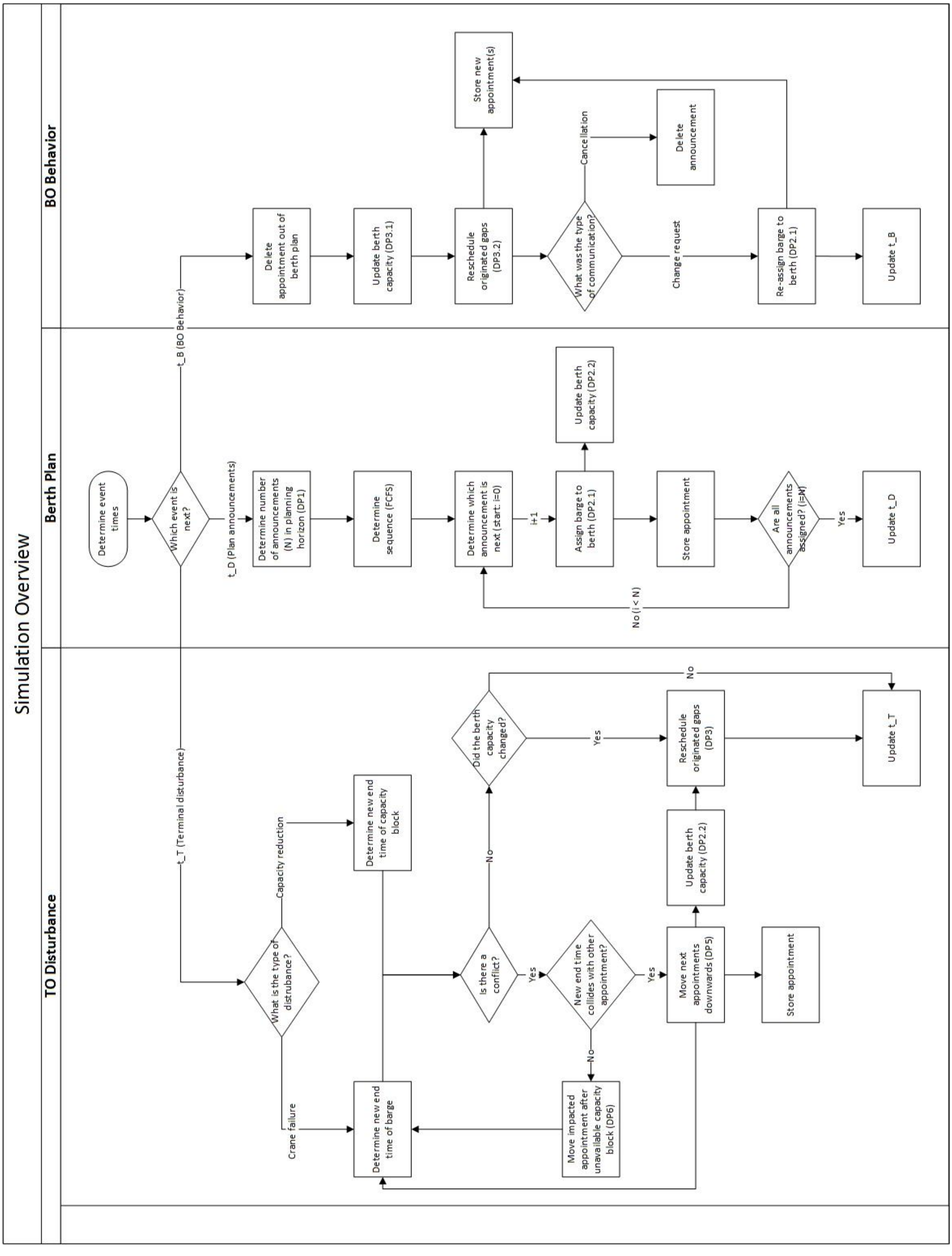

Figure 33: Schematic overview of the simulation model

11.4. Appendix D: Design Parameters

Here, the rules for the design parameters are clarified and parameterized for the sake of precision. The variable definitions are partly based on the vessel arrival planning model constructed by Lang and Veenstra (2009) and can be found in the variables list of this thesis.

11.4.1. Initial Berth Plan

DP1: Release of announcements to the planner

The terminal operator has secured an announcement deadline and is in practice around the 30 hours before the preferred arrival time; however, a 24 hour planning horizon has been chosen due to the fact that announcements notified slightly after the deadline are taken into account in the berth plan. An announcement consist of information of the call size in TEU, c_i, and the published time of arrival (PTA), p_i.

The planning horizon, π, specifies which announcements are released to the scheduler at time t. Here, the planning horizon is fixed, which means that the start and end time of each plan is fixed as well as the time of planning: every πK moments in time the announcements are released to the scheduler and planned in the berth plan. Note that K is an integer value that keeps track of the number of berth plans made. The scheduler selects all announcements whose p_i is equal or less then $\pi K + 2\pi$ and is later than $\pi K + \pi$, the start time of the next berth plan. Note that the time of receiving the announcement is not relevant and the demand horizon can be seen as the period between 0 and πK. Here, all announcements are handled with identical priority and therefore are planned with the same planning horizon. Every predefined πK point in time a berth plan is constructed, all announcements of which the p_i lies within defined time range are released to the scheduler, as defined in the condition formula:

$$2\pi \geq p_i - \pi K > \pi$$

DP2: Assignment of barges to berths

The released announcements are input for the planner as the barge planner needs to assign the announced barges to a berth and needs to assign a specific start time of handling. The released announcements are planned by the barge planner on a First Come First Served (FCFS) basis. This order of FCFS is created by sorting the announcement ascending based on their p_i. Thus, the announcement with the earliest PTA is first assigned to the berth plan.

The barge planner keeps track of the available capacity per berth with the help of an information system. Therefore, the barge planner can easily spot the available capacity per berth. The berth capacity consists of so-called ‘gaps’ in the berth plan: a block of available capacity that has a specific start and end time due to already planned capacity. Note that berth 1 and 2 both have an ‘infinite’ gap at time t, as the capacity after $\pi K + 2\pi$ is available because this capacity is after the upper limit of the planning horizon. Berth 3 does not has an infinite gap, as there is a predefined block of daily unavailable capacity.

The information of each gap is known, as the start and end time of the gap can be looked up in the system. The start and end times of all gaps per berth can be parameterized as:

$t_{x_{g_L}}$: The lower bound (i.e. start time) of the gap at berth x with numerator g
$t_{x_{g_U}}$: The upper bound (i.e. end time) of the gap at berth x with numerator g

DP2.1 Assignment

With this information, the barge planner decides on the assignment of the announced barge to a specific berth and a planned time of announcement i, t_i. The decision minimizes the t_i and takes into account the following restrictions:

1. The planned time announcement i needs to be equal or later than the published time of arrival:
$$t_i \geq p_i$$
2. The planned time announcement i needs to be at the start of a gap or before the end of a gap:
$$t_{x_{g_L}} \leq t_i < t_{x_{g_U}}$$
3. The handling time of announcement i to fit within the gap at the berth:
$t_i + \frac{c_i}{p_c} \leq t_{x_{g_U}}$, where p_c is the productivity rate of a single crane in TUE per hour.

The announcement is planned at berth x which satisfies the conditions and furthermore minimizes the planned time.

DP2.2 Capacity Control

After the assignment, the corresponding gap is reduced as (part) of the capacity is now unavailable. Here multiple scenarios related to the gap are possible:

1. The planned time of announcement i is equal to the lower bound of the corresponding gap (i.e. $t_{x_{g_L}} = t_i$). Here, two scenarios can take place:
    i. The handling time of announcement i is equal to the length of the gap, i.e. $\frac{c_i}{p_c} = t_{x_{g_U}} - t_{x_{g_L}}$. Then, gap $x_g$is totally planned and the gap is no more available. The gap x_g becomes gap x_{g+1}, gap x_{g+1} becomes gap x_{g+2}, and so on.
    ii. The handling time of announcement i is less than the length of the gap, i.e. $\frac{c_i}{p_c} < t_{x_{g_U}}$ - $t_{x_{g_L}}$. Here, the lower bound of gap x_g becomes equal to the end time of handling time planned barge: $t_{x_{g_L}}$= $t_i + \frac{c_i}{p_c}$.

2. The planned time of announcement i is not equal to the lower bound of the corresponding gap (i.e. $t_{x_{g_L}} \neq t_i$). Here, as well two scenarios can take place:
    i. The planned time plus the handling time of announcement i is equal to the upper bound of gap x_g: $t_i + \frac{c_i}{p_c} = t_{x_{g_U}}$. Then, the upper bound of gap x_g becomes equal to the planned time of announcement i: $t_{x_{g_U}} = t_i$.
    ii. The planned time plus the handling time of announcement i is not equal to the upper bound of gap x_g: $t_i + \frac{c_i}{p_c} \neq t_{x_{g_U}}$. Then, gap x_g is separated in two new gaps. Thus, the gap x_{g+1} becomes gap x_{g+2}, gap x_{g+2} becomes gap x_{g+3}, and so on. The two "new" gaps have the following new bounds:
        - Gap x_{g+1}: $t_{x_{g+1_L}} = t_i + \frac{c_i}{p_c}$ and $t_{x_{g+1_U}} = t_{x_{g_U}}$
        - Gap x_g: $t_{x_{g+1_U}} = t_i$

After updating the capacity availability the next announcement is assigned; this goes on until all released announcement are included in the berth plan.

11.4.2. Behavior of Barge Operators

Here, the rescheduling rules are elaborated concerning the impact of the behavior of the barge operators on the berth plan: cancellations and change requests.

DP3: Rescheduling of appointments due to a barge operator cancellation

Barge operators can freely, at any point in time, cancel an appointment with the terminal operator. A cancellation consist of information of the specific announcement i and is communicated by the barge operator a certain amount of time prior to the ETA of the barge arrival of announcement i, which is denoted by t_{i_c}. This time of cancellation is earlier than the planned time, i.e. $t_i - t_{i_c} > 0$. Based on the announcement information, it is known between which two gaps capacity becomes free. First, the multiple scenarios related to the gaps are discussed, and after that the rescheduling heuristics are presented.

The cancelled announcement i had a planned time that was planned somewhere between two gaps, as multiple barges can be planned in a row without intermediate gaps. These two gaps can be described by the upper bound and lower bound of respectively the gap before and the gap after the 'old' planned time of announcement i: $t_{x_{g_U}}$ and $t_{x_{g+1_L}}$.

DP3.1 Capacity Control

Comparable to the DP2, here as well multiple scenarios related to the gaps are possible:

1. The old planned time of announcement i is equal to the upper bound of the preceding gap (i.e. $t_{x_{g_U}} = t_i$). Here, two scenarios can take place:
    - i. The handling time of announcement i is equal to the time between the two successive gaps, i.e. $\frac{c_i}{p_c} = t_{x_{g+1_L}} - t_{x_{g_U}}$. Then, gaps x_g and x_{g+1} are merged and gap x_{g+2} becomes gap x_{g+1}, gap x_{g+3} becomes gap x_{g+2}, and so on. The merged gap x_g has the following bounds: $t_{x_{g_L}} = t_i$ and $t_{x_{g_U}} = t_i + \frac{c_i}{p_c}$.
    - ii. The handling time of announcement i is less than the time between the two successive gaps, i.e. $\frac{c_i}{p_c} \neq t_{x_{g+1_L}} - t_{x_{g_U}}$. In this case, the bounds of gap x_{g+1} remains the same, while the upper bound of gap x_g becomes higher: $t_{x_{g_U}} = t_i + \frac{c_i}{p_c}$.
2. The old planned time of announcement i is was later than the upper bound of the preceding gap (i.e. $t_{x_{g_U}} < t_i$). Here, two scenarios can take place:
    - i. The old planned time plus the handling time of announcement i is equal to the lower bound of the successive gap x_{g+1}: $t_i + \frac{c_i}{p_c} = t_{x_{g+1_L}}$. Then, the bounds of gap x_g remains the same, while the lower bound of gap x_{g+1} becomes lower: $t_{x_{g+1_L}} = t_i$.
    - ii. The old planned time plus the handling time of announcement i is not equal to the lower bound of the successive gap x_{g+1}: $t_i + \frac{c_i}{p_c} \neq t_{x_{g+1_L}}$. Then, the bounds of both gaps remain; however, a new gap between those gaps arises. Therefore, gap x_{g+1} becomes gap x_{g+2}, gap x_{g+2} becomes gap x_{g+3}, and so on. The new gap x_{g+1} has the following bounds: $t_{x_{g+1_L}} = t_i$ and $t_{x_{g+1_U}} = t_i + \frac{c_i}{p_c}$.

DP3.2 Re-planner

Due to the cancellation new capacity becomes available and can be used to reschedule other appointments in order to provide them with a planned time closer to their PTA. However, as assumed in Section 5.2, no rescheduling is possible in case a barge operator communicated the cancellation within two hours of the ETA. Therefore, two scenarios related to rescheduling can take place; these are described here, as well as the rescheduling rules:

- I. The time of cancellation is earlier than two hours prior to the ETA of announcement i (i.e. $t_i - t_{i_c} > 2$). Then, for each announcement with a planned time later then $t_{x_{g_U}}$, the lowest bound in the berth plan which (possibly) was adjusted, it is checked whether the announcement can be rescheduled to an earlier time. This is thus based on the adjusted (and new) gaps and this 're-planning' follows the same rules as DP2. However, one restriction is added which makes sure the re-planning movement is an improvement for the rescheduled announcement: $t_{i,new} < t_i$. If a re-planning movement was executed, the old planned time of the announcement i can be used for a new rescheduling cycle, which starts by adjusting the capacity as described in the beginning of this DP.

II. The time of cancellation is within two hours prior to the ETA of announcement i (i.e. $t_i - t_{i_c} \leq 2$). Here, no rescheduling takes place.

DP4: Rescheduling of appointments due to a barge operator request;

Similar to cancellations, barge operators can freely, at any point in time, request a change in their arrival time. A change request consist of a new PTA for a specific announcement i and is communicated by the barge operator a certain amount of time prior to the ETA of the barge arrival of announcement i, which is denoted here by t_{i_r}. This time is earlier than the planned time, i.e. $t_i - t_{i_r} > 0$ and furthermore, in case this announcement i is cancelled at a certain time, the change request is earlier than the cancellation ($t_{i_r} > t_{i_c}$). It is assumed that the appointment of an announcement of which the PTA is changed, is first removed out of the berth plan before the appointment is rescheduled. Therefore, the treatment of a change request is identical to that of a cancellation, as both the updating of gaps and rescheduling is done precisely in the same way as in DP3.

However, here, after rescheduling, the announcement which had the change request involved is re-planned into the berth plan. The p_i of this announcement i was updated and the announcement is treated as a new release to the scheduler and is therefore assigned to a berth identically as in DP2.

11.4.3. Terminal Disturbances

Here, the rescheduling rules are discussed concerning the impact of terminal disturbances on the berth plan: crane failures and barge capacity reduction.

DP5: Rescheduling of appointments due to a crane failure

After the arrival of a barge the barge is handled at the berth with a deterministic crane performance, as assumed in Section 5.2. However, due to crane failures, there is a certain probability that the handling of a barge gets delayed. In this model it is assumed that the crane failure is known at the start time of handling the specific barge. The duration until repair of the crane is known and thus the impact on the berth plan can be processed. Here, the rescheduling rules concerning a crane failure are explained.

A crane failure is associated with a specific announcement i and is thus known at the planned start time of announcement i. The duration until repair of the crane, t_r, can be seen as the extra handling time of the barge of announcement i. Possibly, this extra handling time causes conflicts in the berth plan; therefore, rescheduling rules are defined. Note that, as explained in the previous DPs, the information about capacity availability is known, as all bounds of the gaps are known. Furthermore, note that this rescheduling rule for berth 3 needs to be different than for berths 1 and 2, as berth 3 has a fixed daily block of unavailable capacity. Here, for both scenarios the heuristic is explained.

DP5.1: Crane Failures at Berth 1 and 2

Here, in three steps the rescheduling heuristic for berths 1 and 2 is given:

1. Determine the new (handling) end time of announcement i, $t_{i,end}$: $t_{i,end} = t_i + \frac{c_i}{p_c} + t_r$.
2. Indicate whether the planned time of the subsequent announcement i^* in the berth plan, t_{i^*}, is in conflict with $t_{i,end}$, i.e. $t_{i,end} < t_i^*$. If this is not the case, then stop rescheduling. Else, go to the next step.

3. The new planned time of announcement i^* is equal to the new end time of the preceding announcement: $t_i^* = t_{i^*,end}$ and thus, the new planned end time is: $t_{i^*,end} = t_{i^*} + \frac{c_{i^*}}{p_c}$. Now, use this end time as input for step 2.

DP5.2: Crane Failures at Berth 3

At berth 3, the rescheduling rule is adjusted due to the fact that there are daily unavailable capacity blocks in the berth plan. This means that step two and three of the heuristic above is changed in order to deal with this unavailable barge capacity. The adjustment is as follow:

i. Indicate whether $t_{i,end}$ is in conflict with either the subsequent announcement i^* in the berth plan, t_{i^*}, or with the lower bound of the next unavailable capacity block, t_{b_L}. In case $t_{i,end}$ is in conflict with one of these:
    a. t_{i^*} (i.e. $t_{i,end} > t_{i^*}$): The new planned time of announcement i^* is equal to the new end time of the preceding announcement: $t_i^* = t_{i^*,end}$ and thus, the new planned end time is: $t_{i^*,end} = t_{i^*} + \frac{c_{i^*}}{p_c}$. Now, use this end time as input for step i.
    b. t_{b_L} (i.e. $t_{i,end} > t_{b_L}$): The new planned time of announcement i^* is equal to the upper bound of the next unavailable capacity block, t_{b_U}.: $t_i^* = t_{b_U}$ and thus, the new planned end time is: $t_{i^*,end} = t_{b_U} + \frac{c_{i^*}}{p_c}$. Now, use this end time as input for step i.

Note that, in case the initial announcement with the crane failure has a new handling time that is longer than the time between two unavailable capacity blocks, this barge does not fit any more on berth 3. In that special case, this barge is planned on the earliest possible time at berth 1 or 2.

After rescheduling due to a crane failure, possibly new gaps in the berth plan have been originated. These are rescheduled based on the same rescheduling rules as in DP3.

DP6: Rescheduling of appointments due to a barge capacity reduction

Another uncertainty in the performance of the barge handling, are the terminal disturbances that do not contain a crane failure. These other disturbances can for example be originated due to late arrivals or delayed handling of sea vessels. This can be seen as a reduction of the barge capacity, which in this case only can take place at berth 3. In this model it is assumed that the capacity reduction is known at the middle of the unavailable capacity block. Furthermore, the length of the capacity reduction is known at that point in time. Thus, at that point in time, the berth plan needs to be re-planned.

A capacity reduction is associated with a specific unavailable capacity block with a lower bound, t_{b_L}, and upper bound, t_{b_U}. The capacity reduction length, t_c, can cause conflicts in the berth plan, as the upper bound of the unavailable capacity blocks is extended. Based on this new upper bound, $t_{b_U} + t_c$, it is determined whether the planned time of an announcements needs to be re-planned to this upper bound. Here, the same rescheduling rules apply as in DP5.1. However, in the case the capacity reduction overlaps with the next unavailable capacity block, also this block is moved downwards.

11.5. Appendix E: Selection of Allocation Rules

Table 16: The allocation of capacity (in hours) for different allocation rules

Rule	Group	Berth 1		Berth 2		Berth 3	
		Start	*End*	*Start*	*End*	*Start*	*End*
A	X	0	0	0	0	4	20,5
	Y	0	0	0	22	0	0
	X	0	24	22	24	0	4
B	X	0	0	22	24	4	20,5
	Y	0	0	0	22	0	2
	X	0	24	19	24	0	4
C	X	0	0	22	24	2	20,5
	Y	0	0	0	22	0	5
	X	0	24	19	24	0	8
D	X	0	24	0	24	0	20,5
	Y	0	24	0	24	0	20,5
	X	0	24	0	24	0	20,5
E	X	0	24	0	24	0	7
	Y	0	24	0	24	0	14
	X	0	24	0	24	0	20,5
F	X	0	24	0	15	0	0
	Y	0	24	0	24	0	3
	X	0	24	0	24	0	24

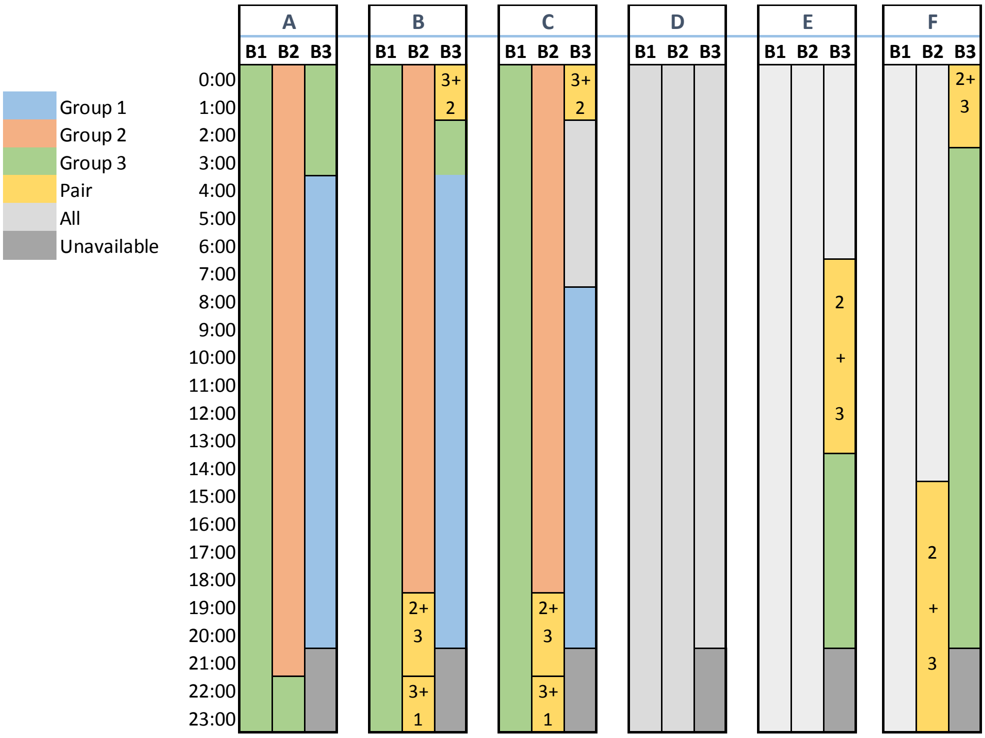

Figure 34: Graphical capacity allocation per berth (B1, B2 and B3) for each group

Table 17: Output results for the six allocation rules

Simulation output per allocation rule (3 runs)								
Rule	**Run**	N_M	$\bar{w}_X$	$\bar{w}_Y$	$\bar{w}_Z$	$\bar{w}$	$C\%$	$R\%$
A	1	3009	13,67	15,36	13,26	13,88	3,26%	1,38%
	2	3136	14,09	17,17	14,96	15,29	2,86%	1,74%
	3	3119	13,10	16,16	14,10	14,36	2,75%	1,25%
B	1	2146	3,87	16,77	14,64	12,56	3,21%	1,44%
	2	2348	4,61	17,78	16,48	13,86	2,96%	1,81%
	3	2238	5,54	18,63	16,38	14,28	2,86%	1,36%
C	1	2171	3,97	17,01	14,14	12,39	3,30%	1,44%
	2	2369	4,03	17,58	15,59	13,22	3,02%	1,75%
	3	2140	4,76	18,63	15,79	13,78	2,82%	1,38%
D	1	2096	2,63	12,30	18,79	13,28	3,34%	1,40%
	2	2171	3,27	14,21	20,46	14,68	2,99%	1,77%
	3	2198	4,61	14,92	20,47	15,21	2,84%	1,45%
E	1	2234	3,34	13,85	18,47	13,67	3,29%	1,41%
	2	2220	3,67	15,20	19,98	14,77	2,90%	1,85%
	3	2221	4,36	14,94	19,35	14,59	2,81%	1,43%
F	1	2237	2,97	14,75	16,29	12,69	3,34%	1,36%
	2	2420	3,74	16,88	18,64	14,53	2,97%	1,91%
	3	2327	4,21	16,85	17,95	14,31	2,91%	1,35%

11.6. Appendix F: Simulation Output To-be-1

Table 18: Output results in the PH-1 scenario

PH-1									
BI-1	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	2226,7	2155,0	2328,0	2339,0	2155,7	2484,7	2501,7	2193,0	2609,0
$\bar{w}_X$	4,25	3,51	3,64	4,40	3,97	4,39	5,41	3,96	4,47
$\bar{w}_Y$	17,74	13,81	16,16	15,63	13,17	14,86	18,98	14,90	16,46
$\bar{w}_Z$	15,17	19,91	17,63	17,63	22,40	20,49	16,84	22,59	20,17
$\bar{w}$	13,13	14,39	13,84	13,49	14,87	14,58	13,98	14,71	14,33
$C\%$	3,05%	3,05%	3,07%	3,26%	3,36%	3,35%	3,35%	3,36%	3,37%
$R\%$	5,32%	5,38%	5,39%	5,84%	5,76%	5,76%	5,79%	5,76%	5,75%
BI-2	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	1705,7	1720,7	1768,7	1785,7	1684,0	1935,3	1786,7	1682,7	1883,7
$\bar{w}_X$	3,90	3,08	3,40	4,81	3,49	3,51	5,33	3,76	4,11
$\bar{w}_Y$	17,75	13,50	16,79	19,40	14,39	16,45	19,79	14,17	16,78
$\bar{w}_Z$	15,44	19,93	17,12	15,50	21,21	18,58	15,25	21,29	18,95
$\bar{w}$	13,19	14,22	13,68	13,66	14,52	13,90	13,78	14,38	14,18
$C\%$	2,29%	2,30%	2,30%	2,27%	2,36%	2,35%	2,31%	2,42%	2,35%
$R\%$	4,63%	4,69%	4,65%	4,81%	4,82%	4,86%	4,81%	4,78%	4,82%
BI-3	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	1150,3	1162,3	1295,7	1249,0	1182,3	1316,7	1299,3	1190,3	1372,7
$\bar{w}_X$	3,67	2,76	3,03	4,43	3,28	3,12	5,67	3,74	3,70
$\bar{w}_Y$	18,12	12,98	16,21	19,59	14,09	16,23	22,87	15,16	17,51
$\bar{w}_Z$	15,58	20,48	18,62	15,49	22,32	19,27	14,81	23,63	19,75
$\bar{w}$	13,30	14,31	14,21	13,67	14,92	14,10	14,42	15,09	14,22
$C\%$	1,67%	1,72%	1,67%	1,69%	1,74%	1,69%	1,72%	1,73%	1,72%
$R\%$	3,57%	3,61%	3,61%	3,66%	3,66%	3,65%	3,78%	3,79%	3,81%

Table 19: Output results in the PH-2 scenario

PH-2									
BI-1	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	1601,0	1584,0	1814,0	1727,7	1565,0	1815,7	1765,0	1638,3	1979,0
$\bar{w}_X$	6,13	5,44	6,44	6,52	6,08	6,46	7,07	5,95	6,91
$\bar{w}_Y$	18,17	14,40	17,54	15,60	13,62	15,30	18,03	15,22	17,29
$\bar{w}_Z$	14,83	17,74	17,87	16,23	19,35	18,51	15,38	19,88	18,93
$\bar{w}$	13,51	13,91	14,99	13,42	14,18	14,36	13,61	14,30	14,80
$C\%$	2,33%	2,34%	2,39%	3,35%	3,35%	3,35%	3,39%	3,36%	3,40%
$R\%$	4,09%	4,28%	4,39%	5,75%	5,75%	5,75%	5,76%	5,78%	5,76%
BI-2	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	1277,7	1214,7	1398,7	1312,0	1208,3	1493,0	1362,3	1194,7	1483,0
$\bar{w}_X$	5,89	5,27	6,12	6,94	5,48	7,11	7,58	6,04	6,69
$\bar{w}_Y$	18,24	15,60	17,91	19,44	14,97	18,91	19,53	15,00	17,72
$\bar{w}_Z$	14,77	16,84	17,19	15,03	18,57	17,74	14,54	19,10	18,09
$\bar{w}$	13,44	13,72	14,65	14,03	14,02	15,21	14,03	14,31	14,81
$C\%$	1,72%	1,81%	1,77%	1,70%	1,81%	1,79%	1,76%	1,81%	1,84%
$R\%$	3,49%	3,25%	3,70%	3,72%	3,80%	3,76%	3,73%	3,78%	3,88%
BI-3	**STR-1**			**STR-2**			**STR-3**		
	C	*D*	*F*	*C*	*D*	*F*	*C*	*D*	*F*
N_M	836,3	809,3	1039,7	862,0	966,0	993,0	953,3	866,7	1063,7
$\bar{w}_X$	5,64	4,62	5,05	6,60	4,65	6,63	7,97	5,89	7,31
$\bar{w}_Y$	18,43	13,68	16,96	19,34	14,07	18,14	21,16	15,47	19,10
$\bar{w}_Z$	14,26	17,86	18,34	14,75	20,13	19,30	13,29	20,14	19,47
$\bar{w}$	13,17	13,60	14,75	13,84	14,31	15,58	13,99	14,44	15,67
$C\%$	1,24%	1,27%	1,42%	1,25%	1,46%	1,30%	1,34%	1,35%	1,39%
$R\%$	2,65%	2,70%	3,04%	2,75%	3,06%	2,85%	2,85%	2,96%	2,96%

11.7. Appendix G: Hypotheses

G.3 Hypothesis 3

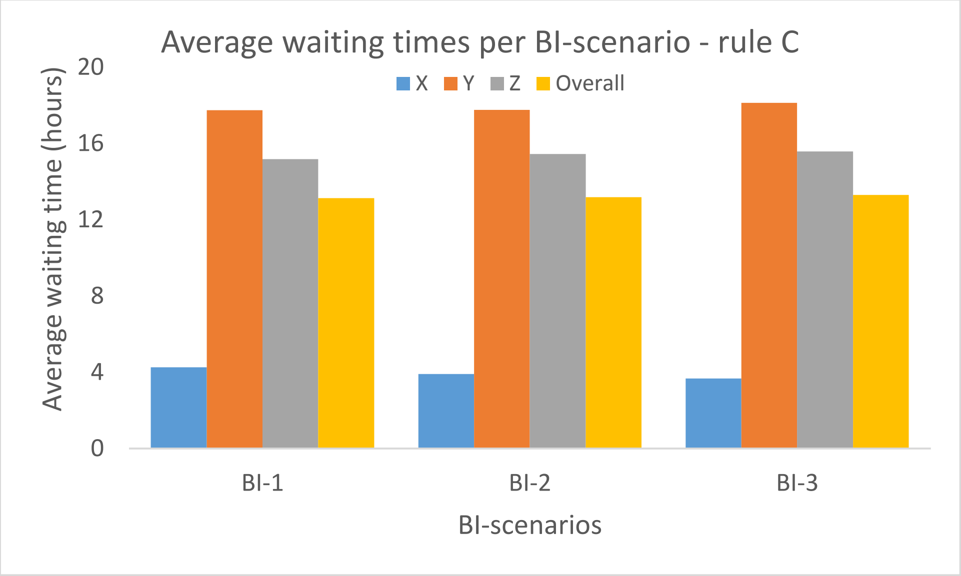

Figure 35: Average waiting times for rule C specified per BI-scenario. Scenario: PH-1 / STR-1

G.4 Hypothesis 4

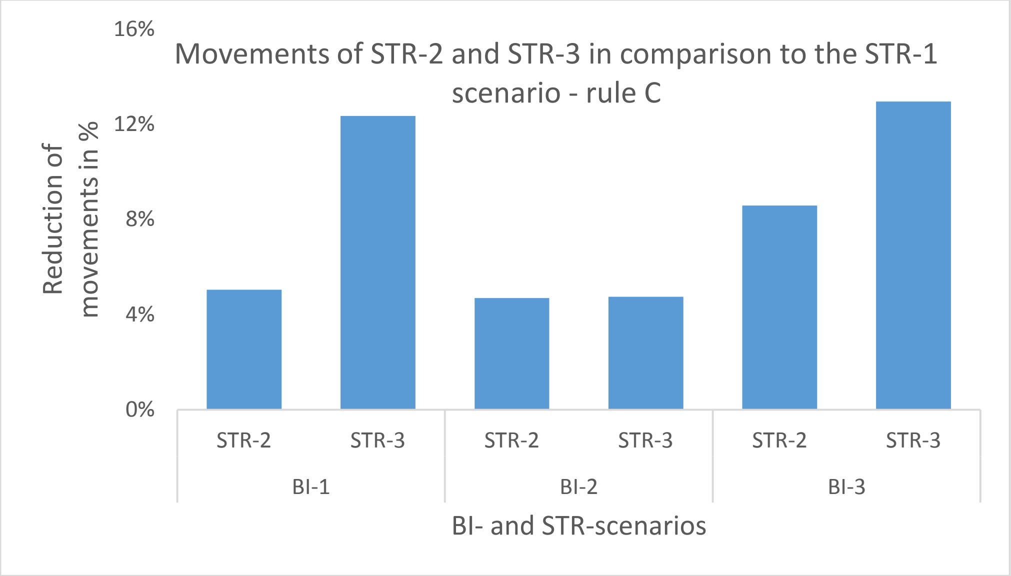

Figure 36: Movements per strictness and behavioral scenario for allocation rule C. Scenario: PH-1

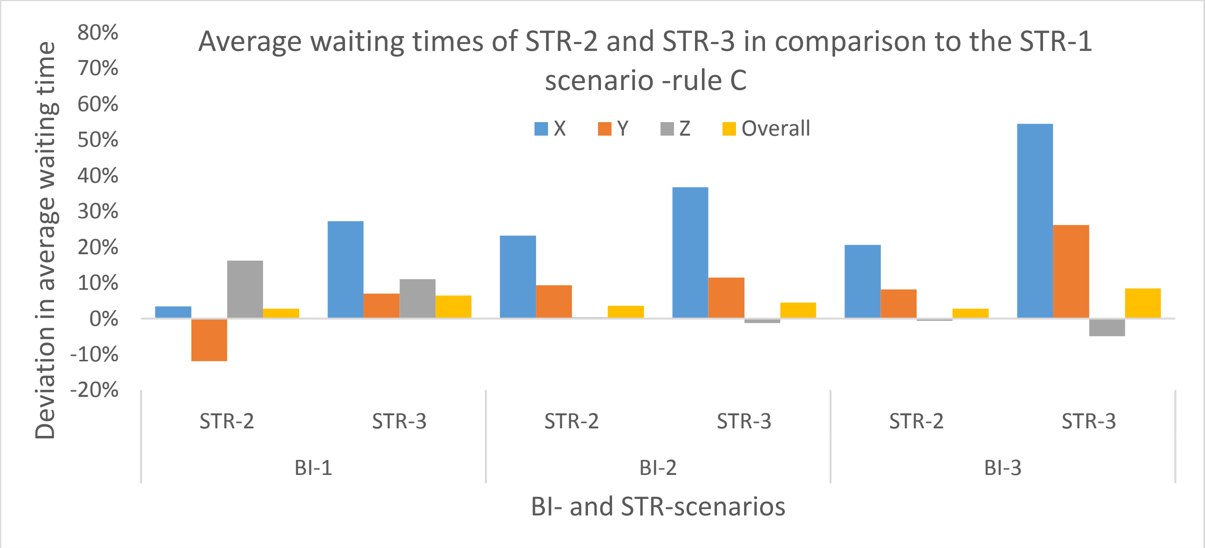

Figure 37: Average waiting time per strictness and behavioral scenario for allocation rule C. Scenario: PH-1

G.5 Hypothesis 5

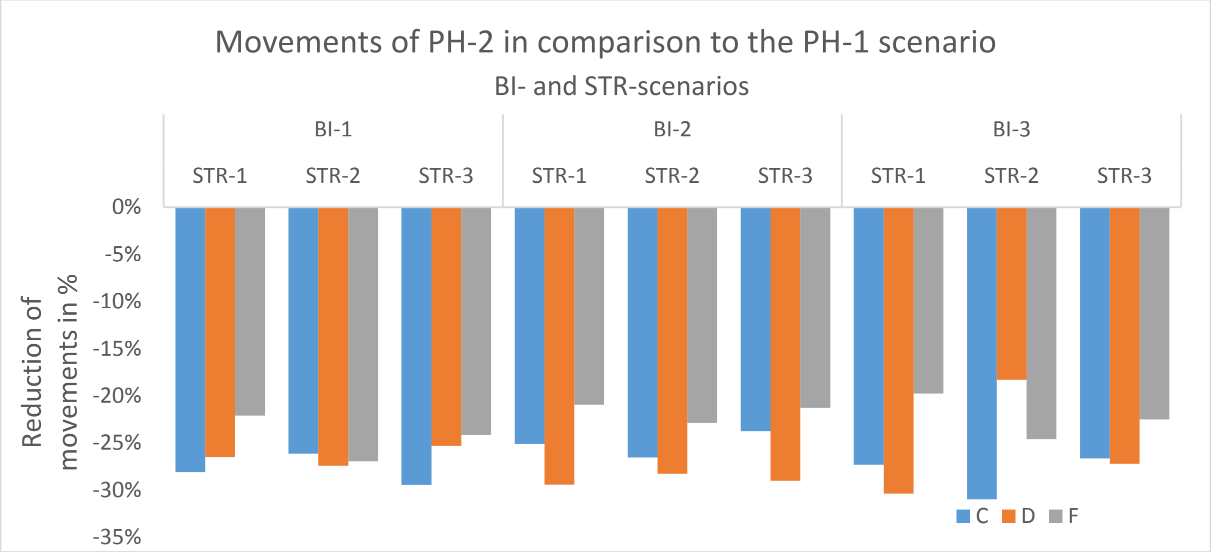

Figure 38: Workload comparison between PH-1 and PH-2

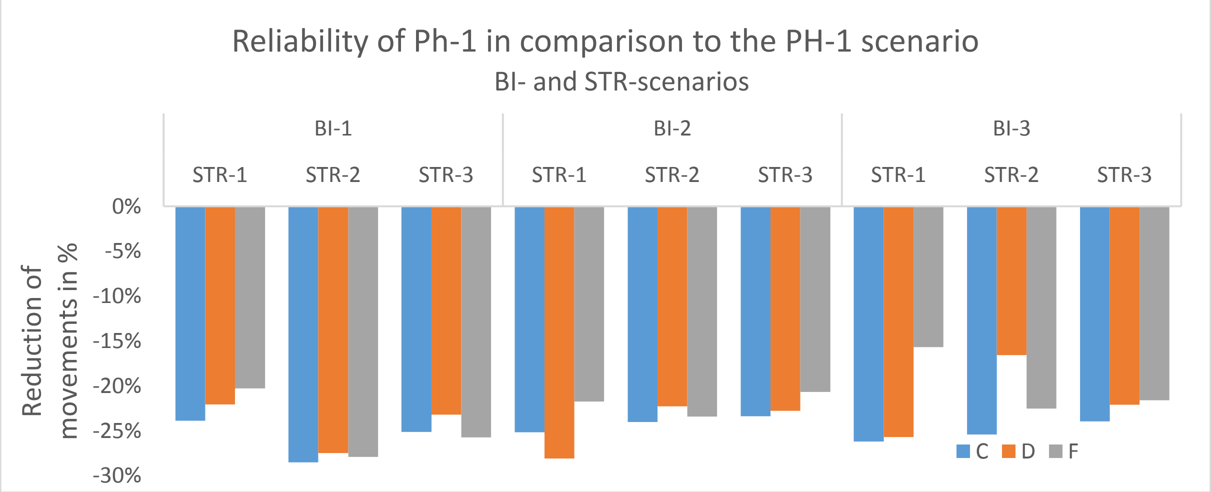

Figure 39: Reliability comparison between PH-1 and PH-2

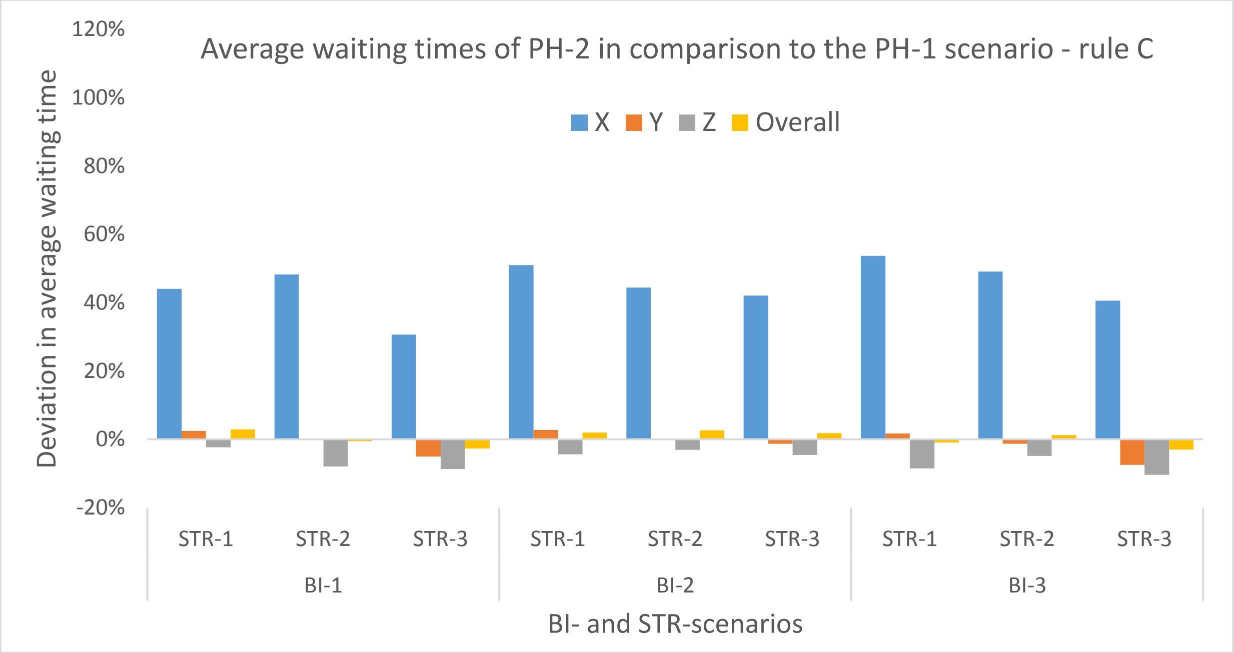

Figure 40: Average waiting time per strictness and behavioral scenario for allocation rule C. Scenario: PH-2

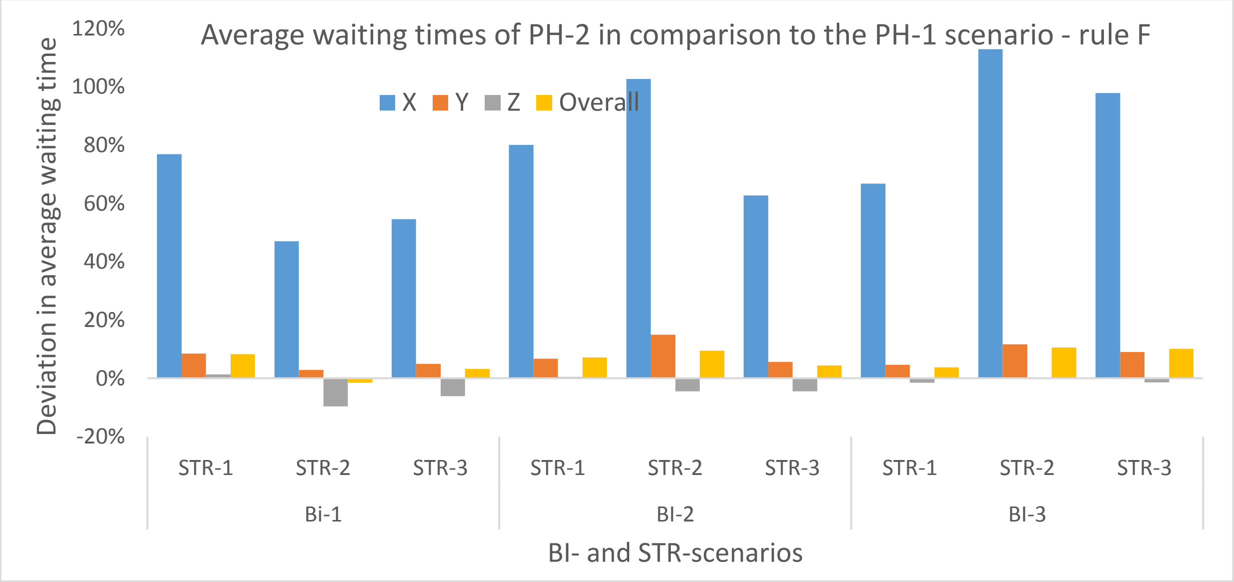

Figure 41: Average waiting time per strictness and behavioral scenario for allocation rule F. Scenario: PH-2

11.8. Appendix H: Best Redesign

Table 20: Average waiting time per design (note that these are the averages of the output of the BI-scenarios)

PH	Rule	STR	X	Y	Z	Overall
PH-1	D	STR-1	3,11	13,43	20,11	14,31
		STR-2	3,58	13,88	21,98	14,77
		STR-3	3,82	14,74	22,51	14,73
	F	STR-1	3,36	16,39	17,79	13,91
		STR-2	3,67	15,85	19,45	14,19
		STR-3	4,09	16,92	19,62	14,24
PH2	D	STR-1	5,11	14,56	17,48	13,74
		STR-2	5,40	14,22	19,35	14,17
		STR-3	5,96	15,23	19,71	14,35
	F	STR-1	5,87	17,47	17,80	14,80
		STR-2	6,73	17,45	18,51	15,05
		STR-3	6,97	18,04	18,83	15,09

Table 21: Number of movements per design (note that these are the averages of the output of the BI-scenarios)

PH	STR	D	F
PH-1	STR-1	1679,3	1797,4
	STR-2	1674,0	1912,2
	STR-3	1688,7	1955,1
PH-2	STR-1	1202,7	1417,4
	STR-2	1246,4	1433,9
	STR-3	1233,2	1508,6

Table 22: Reliability percentage per design (note that these are the averages of the output of the BI-scenarios)

PH	STR	D	F
PH-1	STR-1	6,92%	6,90%
	STR-2	7,23%	7,22%
	STR-3	7,28%	7,27%
PH-2	STR-1	5,22%	5,57%
	STR-2	6,41%	6,27%
	STR-3	6,34%	6,39%