MASTER

Simulating a hub network for container barging

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Simulating a hub network for container barging

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Abstract

This report describes the use of a hub in a container barge network. Currently, barges are severely delayed at container terminals in the Port of Rotterdam. Business is looking for new solutions to increase the performance of their barge networks. The use of a hub, where containers can be exchanged for a more efficient operation in the Port of Rotterdam, is put forward as one of these solutions. Based on a real-life data set provided by Brabant Intermodal, a subsidiary organisation of four inland terminal operators, a model was built in AIMMS that was able to simulate the current way of operating, and the proposed way of operating: a hub network. Both networks were analysed at the operational level, which involved constraints as opening hours of terminals, latest delivery times of containers, and delays in the Port of Rotterdam. The hub network is cost efficient in two situations. First, when the delays decrease by 75% because the hub is introduced, combined with a 25% more efficient handling at the hub. Second, a 50% more efficient handling at the hub is also sufficient. Furthermore, more capacity is created with less equipment, which can attract more cargo. The fact that the inland terminals become better connected makes it possible to re-use more empty containers. However, this requires network coordination and a more efficient terminal planning at the hub, which needs to be compensated by the benefits. This makes it a strategic decision whether to implement such a network or not.

Management summary

Introduction

In this thesis we analysed a network of container barges. Currently, these barges spend a large part of their roundtrips in the Port of Rotterdam. This is caused by the presence of many barges in the port area, which visit, on average, three to seven port terminals during a roundtrip. This leads to waiting times at these terminals. To be able to absorb the expected growth of container barging in the hinterland of the Port of Rotterdam, a better performance is necessary. One of the ways this can be accomplished, is by introducing a hub in a network of container barges. In a hub network barges sail via a hub, where containers are exchanged to decrease the port turnaround time. Currently, barges sail directly to the Port of Rotterdam and therefore have to stop at more terminals. In this thesis a part of the network of Brabant Intermodal is considered, existing out of inland terminals in Veghel, Waalwijk, Tilburg, and Oosterhout, all located in The Netherlands. The research objective in this thesis was stated as follows:

Research objective:
Design a barge network that has a better operational performance than the current network.

Designing the simulation tool

For the analysis of the hub network a model was developed in AIMMS. A real-life data set was transformed into a set with container movements so that the network could be tested with a case out of practice. The input for this model was the network of Brabant Intermodal, consisting of five inland terminals and seventeen barges. All the port terminals out of the set with container movements were included as well, and five of these terminals were modelled with a fixed delay, to simulate the problems currently faced in the Port of Rotterdam.

The model was designed in such a way that it was able to simulate the planning of container barges. Two networks, the current network and the hub network, could be tested in the model. The model consists out of a Vehicle Routing Problem with Pick-up and Deliveries and Time Windows, together with own-developed algorithms that arrange the allocation of containers and the dispatching of barges. There were two main performance indicators selected for the comparison: the percentage of late containers, and the costs per TEU (Twenty-foot Equivalent Unit; a common way for the measurement of containers). To be able to compare the networks more detailed, the tool also contained the fixed and variables costs of barges, handling costs, and the costs for last-minute trucking (whenever a container is delivered too late we assumed it would have been transported by a truck).

Designing the hub network

Oosterhout was designated as hub. In the BIM network this is the best location, because this terminal has no restrictions on its opening hours, all barges in the BIM network are able to sail to Oosterhout, it is located closest to the Port of Rotterdam, and there are two cranes that ensure an efficient handling of barges.

Savings in the Port of Rotterdam should compensate the time it takes to sail via Oosterhout. The largest savings that could be made are calling less at delayed port terminals, and making a distinction between the two sailing areas in the Port of Rotterdam (Stad and Maasvlakte 1, which are located 30 kilometres from each other). Based on the fact that for every four TEU to the Maasvlakte 1 area, there is only one TEU from or to the Stad area, while the Stad area consists out of more terminals, together with an analysis about the distribution of containers over the inland and port terminals, a design was made. In this design the sailing area the barge is dedicated to was set. For Stad barges, at most four terminals can be visited in a roundtrip, while Maasvlakte 1 barges are dedicated to one of the delayed terminals (ECT East, ECT North, Euromax, or APM). Besides this dedicated terminal, the barge is allowed to visit one of the other, non-delayed, Maasvlakte 1 terminals.

This design leads to a better use of barges, both by increasing the number of roundtrips as well as the utilisation. Because all barges will stop at Oosterhout, two of the three Oosterhout barges can be taken out of order. This leads to an expected saving of around €120.000, while the expected extra costs for handlings at Oosterhout lay around €60.000. These handlings are kept to a minimum by introducing allocation rules. For example the barge VOS60.2. Since Tilburg Vossenberg has barges that are dedicated to APM and ECT North, this barge will not load containers with one of these two terminals as destination. The other way around there are also allocation rules, which depend on the destination of containers. This same barge, VOS60.2, will for example not load containers with Waalwijk and Veghel as destination, to avoid unnecessary handlings at Oosterhout.

Barge	Dedicated inland terminal	Capacity (in TEU)	Dedicated sailing area	Dedicated port terminal
ITV28.1	Veghel	28	Stad	
ITV28.2	Veghel	28	Stad	
BTT32.2	Tilburg Loven	32	Stad	
BTT32.2	Tilburg Loven	32	Stad	
ROCW36	Waalwijk	36	Stad	
VOS44.1	Tilburg Vossenberg	44	Maasvlakte 1	APM
VOS44.1	Tilburg Vossenberg	44	Maasvlakte 1	APM
ROCW48.1	Waalwijk	48	Maasvlakte 1	Euromax
ROCW48.2	Waalwijk	48	Maasvlakte 1	ECT East
ITV52	Veghel	52	Maasvlakte 1	APM
VOS60.1	Tilburg Vossenberg	60 / 90*	Maasvlakte 1	ECT North
VOS60.2	Tilburg Vossenberg	60 / 90*	Maasvlakte 1	Euromax
ITV90.1	Veghel	90	Maasvlakte 1	Euromax
ITV90.2	Veghel	90	Maasvlakte 1	ECT East
OCT108.1	Oosterhout	108	Out of order	
OCT108.2	Oosterhout	108	Out of order	
OCT144	Oosterhout	108	Maasvlakte 1	ECT East

Table 1: Design of the hub network (: this barge has a capacity of 90 TEU between Oosterhout and the Port of Rotterdam)*

Analysis of the hub network

The performance of both networks was tested with a reference situation. This situation can be compared with the current situation in practice. The most important input for this situation was the container handling time at inland terminals (four minutes to move one container), the handling capacity at Oosterhout (two barges at the same time), and the delays in the Port of Rotterdam (200 minutes at APM, 300 minutes at ECT East, ECT North, ECT City, and Euromax).

Based on this situation the hub network underperformed. Whereas in the current network 4,8% of the containers were delivered too late and the costs per TEU were €40,70, the hub network had 9,2% of the containers delivered too late with costs per TEU of €47,29.

This high number of containers delivered too late was caused by queues at Oosterhout. The total waiting time at Oosterhout increased from 16 hours in the current network to 939 hours in the hub network. The quay at Oosterhout had an utilisation of 57,2% in the hub network, which caused these high waiting times, and led to more containers delivered too late. For a successful hub network, the efficiency of handling had to be increased.

For reaching this, there are two options to consider. First, when the situation in the Port of Rotterdam remains unchanged, the handling time has to decrease by 50%, to two minutes per container. In this case the number of containers delivered too late decreases to 4,8%, which is the same as in the current network. However, the costs per TEU decrease to €39,70, which is lower than the current network. A handling time of two minutes per container requires more efficient terminal operations, by dedicating cranes fully to barges when a barge is docked, and containers for barges that will arrive soon placed as close to the quay as possible. The second option is to consult the port terminal operators of the delayed terminals. Whereas in the current situation a large part of the BIM barges call at these terminals, with sometimes a low amount of containers, this decreases to one barge for ECT North and three barges for the other terminals, with more containers per call. This is preferable for port terminals, and therefore BIM can use this for bargaining better handling at these terminals. We assumed that in this case the delays will decrease by 75%. When this is combined with a decrease of 25% for the handling time at Oosterhout, to three minutes per container, 4,1% of the containers is delivered too late, and the costs per TEU are €39,82.

In both of these options there is one extra change necessary to reach these decreased costs per TEU. Currently, some of the barges are paid per roundtrip, and some are paid per week. Implementing a hub network leads to an increase in the number of roundtrips, and therefore an increase in the costs for barges paid per roundtrip. Depending on the exact situation, at least a part of the contracts of these barges have to be renegotiated so that these barges can also be paid per week.

The performance of both networks was also compared amongst several delay situations. The delay was set at 25%, 100% (which is the reference situation as described above), 200%, and 300%. For the hub network six settings were tested: handling times of two, three, and four minutes, and the ability to handle two or three barges at the same time in Oosterhout. For being able to handle three barges at the same time in Oosterhout, an extra crane is necessary, which increases the costs per TEU with around €1. The results of these test are displayed in Figure 1. Whereas the costs per TEU and the percentage of containers delivered too late increases exponentially with increasing delays in the current network, this increase is linear for the hub network, meaning that a hub network can better cope with increasing delays. The investment for an extra crane does not lead to enough savings, and therefore the improved handling is put forward as solution for the queues at Oosterhout.

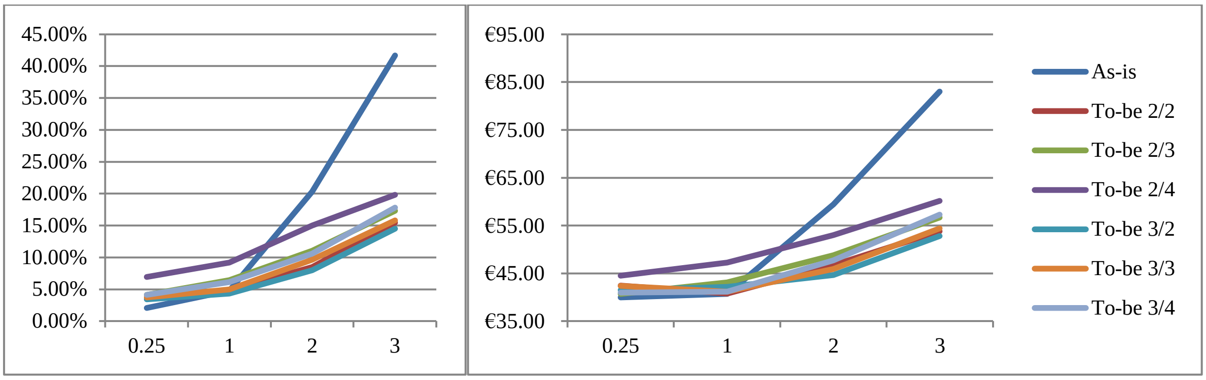

Figure 1: The percentage of containers delivered too late (left graph) and costs per TEU (right graph) for different settings. The horizontal axis represents the different delay conditions in the Port of Rotterdam, where 1 is the reference situation (as-is = current network, to-be X/Y is the hub network, where the number of barges that can be handled at Oosterhout is X, and handling a container takes Y minutes)

Conclusion

In academic literature, the hub network applied to container barging was never analysed at the operational level. We have shown that a hub network is still feasible at the operational level after some changes in the handling time at the hub, optionally combined with lower delays at port terminals. When the handling time per container at Oosterhout is decreased, and the hub network is used for bargaining a more efficient handling at port terminal, savings can be made and a better service level can be reached. Moreover, introducing a hub network also has side effects. First, all the inland terminals are connected via Oosterhout, which makes the re-use of empty containers easier. Re-using empty containers can save money, by decreasing the number of empty moves between the Port of Rotterdam and the inland terminals. Second, containers with its origin or destination in Antwerpen are currently transported by a barge that departs from Oosterhout. The hub network makes it easier to transport containers to and from Oosterhout, which can decrease the lead time for Antwerpen containers, and increase the number of containers transported by barge to Antwerpen. Last, the number of departures from inland terminals increases significantly (depending per situation and terminal with around 15 to 30%). This means more capacity is created with the same equipment, but also that the lead time of containers will be shorter, and ultimately extra cargo can be attracted, or containers that are transported by truck can be transported by a barge in the hub network.

Whether the extra effort for a hub network, caused by a need for an integrated network planning, and a more efficient operation at Oosterhout, is compensated by the positive effects is a strategic decision for BIM. Not all effects can easily be quantified, and BIM should decide if they are confident this new way of operating will lead to a competitive advantage in the future.

Preface

The report you are about to read is the product of six months of hard work on this project, in order to fulfil my master degree in Operations Management & Logistics at Eindhoven University of Technology. I hope you enjoy reading this thesis, but first I would like to express my gratitude to some people.

First of all, special thanks go out to my first supervisor Albert Veenstra. From the first time we met he helped me by choosing a decent subject, and he helped me by finding a company to write this thesis, which is one of the most important things that made the result of this project, at least in my opinion, a success. From the start of the literature review and throughout the thesis he provided me with useful feedback, while leaving organisation of the project to me. I also want to thank Dmitry Krushynskyi as my second supervisor, who always gave detailed feedback that helped me improving my thesis.

Furthermore, I would like to thank Ab Ovo for giving me the opportunity to write my thesis at this company. Thanks to Walter Kusters as initiator for the project, and as my company supervisor. I also want to thank Erik Stienstra, who was able to help me very good due to his recent graduation for the same master. Also, thanks to everyone else who helped me with their knowledge about container barging. The different projects the Ab Ovo consultants conducted in this sector helped me very much in the process towards this end product. I also want to thank all other people at Ab Ovo, even if they were not involved in the project. Thanks to all of them I had a great time at Ab Ovo. Special thanks go out to Ben van Rooy from Brabant Intermodal, who helped me by providing a data set and all other relevant information about their network.

At last, I would like to thank all my fellow students, friends, and family, who have always been a great support to me. This thesis is not only the end of my project, but also the closure of a very special period in my life, were I have studied in Groningen, Eindhoven, and even the United States of America. I met loads of nice people and had unforgettable experiences. I can say that it has been an amazing period of my life.

Bas de Vries

Amsterdam, August 2015

List of abbreviations

AIMMS: Advanced Interactive Multidimensional Modelling System

BIM: Brabant Intermodal

BTT: Barge Terminal Tilburg Loven

D&D: Demurrage and detention

ITV: Inland Terminal Veghel

OCT: Oosterhout Container Terminal

PoR: Port of Rotterdam

ROCW: Regionaal Overslagcentrum Waalwijk

TEU: Twenty-foot Equivalent Unit

VOS: Barge Terminal Tilburg Vossenberg

VRP: Vehicle Routing Problem

VRPPD: Vehicle Routing Problem with Pick-up and Deliveries

VRPPDSTW: Vehicle Routing Problem with Pick-up and Deliveries and Soft Time Windows

VRPSTW: Vehicle Routing Problem with Soft Time Windows

List of definitions

Barge: a vessel specifically designed to sail on inland waterways.

Barge operator: a company that owns or hires several barges and provides them to other companies.

Call: visiting a terminal for loading and/or unloading cargo.

Container: a large box, where goods can be placed in, which can be moved from one place to another on a ship, barge, train, or truck, due to its universal design.

Container barge: a barge specifically designed or adjusted to transport containers.

Hinterland: the area where the origins and destinations of the main port users are located.

Hinterland transportation: transportation in the hinterland performed by a truck, barge, train, or a combination of these three modes.

Hub network: a network with a hub. At the hub (a part of) the cargo is unloaded and other cargo is loaded, in order to be more efficient.

Inland terminal: a terminal in the hinterland, where containers are temporarily stored, and can be exchanged between different modes of transportation. Inland terminals are accessible by truck, and almost always by barge or train, or both.

Inland terminal operator: the company that operates the inland terminal.

Intermodal transportation: a type of multimodal transportation, where the load, an intermodal transportation unit like a container, is transported from its origin to its destination without handling of the goods themselves when changing modes.

Multimodal transportation: the usage of at least two different modes of transportation when transporting goods.

Port turnaround time: the total time a barge spends in a port during a roundtrip.

Roundtrip: the total trip from the inland terminal where the barge is loaded, when applicable via other inland terminals, to the port, and back to the inland terminal, when applicable via other inland terminals, where the barge is unloaded.

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1. Introduction

1.1. Introduction to the project

The container throughput in the Port of Rotterdam (PoR) is growing, and the outlook for the coming years is positive. This puts pressure on hinterland transportation, where currently trucks transport most of the containers. Trucks are affected by traffic jams, and this mode of transportation is expensive and creates more emission of CO_2 than the train or barge. Governmental and port regulations, and also more consciousness by companies that there should be a focus on more climate friendly transportation, make that the share of train and barge transportation will grow. These modes, which are in general slower but cheaper than trucking, need to improve their performance to be able to absorb the expected growth.

At this moment the barge is subjected to high delays in the PoR. This forces consignees to (temporarily) make use of trucking (Logistiek.nl, 2014), and it leads to more unplanned trucked containers (Schuttevaer, 2015). Whilst there is put huge effort by the PoR to align hinterland operations with the port operations, a part of the required performance improvement should be reached by better arranged operations in the hinterland.

Most of the inland terminals have their own barge services to the PoR. With around 25 inland terminals with barge connections in The Netherlands (Inlandlinks, 2015), and other terminals with connections to the PoR outside The Netherlands, this leads to a high number of barges that call at the different terminals in the PoR during a day. The latest figures show that the number of calls during a roundtrip in the PoR keep growing (see Table 2), and the port turnaround time fluctuates around 28 hours (Nextlogic, 2015). A concept that is put forward as a solution for this inefficiency is the use of a hub. At a hub containers can be exchanged to make better use of equipment, avoid delays, and ultimately decrease delays in the PoR.

To examine whether this concept is (a part of) the solution to the congestion in the PoR, this project was conducted at Ab Ovo in close cooperation with Brabant Intermodal (BIM). These companies will be described in the next section. After this, in Chapter 2, a summary of the literature review, conducted as a preparation for this project, will be provided. In Chapter 3 the outline of the thesis will be explained by setting the research design.

Barge length	2012	2013	2014
Smaller than 86 metre	2,5	2,4	3,0
86 – 111 metre	4,4	4,7	5,8
Larger than 111 metre	5,6	5,8	7,0

Table 2: The average number of calls during a roundtrip in the PoR (Nextlogic, 2015)

1.2. Company descriptions

1.2.1. Ab Ovo

Ab Ovo is a business and software solutions provider, with expertise in the areas of logistics and advanced planning & scheduling. The company is mainly active in the rail, maritime, and freight forwarding sectors, and provides companies in these sectors with planning systems and consultancy. The company has a broad experience in the maritime sector, from ocean shipping to barging, and from barge operators to inland terminals. Besides this, the company is actively involved in governmental programs that want to make the barging sector more efficient, to be able to absorb the expected growth in container throughput and goals that have been set by the Port of Rotterdam and the European Commission. Therefore this is a good company for this project. Ab Ovo has offices in The Netherlands (Capelle aan den IJssel (headquarters) and Amsterdam) and Germany (Düsseldorf).

1.2.2. Brabant Intermodal

BIM is a subsidiary company of four inland terminal operators with seven terminals in the southern part of The Netherlands. The company focusses on improving customer service by collaboration between the terminals. An example of a result of the collaboration, is the exchange of empty containers between the inland terminals. In this way a lot of empty container moves between the ports of Antwerp and Rotterdam and the inland terminals are saved. This collaboration is a good starting point for the project, since willingness for cooperation should exist. BIM provided a data set that could be used during this project.

2. Literature review

Before the project was started, a literature review about container barging was performed. In this section a summary is provided with the relevant information for this project.

2.1. Introduction

In recent history we noticed an increase in the attention towards container barging. This is mainly driven by the problems larger ports are facing, like congestion and pollution in the port area, and delays at port terminals (Veenstra et al., 2012). It is believed that the barging sector can be a part of the solution. In parallel with this we see that hinterland connections are becoming more important (Fransoo & Lee, 2013). This is driven by the goals of governments and ports, the increasing required reliability of connections, and an increased awareness of the climate and costs of transportation.

However, the barging sector itself is facing some problems as well. The barges are part of the congestion problem in the port, and suffer from it. Barges have to call at many port terminals, which increases waiting times at these terminals and the port turnaround time. One of the concepts that has received more academic interest in the past decade is the consolidation of goods, merely executed by the hub-and-spoke concept. This concept contributes mainly to the problem of the high amount of calls at port terminals, which is one of the reasons for congestion in the port. By transhipping the containers at a consolidation point, the number of calls for individual barges as well as for the network can be decreased.

2.2. Container transportation and barging

Since the container was introduced in the 1960s, nowadays 90% of the non-bulk cargo is transported in containers (Ypsilantis et al., 2014). The total trade volume in 2012 was 155 million TEUs (United Nations, 2013), and a further growth is expected. Because the container standardises the form of goods that have to be transported, it is encouraged to use multimodal transportation. In this way costs, congestion, and emissions are reduced (Fazi, 2014).

The PoR reported a total throughput of 12,3 million TEUs in 2014 (Port of Rotterdam Authority, 2015d). After some years of a decrease, an increase could be reported over 2014 (see Figure 2), and a further increase is expected. The PoR expects the share of containers in its total throughput will increase from 24% in 2010 to 42% in 2030, and an increase in the container throughput itself of 100 to 200% by 2030 (Port of Rotterdam Authority, 2011). This growth will have a huge impact on the hinterland connections.

In container transportation most bottlenecks exist in hinterland transportation. We notice a need for coordination in the hinterland because of these bottlenecks, and because of the high costs of hinterland transportation. Between 40 and 70% of the total transportation costs exist of the costs for hinterland transportation (Fazi, 2014). Moreover, the consolidation of containers in the hinterland is difficult, because of the different destinations and the importance of on-time deliveries. Therefore the truck is still used a lot as buffer solution (Fazi, 2014). In the PoR, in 2013 54,6% of the containers were transported by truck, 34,8% by barge, and 10,7% by rail. The goals of the PoR are to have at most 35% transported by truck and around 45% by barge by 2030 (Port of Rotterdam Authority, 2011). This modal split over the last years and the goal for 2030 can be found in Figure 3.

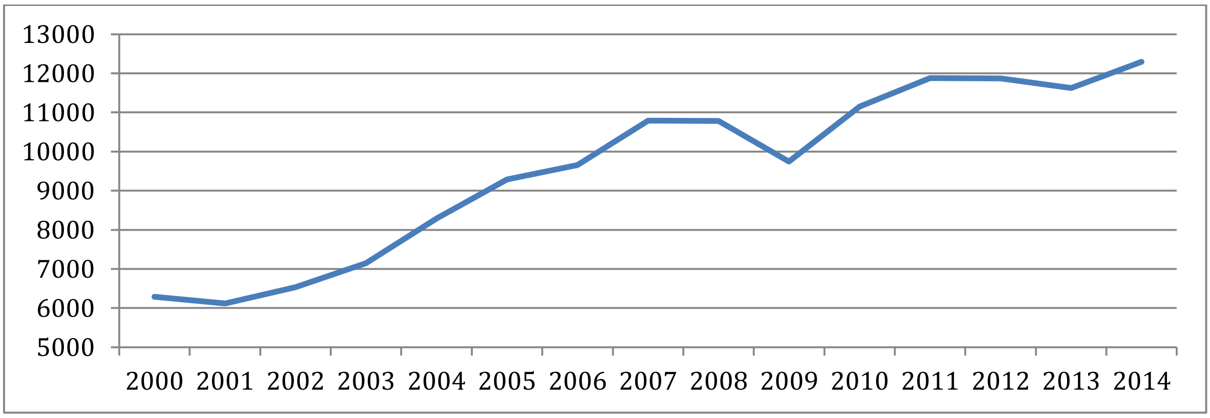

Figure 2: The throughput of containers in the PoR, in TEUs (x 1.000) (Port of Rotterdam Authority, 2015a)

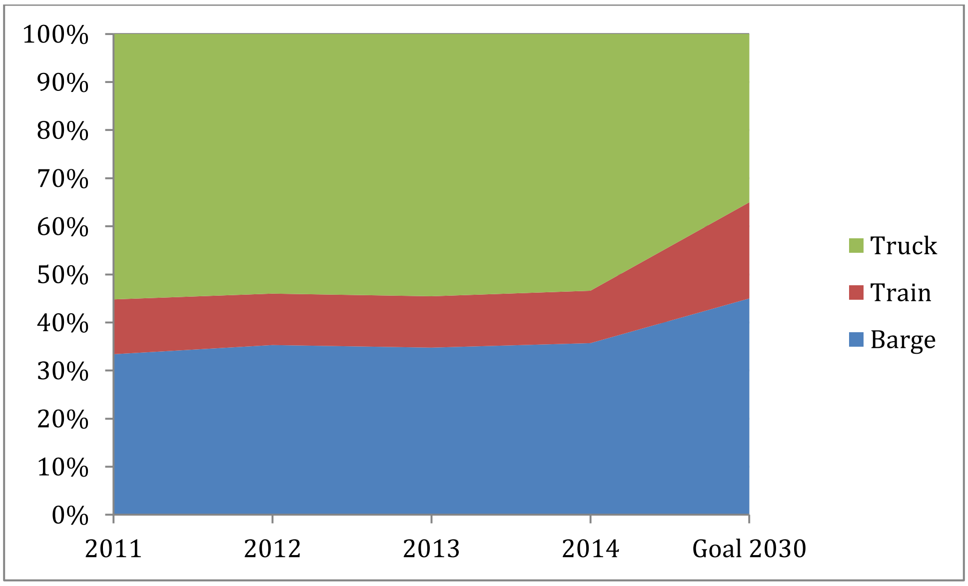

Figure 3: The modal split in the PoR (Port of Rotterdam Authority, 2011, 2015d)

The container barging sector needs to improve its performance in the coming years, to be ready for the change in modal split, and the further growth in container throughput in the PoR (Konings et al., 2013). A relatively high share of barges in container transportation and growing volumes lead to problems with the handling of barges of the PoR (Douma et al., 2011). The barges have a high port turnaround time (Konings et al., 2013), which has different causes. Barges have to call at many terminals during a trip in the port: on average eight terminals (Ypsilantis et al., 2014). A lot of these calls are small when looking at the number of containers transhipped. At different terminals the fraction of call sizes smaller than 11 container accounted for 8 to 54,3% of the total number of calls (Nextlogic, 2014). Since all these barges call at the same terminals, the waiting times are long (Fazi, 2014). Moreover, sea-going vessels receive priority at the terminals. Measurements have shown that 59% of the starting times of handling at port terminals deviated by more than two hours compared with the planned starting time (Konings et al., 2013). Barge operators plan large buffers in their schedules to absorb these inefficiencies. The hub-and-spoke network can be a solution for this problem, since the concept can lower the amount of calls per roundtrip, and therefore the uncertainty.

2.3. Planning levels

In intermodal planning literature there is in general a distinction made in operational, tactical, and strategic models. However, a minority of the models consider barging and there is no consensus on the three levels. For this reason we came up with a possible way of distinguishing models.

Operational planning consists of the specific scheduling and planning of cargo and barges (which will be a roundtrip planning or week planning), the exact placement of cargo on the ship (for both the balance of the ship, and avoiding unnecessary movements at terminals), the specific schedules (including expected departure and arrival times at port terminals), and day-to-day adjustments of schedules due to events like a delay. One important characteristic of operational planning models is that the exact loading is known, in contrast with strategic and tactical model where demand patterns, historical data, or forecasts are used. This is also the reason we consider the model of Sharypova (2014) as operational.

2.4. Hubs in hinterland container transportation

A hub-and-spoke network can be defined as follows: "*one node is designated the hub, and all transports call this node for transfer, even for transports between adjacent origins and destinations*" (Woxenius, 2007, p. 795). Such a network is shown in Figure 4. However, the application of hybrids of designs is common. When we apply the concept to container barging, we are looking at barges that pick-up containers at one or more terminals in the hinterland, and after that drop off and pick up all or a part of the containers at the hub. After this the containers are transported to the port terminals

(Konings et al., 2013; Konings, 2006; Kreutzberger, 2001; Notteboom, 2008; Pielage et al., 2007). By reallocating the containers in a proper way one can lower the amount of terminals visited. A design of applying this network can be found in Figure 5.

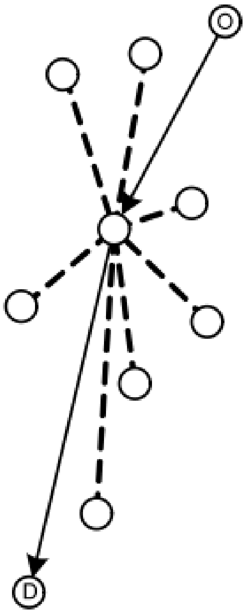

Figure 4: Hub-and-spoke network design (o: origin, d: destination. Source: Woxenius (2007))

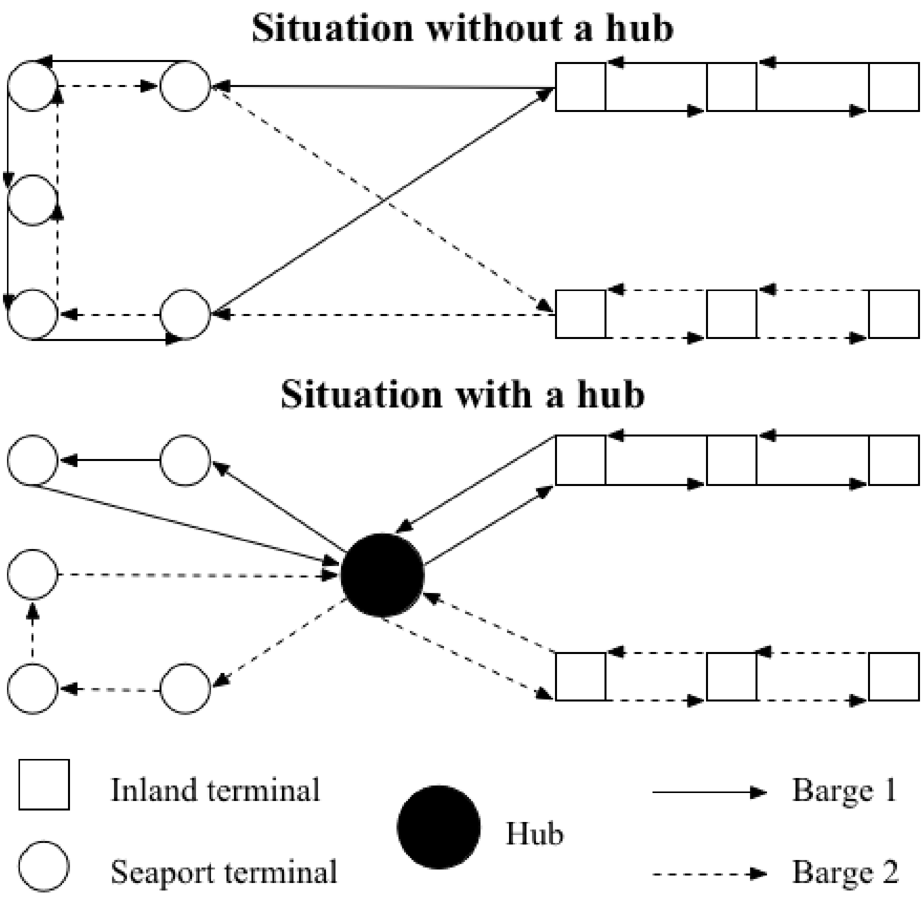

Figure 5:A possible hub-and-spoke design for a container barge network

We found six articles that have hub-and-spoke networks in container barging as their main subject. We summarized all advantages and disadvantages of the hub-and-spoke network, and these can be found in Table 3 (Fu et al., 2010; Konings et al., 2013; Konings, 2006; Kreutzberger, 2001; Notteboom & Rodrigue, 2009; Pielage et al., 2007). One should be careful when interpreting these (dis)advantages, because these are very dependent on the way the network is operated. However, the (dis)advantages should be taken into account when designing a network.

Advantages	Disadvantages
Reduction in total fixed handling time	Need for extra storage capacity
Shorter turnaround time	Extra handling costs and waiting times at the hub
Higher frequencies	Investments needed
Higher loading degrees	Detours
Shorter waiting times	More transportation units needed
More reliable service	High, unnecessary, peak capacities
Better performance of ports	Vulnerable to disruptions
Reduction in containers waiting time	Organisational barriers for implementation
Extra revenue for different actors	
Sustainable and safety benefits	

Table 3: Advantages and disadvantages of hub-and-spoke networks in container barging

Types of operations can be distinguished on how the barges are sailing and how the cargo is exchanged. Barges can sail *on-going*, which means they stop at the hub to exchange cargo, and after that continue to the final destination, and *dedicated*, which means all containers are unloaded at the hub, containers are loaded again at the barge and it returns to its origin location. A *mixed* form is also possible.

The exchange can be done *simultaneous* or *sequential*. With simultaneous exchange two barges are present at the hub and containers are exchanged between these two barges. When using sequential exchange, a barge can only load containers of a barge that arrived earlier and unloaded the containers, and it can only unload containers for a barge that will arrive later on. The actual exchange of containers can be done *horizontally* or *vertically*; the first way implies the use of push barges whereas the second way means the use of cranes or reach stackers. Push barges are barges that are pushed by a motor vessel. This means that several transportation units can be pushed by one motor vessel, and these transportation units are exchangeable. Therefore this is called horizontal exchange, because the units will be exchanged via the water. With vertical exchange this is not the case; the containers are lifted from the barge and placed on another barge. This is done by a reach stacker, which is a truck that can lift containers, or a crane, which are large machines that usually move over rails, and can lift the containers.

Hub-and-spoke applied to container barging did not receive a lot of academic interest in the past years. The papers that are present are mainly focussed on strategic and tactical decisions, like the location of the hub. Besides this, some papers also globally calculate the costs of these networks. It is difficult to compare these papers, since there are a lot of ways to operate such a network. In general we noticed that these networks can be cost efficient. However, no one has looked at this from an operational level. Operational decisions consist of, at least, the disposition of transportation equipment, and the planning of the exact tours for transportation units. Three important details in container hinterland transportation that are present on an operational level are the time slots of containers (for pick-up and delivery), the opening hours of terminals, and the delays at port terminals.

Before moving on to the research questions that will be based on the gap we found in literature, we will clarify the definition of hub-and-spoke for the remainder of the thesis. Real hub-and-spoke networks do not exist, and especially not in container barging. When we would apply the network as shown in Figure 4 to container barging, some of the flows from the hub to a port terminal would be too small (a few containers), to be transported dedicated by one barge. The flows in these inland networks are distributed in such a way that combining flows is necessary. Therefore such a network applied to containers barging needs to be called a hybrid hub-and-spoke network. However, for the remainder of this thesis we will refer to such a network as a *hub network*, which means no more than, at least a part of, the containers will be exchanged at a hub, with the goal to be more cost efficient.

3. Research design

Depending on the case, it is already shown whether a hub network can be beneficiary or not. However, this was mainly on strategic and tactical levels. At the operational level there are more constraints that have to be taken into account, for example the latest delivery time (closing time) of containers, and the opening hours of terminals. Therefore the objective of this thesis is to design a new barge network that has a better performance at the operational level:

Research objective:
Design a barge network that has a better operational performance than the current network.

When analysing a hub network, a reference situation is necessary to be able to compare the hub network to the current situation. For the remainder of this thesis, the current network is referred to as *as-is situation* or *as-is network*, while the hub network is referred to as *to-be situation* or *to-be network*. The as-is network will be simulated so that we are able to compare it to the to-be network. First, it should be known how the performance of such networks can be compared, and after that the design of the simulation needs to be set:

Research question 1:
How is the performance of a container barge network measured?

Research question 2:
Can the performance of the as-is network be simulated in a realistic way?

When the reference situation is known, and the indicators for comparing the networks are set, the to-be network will be set. In Chapter 2 we showed that there are several designs possible for a hub network. Therefore, a hub network will be designed, and the performance will be compared with the as-is network:

Research question 3:
Can a to-be network be designed that has a better performance than the as-is network?

These research questions are answered as follows. In Chapter 4 the as-is network is analysed, by describing the physical network (terminals), equipment (barges and terminals), the way of planning, and difficulties in planning. This will be used as input for answering the first two research questions. Furthermore, the data set from BIM is analysed and transformed into a set that will be used during the simulations. Chapter 5 describes the design of the as-is simulation. The different delay conditions that will be simulated are set, and the performance indicators to compare the different situations and networks are described. Furthermore, the technical design is described, and the output, which will be the reference situation, will be analysed. In Chapter 6 the design and analysis of the to-be network is performed. The way of operating this network is set based on an analysis. Changes to the simulation will be discussed, and the output, based on the reference situation, will be analysed. In Chapter 7 the two networks will be analysed across the different situations. This is the main part of the thesis, where the question will be answered whether it is operationally still feasible to operate a hub network. In Chapter 8 we will conclude on the research, by forming a discussion, conclusion, and possibilities for further research. A representation of this research design can be found in Figure 6.

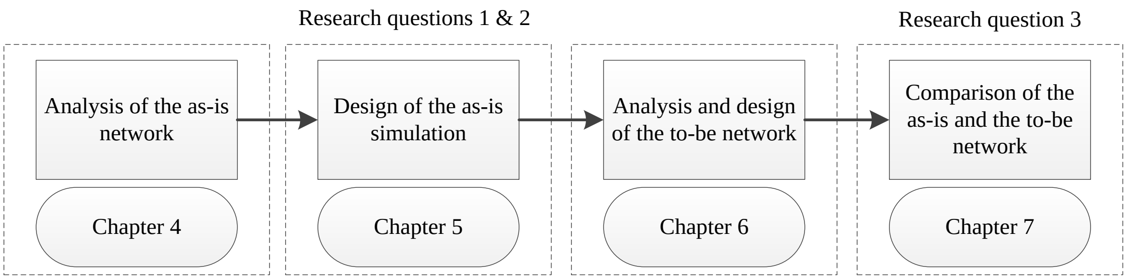

Figure 6: Research design

4. Analysis of the current network

In this chapter the BIM network, and the planning of barges is analysed, which will be used in the next chapter for designing the simulation. This is done by describing the network in Section 4.1, and the way of operating, including all relevant details about terminals, barges, and waterways, in Section 4.2. In Section 4.3 the data set will be analysed and transformed to form a reliable and usable set. All data presented in this chapter are gathered by interviews with experts in the field of container barging. The source of specific data in this chapter can be found in Appendix B.

4.1. Network description

When looking at the network of BIM, this can be split up in three categories of terminal locations, namely inland terminals if BIM, PoR terminals, and Antwerpen terminals.The latter one, the Port of Antwerp and its terminals, are out of scope for this project. We are focussing on the PoR for two reasons. The congestion is the most constraining in the PoR. Furthermore, most of the containers (more than 95%) transported from or to the BIM terminals have their origin or destinations in the PoR.

The BIM network consists of seven inland terminals, of which five are located in a way that it is interesting to look at a hub network is this area, because the terminals are located close to each other, and the barges sail (almost) via the same route to the PoR. The terminals we take into account all have the possibility for barging and trucking. The five terminals are:

- Veghel
- Tilburg Loven (east side of Tilburg)
- Tilburg Vossenberg (west side of Tilburg)
- Waalwijk
- Oosterhout

The Tilburg Loven terminal also has a rail yard, which adds the option for transporting containers by train. However, since we focus on container barging in this thesis, we will not take this flow of containers into account. For this same reason we will also not take the containers that are trucked into account.

The Port of Rotterdam (PoR) consists of around 30 container terminals and empty depots, which are located in four areas; Maasvlakte 1, Maasvlakte 2, Botlek, and Stad. Maasvlakte 2 is a recently built part of PoR, which is still not fully operational. Because there is no data for the terminals in this area, the Maasvlakte 2 is out of scope for this thesis. The total overview of the network can be found in Figure 7 (Moerdijk is not part of the PoR, but BIM sometimes has to pick-up or deliver containers in Moerdijk).

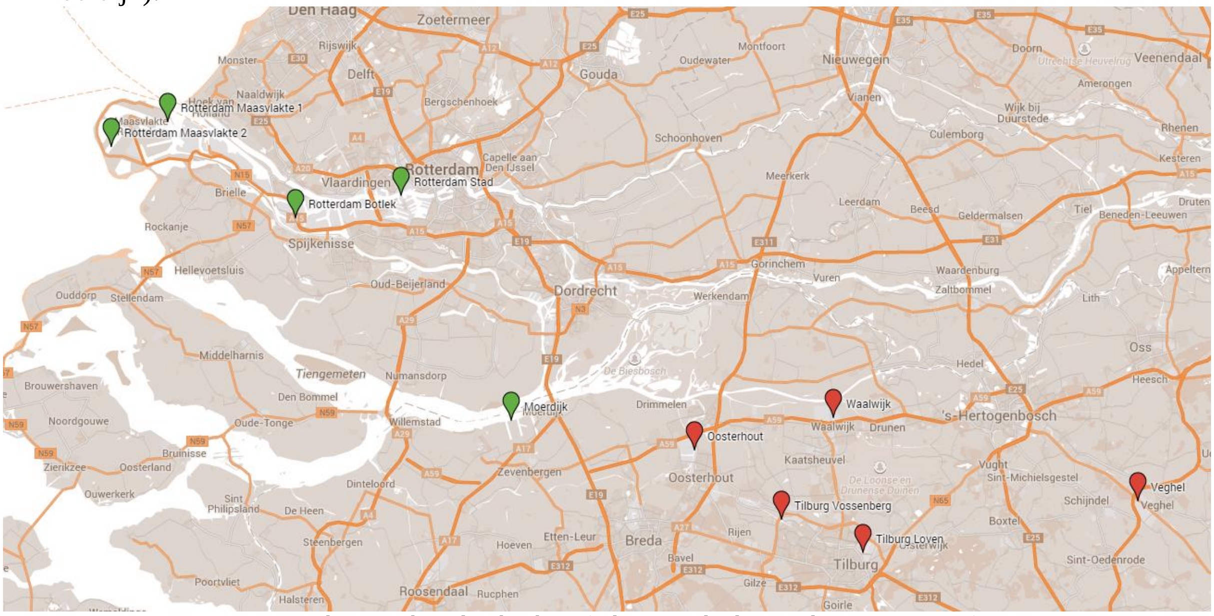

Figure 7: The network used in this thesis (red = BIM inland terminal, green = port area)

4.2. Current way of operating

In this section the current way of operating will be described. There are a lot of factors that influence or determine the planning of containers barges. First, a general description of container barge planning will be given, followed by a more extensive explanation about barges, inland terminals, port terminals, last-minute trucking, and waterways.

In the current situation the inland terminals have dedicated barges. This means barges sail in a so-called point-point connection from the inland terminal to the PoR and back. Containers have different origins, destinations, earliest pick-up times, and latest delivery times. All these factors have an influence on the possible planning of a barge. There is a distinction made between import and export containers.

Import containers are containers that are loaded with goods and need to be delivered to a customer close to the inland terminal. The pick-up place in the PoR is one of the container terminals. There is a theoretically first pick-up time, which is some time later than the arrival of the sea-going container vessel. The problem with planning is that this theoretic first pick-up time is not always the real first pick-up time. It can happen that the sea vessel is delayed, the customer has not paid the fees to the owner of the container, customs have not released the container yet, and other factors make the container is not yet released for pick-up. This means that uncertainty already forms a barrier for a good planning. Moreover, containers have different pick-up terminals, so barges have to call at several terminals during a roundtrip in the PoR.

Export containers are containers that are filled with goods and need to be delivered in the port. The delivery place is one of the container terminals, and the latest delivery time is 24 hours before the departure of the sea-going vessel that will deliver the container overseas. Besides these import and export containers, there are also empty moves: the movement of an empty container. An inland terminal operator will try to re-use containers where possible. This is possible when an import container is transported to the customer, and delivered empty at the inland terminal. This empty container can be used by another customer of the inland terminal as an export container. Whether this is possible depends on a match in container type and cleanliness, the dates that the empty container is returned to the inland terminal and the container needs to be delivered at the other customer, and the requirements of the shipping line, which is the owner of the containers. There are around twenty container types, and an overview of the different types of containers can be found in Appendix A. When the time between the return of the empty container and the delivery of the empty container to the customer is too long, the shipping line demands the container is delivered back in the port, or a fee has to be paid per day the container is delivered too late. Moreover, shipping lines can demand that containers are brought back to the port, even when re-use is possible. An inland terminal can have a *depot function*. An example is the Tilburg Vossenberg terminal, which is a depot for Maersk (one of the largest shipping lines). In this case containers can be stored at the terminal and do not necessarily have to be delivered to the port within a few days.

As can be seen there are a lot of dependencies for the re-use of containers. This leads to the movements of empty containers, since finding a match will be difficult. These containers sometimes have to be delivered or picked up at empty depots; terminals that temporarily store and, when necessary, repair containers. This leads to extra stops next to the container terminals during a trip in the PoR.

An important bottleneck in the current planning, scheduling, and the real-time adjustments of schedules, are the time slots that are assigned to barges by port terminals. When the planner of a barge knows which containers will be assigned to the barge, he can request time slots at port terminals. Depending on the port terminal, this can be done via fax, e-mail, telephone or Portbase (a platform where these time slots are requested and assigned). The planner can also choose not to make an appointment, but leaving the responsibility of making an appointment to the skipper. This is mainly done for the smaller terminals, which are more flexible. The largest bottlenecks are the large port terminals, which are inflexible in the assignment of time slots. The planner makes a concept planning so that he knows around which time the barge can possibly arrive the terminals, and applies for time slots. However, in general a different time slot is assigned, which of course has effects on the other, assigned or unassigned, time slots. Moreover, these timeslots can be adjusted when the barge is already close to the terminal, for example because a sea-going vessel that would be handled before the barge is delayed. This situation with time slots leads to a high uncertainty in the execution of the planning, which planners compensate by planning slack in the schedules.

Another factor that restricts the planning is demurrage and detention (D&D). D&D has a high impact on the planning of container transportation in general. D&D are the rules that apply to the number of days a container may spend at the port terminal (demurrage) or outside the port terminal (detention). The D&D rates differ per shipping line, and can even differ across customers. The planner has to make a decision when the container is picked up, which depends on whether a barge will visit that terminal, when the customer wants the container, and how long a customer needs the container for loading or unloading. When the container stays longer at the port terminal or in the inland transportation process than the agreed number of days, a fee applies. For every day the demurrage or detention is exceeded the customer pays, differing per shipping line, between €14 and €75 per day (Fazi, 2014). We will now describe the D&D processes for import and export containers.

An import container arrives at the port terminal by a sea-going container vessel. When this vessels arrives, the container is unloaded and transported to a stack at the port terminal. However, at this moment the container is not necessarily available for pick-up. Some administrative tasks have to be executed, for example checking whether there is paid for the container, and checks by customs. It differs per shipping line when the demurrage period starts. This can be when the container arrives at the port terminal, or when the container is released for pick-up. The demurrage-free period is in general between three and five days. When the container is picked up, the demurrage period stops, and the detention period starts. The detention-free period depends on the mode the container is transported with. For barging, this free period is in general between three and ten days. In this time the container has to be transported to the customer, unloaded, and brought back to the port terminal or empty depot (Fazi, 2014). An overview of this process can be found in Figure 8.

When an empty container is picked up at a port terminal or empty depot the detention period starts. In this period the container has to be transported to the customer, loaded with goods, and transported back to the port terminal. When the container is delivered at the port terminal, the demurrage period starts (Fazi, 2014). However, there are restrictions on when the container can be delivered at the port terminal. This depends on when the sea-going vessel on which the container is booked will depart. The container should be delivered at least 24 hours before the departure. The port terminal also has a *cargo opening time*, which is the earliest time a container may be delivered at the port terminal. This differs per terminal, but is in general around seven or eight days before the arrival of the sea-going vessel the container is booked on (APM Terminals, 2015; ECT, 2008), and thus longer than the commonly used demurrage periods. An overview of this process can be found in Figure 9.

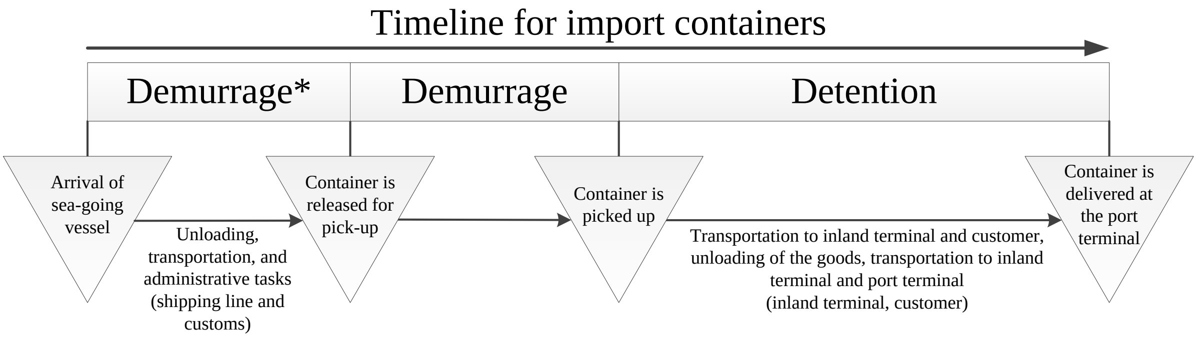

Figure 8: The D&D timeline for import containers (: for some shipping lines the demurrage period starts here)*

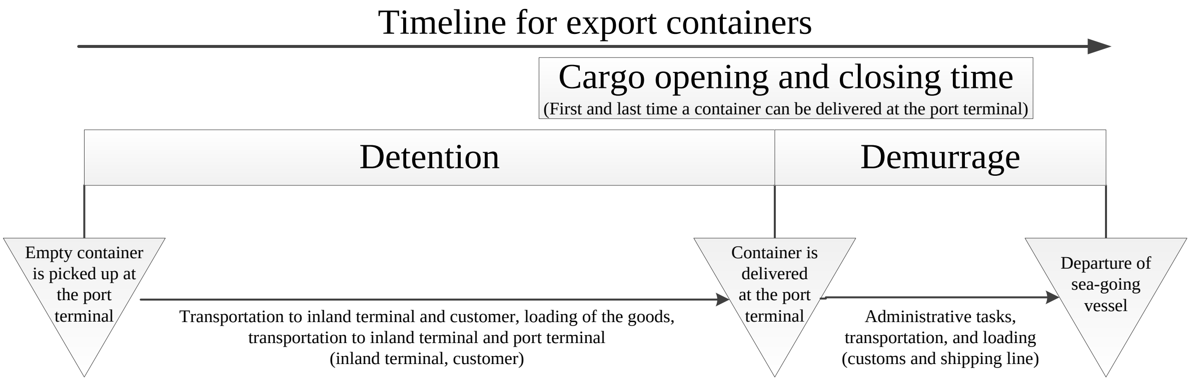

Figure 9: The D&D timeline for export containers

4.2.1. Barges

BIM currently deploys seventeen barges to the PoR. These barges have capacities that range from 32 to 144 TEU. The exact capacity of a barge depends on its location. For example a Tilburg Vossenberg barge, with a capacity of 60 TEU when it is sailing from or to Tilburg Vossenberg. This barge is able to handle 90 TEU, but due to a bridge that is located directly after the Tilburg Vossenberg terminal the capacity decreases to 60 TEU.

Using a barge incurs fixed and variable costs. BIM does not own barges: all barges are rented from a barge operator. It depends per barge how these fixed costs are charged. Barges can be charged on a weekly basis, which means there is a fixed price for renting the barge during a whole week. It can be the case that barges are not available throughout the whole week, but for example only during working days. Another way of charging these fixed costs is by the number of single trips a barge makes. Actually this is not a fixed cost, since it depends on the use. However, further on will be referred to this as fixed costs, since there are also variable costs based on the fuel usage. A single trip is in this case a trip from the inland terminal to the PoR or the other way around. The variable costs of a barge depend on the fuel usage. In April 2015 a cubic metre of gas cost €450, and when dividing this by the average amount of gas used during a roundtrip the costs per kilometre is known (the actual gas usage depends on more factors, like the actual loading of a barge). The barges that are charged per single trip have a different way of charging variable costs. For every single trip price there is a gas price *in the price*. When a barge has €400 of gas *in the price*, the barge operator pays €400 per cubic metre of used gas. This is an incentive for the skipper to sail as economically as possible.

Two other important aspects in barging are the fixed handling time at a terminal, and the sailing speed. The fixed time consists of docking and undocking, which both takes ten minutes. While the sailing speed depends on factors like the actual loading and flow rate, this is on average 13 kilometres per hour. Furthermore, there is an expectation about the number of roundtrips a barge makes in a week. A summary of all barges and associated terminals, capacities, costs and usage can be found in Table 4. For the remainder of this thesis the barge identifier consists of the abbreviation of the inland terminal it normally sails to and from, its capacity to and from this terminal, and when a terminal has more than one barge of this type, an additional number is added.

Besides the capacity in TEU, the barge's capacity can also be restricted by other factors. This all starts with the stowage plan, which is the responsibility of the skipper. In this plan the exact location of all containers are set, so that a minimum number of handlings is necessary at the port terminals (handlings at port terminals other than the containers to or from that specific terminal are very expensive), taking into account the balancing restrictions. A balancing restriction is for example that a combination of two layers of empty containers and a layer of full containers on top of that is impossible. In this stowage plan the weight of containers is also taken into account, because barges have a maximum and sometimes even minimum weight. This minimum weight can be required so that the barge can pass certain bridges. However, newer barges are able to store water in tanks, to reach to minimum draft without having enough weight from the containers. The height of containers is also an important factor. Some containers are of the type *high cube* (see Appendix A). Three layers of high cube containers stacked on top of each other is one metre taller than three normal containers. Adding this altogether forms the stowage plan, and the outcome of the stowage plan is whether a barge can sail or not. When not, which sometimes happens in practice, containers have to be added or removed to come to a feasible stowage plan.

4.2.2. Inland terminals

The terminal equipment consists of the quay length, the number of cranes, and the number of reach stackers. This combination gives the maximum number of barges that can be handled simultaneous. This also depends on the size of the barge that calls at the terminal. For example Oosterhout, which has large barges. These cannot be (completely) handled by reach stackers, and therefore only two barges can be handled at the same time. This equipment is also used to handle the trucks, and therefore the handling of one container takes slightly longer than at port terminals: four minutes.

The opening hours of inland terminals are guidelines; effectively the terminals can be open 24/7, but the terminal operating companies try to keep to these hours. An exception is Tilburg Vossenberg, which cannot be open outside these hours due to regulations.

Depending on who owns the port the terminal is located, port fees can be applicable for barges. For all terminals except Oosterhout this is the case. Two cost regimes exist in this network, where a fee applies for every container move (loading or unloading a container), or for every full container move (i.e. the fee only applies to full containers). All details about the inland terminals can be found in Table 5.

Inland terminals charge handling costs for handling a container. In general these handlings are in the price a customer pays for the transportation of a container. However, sometimes extra handlings are needed, for example for an empty container that is transported to another BIM terminal. Internally, BIM terminals charge €10 per handling.

Barge identifier	Fixed inland terminal	Capacity from inland terminal (TEU)	Fixed cost per week (€)	Days/week in use	Fixed cost per day (€)	Fixed cost per single trip (€)	Gas (€ per cubic metre in the price)	Variable costs per kilometre (€)	Expected roundtrips per week
ITV28.1	Veghel	28				850	400	0,19	3,5
ITV28.2	Veghel	28				850	400	0,19	3,5
BTT32.1	Tilburg Loven	32				800	300	0,66	4
BTT32.2	Tilburg Loven	32				800	300	0,66	4
ROCW36	Waalwijk	36	4650	5	930			1,98	4
VOS44.1	Tilburg Vossenberg	44				1000	300	0,65	4
VOS44.2	Tilburg Vossenberg	44				1000	300	0,65	4
ROCW48.1	Waalwijk	48	5080	5*	1016			3,21	5
ROCW48.2	Waalwijk	48	5080	5*	1016			3,21	5
ITV52	Veghel	52				1200	400	0,2	3,5
VOS60.1	Tilburg Vossenberg	60	8200	6	1367			2,68	4
VOS60.2	Tilburg Vossenberg	60	8200	6	1367			2,68	4
ITV90.1	Veghel	90	8200	6	1367			2,10	3,5
ITV90.2	Veghel	90	8200	6	1367			2,10	3,5
OCT108.1	Oosterhout	108	11500	7	1643			3,90	4-6
OCT108.2	Oosterhout	108	11500	7	1643			3,90	4-6
OCT144	Oosterhout	144	12000	7	1714			3,90	4-6

Table 4: Details of all barges in the network (: these barges sail according to a 10/4 schedule (ten days in operation, four days off. For the calculation of the day price five days can thus still be used)*

Inland terminal	Quay length (metre)	Cranes	Reach stackers	Maximum number of barges to be handled simultaneous	Opening hours working days	Opening hours saturdays	Opening hours sundays	Port fees
Oosterhout	325	2	3	2	All day	All day	All day	None
Tilburg Loven	500	1	3	2	07:00 - 22:00	08:00 - 17:00	Closed	€1,10 (PFCM)
Tilburg Vossenberg	250	1	2	2	06:00 - 22:00	08:00 - 17:00	Closed	€1,10 (PFCM)
Veghel	500	1	4	2	05:00 - 23:00	05:00 - 23:00	Closed	€0,58 (PCM)
Waalwijk	190	1	1	2	05:00 - 22:00	08:00 - 12:00	08:00 - 12:00	€1,65 (PFCM)

Table 5: Details of the inland terminals (PCM = per container move, PFCM = per full container move)

4.2.3. Port terminals

Port terminals have in general large quays and enough handling equipment for barges, since these terminals are also able to handle the largest barges, and sea-going vessels. The most restricting factor for port terminals are the opening hours, which can be found in Table 6. In this table, the sailing area the terminal is located is also displayed. Handling a container takes three minutes at port terminals, since they have dedicated equipment for handling barges and sea-going vessels, and trucks are handled with other equipment. As in inland ports, the PoR also charges port fees. These port fees depend on:

- The environmental impact of the barge;
- The deadweight tonnage of the barge (the difference between the maximum weight en the weight of the empty barge);
- The capacity of the main engine.

Combining all these factors together, the yearly costs for a BIM barge that visits the PoR lays between €1800 and €20000 (Port of Rotterdam Authority, 2015b, 2015c; Pro-Log, 2015).

Port terminal	Area	Weekdays	Saturdays	Sundays
APM	Maasvlakte 1	All day	All day	All day
Barge Center Waalhaven	Stad	06:00 - 22:00	07:00 - 15:00	Closed
Cetem Containers	Botlek	07:00 - 20:30	07:00 - 20:30	07:00 - 20:30
Combined Cargo Terminals Moerdijk	Moerdijk	05:00 - 23:00	Closed	Closed
Delta Container Services	Maasvlakte 1	All day	All day	All day
ECT City	Stad	All day	All day	All day
ECT East	Maasvlakte 1	All day	All day	All day
ECT North	Maasvlakte 1	All day	All day	All day
Euromax	Maasvlakte 1	All day	All day	All day
Mainport Rotterdam Services	Stad	06:00 - 22:00	Closed	Closed
Medrepair Netherlands	Stad	07:00 - 20:30	07:00 - 20:30	07:00 - 20:30
Pernis Combi Terminal	Stad	07:00 - 23:30	Closed	Closed
Port Container Services	Stad	07:00 - 20:30	07:00 - 20:30	07:00 - 20:30
Progeco Eemhavenweg	Stad	07:30 - 16:00	Closed	Closed
Progeco Zaltbommelstraat	Stad	07:30 - 16:00	Closed	Closed
Rotterdam Container Terminal	Maasvlakte 1	All day	All day	All day
Rotterdam Shortsea Terminal Noord	Stad	All day	All day	All day
Rotterdam Shortsea Terminal Zuid	Stad	All day	All day	All day
SCA Terminals	Stad	06:00 - 20:45	06:00 - 20:45	06:00 - 20:45
Uniport Multipurpose Terminals	Stad	All day	All day	All day
United Container Freight Station	Stad	07:30 - 17:00	Closed	Closed
United Waalhaven Terminals	Stad	06:00 - 21:45	07:00 - 13:00	Closed
Van Doorn Container Depot	Maasvlakte 1	05:00 - 23:00	Closed	Closed
Waalhaven Botlek Terminal	Botlek	06:00 - 22:00	Closed	Closed

Table 6: Opening hours of all port terminals (for the areas, we refer to Figure 7)

4.2.4. Last-minute trucking

While the main topic of this thesis is container barging, it happens that containers have to be trucked last-minute, as explained in the introduction. BIM terminals own trucks, but also charter transports to truck operators. The costs for a truck used internally by BIM are: €35 per hour, and €0,50 per kilometre. Furthermore, 60 minutes of fixed handling time applies when transporting a container (20 minutes at the inland terminal and 40 minutes at the port terminal). In general the truck is empty 50% of its time when containers are transported last-minute, and therefore only a container that has to be transported for the trip towards or from the port will be on the truck. This is the case most of the times when trucking a container. The costs do not depend on the size of the container; combining two 20 feet containers on a truck is in general not possible, because of weight or balancing restrictions. Based on Google Maps a distance matrix for trucking was composed, and an average speed of 60 kilometres per hour was assumed. Therefore the costs of trucking a container can be stated as:

$$\text{Trucking costs} = 2 * \left(\left(1 + \frac{\text{Distance(Pickup,Delivery)}}{60} \right) * €35 + \text{Distance(Pickup,Delivery)} * €0{,}50 \right)$$

The costs for trucking a container from or to the different areas can be found in Table 7.

Inland terminal	Stad	Botlek	Maasvlakte 1	Moerdijk
Oosterhout	€ 150,70	€ 170,20	€ 224,80	€ 91.55
Tilburg Loven	€ 227,62	€ 247,12	€ 321,00	€ 169.33
Tilburg Vossenberg	€ 207,25	€ 226,75	€ 282,00	€ 148.53
Veghel	€ 256,00	€ 275,50	€ 329,67	€ 247.33
Waalwijk	€ 181,90	€ 201,62	€ 256,00	€ 123.62

Table 7: Costs for trucking a container

4.2.5. Waterways

Waterways, bridges, and locks form restrictions for barges. This means that a barge cannot sail to a certain inland terminal, or is restricted in its capacity due to height restrictions. In Table 8 an overview can be found about the capacity of barges when sailing to or from an inland terminal. When a cell in this table is empty, this means the barge cannot sail to this terminal. The sailing distances between inland terminals can be found in Table 9. Furthermore, the number of locks located along a waterway influences the sailing time. The locks in the BIM network are open 24/7, and are lowly utilised, which means it takes about 30 minutes to pass a lock. The number of locks located on a waterway can be found in Table 10.

Another factor that can reduce the capacity, or even the possibility for using a certain type of barge, is the water level. During the year the water level can fluctuate, depending on the specific location. However, for the BIM terminals this never forms a restriction.

Barge	Oosterhout	Tilburg Loven	Tilburg Vossenberg	Veghel	Waalwijk
ITV28.1	28	28	28	28	28
ITV28.2	28	28	28	28	28
BTT32.1	32	32	32	32	32
BTT32.2	32	32	32	32	32
ROCW36	36	36	36	36	36
VOS44.1	44		44	44	
VOS44.2	44		44	44	
ROCW48.1	48		48	48	48
ROCW48.2	48		48	48	48
ITV52	52		52	52	
VOS60.1	90		60	90	
VOS60.2	90		60	90	
ITV90.1	90		60	90	
ITV90.2	90		60	90	
OCT108.1	108				
OCT108.2	108				
OCT144	144				

Table 8: The capacities of the waterways to inland terminals, expressed in the number of TEU a barge can carry to that inland terminal (when the column is empty, the barge cannot sail to this terminal)

	Botlek	Cetem*	Maasvlakte 1	Moerdijk	Oosterhout	Stad	Tilburg Loven	Tilburg Vossenberg	Veghel	Waalwijk
Botlek		8,3	16,9	45,4	60,6	16,2	84	74,6	110,2	73,3
Cetem*	8,3		27,8	38,2	53,4	7,9	76,8	67,4	103	66,1
Maasvlakte 1	16,9	25,1		62,3	77,5	27,8	100,9	91,5	127	90,2
Moerdijk	45,4	38,2	62,3		24,7	45,4	48,1	38,7	74,3	37,4
Oosterhout	60,6	53,4	77,5	24,7		60,6	23,4	14	60,1	23,2
Stad	16,2	7,9	27,8	43,7	60,6		84	74,6	110,2	73,3
Tilburg Loven	84	76,8	100,9	48,1	23,4	84		9,4	83,5	46,7
Tilburg Vossenberg	74,6	67,4	91,5	38,7	14	74,6	9,4		74,1	37,3
Veghel	110,2	103	127	74,3	60,1	110,2	83,5	74,1		40,5
Waalwijk	73,3	66,1	90,2	37,4	23,2	73,3	46,7	37,3	40,5	

Table 9: Sailing distances (in kilometres)

(: Cetem is located in the Botlek area. However, it is located quite far away from the other terminal in the Botlek. Since there are only two Botlek terminals in the tool, we calculated the distances to both terminals)*

	Botlek	Cetem	Maasvlakte 1	Moerdijk	Oosterhout	Stad	Tilburg Loven	Tilburg Vossenberg	Veghel	Waalwijk
Botlek							3	1	3	1
Cetem							3	1	3	1
Maasvlakte 1							3	1	3	1
Moerdijk							3	1	3	1
Oosterhout							3	1	3	1
Stad							3	1	3	1
Tilburg Loven	3	3	3	3	3	3		2	6	4
Tilburg Vossenberg	1	1	1	1	1	1	2		4	2
Veghel	3	3	3	3	3	3	6	4		4
Waalwijk	1	1	1	1	1	1	4	2	4	

Table 10: Number of locks between the sailing areas and/or inland terminals

4.3. Data analysis and processing

The data set, provided by BIM, consists of all containers that have been transported to customers between 01-09-2014 and 31-10-2014, for all terminals in the BIM network, and all modalities (truck, barge, and rail). The set consists of bookings, and a booking has at least an import movement (from the port to the inland terminal), or an export movement (from the inland terminal to the port).

A reliable and usable data set will be formed, that will used for the remainder of this thesis. Since the container movements are the most important for this project, the set was split into import and export movements. For both subsets all containers were deleted that have not been transported to or from the five terminals that are in the scope in this thesis, and the truck and rail movements were also deleted. A description of the process for transforming the subsets into a final set will follow in the next two subsections.

4.3.1. Import movements

A set consisting of five weeks was selected. Four weeks of data is a good representation for the simulation. However, the simulation tool will have certain have “start-up” and “cool-down” phases for the first and last roundtrips. Therefore an extra week of movements was added, that can be used for these phases.

All import movements that have an inland transportation date between 11-09-2014 and 15-10-2014 were selected. The inland transportation date is the date the customer wants the container the latest. Before analysing the empty values, some container movements were deleted:

- All containers to and from Antwerpen, since Antwerpen is not in the scope of this project;
- Containers from and to the terminals *DP World Germesheim* and *Groenenboom Containertransferium Ridderkerk*, since these are exceptional movements that are transported on a charter base;
- All containers that have been moved from one inland terminal to another inland terminal (*internal movements*), since these containers are transported by a separate barge that does not visit the PoR.

There were movements without an inland transportation time. This is the latest time the container has to be delivered at the customer, and is a requirement of the customer. The planner can, in consultation with the customer, decide to change this time. For this reason it is very difficult to come up with good inland transportation times for the empty fields. We used 22:00 as inland transportation times for the empty fields, which is the earliest time that an inland terminal closes during weekdays. Furthermore, it is assumed that the container should be delivered at the inland terminal the latest at the inland transportation time. Customers are in most of the cases close to the inland terminal, so the transportation time from the inland terminal to the customer is short. Furthermore, most of the containers will be delivered some time before the inland transportation time, so that there will be an on time delivery.

For the movements without an earliest pick-up date, which is the time the container is available for pick-up at a port terminal, a distinction between full and empty containers was made. For full containers that had an earliest pick-up date, the average time between earliest pick-up and inland transportation date was 6,2 days. However, this is a very long time. When looking at the detention rate, this is around seven days on average (Fazi, 2014), in which a container also has to be delivered back at the port terminal. Besides the detention, the demurrage days are also used for storage, so that the container is not unnecessarily using space at the inland terminal or customer. Therefore the average for containers without a pick-up date will not be a correct assumption, because containers will be picked up too early in the simulation. Moreover, the dates that are filled in are not reliable. The earliest pick-up date can be the date that the sea-going vessel arrived, the date all administrative tasks are finished, or a date that is filled in manually by the planner. There are too many inconsistencies for using the available dates, and therefore fixed a number of days for the inland transportation of full import containers will be used. After consultation with BIM about what would be an acceptable number of days between the earliest pick-up and inland transportation dates, three days was used as time that can be used for transporting the container. For these reasons the earliest pick-up date of all full import containers were changed; the pick-up date and time is changed to the inland transportation date and time minus three days. For the empty containers the average is used, which is 3,9 days. The inland transportation date minus four days was used for these containers, and 00:00 as time when this was an empty field. This time can be used since detention is calculated per day, so the exact time an empty container is picked up does not matter. An overview of the changes to the import movements can be found in Figure 10.

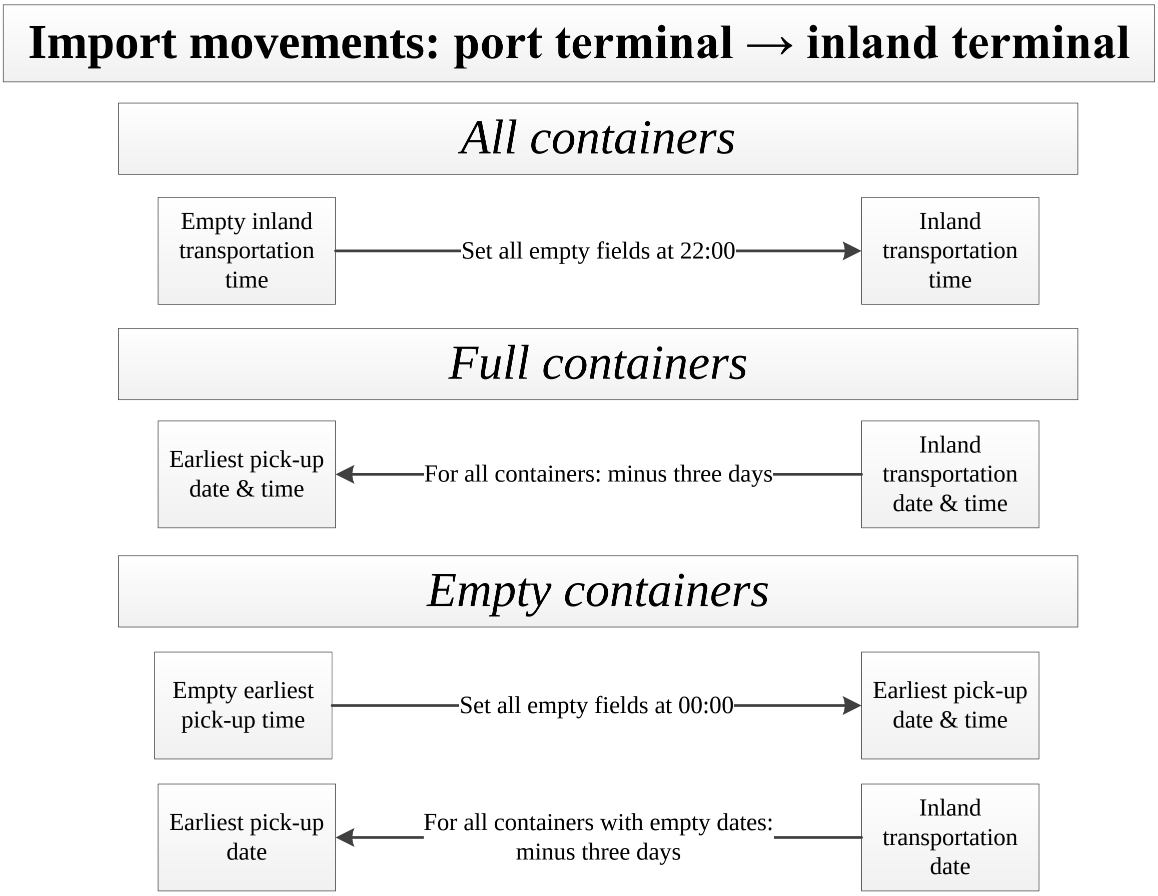

Figure 10: Changes made to the import movements

4.3.2. Export movements

For the export movements, closing dates (the latest time a container has to be delivered) between 11-09-2014 and 15-10-2014 were selected. However, there were a lot of empty fields. For this reason the departure date was used as filter; the date that the container was actually transported to the port. Except for some containers of two terminals, all full containers had a closing date. For *Rotterdam Shortsea Terminal Zuid*, a port terminal, the average time between the gate-in date (which is the time the container was available at the inland terminal) and the closing date is 2,25 days. For these containers we added two days to the gate-in date, and used the same time as the gate-in time. For *Combined Cargo Terminals Moerdijk*, a terminal close to the port but not part of the BIM network (this terminal is seen as a port terminal), this average number of days was 3,7, and therefore four days were added to the gate-in date. All containers for this terminal had no closing time, and the time the terminals closes on weekdays, 22:00, was used as latest delivery time. Besides these two terminals, there were also containers that had no closing time. The actual closing time mainly depends on the departure of vessel on which the container would be transported. We cannot find these times anymore, and therefore 23:59 was used as closing time.

For the empty containers the average number of days between the gate-in date and latest delivery time was very high; some containers had more than 100 days between these two dates. This happens when the terminal has a depot function. At a certain moment the container will be brought back, but this will never be done when there are other containers that really have to be delivered, and for this reason the difference between gate-in and latest delivery is very high. When these containers are not taken into account, the average time between gate-in and latest delivery for empty containers is 4,17 days, and therefore four days were added to the gate-in date. Since detention is charged per day, the latest delivery time is set at 23:59.

The same as with the import movements, the Antwerpen and DP World Germesheim containers were deleted (Groenenboom Containertransferium Ridderkerk had not export movements), together with internal BIM movements. An overview of the changes to the export movements can be found in Figure 11.

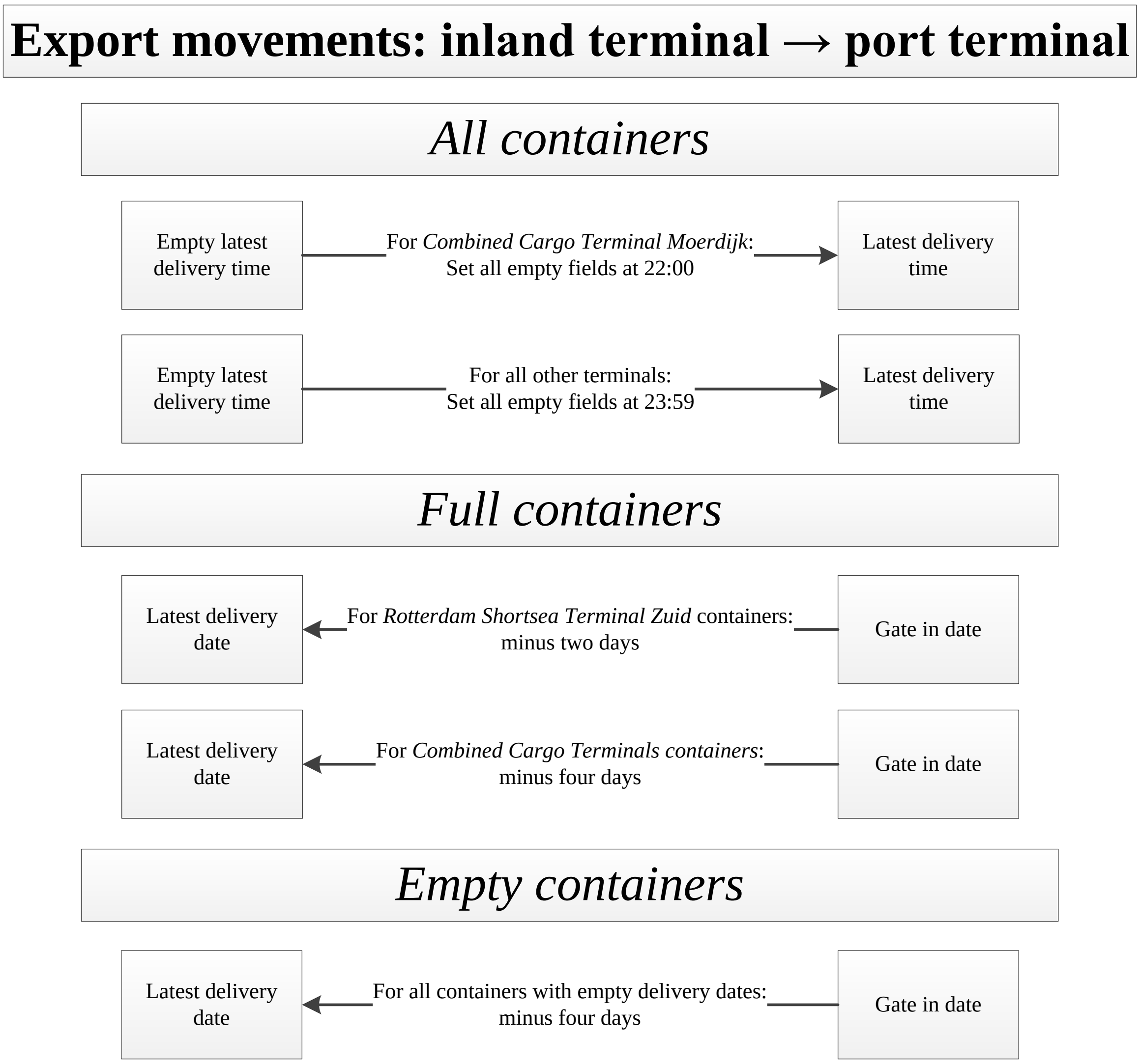

Figure 11: Changes made to the export movements

4.3.3. Complete set

The final set consists of 15689 container movements. In total the set consists of five inland terminals, and 24 port terminals. A movement consists of a unique container number, the size (20, 40, or 45 feet), the pick-up terminal and earliest pick-up time, the delivery terminal and latest delivery time, and whether the container is full (1) or empty (0). An example of a movement can be found in Table 11. An analysis on the distribution of the containers across the terminals can be found in Appendix C.

Container number	Container type	Pick-up terminal	Earliest pick-up time	Delivery terminal	Latest delivery time
ITV27469EXP	20	Veghel	30-09-2014 14:24	ECT East	03-10-2014 22:00

Table 11: An example of a container movement

5. Design and analysis for the simulation of the as-is network

In this chapter the simulation tool we be designed. Chapter 4 is used as input, and the tool will be able to simulate the as-is network. This will be done by answering the first two research questions:

- *How is the performance of a container barge network measured?*
- *Can the performance of the as-is network be simulated in a realistic way?*

In Section 5.1 the indicators that will be used for the comparison, and the different delays that will be simulated, to compare performance of as-is and to-be networks, will be described. This answers the first research question. In Section 5.2, an explanation will follow about which factors, that have been discussed in the previous chapter, will be included in the simulation. In Section 5.3 the functions of the simulation will be discussed, starting with an explanation of the modelling choices, followed by the exact functioning of the simulation. The output of the tool will be also be analysed in this section. This answers the second research question.

5.1. Performance indicators and changing delays

The most important factor for container barging is on-time delivery of containers. Therefore the *percentage of containers delivered too late* will be the main performance indicator. Furthermore, the costs associated with these late containers, the *last-minute trucking costs*, will be a performance indicator. The costs of barges, split up in *variable costs*, and *fixed costs*, will also be performance indicators. When all costs are added and divided by the number of TEU transported, the *costs per TEU* is known, a performance indicator that is used in practice for accounting purposes, and therefore this will also be a main performance indicator. Furthermore, some indicators about the barges will be included: the *number of roundtrips* made during the simulation, and the average *barge utilisation*. All these indicators can be used to make a comparison between the current situation and the hub network.

The performance of container barge networks can be assessed by changing certain factors in the simulation. Currently, waiting times at port terminals have the largest effect on the planning and adjustments of schedules. These waiting time differ, and can be as large as six days (see for example Logistiek.nl (2014), where barges had to wait up to six days for being handled at the ECT Delta terminal). Because the delays have a high impact on the planning, as also is described in Section 4.2, the effect of changing delays will be simulated to analyse what the effect of this is in both networks. These delays, for which the “normal” delays will be set during the design of the in Section 5.3.5, will be split into four *delay conditions*: low, average, high, and extreme high delays. These conditions will be based on the base condition The conversion factors can be found in Table 12.

Condition (delays)	Conversion factor
Low	0,25
Average	1 (base condition)
High	2
Extreme high	3

Table 12: Conversion factors for delay conditions

5.2. Included and excluded factors, and assumptions in the simulation

In Section 4.2 all factors that influence the planning and/or the costs incurred have been discussed. However, not all factors will be included. In Table 13 the factors that will be included in the simulation are described, followed by the factors that are out of scope in Table 15, and the assumptions in Table 16. All numerical details can be found in Section 4.2.

Factor	Explanation
Barges	
Speed	A fixed speed of 13 km/h is used during the whole simulation.
Capacity	The capacity of barges is expressed in TEUs and depends on the location of the barge.
Fixed costs	The fixed costs are converted to daily costs for the barges that are charged on a weekly basis. The costs for barges that are charged per single trip remain unchanged.
Variable costs	The variable costs, when applicable adjusted for gas in the price, remain unchanged.
Fixed handling time	For every call at a terminal, there is a fixed handling time of 20 minutes.
Inland terminals	
Handling capacity	The number of barges that can be handled simultaneously is known. A handling time of four minutes, as described in Section 4.2.2, is used during the simulation.
Opening hours	The opening hours as stated in Table 5 are used in the simulation. As long as the barge calls before the closing time it will be handled. This is happening in practice; as described before the terminals can be open longer than the current opening hours. Therefore a barge will be handled when necessary, since it will otherwise wait for around eight hours.
Port terminals	
Handling capacity	The number of barges that can be handled simultaneously is finite, but this will not be taken into account. Equipment can be shared with sea-going vessels, and are always shared with other barges than those from the BIM network. Since all these calls are not known, we assume that a barge can always call at a port terminal, possibly after some (fixed) delay. Handling a container at a port terminal takes three minutes.
Opening hours	The opening hours as stated in Table 6 are used in the simulation. The barge will only be handled when the call (docking, unloading, loading, and undocking) is completed within opening hours.
Delays	As described in Section 4.2, delays occur on a daily basis. Simulating this process is complicated, since it depends on agreements between port and inland terminals, the arrival of sea-going vessels, and many more. For these reasons a fixed delay at five terminals is used: ECT East, ECT North, ECT City, Euromax, and APM, determined in consultation with BIM. The conditions at APM are slightly better, and therefore APM has ⅔ of the delay of the other terminals. Furthermore, the exact delay depends on the number of containers that will be (un)loaded, since in general a small call can be handled easier between two other appointments. This can be found in Table 14. The exact delays will be set during the simulation, to come up with a situation that is aligned with the real-life situation as much as possible.
Last-minute trucking	
Late containers	Whenever a container is delivered too late, we assume it would have been trucked. For this the costs as stated in Table 7 will be used.
Waterways	
Inter-area distances	The waterways will be implemented as described in Section 4.2.5. However, there is no distance defined for sailing from one terminal to another within one area (Stad or Maasvlakte 1). In practice this can take a few minutes (i.e. only crossing the canal), up to 45 minutes at maximum. Therefore 30 minutes seems as a reasonable assumption, which is 6,5 kilometre when the sailing speed is set at 13 km/h.

Table 13: Included factors for the simulation

Call size (number of containers (un)loaded	Fraction of delay
< 10	⅓
≥ 10, < 20	⅔
≥ 20	1

Table 14: Call size dependent delays

Factor	Explanation
Stowage plan	The stowage plan depends on a lot of factors: the size and weight of containers, point of delivery or pick-up, and the minimum and maximum weight of a ship. While this can be restricting, especially the weight, this is not included in the simulation, since it is a very difficult process that is the responsibility of the skipper. The scope of this thesis is the actual planning and therefore it is assumed that every allocation, as long as the capacity in TEUs is not exceeded, is possible. For this reason *balancing restrictions*, *weight of containers*, and *height of containers* will also not be implemented in the simulation.
Water levels	As described in Section 4.2.5, water levels form no restrictions and will therefore not be implemented in the simulation.
Detention & demurrage	D&D will not be accounted for in the simulation, since these periods are included in the pick-up and delivery dates in the data set. Furthermore, all customers have arrangements with the shipping line about the D&D free periods and rates, which makes it difficult to implement this, while the effect will be very small. Whenever the latest delivery date is violated it is assumed the container would have been trucked.
Empty container repositioning	More emphasize is placed on the re-use of empty containers. When an empty container is transported to the port, and one day later the exact same type of container is transported back to the inland terminal again, this is a waste of resources. Therefore inland terminal operators are looking at ways to re-use containers, as also described in Section 4.2. This will not be included in the simulation, since the repositioning of empty containers depends on several factors: ▪ The exact agreement on D&D for specific customers; ▪ The detention days left when the container is back at the terminal; ▪ The willingness of shipping lines to enable re-use of containers; ▪ The cleanliness of specific containers; ▪ The type of the container. All these factors are unknown in the data set. Furthermore, when a container was re-used in the period of the data set, this container has no import movement. The main topic of this project is the difference in two ways of operating, and a set of containers that have been transported is the most important for the simulation. Therefore empty container repositioning will not be included.
Handling costs	For the simulation of the current situation handling costs will not be taken into account. The costs for handling a container at the inland terminal the container is transported from or to do not change between the current situation and the hub network, while it is difficult to come up with a good price for this.
Port fees	Port dues in the PoR are relatively low compared to the costs of barges, and normally these dues are billed on a yearly basis. Furthermore, these dues have to be paid anyway, no matter of the number of times the PoR is visited, and therefore there will be no difference between the current situation and the hub network. The same holds for inland ports, since these are based on the number of containers that are moved, which will not change between the two networks.

Table 15: Factors that are excluded in the simulation

Factor	Explanation
24/7 availability of barges	Currently, some barges are not available 24/7, but 24/5 or 24/6. However, a 24/7 availability of barges is assumed, to be more responsive to some discrepancies in the data set and modelling assumptions. Moreover, because of an overcapacity in the barging sector in The Netherlands (Financieel Dagblad, 2015), it can be assumed that the barges that are contracted for 24/5 or 24/6 operation, can also be hired for a 24/7 operation, or at least the same kind of barge can be hired for a 24/7 operation
No fixed time slots at port terminals	Some inland terminals have fixed time slots at port terminals, which means that they know for every day in the week if, and what time they will be handled. However, this depends per inland terminals and port terminal combination, and the time slots are changed quite often. The uncertainty in the port is already accounted for by modelling the delays, and these fixed time slots do not add to that.

Table 16: Assumptions in the simulation

5.3. Design of the simulation tool

Now that the input of the simulation is set, the technical part of the simulation can be designed. Looking to this network from an academic perspective, one will almost directly think of the Vehicle Routing Problem (VRP), extended to container barging, and with the possibility of exchanging containers at a hub. An example of this is the thesis of Fazi (2014), who developed an approach to a VRP for a situation very similar like the one in this thesis. However, when developing such a model for the operational planning of barges in a hub network we notice two problems. First, developing such a model and corresponding heuristics takes a lot of time; too much time for a MSc. thesis. Even when we will be able to develop this, we will not have time to come up with results that practitioners can use, and in that case we do not reach one of the goals of an MSc thesis; bringing practice and the academic world together. Besides this we will have an oversimplified model that produces results that will be difficult to compare with the current way of operating. Second, in intermodal planning models in general the model plans one trip (in this case inland terminal – hub – port terminals – hub – inland terminal), whereas in container barging the roundtrips of barges throughout the week are more important than one optimal roundtrip.

For these reasons a model will be developed that is able to plan the network, based on a simulation of the actions currently performed by a barge planner. Another reason for using a simulation is that making the planning of several weeks by hand is very labour intensive, since 3000 containers are transported every week in the network of BIM, especially when we want to look at different networks and delay conditions

The simulation tool will be developed in AIMMS, what is an acronym for Advanced Interactive Multidimensional Modelling System. AIMMS is a modelling system that provides certain features that are interesting in our case. AIMMS can be used to model Mixed Integer Linear Programs like the VRP, and AIMMS also makes it possible to model complex environments and build algorithms to come up with solutions for such an environment.

The simulation needs to be able to use the data set that has been formed in Section 4.3, and make a feasible planning according to the input like barges and terminals. This situation will be aligned as much which practice as possible. The simulation will have two important parts: the allocation of containers and dispatching of barges, and the barge routing. The container allocation and barge dispatching design will be described in Section 5.3.1, and the barge routing in Section 5.3.2. The formal description and testing of the barge routing model is described in Section 5.3.3.

5.3.1. Container allocation and dispatching of barges

Planners of container barges focus on the closing times of containers. This means in practice that a planner's goal is to have as few late containers as possible. For this reason, the allocation of containers is implemented in the same way. When a barge is selected for simulation, the time that it is available (and empty) is known. Containers that are available at the inland terminal at that specific time will be allocated to the barge, restricted to a maximum number of calls, a maximum number of calls at delayed terminals, and the capacity of the barge. The allocation is implemented in this way, since it otherwise can happen that barges will visit all delayed terminals in one roundtrip, which will delay containers unnecessarily, and barges will visit a large amount of port terminals while this better can be spread over different barges, which is currently also done by planners.

Containers are allocated for the outgoing and incoming trip. A roundtrip can be seen as two single trips, with two capacities (see Figure 12). Both trips are allocated separately, to make the best use of transportation equipment. Furthermore, the actual dispatch of a barge is based on two other parameters, which are a maximum waiting time, and a minimum utilisation. The tool will allocate containers to the barge at the time it is available. However, it can happen that a low amount of containers is available. In that case it is undesirable to dispatch the barge, and it is better to wait for more containers. The tool adds a waiting time of 60 minutes and allocates extra containers. This is repeated until the minimum utilisation or the maximum waiting time is reached, since keep waiting for a long period of time will delay containers that are already allocated to the barge.

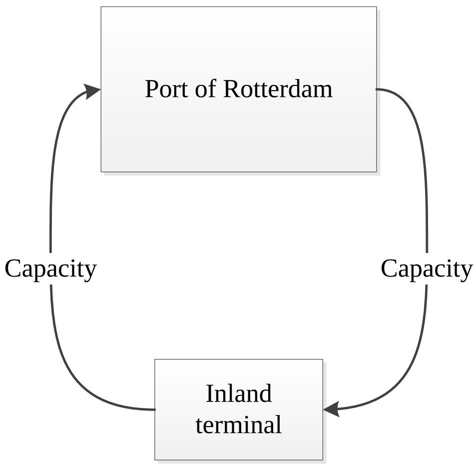

Figure 12: Roundtrip capacity

5.3.2. Barge routing

The routing of barges is modelled as a VRP. The VRP is a problem that designs an optimal route for delivering and/or collecting goods from and to a number of nodes, subjected to certain constraints (Laporte, 1992). The VRP has several extensions, like time windows (see for example Calvete, Galé, Oliveros, and Sánchez-Valverde (2004)), pick-up and deliveries (see for example Wassan, and Nagy (2014)), and cross-docking (see for example Wen, Larsen, Clausen, Cordeau, & Laporte (2009)).

A VRP is modelled as follows. A set of vehicles can be used to move goods from and to a central depot. The goal of the VRP is to find the minimum costs for delivering the goods, given to a set of constraints, like vehicle capacity. This has similarities with container barging; a set of barges (vehicles) can be used to move containers (goods) to and from an inland terminal (central depot). When a VRP will be implemented in the simulation tool, optimal routes for the barges can be calculated. For doing this, the following factors have to be taken into account:

- There is a set of barges, with different capacities;
- There is a set of terminals, with different opening times;
- There is a set of containers, with container-specific earliest pick-up and latest delivery times, and a size in TEU;
- There is a network of waterways that can be used to sail to and from all terminals, where some barges cannot sail on some waterways.

The general problem with the VRP is that real-life instances are becoming too complex to solve within a reasonable amount of time. For example the approach to a VRP of Fazi (2014). A set with fourteen containers took 1604 seconds to solve, and this complexity increases exponentially. In this thesis, such a problem cannot be solved without heuristics. Therefore a relaxed VRP will be implemented, which makes it possible to solve the instances within a reasonable amount of time. Therefore assumptions have to be made to downscale the problem where possible. The complexity increases when more vehicles can be used, time windows are introduced, and the number of nodes that have to be visited increases. Furthermore, the number of containers to be transported has a large effect on the complexity.

The main goal for the routing of barges is making a feasible schedule for the barge from the inland terminal, throughout the PoR, and back to the inland terminal. Therefore it is important that a feasible route is found for a barge. Furthermore, the barge has deliveries and pick-ups in the port. During the whole trip, the barge's capacity has to be respected. This is very important with pick-ups and deliveries, for example in a situation like this: A barge (50 TEU) departs fully loaded from an inland terminal. At port terminal X, the barge has to unload 10 TEU, and load 20 TEU. Therefore, the barge cannot unload and load at this terminal when it is the first terminal it calls. Besides the pick-ups and deliveries, the latest delivery dates of containers should be taken into account, to ensure a minimum amount of containers will be delivered too late, and the opening times of terminals have to be respected.

To make the problem less complex, there are two features that will not be taken into account in the VRP. First, the allocation of containers will be done beforehand (see Section 5.3.1), and used as input for the VRP. When doing this, the VRP does not have to deal with single containers anymore, but only with a "commodity", namely the number of TEUs that have to be picked up and delivered at the terminals. Second, not all barges have to be considered at the same time. In general in VRPs, a set of vehicles is considered that can all be used at the same time. Because we allocate the containers outside the VRP, it is known which barges will visit which nodes, and therefore a single barge can be considered in the VRP. This reduces the complexity of the VRP. Concluding on this, the VRP should be able to:

- Handle pick-ups and deliveries;
- Taking the barge's capacity into account;
- Handle earliest pick-up and latest delivery times of containers;
- Handle opening times of terminals.

Therefore there are two VRP extensions take can be used to reach these requirements; time windows and pick-up and deliveries. When adding time windows to the VRP there are two options: hard or soft time windows. When using hard time windows, there is no option for early or late deliveries. When there is not a feasible option (i.e. there is no routing possible in which all customers are delivered on time), there is no solution for the problem. With soft time windows one can have early or late deliveries, but these are subjected to certain lateness and earliness costs (Calvete et al., 2004). Because all containers have to be delivered, the VRP should be able to deliver containers too late, and thus to find a feasible routing even when containers will be delivered too late. Therefore soft time windows will be used.

These time windows in VRPs are in general implemented as an earliest arrival and latest departure time, where the complete service of the vehicle has to be somewhere in between these two times. For every time unit the vehicle is too early or too late, a "fine" is charged. In container barging there are two time windows that have to be taken into account; time windows of the containers, and opening hours of port terminals. The latter one is difficult to implement correctly in a VRP, since "single" time slots are used in VRPs, whereas opening times of terminal consists of multiple time slots (i.e. a VRP works with an input like earliest time at terminal X: 01-01-2015 09:00, latest time at terminal X: 01-01-2015 17:00, whereas the terminal can also be visited on 02-01-2015 between these times). Since the VRP will be solved multiple times during the simulation, the VRP can be solved with a single time slot (i.e. the time slots of 01-01-2015), after which the output will be analysed. When the terminal is visited outside opening hours, the VRP can be solved again with the 02-01-2015 time slot.

Another problem is the container-specific time slots, but these can be merged into one time slot: the earliest time at a terminal will be the latest time a container at that terminal will be available for pick-up (so that the barge will not call at the terminal when some of the allocated containers are not available), and the latest time at a terminal will be the earliest time a container on board of the barge for that terminal has to be delivered (so that the barge will call at the terminal before the first container on board has to be delivered).

Whereas general VRPs deal with pickup or deliveries, the Vehicle Routing Problem with Pickup and Deliveries (VRPPD) can handle both. Especially in container barging this is important, because there are import and export containers that have to be picked up and delivered in one roundtrip to make optimal use of the barge's capacity.

VRPPDs exist in many versions. Berbeglia, Cordeau, Gribkovskaia, & Laporte (2007) developed a framework to classify VRPPDs, and this was used to find the VRPPD that fits the problem in this thesis the best. The VRPPD can be classified along three categories, namely *structure*, *visits*, and *vehicles*.

The category *structure* tells how many origins and destinations the goods have. In this case, export containers have one origin (the inland terminal), and many destinations (the port terminal), and import containers have many origins, and one destination. This can be classified as a one-to-many-to-one structure (one inland terminal to many port terminals to one inland terminal). The category *visits* specifies how visiting the customers is performed. The main consideration is whether a customer can be visited only once for a combined pickup and delivery, or whether it is allowed to visit each customer twice (and thus allow a split in pickup and deliveries). When considering this for container barging, the question is if split visits exist in practice, and if it is necessary to allow this. Split deliveries take a lot of time, especially when the barge will travel twice between the Stad and Maasvlakte areas. Moreover, this does not happen in practice, since appointments have to be made at terminals, which increases the delay for barges. Therefore split pickup and deliveries are not allowed. The category *vehicles* specifies how many vehicles are used in the model. This will be one vehicle, to keep the problem solvable within a reasonable amount of time.

Most of the VRPPDs assume the transportation of commodities, and the vehicle's capacity is measured in, for example, kilograms. Containers are a commodity, but every container has its own specifications and needs to be delivered at a specific customer. However, TEUs can be used as "commodity", since every container can be converted into TEU, and the barge's capacity is measured in TEU. Since allocation of containers will be done beforehand, there are no barriers for doing this. The pickup and deliveries of the correct containers can be done outside the VRP, to make sure the specific containers are delivered at the right terminal.

A combination of a VRP with Soft Time Windows (VRPSTW) and a VRP with pickup and deliveries is needed. This will be called the *Vehicle Routing Problem with Pick-up and Deliveries and Soft Time Windows* (VRPPDSTW). This combination already exists in literature, however not as specified in this section. Therefore two VRPs will be combined them into a new one; the VRPSTW of Calvete, Galé, Oliveros, and Sánchez-Valverde (2004), and the VRPPD of Wassan, and Nagy (2014). Both models allowed the use of multiple vehicles, which was deleted for our model. Furthermore, the models overlapped at some parts. The model will be described in the next subsection.

5.3.3. Model description

For every time the VRPPDSTW is executed, the nodes that have to be visited are loaded. Each terminal can have two nodes; a load node and an unload node.

$Sets$:

		$Indices:$
N:	$all\ nodes\ in\ the\ model$	i, j
B:	$all\ load\ nodes\ in\ the\ model\ (subset\ of\ N)$	b
A:	$all\ unload\ nodes\ in\ the\ model\ (subset\ of\ N)$	a
U:	$all\ (a, b)\ combinations\ that\ belong\ to\ one\ terminal$	

Of the nodes, index 1 is the inland terminal, which is not split in two nodes. The other nodes are unload and load nodes of the port terminals. The symbol n denotes the total amount of nodes.

$Parameters$:

z_{ij}:	$sailing\ time\ from\ terminal\ i\ to\ j$
s_i:	$service\ time\ at\ terminal\ i$
e_i:	$earliest\ start\ time\ of\ service\ at\ terminal\ i$
l_i:	$latest\ end\ time\ of\ service\ at\ terminal\ i$
C:	$barge\ capacity\ in\ TEU$
c	$variable\ costs\ of\ the\ barge\ (€/minute)$
q_i:	$TEU\ to\ deliver\ at\ terminal\ i$
p_i:	$TEU\ to\ pickup\ at\ terminal\ i$
ce_i:	$costs\ of\ being\ too\ early\ at\ terminal\ i\ (€/minute)$
cl_i:	$costs\ of\ being\ too\ late\ at\ terminal\ i\ (€/minute)$
cw_i:	$costs\ of\ waiting\ at\ terminal\ i\ (€/minute)$
M:	$a\ large\ number$
V_i	$1\ if\ a\ node\ has\ to\ be\ visited, 0\ otherwise$
$S_{T\,i}$	$1\ if\ both\ load\ and\ unload\ are\ visited, 0\ otherwise$

The sailing times are defined, and consist of the time of sailing and a fixed waiting time at locks. The service time at terminals consists of the loading and unloading, a delay, and a fixed handling time. The earliest and latest time of service at the terminal depends on the terminal's opening hours, or containers' earliest pickup or latest delivery dates. The capacity of barges differs per barge, but this parameter is changed before the VRPPDSTW is executed. Therefore C is not related to an index, and the same holds for c. The costs of being too early at a terminal are set at €100/minute, while costs of being too late are set at €10/minute. Furthermore, waiting costs are set slightly lower than the sailing costs per minute of the barge. We chose the high costs for being too early, because a barge can never be too early at a terminal; it can be the case that a container is not ready for pick up, or the terminal is closed. In that case, the model should choose for waiting at the terminal. Whenever the option for waiting was not included in the model, the barge would still call at the terminal even when it is not possible. These waiting costs are slightly lower than sailing costs, because the model otherwise will make unnecessary detours so that it is not too early, while in practice a barge would just wait. Moreover, the barge should wait at the terminal with the restricted opening times, and therefore the costs are slightly lowered at those terminals. The lateness costs can be changed to enforce being on time at terminals with limited opening hours. The costs are then changed to €20/minute for those specific terminals. M is the total amount of minutes in the planning horizon + 10. V_i and S_{Ti} are parameters that will be used to force the model that only nodes will be visited that need a visit, and to force unload and load nodes of a port terminal are visited in sequence.

$Decision\ variables$:

x_{ij}:	$1\ if\ a\ vehicle\ travels\ from\ terminal\ i\ to\ j, 0\ otherwise\ (i \neq j)$
a_i:	$start\ of\ service\ at\ terminal\ i$
d_i:	$departure\ time\ at\ terminal\ i$
ga_i^+:	$minutes\ too\ late\ for\ earliest\ arrival\ time\ a_i$
ga_i^-:	$minutes\ too\ early\ for\ earliest\ arrival\ time\ a_i$
gd_i^+:	$minutes\ too\ late\ for\ latest\ departure\ time\ d_i$
gd_i^-:	$minutes\ too\ early\ for\ latest\ departure\ time\ d_i$
L_{ij}:	$TEU\ of\ import\ containers\ on\ board\ on\ arc\ (i,j)$
U_{ij}:	$TEU\ of\ export\ containers\ on\ board\ on\ arc\ (i,j)$
y_i:	$waiting\ time\ at\ customer\ i$

The departure time is defined as $d_i = a_i + s_i$. The four variables with g as prefix are deviational variables, that represent the difference between the e_i and l_i parameters and the actual arrival and departure times. The values of ga_i^+ and gd_i^- variables do not have any consequences, while the other two incur a penalty for being too early or too late. L_{ij} and U_{ij} represent the import and export containers that are on the barge between two nodes, measured in TEU.

$Objective\ function$:

$$min \sum_{i,j} c\ t_{ij}\ x_{ij} + \sum_{i} (ce_i\ ga_i^- + cl_i\ gd_i^+ + cw_i\ \mathrm{y_i})$$

$Constraints$:

$$\sum_{i=1}^{n} x_{ij} = V_i \qquad j = 1, \dots, n \qquad (1)$$

$$\sum_{j=1}^{n} x_{ij} = V_i \qquad i = 1, \dots, n \qquad (2)$$

$$\sum_{i=1}^{n} L_{ij} + p_j = \sum_{i=1}^{n} L_{ji} \qquad j = 2, \dots, n \qquad (3)$$

$$\sum_{i=1}^{n} U_{ij} - q_j = \sum_{i=1}^{n} U_{ji} \qquad j = 2, \dots, n \qquad (4)$$

$$\sum_{i=2}^{n} L_{1i} = 0 \qquad (5)$$

$$\sum_{i=2}^{n} U_{i1} = 0 \qquad (6)$$

$$x_{ab} = S_{T_a} \qquad \forall\ (\mathrm{a,b}) \in \mathrm{U} \qquad (7)$$

$$L_{ij} + U_{ij} \leq Cx_{ij} \qquad i,j = 1, \dots, n \qquad (8)$$

$$d_j - d_1 + \left(1 - x_{1j}\right)M \geq s_j + t_{1j} + y_j \qquad j = 2, \dots, n \qquad (9)$$

$$d_j - d_1 - \left(1 - x_{1j}\right)M \leq s_j + t_{1j} + y_j \qquad j = 2, \dots, n \qquad (10)$$

$$a_j - d_i + \left(1 - x_{ij}\right)M \geq t_{ij} + y_j \qquad i,j = 2, \dots, n \qquad (11)$$

$$a_j - d_i - \left(1 - x_{ij}\right)M \leq t_{ij} + y_j \qquad i,j = 2, \dots, n \qquad (12)$$

$$d_i + ga_i^- - ga_i^+ = e_i + s_i \qquad i = 2, \dots, n \qquad (13)$$

$$d_i + gd_i^- - gd_i^+ = l_i \qquad i = 2, \dots, n \qquad (14)$$

$$a_1 + gd_1^- - gd_1^+ = l_1 \qquad (15)$$

$$a_1 - d_i + (1 - x_{i1})M \geq t_{ij} \qquad i = 2, \dots, n \qquad (16)$$

$$a_1 - d_i - (1 - x_{i1})M \leq t_{ij} \qquad i = 2, \dots, n \qquad (17)$$

$$x_{ij} \in \{0,1\}$$

$$a_i, d_i, ga_i^+, ga_i^-, gd_i^+, gd_i^-, L_{ij}, U_{ij}, y_i \geq 0$$

The objective function is to minimize the total costs, consisting of sailing costs, costs for being too early and too late, and waiting costs. The constraints (1) and (2) ensure that every node that has to be visited has an incoming and an outgoing arc, while constraints (3) and (4) guarantee that the containers to load or unload are loaded or unloaded at the specific node. Constraint (5) and (6) guarantee that no import containers are on board when leaving the inland terminal, and no export containers are on board when coming back to the inland terminal. Constraints 7 ensure that, when both the unload and load node of a terminal have to be visited, the unload and load nodes are visited in sequence. Constraints 8 ensure that the capacity of the barge is never exceeded on all used arcs. Constraints (9) – (12) make sure that departure at a terminal follows right after the departure of the preceding terminal, with adding the sailing, waiting, and service time. Constraints (13) – (15) ensure the deviational variables are set in such a way that the e_i and l_i values are reached, and constraints (16) and (17) set the arrival times at the inland terminal.

Whether the VRPPDSTW was working correctly, was tested amongst several situations. The output was checked by hand to see if the VRPPDSTW gave a workable outcome. Furthermore, the simulation tool reads the VRPPDSTW output, and when it is not correct it will display an error. First, the model was tested without restricting time windows (i.e. the time windows do not play an important role; they will be met in any possible routing). The solving time can be found in Table 17. The number of terminals means the load and unload node, and thus in fact a double amount of nodes is visited. Twelve terminals is a situation that will never happen in the simulation tool. When the VRPPDSTW was applied in the simulation situation, and thus with restricting time windows but without the high amount of terminals as in Table 17, the solving time was always smaller than one second. The experiments were performed on a Interl®Core™i7 machine with 2,70 GHz and 8 GB RAM memory, with CPLEX 12.6.

Number of terminals	Solving time in seconds
1	0,02
2	0,03
3	0,03
4	0,12
5	0,47
6	2,2
7	3,73
8	4,91
9	2,31
10	7,22
11	11,67
12	5,13

Table 17: Solving time without restricting time constraints

5.3.4. The complete simulation

The simulation tool is built in such a way that it simulates roundtrips of barges until all containers in the tool are delivered. The tool looks over a time frame, and every time the barge that is the earliest "available" in this time frame is selected. The barge has a fixed inland terminal, which means that during the simulation of one roundtrip of a barge, the routing from inland terminal to inland terminal via the PoR is simulated. The following steps are executed to simulate the roundtrip of a barge:

1. Allocate containers to the barge (see Section 5.3.1);
2. Load and execute the VRPPDSTW (see Section 5.3.2);
3. Execute the roundtrip according to the result of the VRPPDSTW;
4. If there are still containers available; select next barge and return to step 1.

During the simulation, the tool is bounded to some restrictions:

- The opening hours of terminals;
- The capacity of barges;
- The quay availability at inland terminals.

Combining this altogether, the tool gives a feasible solution of transporting all containers in the tool. The output consists of allocation of containers to barges, the routing of barges, and the performance indicators (see Section 5.1) associated with the solution. An extensive description of the decisions that are made in the tool can be found in Appendix D.

5.3.5. Interpretation of output

After the simulation tool had been finished, the output can be analysed. As stated before, the delays at port terminals can be used to form the reference situation, which is closely aligned with practice. While the exact performance of the real-life situation is difficult to measure, a percentage of around five for late containers (the main indicator) is reasonable for two reasons. First, a 100% service level will never be reached. Second, the simulation is not perfect and will always have some discrepancies, combined with the fact that the data is not perfect. In the simulation the delays where set as shown in Table 18. With these settings, 4,8% of the containers is delivered too late, and the price per TEU is €40,70. All performance indicators that were defined in Section 5.1 can be found in Table 19.

The simulation started at 08-09-2014 at 21:00, and ended 17-10-2014 at 05:21. This means the simulation took almost six weeks in total. The number of roundtrips the barges made in the simulation, together with the expected number and the utilisation, can be found in Table 20. The number of roundtrips in the simulation lays around the number of roundtrip expected in practice. The deviations exist because of the way delays are modelled, and because a 24/7 availability of barges is assumed. There is no data available about the utilisation of barges in practice. However, it is known that the utilisation of Veghel and Tilburg Loven barges is rather low, which explains the low utilisation in the simulation. The utilisation of the other barges differs from 50 to 75%, which is in a way also quite low, but this is also caused by the way the simulation works. In the beginning and end of the simulation there is less loading available, which directly leads to a lower utilisation. Therefore there is also a corrected utilisation presented in Table 20, which does not take the first and last three roundtrips into account. This shows that in the "middle" of the simulation, the utilisation of barges is higher.

Terminal	Delay (minutes)
ECT Delta East	300
ECT Delta North	300
ECT City	300
Euromax	300
APM	200

Table 18: Used delays for the reference situation

Performance indicator	Value
Containers delivered too late	4,8%
Costs for last-minute trucking	€159.802
Variable costs barges	€164.272
Fixed costs barges	€812.211
Total costs	€1.136.285
Costs per TEU	€40,70

Table 19: Performance indicators for the simulation of the as-is network

Barge identifier	Roundtrips in simulation	Roundtrips expected in practice	Utilisation	Corrected utilisation
ITV28.1	22	21	59,4%	60,4%
ITV28.2	24	21	46,1%	50,3%
BTT32.1	25	24	24,6%	25,6%
BTT32.2	25	24	27,8%	28,1%
ROCW36	28	24	57,4%	57,6%
VOS44.1	22	24	77,7%	85,8%
VOS44.2	24	24	70,1%	75,9%
ROCW48.1	25	30	54,2%	55,9%
ROCW48.2	26	30	60,3%	64,6%
ITV52	22	21	38,4%	38,6%
VOS60.1	22	24	72,9%	79,8%
VOS60.2	21	24	74,1%	89,2%
ITV90.1	22	21	23,7%	28,8%
ITV90.2	22	21	27,0%	30,3%
OCT108.1	25	24 – 36	70,6%	75,0%
OCT108.2	26	24 – 36	64,2%	72,7%
OCT144	22	24 – 36	73,9%	75,8%

Table 20: Number of roundtrips and the utilisation of barges
(corrected utilisation means the first and last three roundtrips have not been taken into account)

6. Design and analysis of the simulation of the to-be network

In this chapter the design and analysis of the to-be network will be described. In Section 6.1 the basics for the hub network will be set: the location of the hub and the type of operations. After that, in Section 6.2, an extensive analysis based on the data set and simulation of the as-is network will be performed, to form the design of the to-be network. After this hypotheses will be formed about the performance to the to-be network, which will be tested in the next chapter. In Section 6.3 the changes that have to be made to the simulation will be described.

6.1. The hub network

6.1.1. Hub location

Oosterhout is the best location for the hub for several reasons. First of all, the terminal is located closest to the port, so barges do not have to sail in the opposite direction of the port for exchanging containers. Second, the barges that depart from the Tilburg terminals already sail by Oosterhout, and the barges of Veghel and Waalwijk only have to make a small detour of around ten kilometres. Furthermore, the terminal already the ability to handle two barges at the same time, because the length of the quay is sufficient for the two largest barges in the BIM network, and the availability of two cranes. The inland port of Oosterhout does not charge any fees, and lastly, there are no size constraints for the barges in the current BIM network that want to sail via Oosterhout (i.e. all barges in the BIM network can exchange at Oosterhout).

In this way the disadvantages about hub network (see Section 2.4) we found are accounted for; there is no investment needed, the detours are kept to a minimum, and the organisational barriers are not as high as normally since the terminals are already cooperating. The other disadvantages are not necessarily influenced by the choice of the network. The need for extra storage capacity still stands, but the Oosterhout terminal has extra capacity for (short-term) storage (see Section 6.1.2).

6.1.2. Type of operations

The network we will look at makes use of *on-going* barge services. We are doing this for two reasons. First, this way of operating does not need a change in the equipment; current barges can be used in the new network. This is important because we want to show that the operation can be done more efficient without a change in equipment. One of the disadvantages related with hub networks, was that investments are needed, and we want to diminish this disadvantage as far as possible. Second, the use of dedicated barges implies that barges have to be unloaded and loaded completely at the hub. This takes a lot of time. Imagine a 90 TEU barge. With an average container size of 1.8 TEU, which thus has 50 containers on board when it is completely utilised. One container move takes four minutes, and thus completely unloading the barge takes 3,3 hours. Completely unloading and loading a barge of this size takes then almost seven hours, which will lead to a very high utilisation of the available quay in Oosterhout, and possibly needs an investment in equipment at Oosterhout. Furthermore, the distances in this network are quite small, which will lead to barges spending most of their time loading and unloading. One of the reasons to introduce the hub network is to spend more time sailing instead of waiting, and this effect is diminished in this network when using dedicated services.

We will make use of *sequential exchange*. Exchanging simultaneously requires coordination of arrival times at the hub terminal. This means that one barge needs to be delayed, because a simultaneous arrival will never be accomplished. The exact delay can be a few minutes to a few hours, but with an average of ten outgoing trips per day for the current network, this will on average be around 2-2,5 hours. Furthermore, there are less possibilities for exchanging containers compared to using sequential exchange, because there are only the port terminals that are on board of the two barges that can be considered, while with sequential exchange there are more possibilities. Because there are in total around twenty potential hub stops on an average day, using simultaneous exchange will mean the quay cannot be used for quite a long time, while with sequential exchange this will be less of a problem, because the barges have their own schedule, which can lead to two barges at the quay, but the chance two barges are at a quay is much smaller. Simultaneous exchange is better in other areas, where there are less barges stopping by and there are more calls on board of the barges (for example in the northern part of The Netherlands, using Utrecht as a hub. There will be a few inbound and a few outbound barges, with more calls on board). As found in the literature review (see

Section 2.4), sequential exchange requires storage capacity and leads to more moves. The storage capacity is accounted for, because Oosterhout has storage capacity for at least 400 TEU. When we do not count the Oosterhout containers (there is of course already capacity for these containers), there is on average 450TEU transported (inbound and outbound together) per day, from and to the other terminals. This means that, when we assume an average stay of 24 hours at the hub, which is already long, 89% of the containers can be exchanged and stay for 24 hours at the hub. The extra moves for a container are still present, since the containers first have to be stacked, and then will be moved again when the barge for the container has arrived. However, one of the main benefits of using a hub is a shorter turnaround time of barges. Simultaneous exchange will unnecessarily extend this time, when we are looking at the costs of barges. Therefore we expect that the extra move of the container can be outweighed by the benefits of the hub network, which will be further analysed in the next subsection.

The exchange of containers will be done *vertically*. There are a lot of different types of barges used in the network, of which only one is a push barge. When using horizontal exchange the options for exchange are almost zero, and since we do not want huge investments in equipment we must make use of cranes and reach stackers for the exchange of containers.

6.2. Analysis for network design

For designing the hub network it should be known what the possible savings are, and based on these savings the network can be designed. The biggest saving can be made when there are less barges needed in the network. To be able to reach at least the same customer service level (fraction of late containers) with less barges, barges should be higher utilised, and preferably make more roundtrips. For making more roundtrips, time savings should be made. Time savings that can be made can be split up into three categories, namely less calls during a roundtrip, less visits to areas in the PoR, and a lower delay at port terminals.

Within a sailing area a call takes 50 minutes: 20 minutes for docking and 30 minutes for sailing. The (un)loading of containers is not a saving since the containers still have to be (un)loaded. Therefore the saving for every call within an area is 50 minutes. Ultimately, a barge will visit only one area. This savings are higher. Consider the following sailing times (visiting terminals is excluded):

- Oosterhout – PoR: Stad area – Port: Maasvlakte 1 area – Oosterhout: 761 minutes
- Oosterhout – PoR: Stad area – Oosterhout: 560 minutes
- Oosterhout – PoR: Maasvlakte 1 area – Oosterhout: 706 minutes

The savings for not visiting the Stad is almost an hour, and not visiting the Maasvlakte three hours (when assuming a barge visits both areas now). Furthermore, when redistributing the containers in a smart way, barges can possibly visit less delayed terminals. According to the way we modelled delays now, not visiting a terminal which is delayed can lead to a saving between one and five hours per visit per terminal (depending on the terminal and the call size).

These savings must be at least the same, but preferably higher than the time it takes to sail via the hub, which exists of a detour for sailing to the hub, time for the redistribution of containers, and a waiting time at the hub.

When a barge stops at the hub before going to the PoR this takes time. The Tilburg barges already sail via the hub, so stopping there only incurs the fixed handling time of 20 minutes. Waalwijk and Veghel barges have to make a detour, which takes 50 minutes for sailing via the hub, and 20 minutes for the fixed handling time. Besides this fixed detour time, it takes four minutes for loading or unloading one container. Depending on the number of containers that will be exchanged this can take four minutes (one container) to several hours. Due to a higher quay utilisation at Oosterhout, barges can also incur some waiting time at the hub when the quay is already in use.

6.2.1. Data set analysis for the to-be network

Now that it is clear what the possible savings are, an analysis can be performed on the data set to see whether these savings can be reached. The most time can be saved when calling less at delayed terminals, followed by a split in areas, and by lowering the amount of calls in general. These savings lead to higher utilised barges, and therefore less barges are needed in the to-be network. Since the inland terminals, except Oosterhout, should still have enough departures during the simulation, only Oosterhout barges can be taken out of use. When Oosterhout barges will not be in use in the to-be network, the other barges that stop at Oosterhout should compensate this loss in capacity. In the as-is network, the Oosterhout barges transported 12105 TEU, while the other barges have not used 20093 TEU of their capacity (see Table 21). Therefore this might be possible, but a more detailed analysis is necessary to be sure enough capacity is created.

	Capacity (TEU)	Roundtrips in as-is simulation	Utilisation	Used capacity (TEU)	Unused capacity (TEU)
ITV28.1	28	22	59,4%		500
ITV28.2	28	24	46,1%		724
BTT32.1	32	25	24,6%		1206
BTT32.2	32	25	27,8%		1155
ROCW36	36	28	57,4%		859
VOS44.1	44	22	77,7%		432
VOS44.2	44	24	70,1%		631
ROCW48.1	48	25	54,2%		1099
ROCW48.2	48	26	60,3%		991
ITV52	52	22	38,4%		1409
VOS60.1	60	22	72,9%		715
VOS60.2	60	21	74,1%		653
ITV90.1	90	22	23,7%		3021
ITV90.2	90	22	27,0%		2891
OCT108.1	108	25	70,6%	3812	
OCT108.2	108	26	64,2%	3605	
OCT144	144	22	73,9%	4682	
Sum				**12100**	**16288**

Table 21: Used and unused capacity for the barges in the as-is simulation

The two areas that will be analysed are Stad and Maasvlakte 1. The terminal *Cetem Containers* was added to Stad area, since it is located closest to this area, the *Waalhaven Botlek Terminal* was added to the Maasvlakte 1 area, since barges pass this terminal when sailing to the Maasvlakte 1. *Combined Cargo Terminals Moerdijk* was arbitrarily added to Maasvlakte 1, since the effect is very small (only 0,9% of the containers in the BIM network have its origin or destination at this terminal). The distribution of containers over the two areas is around 20/80% (Stad/Maasvlakte 1), which can be seen in Figure 13.

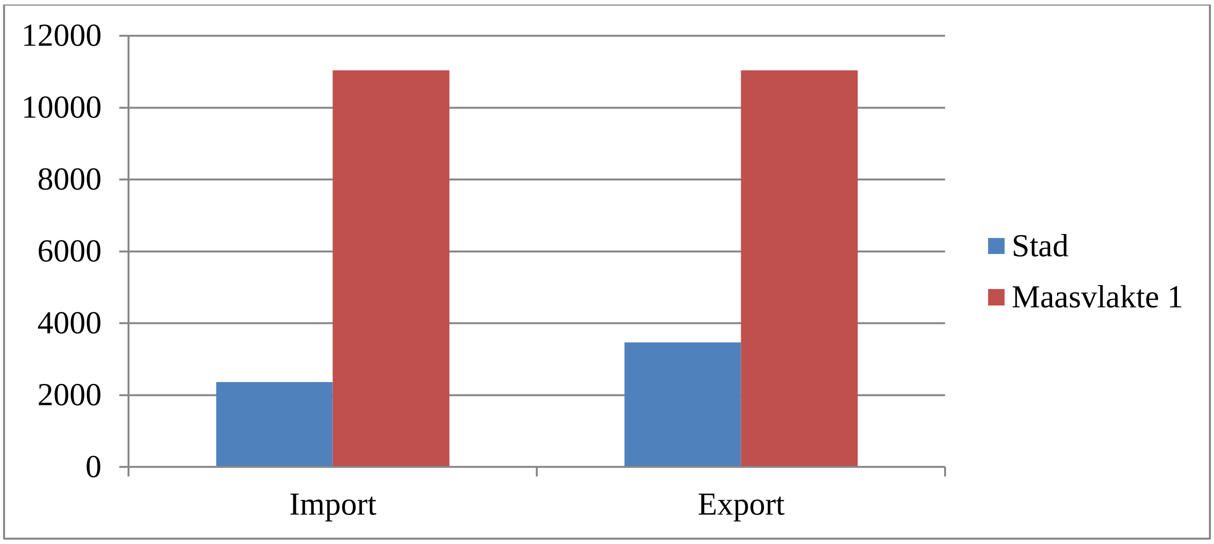

Figure 13: Distribution of containers over the two areas (in TEU)

When looking at the terminals in these areas, there are fifteen located in the Stad area, and nine in the Maasvlakte 1 area. This means that, when a split in areas would be made, the largest part of the capacity has to be allocated to the Maasvlakte 1 area, where large calls can be accomplished. When this is done, this is also positive for the reduction in total delay, since four of the five terminals that are delayed in the simulation are located in Maasvlakte 1.

To ensure there will be sufficient capacity to both areas, barges will be dedicated to one of the two areas. When doing this, the distribution of created capacity should be close to the distribution in containers as presented in Figure 13. Furthermore, since the call sizes are small in the Stad area, the small barges will be assigned to the Stad area, because otherwise barges will have to make many calls during a roundtrip when they are dedicated to the Stad area.

Under the assumption that the number of roundtrips during the simulation stays the same, it is possible to calculate the capacity of a barge during the whole simulation. For this, the capacity of a barge from and to Oosterhout is used, since sufficient capacity should be created to and from the hub. When multiplying this capacity by the number of roundtrips and doubling this number (there is capacity *to* and *from* the hub), there is a total capacity as can be found in Table 22. The total created capacity (54124 TEU) is much higher than the required capacity (27918 TEU), and even without the Oosterhout barges there still is sufficient capacity (35908 TEU). This is caused by the fact that barges are not 100% utilised (see Table 22), and by the two VOS60 barges that have a capacity of 90 TEU from and to the hub.

Barge identifier	Capacity to and from the hub (TEU)	Roundtrips in simulation as-is network	Capacity from and to hub combined (TEU)
ITV28.1	28	22	1232
ITV28.2	28	24	1344
BTT32.1	32	25	1600
BTT32.2	32	25	1600
ROCW36	36	28	2016
VOS44.1	44	22	1936
VOS44.2	44	24	2112
ROCW48.1	48	25	2400
ROCW48.2	48	26	2496
ITV52	52	22	2288
VOS60.1	90	22	3960
VOS60.2	90	21	3780
ITV90.1	90	22	3960
ITV90.2	90	22	3960
OCT108.1	108	25	5400
OCT108.2	108	26	5616
OCT144	144	22	6336
Sum			**54124**
Sum without Oosterhout barges			**35908**

Table 22: Capacity to and from the hub based on the as-is simulation

A distribution of 22,7/77,3% (Stad / Maasvlakte 1) is reached when ITV28.1, ITV28.1, BTT32.1, BTT32.2, and ROCW36 are assigned to the Stad area, and the other barges (without the Oosterhout barges) to the Maasvlakte 1 area, which is the closest to 21/79% (the distribution in the data set) as possible.

Now that there is a split between Stad and Maasvlakte 1 barges, both flows can be analysed on its own. The highest savings that can be made for Maasvlakte 1 barges, is to minimise the number of calls at the delayed terminals in the Maasvlakte 1 area, which account for 89% of the supply and demand of containers in this area. This can be reached by having dedicated barges to these terminals. That means that a barge is only visiting one of the four delayed terminals, and eventually another Maasvlakte 1 terminal. However, this only works out if the supply and demand pattern does not differ too much. If the ECT East terminal has a combined flow of 2000 TEU in a week 1, and 500 TEU in week 2, this will not work out well. Therefore, the containers that had to be delivered in a week (export) and could be picked up in that same week (import) were added together. The result of this is shown in Figure 14. As can be seen, all the different terminal categories follow more or less the same pattern, and there are no large deviations that can lead to problems with dedicated terminal barges.

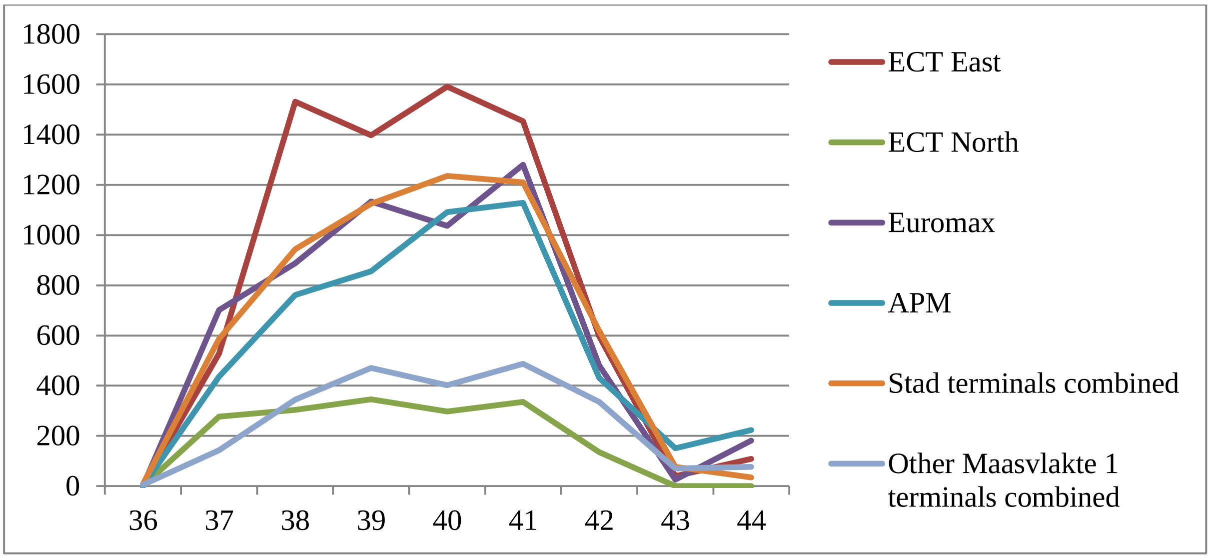

Figure 14: The number of TEU to be delivered or picked up in a week at the port terminals

To verify that enough capacity is created, the calculation in Table 22 was made again for the Maasvlakte 1 barges. This showed that the nine barges create 27740 TEU to and from the hub, while the supply and demand is 22080 TEU. At first sight this seems enough, but as shown in Figure 14 the distribution of containers over the simulation period is not uniform. In the beginning and end of the simulation there is not a lot of supply and demand, while in the middle four weeks the pattern is more or less stable. Therefore it is expected that taking all Oosterhout barges out of order will lead to more late containers. Therefore OCT144 was added to the network, because the price difference with the OCT108 is small (€71 per day), and it can easily be switched or taken out of order again. When this is done, there is 34076 TEU created to and from the Maasvlakte 1 area.

The number of barges of ten is also more convenient for having dedicated barges. The pattern over the four different terminals is shown in Figure 15. Based on these patterns, assigning three barges to all terminals except ECT North, which then will get one barge, fits the best. To be sure enough capacity is created to all terminals, the larger barges will be assigned to ECT East. Furthermore, ECT North needs a large barge because fluctuations in supply and demand can only be absorbed by this barge, and this barge also needs to have short roundtrips to be sure as much containers are delivered on time as possible. Therefore a Tilburg Vossenberg barge is the best option.

The same as with dedicating barges to the two different areas, with dedicating barges to terminals the distribution in created capacity should be as close to the distribution of supply and demand as possible. Furthermore, the number of handlings should be kept to a minimum. Based on the distribution of the total demand and supply of these four terminals over the inland terminals (Figure 16), Tilburg Vossenberg should have at least one APM and one Euromax barge.

Taking this all into account, the distribution as shown in Table 23 gives the best outcome. The distribution of capacity associated with this assignment is shown in Table 24. Especially the capacity to and from APM deviates from the actual distribution. However, this has several reasons. First, Tilburg Vossenberg also has a lot of containers from and to Euromax, so this terminal needed the larger barge. Second, the created capacity is still enough to reach the actual number of TEU to and from APM. Lastly, this is based on the current roundtrips. The expectation is that those will be shorter for APM terminals, since this terminal has a lower delay. Therefore the expectation is that there will be enough capacity to the APM terminal.

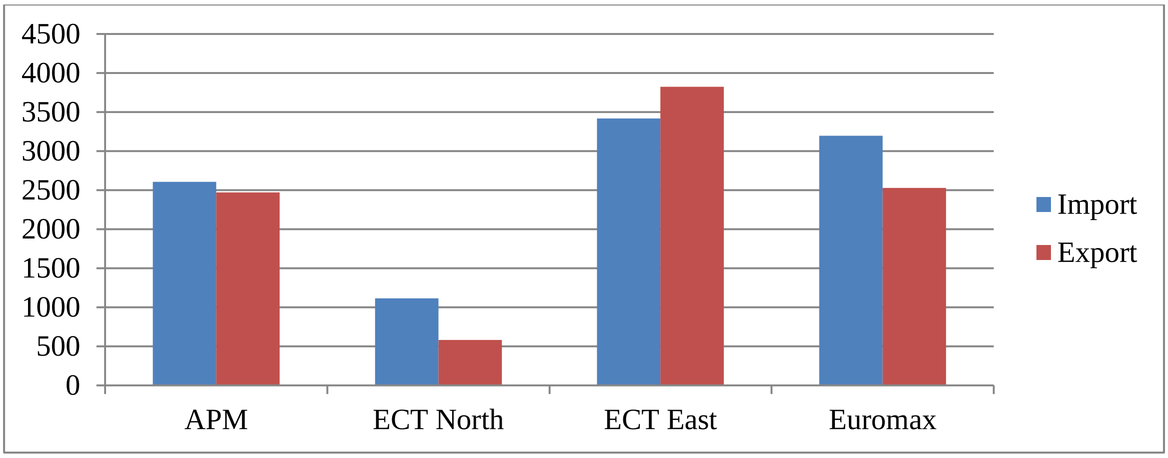

Figure 15: Number of TEU per delayed Maasvlakte 1 terminal

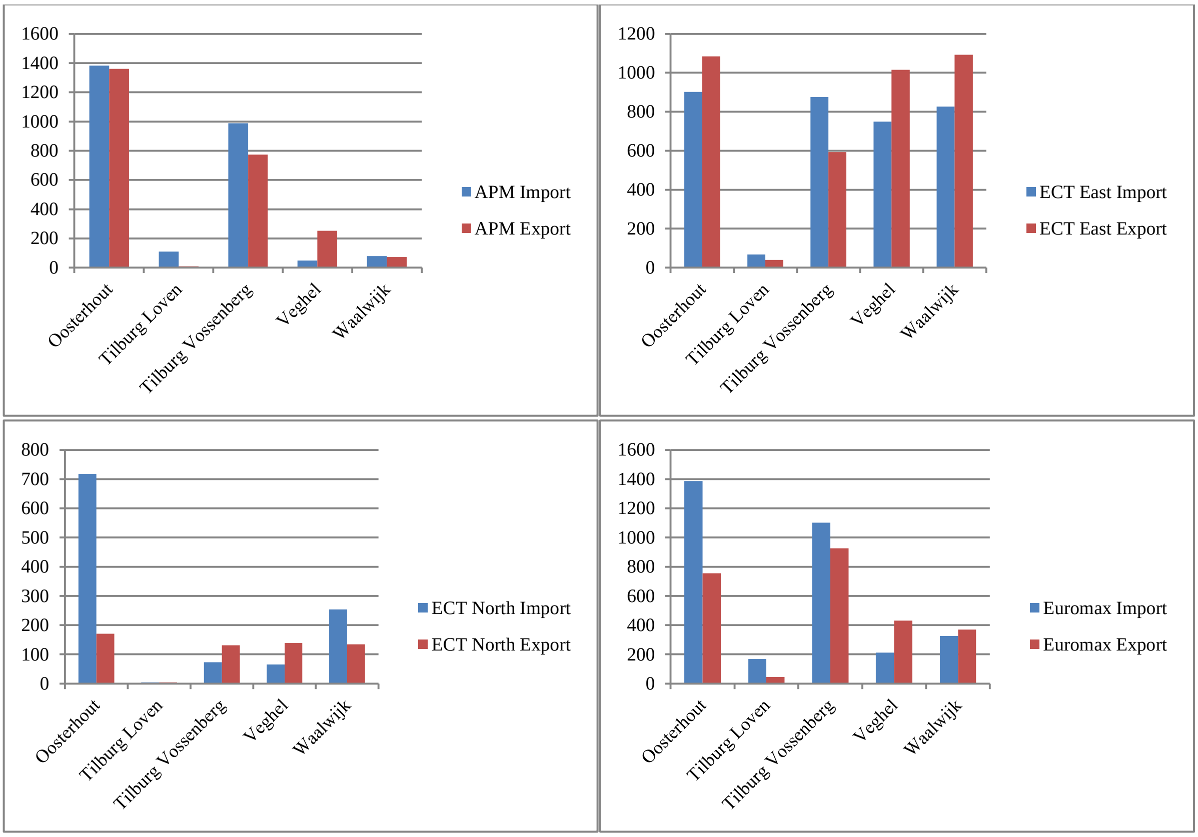

Figure 16: The distribution of containers to and from delayed Maasvlakte 1 over the inland terminals

ECT East	ECT North	Euromax	APM
ROCW48.2	VOS60.1	ROCW48.1	VOS44.1
ITV90.2		VOS60.2	VOS44.2
OCT144		ITV90.1	ITV52

Table 23: Dedicated barges to the delayed Maasvlakte 1 terminals

Terminal	TEU created	%	Distribution in supply and demand
APM	6632	19,1%	26%
Euromax	10692	30,5%	29%
ECT North	3780	11,9%	9%
ECT East	12972	38,5%	37%

Table 24: Distribution of capacity and supply & demand over the delayed Maasvlakte 1 terminals

In total, there are fifteen terminals in the Stad area where containers have to be transported to or from. The total flow from these terminals to the BIM terminals is 2368 TEU, and the flow from the BIM terminals to the Stad terminals is 3470 TEU. There is a significant difference between the import and export TEU, which is not the case for the Maasvlakte 1 terminals. This should be taken into account when analysing the capacity.

Based on Table 22, this creates 4084 TEU from, and 4084 TEU to the Stad area. For import containers this is enough, while it can be form problem for export containers. However, the expectation is that roundtrips for these barges will be shorter. There is only one delayed terminal in this area, the ECT City terminal. This terminal accounts for 6,9% of the containers to and from the Stad area, which means that the delay for Stad barges will be minimised, which already leads to shorter roundtrips. Furthermore, savings for these barges are the largest for the split in sailing areas. Therefore we expect that the created capacity will be sufficient

Now that all barges are assigned to areas and terminals, a more thorough calculation can be performed to calculate whether still enough capacity is created to all areas and terminals. Before calculating the expected number of roundtrips, it is important to start with *allocation rules*, which state for every barge which containers can be loaded. To reach a minimum number of handlings at the hub, because every handling incurs a cost and increases the quay utilisation, a barge should only load containers that will not be loaded on another barges from that inland terminal. For example at Veghel, where the barge ITV52 is dedicated to APM. Therefore, the four other Veghel barges will not load containers for APM. Combining this altogether gives the distribution as presented in Table 25. In this table the maximum number of calls for Stad terminals is set at four. Dividing fifteen terminals over five barges gives a number of three terminals per barge. However, the number of containers is not uniformly distributed over the terminals, and therefore it can happen that more than one barge has to call at a terminal shortly after each other. It is expected that a maximum of four terminals per roundtrip should be sufficient. Furthermore, in this table there is a column *priority*. This means that this barge will load for the terminal(s) it is dedicated to before other terminals will be loaded. This is not the case for Tilburg Loven and Oosterhout barges. The Tilburg Loven terminal only has two barges that are both dedicated to Stad terminals. Therefore all containers should be loaded based on closing times, since no other barges will come for Maasvlakte 1 terminals. The Oosterhout barge starts its roundtrips at the hub, and therefore this barge does not have to load with priority.

All Maasvlakte 1 barges can load for the other Maasvlakte 1 terminals (four in total), and only one terminal will be loaded per roundtrip to ensure not too many calls are made at these terminals. This does not hold for the VOS60.1 barge. Because this is the only barge to the ECT North terminal the roundtrips should be as short as possible and therefore no other terminals will be visited during these roundtrips. Furthermore, all the Tilburg Vossenberg barges also load for Stad terminals, since there are no Tilburg Vossenberg barges assigned to the Stad area. The same allocation rules are made for the import route. For example when the ITV52 barge loads at APM, it should not load containers for Tilburg Vossenberg, since this terminal has its own barges dedicated to APM. When ITV52 would load containers for this inland terminal, this would add two unnecessary handlings per container. These assignment rules can be found in Table 26.

Barge identifier	Dedicated to sailing area	Maximum calls at Stad terminals	Maximum calls at other Maasvlakte 1 terminals	Priority load at inland terminal	ECT East	ECT North	Euromax	APM	Other Maasvlakte 1 terminals	Stad terminals
ITV28.1	Stad	4		X		X				X
ITV28.2	Stad	4		X		X				X
BTT32.1	Stad	4			X	X	X	X	X	X
BTT32.2	Stad	4			X	X	X	X	X	X
ROCW36	Stad	4		X		X		X		X
VOS44.1	APM		1	X	X			X	X	X
VOS44.2	APM		1	X	X			X	X	X
ROCW48.1	Euromax		1	X		X	X	X	X	
ROCW48.2	ECT East		1	X	X	X		X	X	
ITV52	APM		1	X		X		X	X	
VOS60.1	ECT North		1	X	X	X	X			X
VOS60.2	Euromax		1	X	X		X		X	X
ITV90.1	Euromax		1	X	X	X			X	
ITV90.2	ECT East		1	X		X			X	
OCT144	ECT East		1		X				X	

Table 25: Allocation rules at the inland terminals (X = the barge will load containers for this terminal or with priority. The six columns on the right represent whether a barge loads containers for this port terminal)

Barge identifier	Dedicated to terminal	Oosterhout	Veghel	Tilburg Loven	Tilburg Vossenberg	Waalwijk
VOS44.1	Euromax	X		X	X	X
VOS44.2	ECT East	X		X	X	X
ROCW48.1	APM	X		X		X
ROCW48.2	ECT North	X		X	X	X
ITV52	Euromax	X	X	X		X
VOS60.1	Euromax	X	X	X	X	X
VOS60.2	ECT East	X		X	X	
ITV90.1	ECT East	X	X	X		
ITV90.2	Euromax	X	X	X	X	
OCT144	ECT East	X		X	X	

Table 26: Allocation rules at the dedicated delayed Maasvlakte 1 terminals (X = the barge will load containers for this inland terminal)

Based on the allocation rules in Table 25 and Table 26 the expected length of roundtrips can be calculated, together with an approximation of the number of handlings. This is the most important, since handlings will add costs to the to-be network. Based on this calculation we can approximate whether the to-be network will be cost efficient. Furthermore, the expected quay utilisation at the hub will be calculated, to see whether the hub can handle this design of the to-be network.

Based on the data set the number of TEUs to the different areas is calculated. Since it is known which barges will load which containers, it can be calculated what the number of TEU per roundtrip per barge is. This is in the beginning based on the simulation of the as-is network, together with an even distribution of containers over the barges. An example of such a calculation can be found in Table 27, which is based on the export to Stad terminals. The total capacity to the hub is known, together with the needed capacity for Stad terminals (742 TEU). Thus, per roundtrip the VOS44.1 barge will load (44/4604)*742 = 7,1 TEU for Stad terminals. Calculating this for all area/inland terminal combinations, gives the number of TEU a barge will on average arrive with at the hub.

It is known which part of these containers will be unloaded, namely all containers that do not have the terminal(s) the barge is dedicated to as destination. Furthermore, the extra containers that will be loaded on the barge can be calculated, based on a similar way as at the inland terminal. An example can be found in Table 28, which is based on the export to ECT East (there is a total of 3826 TEU to export to ECT East). When the number of TEU that is already loaded at the inland terminal is subtracted from this, the number if TEU that will be loaded at Oosterhout is known. This is again done for all area/inland terminal combinations.

The same calculations are performed for the import route, starting with the loading at the port terminals. There is a difference for the Stad and Maasvlakte 1 barges, since Stad barges will load containers for all destinations, whereas Maasvlakte 1 barges load as proposed in Table 26. In Table 29 a calculation for Euromax is shown (based on allocation rules, so for example only ROCW48.2 loads containers for Waalwijk at Euromax, and a total import of 3197 TEU). This calculation is performed for all delayed Maasvlakte 1 terminals, and altogether for the other terminals. Furthermore, in Table 30 the calculation is shown for Stad barges (a total import TEU of 2368).

It is known which of these containers will be unloaded at Oosterhout. It is assumed that the barges transport containers uniformly to the inland terminals, as in the other calculations. An example for Tilburg Loven is shown in Table 31 (a total of 543 TEU needs to be transported to Tilburg Loven). This number is subtracted by the number of TEU that stays on the barge after unloading at Oosterhout, to get the number of TEU that will be loaded at Oosterhout.

Barge identifier	Capacity from Tilburg Vossenberg (TEU)	Roundtrips	Total capacity (TEU)	TEU for Stad terminals per roundtrip
VOS44.1	44	22	968	7,1
VOS44.2	44	24	1056	7,1
VOS60.1	60	22	1320	9,7
VOS60.1	60	21	1260	9,7
	Sum		**4604**	

Table 27: An example calculation, based on Stad containers from Tilburg Vossenberg

Barge identifier	Capacity from Oosterhout (TEU)	Roundtrips	Total capacity (TEU)	TEU for ECT East per roundtrip
ROCW48.2	48	26	1248	28,7
ITV90.2	90	22	1980	53,8
OCT144	144	22	3168	86,1
	Sum		**6396**	

Table 28: An example calculation, based on ECT East export containers and ECT East barges

Barge identifier	Capacity to Oosterhout (TEU)	Roundtrips	Total capacity (TEU)	Import TEU from Euromax
ROCW48.1	48	25	1200	24,5
VOS60.2	90	21	1890	46,0
ITV90.1	144	22	3168	73,6
	Sum		**6258**	

Table 29: An example calculation, based on Euromax import containers and Euromax barges

Barge identifier	Capacity to Oosterhout (TEU)	Roundtrips	Total capacity (TEU)	Import TEU from Stad terminals
ITV28.1	28	22	616	17,0
ITV28.2	28	24	672	17,0
BTT32.1	32	25	800	19,4
BTT32.2	32	25	800	19,4
ROCW36	36	28	1008	21,9
	Sum		**3896**	

Table 30: An example calculation, based on Stad import containers and Stad barges

Barge identifier	Capacity to Tilburg Loven (TEU)	Roundtrips	Total capacity (TEU)	Import TEU to Tilburg Loven
BTT32.1	32	25	800	10,9
BTT32.2	32	25	800	10,9
	Sum		**1600**	

Table 31: An example calculation, based on import containers for Tilburg Loven

This information can be used to calculate the time an average roundtrip takes, and thereafter how many handlings are expected at Oosterhout. To get the number of containers, all TEU numbers are divided by 1,8, which is the average TEU per container in the data set. A roundtrip is calculated by adding:

- The loading time at the inland terminal and the sailing time to the hub;
- The docking, unloading, and loading time at Oosterhout;
- The sailing time to and from the PoR;
- The total docking time in the PoR and the delay at the dedicated terminal when applicable;
- The sailing time inside the PoR when several terminals are visited;
- The total handling time (loading and unloading) in the PoR;
- The sailing time to the hub
- The docking time, unloading, and loading time at Oosterhout;
- The sailing time to the inland terminal;
- The docking, and unloading time at the inland terminal.

For OCT144 this calculation is slightly different, since this barges is fully unloaded and loaded directly at Oosterhout. This gives the expected time a roundtrip takes, and when 42 (the total number of days the simulation of the as-is network took) is divided by this time, the total number of roundtrips is known. In the actual simulation this number will be lower due to insufficient containers in the beginning and end of the simulation, delays at the hub, and opening hours for terminals. The numbers are shown in Table 32. However, for all barges the calculated number is higher than the number of roundtrips as in the simulation of the as-is network. The simulation has to prove that there is enough capacity created to all terminals. The number of roundtrips is inserted into the calculations that were shown in Table 27 to Table 31, because otherwise the expectation of the number of handlings will not be correct. The number of handlings is the total handlings that are performed at Oosterhout, subtracted by the total number of containers to and from Oosterhout, since these handlings are not caused by the to-be network. This gives a number of 6210 handlings. This equals to a cost of €62.100, which is less than the costs for the barges OCT108.1 and OCT108.2, which was €129.797 in the as-is simulation.

Barge identifier	Roundtrip length (in days)	Total number of roundtrips
ITV28.1	1.12	38
ITV28.2	1.12	38
BTT32.1	0.92	46
BTT32.2	0.92	46
ROCW36	0.86	49
VOS44.1	1.02	42
VOS44.2	1.02	42
ROCW48.1	1.14	37
ROCW48.2	1.11	38
ITV52	1.38	31
VOS60.1	1.17	36
VOS60.2	1.14	37
ITV90.1	1.47	29
ITV90.2	1.51	28
OCT144	1.04	41

Table 32: Expectation for roundtrip length and number of roundtrips
(not corrected for opening hours and expected waiting times at Oosterhout)

Furthermore, the quay utilisation can be calculated by adding all handling times and docking times at Oosterhout together, and dividing this by the availability (which equals two quays times the total time in the simulation). This gives an utilisation of 61%. In the simulation of the to-be network this will probably be slightly lower since the number of roundtrips is expected to be lower than shown in Table 32, which leads to less docking time (the number of handlings stay the same).

6.2.2. The expectation of the performance of the to-be network

Based on the calculations in the previous subsection hypothesis will be formed about the expected performance of the to-be network. The fixed costs for the two Oosterhout barges are higher than the costs for the handlings. However, also extra fixed costs will be added because there are barges charged per single trip. This will higher the costs for the to-be network, but it is not known by how much. Furthermore, the variable costs are expected to decrease since barges spend less time sailing in the PoR. Adding this altogether, we expect that the to-be network performs better:

Hypothesis 1:
The to-be network is cost efficient, under the same or a better service level.

The calculations in the previous subsection show how many handlings are expected. These numbers are rounded, because there can never be given a precise number that will be reached:

Hypothesis 2:
There are around 6000 extra handlings at Oosterhout in the to-be network.

Hypothesis 3:
The quay utilisation increases to around 60% in the to-be network.

Furthermore, the stack capacity at Oosterhout should be sufficient for handling the hub containers. The expectation is that the 400 TEU that is available for this is sufficient, as explained in Section 6.1.2:

Hypothesis 4:
The current stack capacity is sufficient for the hub containers.

Now that the hypotheses are formed, and it is analysed that the to-be network can work, the simulation will be changed so that it is able to make use of Oosterhout as hub, based on the allocation rules that are formed. Then, in Chapter 7, the output of this simulation will be analysed, and based on this analysis the four hypotheses will be tested.

6.3. Changes to the simulation

The simulation had to be changed to be able to handle the use of a hub. Therefore the allocation procedures had to be changed, and it had to be enforced that barges stop at Oosterhout. For the allocation of containers, the most important change is that containers had to be allocated on two legs: the inland leg (from the inland terminal to the hub or the other way around, not applicable for Oosterhout containers), and the port leg (from the hub to the port terminal or the other way around). Whenever these two allocations are not the same, this means the container has been exchanged at the hub.

Furthermore, in the as-is simulation the complete roundtrip was simulated at once. To ensure there are no containers loaded at Oosterhout that are not yet available for pick-up, this had to be changed as well. Therefore the roundtrip simulation is split into three parts, namely:

- Loading at the inland terminal, and sailing to the hub;
- The export operation at the hub, and the roundtrip in the PoR;
- The import operation at the hub, sailing to the inland terminal, and unloading at the inland terminal.

The VRPPDSTW remains unchanged, except that the input in the form of the beginning and end terminal is changed. This will be Oosterhout, except for some cases where the barge is fully loaded for its dedicated terminal(s) from the inland terminal (export) or fully loaded with containers for its inland terminal (import).

The dispatching of barges is not dependent on utilisation or waiting times in this simulation. This is not used anymore, since the barges are needed to ensure enough capacity to all terminals. Whenever a specific inland terminal has (almost) no containers available, the barge will still sail to Oosterhout to load containers there.

The procedures to ensure that barges only visit terminals during opening hours also remain unchanged. An overview of the decisions in the new tool can be found in Appendix G, together with an explanation of certain decisions. This decision scheme focusses on the changed parts of the simulation, and therefore checks like the opening hours, and the complete execution of the VRPPDSTW are not explained anymore; these can be found in Appendix D. A screenshot of the new simulation overview can be found in Appendix H.

7. Comparing the as-is network with to-be hub network

In this chapter, the implications of the to-be network on the performance indicators will be tested amongst several situations. The third research question will be answered during this chapter: *Can a to-be network be designed that has a better performance than the as-is network?*

First, in Section 7.1, the output of the simulation tool will be analysed. Based on the reference situation the to-be network is analysed and compared with the as-is network, together with whether the rules that have been formed in the previous chapter give a workable outcome. After that, in Section 7.2, the two networks will be tested amongst the different delay conditions in the PoR. The three hypotheses formed in the previous chapter will be tested in Section 7.3. In Section 7.4, the observations will be combined into possible design for the to-be network.

7.1. Analysing the reference situation

After an initial simulation, the tool required some fine-tuning. This was based on the fact that certain container groups where, relatively compared, more often delivered too late. Therefore certain decision rules had to be changed, and some had to be introduced. It occurred that there was not enough capacity from Waalwijk to ECT East. Therefore ROCW48.2 also loads containers for ECT East. This leads to more handlings, but is necessary to get a satisfying customer service level. Furthermore, most inland terminals have only one barge to one of the delayed Maasvlakte 1 terminals. Therefore, when containers are loaded based on closing time, containers were delivered too late to these inland terminals. A new decision rule was introduced, where containers are also loaded with priority at the delayed Maasvlakte 1 terminals. A barge first loads containers for its inland terminal, and after that for the terminals that the barge is allowed to load for. This is not the case for VOS44.1 and VOS44.2, since there are two barges for Tilburg Vossenberg to APM, for VOS60.1, since this is the only barge to ECT North in the whole network, and OCT144 because this is an Oosterhout barge where all barges at ECT East load for. These rules can be found in Table 33.

Barge identifier	Loads with priority in PoR
VOS44.1	
VOS44.2	
ROCW48.1	X
ROCW48.2	X
ITV52	X
VOS60.1	
VOS60.2	X
ITV90.1	X
ITV90.2	X
OCT144	

Table 33: Whether a barge loads with priority at delayed Maasvlakte 1 terminals (X = barge loads with priority for its inland terminal)

The same settings as in the as-is simulation are used for the delays at the terminals (see Table 18). The simulation with the best customer service level starts at 05-09-2014 at 07:00 and ends at 17-10-2014 at 07:21, which is six weeks in total. 9,2% of the containers were delivered too late, and the price per TEU is €47,29. The same performance indicators as used for the interpretation of the as-is network can be found in Table 34. The costs for handlings at the hub are also included in this table, and the values of the as-is situation are also displayed. As can be seen, the costs per TEU are significantly higher than the as-is simulation, mainly caused by the increased percentage of containers delivered too late. Examining the schedules of barges shows that queues are arising at Oosterhout. The quay usage of Oosterhout increased to 57,2%. This high utilisation leads to waiting times, which in the end leads to more containers that are delivered too late. Furthermore, the decrease in fixed costs is not as high as expected. Based on taking OCT108.1 and OCT108.2 out of service, the fixed costs should be around €120.000 lower in the to-be network, but in the simulation this was only €30.375. This is caused by the fact that a some barges are paid for every single trip. The expectation was that the number of roundtrips would increase, which leads to extra fixed costs for these barges. These two observations will now be examined in the coming two subsections. After that, the number of roundtrips and the utilisation will also be examined.

Performance indicator	Value as-is	Value to-be	Difference
Containers delivered too late	4,8%	9,2%	+ 4,4%.
Costs for last-minute trucking	€159.802	€332.571	+ €172.769
Variable costs barges	€164.272	€141.693	- €22.579
Variable costs handlings	€0	€64.160	+ €64.160
Fixed costs barges	€812.211	€781.836	- €30.375
Total costs	€1.136.285	€1.320.259	+ €183.974
Costs per TEU	€40,70	€47,29	+ €6,59

Table 34: Performance indicators for the reference situation of the as-is and to-be networks

7.1.1. Queues at Oosterhout

To see what the exact difference with the simulation of the as-is network is, an analysis on the waiting times was performed. The waiting time at inland terminals was summed over the whole simulation, under the condition that the waiting time was added to the schedule because the quay was in use (for example added waiting time because the inland terminal was not open yet is not summed). The result of this is displayed in Table 35. The increase in waiting time, in total as well as at the hub, is very high, and this (partly) explains the higher percentage of containers delivered too late.

Since a drop in the service level will not lead to a valid business case for BIM, a solution has to be found for this problem. Handling capacity consists of two factors, namely the quay length, and the capacity for (un)loading containers. The quay length at Oosterhout is 325 metre, while the maximum length of the barges in this network is 110 metres. Where all other barges are smaller, there is sufficient quay length for having three barges at the quay at the same time. The capacity for (un)loading containers is the bottleneck in this case, since two cranes are available for (un)loading containers. Creating extra capacity for (un)loading containers can be done in two ways, namely by speeding up the actual handling, or by adding an extra crane.

Inland terminal	Value as-is	Value to-be	Difference (%)
Oosterhout	16	939	+5879%
Veghel	32	22	-32%
Tilburg Loven	0	0	
Tilburg Vossenberg	36	34	-6%
Waalwijk	1	5	+288%
Sum	85	999	+1075%

Table 35: Waiting times at the inland terminals because the quay was in use (in hours)

Currently the handling of one container is modelled at four minutes, which is an average time. Depending on the weight of the containers, where the container is stacked, and whether the container is on top of the stack or other containers have to be moved, this takes more or less time. To increase the speed of (un)loading containers, the containers that have to be placed on a barge should be as close to the quay as possible, and in the right order. When this is done, the time for handling a container is shorter than four minutes (there is a case at BCTN, an inland terminal located in Nijmegen in The Netherlands, where 30 handlings per hour were reached, and thus two minutes per container). To check whether this increased handling speed would be enough decrease the percentage of late containers to 5% or smaller, the simulation was changed in such a way that handling a container at Oosterhout takes two, three, or four minutes (no change at all other terminals). The results of these tests can be found in Table 36. In this case the variable costs of barges get lower with the increase in handling time, while the fixed costs increase with the handling time. This is caused by the fact that the simulation takes longer with the high percentage of containers delivered too late, and therefore the barges that are paid per week (and in the simulation per day) cost more. However, the number of roundtrips decreases when the handling time increases, and thus the variable costs also decrease.

Performance indicator	Handling time at 2 minutes	Handling time at 3 minutes	Handling time at 4 minutes
Containers delivered too late	4,8%	6,4%	9,2%
Costs for last-minute trucking	€168.374	€232.508	€332.571
Variable costs barges	€149.478	€144.853	€141.693
Variable costs handlings	€60.580	€62.800	€64.160
Fixed costs barges	€759.849	€763.464	€781.836
Total costs	€1.138.281	€1.203.624	€1.320.259
Costs per TEU	€40.77	€43.11	€47,29

Table 36: Performance indicators with simultaneous handling of two barges at Oosterhout (current situation)

When adding an extra crane, three barges can be handled at the same time instead of two. A crane costs €2.000.000. When adding a crane, there are also extra operators (€35.000 per operator per year) and an extra reach stacker (€250.000) needed. This crane will not be in use 24/7, and therefore six operators will be sufficient (€35.000 per operator per year). When the crane will be paid by an annuity loan that will be repaid in 25 years, and an interest rate of 4% is used, the costs per year are € 354,027 (see Appendix E for the details). Variable costs (electricity and fuel) are not included, but those are compensated by the handlings costs of €10 per move. Since in the data set containers of five weeks where selected, it can be calculated what the costs of this extra crane per TEU are. The set consists of 27918 TEU, which is 290342 TEU per year, and thus €1,22 per TEU. In practice more containers are handled, because of the assumptions that were made (for example the removal of the Antwerpen containers). To calculate whether this investment is compensated by the to-be network, the to-be network was simulated with handling capacity for three barges, and handling time was set at four, three, and two minutes. The results of this can be found in Table 37. In this case both the variable and fixed cost decrease when the handling time increases. This is caused by the barges that are paid per roundtrip. These barges make more roundtrips, while the number of days the other barges are in use stays (almost) the same. Therefore the fixed costs get higher, and the variable costs increase because the number of roundtrips increases.

Performance indicator	Handling time at 2 minutes	Handling time at 3 minutes	Handling time at 4 minutes
Containers delivered too late	4,3%	5,0%	6,16%
Costs for last-minute trucking	€154.329	€178.509	€221.972
Variable costs barges	€158.992	€149.926	€137.147
Variable costs handlings	€61.960	€63.880	€62.760
Fixed costs barges	€801.789	€756.802	€727.123
Total costs	€1.177.071	€1.149.117	€1.149.003
Costs per TEU	€42,16	€41,16	€41.16

Table 37: Performance indicators with simultaneous handling of three barges at Oosterhout (by adding an extra crane)

7.1.2. Fixed costs of barges

Currently seven barges are paid per single trip. This means that, with an increasing number of roundtrips, the costs for these barges will be higher in the to-be network. Therefore it can be more cost efficient to replace these barges with barges that are paid per week, or renegotiate the contracts and pay the barges per week. To find out whether this is interesting in the to-be network, first a calculation was made to find out the minimum number of roundtrips to be made per week. The difference was calculated by replacing the barges with the barge that had almost the same capacity, but was paid per week. Then, the costs for sailing (gas usage) was calculated by assuming a trip to the Maasvlakte 1 area and back from the inland terminal, and assuming the barge is in use seven days per week. Based on this input the difference per week was calculated, and can be found in Table 38. Depending on the barge, it is cheaper to pay per week from five or six roundtrips per week or higher. The barges that are paid per single trip are cheaper per kilometre, and therefore the actual savings can be lower.

When analysing the simulation as presented in Table 35, the number of roundtrips in the to-be network has to be analysed to be sure this new way of paying barges is cheaper. Therefore the costs incurred, based on variable and fixed costs, are analysed per barge, and presented in Table 39. As can be seen this is not favourable for all barges, but only for the Tilburg Vossenberg and Tilburg Loven barges. When these barges would have been paid per week, instead of per roundtrip, the fixed costs will decrease with €15.212, which is €0,55 per TEU.

Barge identifier	Replaced with barge	3 roundtrips	4 roundtrips	5 roundtrips	6 roundtrips	7 roundtrips
ITV28.1	ROCW36	€ -2.793,31	€ -1.554,42	€ -315,52	€ 923,38	€ 2.162,27
ITV28.2	ROCW36	€ -2.793,31	€ -1.554,42	€ -315,52	€ 923,38	€ 2.162,27
BTT32.1	ROCW36	€ -2.517,84	€ -1.187,12	€ 143,60	€ 1.474,32	€ 2.805,04
BTT32.2	ROCW36	€ -2.517,84	€ -1.187,12	€ 143,60	€ 1.474,32	€ 2.805,04
VOS44.1	ROCW48.1	€ -2.532,80	€ -1.006,40	€ 520,00	€ 2.046,40	€ 3.572,80
VOS44.2	ROCW48.1	€ -2.532,80	€ -1.006,40	€ 520,00	€ 2.046,40	€ 3.572,80
ITV52	ROCW48.1	€ -2.238,13	€ -613,50	€ 1.011,12	€ 2.635,74	€ 4.260,37

Table 38: Difference between paying barges per roundtrip or per week (negative means paying per week is more expensive)

Barge identifier	Replaced with barge	Roundtrips	Days in use	Sailed kilometres	Costs when paying per single trip	Costs when paying per week	Difference
ITV28.1	ROCW36	24	41	6555	€ 42.045,45	€ 51.108,90	€ -9.063,45
ITV28.2	ROCW36	26	42	7171	€ 45.562,49	€ 53.258,58	€ -7.696,09
BTT32.1	ROCW36	30	40	5272	€ 51.479,52	€ 47.638,56	€ 3.840,96
BTT32.2	ROCW36	28	40	5133	€ 48.187,78	€ 47.363,34	€ 824,44
VOS44.1	ROCW48.1	29	39	5287	€ 61.436,55	€ 56.595,27	€ 4.841,28
VOS44.2	ROCW48.1	30	40	5334	€ 63.467,10	€ 57.762,14	€ 5.704,96
ITV52	ROCW48.1	26	43	7161	€ 63.832,20	€ 66.674,81	€ -2.842,61

Table 39: Difference in paying barges per roundtrip or per week

7.1.3. Roundtrips and utilisation of barges in to-be network

In the to-be situation the same containers have to be transported by less barges. Therefore at least the utilisation or the number of roundtrips will increase. Furthermore, due to the shorter roundtrips, the number of roundtrips will already increase. The outcomes of the reference situation for the as-is and to-be networks can be found in Table 40. As can be seen, the utilisation from the inland terminals to the hub and the other way around is lower than the utilisation in the as-is network, except for two barges. This can be explained by the fact that the same barges are sailing from and to the inland terminals, but the number of roundtrips has increased. Therefore the utilisation is lower. From the hub towards the PoR and the other way around, the utilisation is higher for most barges. There are two exceptions, namely VOS60.1 and OCT144. VOS60.1 is the only barge to ECT North, and therefore an overcapacity was created to this terminal. OCT144 had an increase in its number of roundtrips of 68%, which decreases the utilisation. As expected, the number of roundtrips is the same or higher for all barges.

Barge identifier	Roundtrips in as-is simulation	Roundtrips in to-be simulation	Utilisation in as-is simulation	Utilisation in to-be simulation (hub)	Utilisation in to-be simulation (IT)
ITV28.1	22	24	59,4%	70,5%	43,8%
ITV28.2	24	26	46,1%	70,5%	40,7%
BTT32.1	25	30	24,6%	54,8%	18,1%
BTT32.2	25	28	27,8%	68,0%	27,3%
ROCW36	28	35	57,4%	63,2%	30,5%
VOS44.1	22	29	77,7%	74,4%	68,1%
VOS44.2	24	30	70,1%	70,7%	62,5%
ROCW48.1	25	28	54,2%	65,6%	48,9%
ROCW48.2	26	30	60,3%	70,1%	65,3%
ITV52	22	26	38,4%	65,5%	18,0%
VOS60.1	22	23	72,9%	51,9%	48,0%
VOS60.2	21	22	74,1%	72,0%	78,2%
ITV90.1	22	22	23,7%	45,4%	18,1%
ITV90.2	22	23	27,0%	61,8%	44,7%
OCT144	22	37	73,9%	31,9%	

Table 40: Roundtrips and utilisation of barges for the reference situation in the as-is and to-be simulation (Hub = utilisation from the hub to the PoR and the other way around, IT = utilisation from the inland terminals to the PoR and the other way around, for the as-is situation the utilisation from the inland terminals to the PoR and the other way around is shown)

7.2. Simulating different delays in the PoR

Different delays have been simulated at the port terminals. The reference situation of the as-is was used to simulate the different delays in the as-is network. For the to-be network the decision rules as formed in Chapter 6 and Section 7.1 were used. In this same section it was concluded that the handling at Oosterhout will be the most constraining in the to-be network, and therefore different settings were used for the simulation of delays in the PoR in the to-be network. Six settings were used, namely the different handling times at Oosterhout (two, three, or four minutes), and the handling capacity at Oosterhout (two or three barges at the same time). For all these settings the service level and TEU price was compared, and this can be found in Figure 17 and Figure 18.

For the setting where de delay was set at 25% of the reference situation, the performance of the as-is network is the best, in terms of service level and costs per TEU. This is caused by the fact that one of the two largest savings in a hub network is the decrease in total incurred delays. When these delays decrease to a minimum, the savings do not compensate the time it takes to sail via the hub. In the reference situation there is at first sight no clear result about the best performance, which will be analysed more detailed in Section 7.4. As soon as the delays start to increase, we notice a major advantage for the hub network. The percentage of containers delivered too late and the costs per TEU increase exponentially for the as-is network, while these performance indicators increase linearly for the hub network. The hub network is better able to cope with increasing delays. This is caused by the fact that the delay at a terminal is concentrated on a few barges, and these barges only visit one delayed terminal per roundtrip. In the as-is network more barges visit these terminals, and these barges visit sometimes more than one of these terminals during a roundtrip.

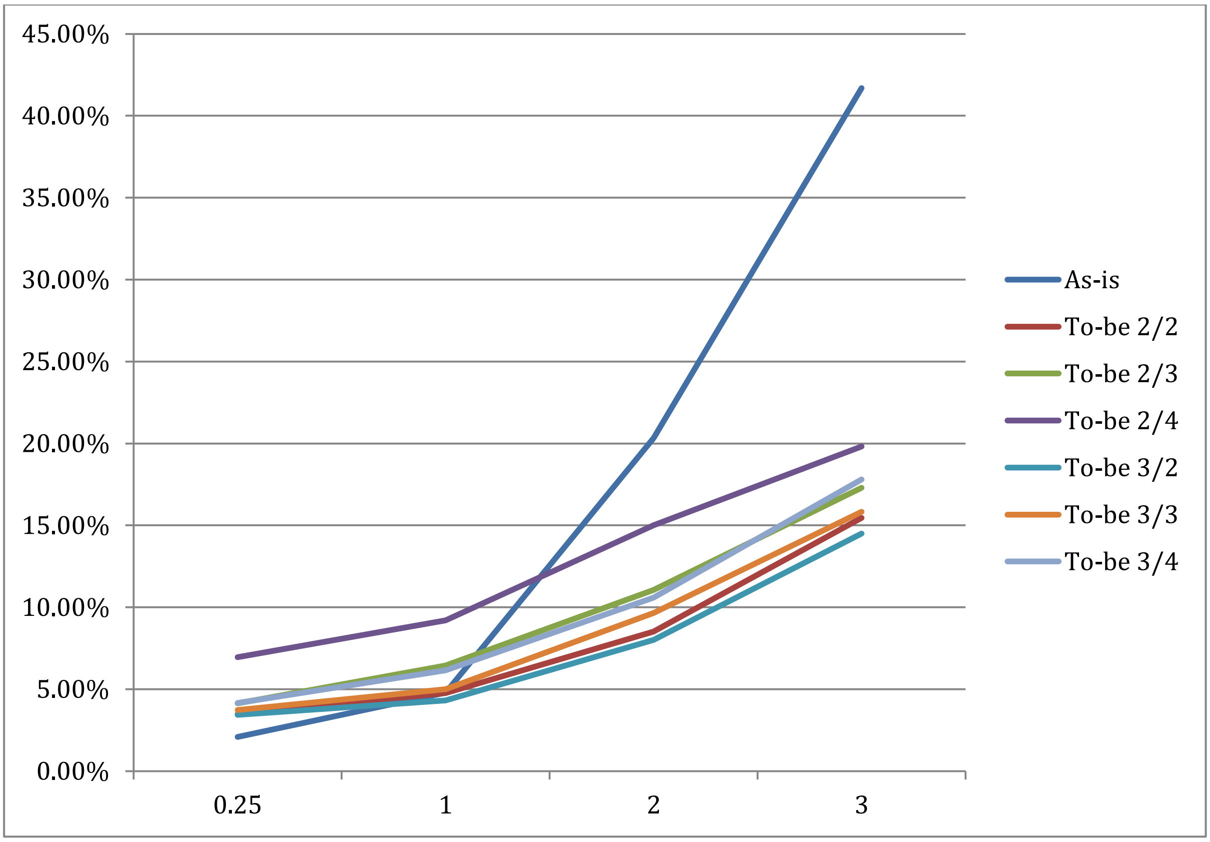

Figure 17: Percentage containers delivered too late (horizontal axis are the different delay conditions, where 1 is the reference situation) (To-be X/Y means the number of barges that can be handled at Oosterhout is X, and handling a container takes Y minutes)

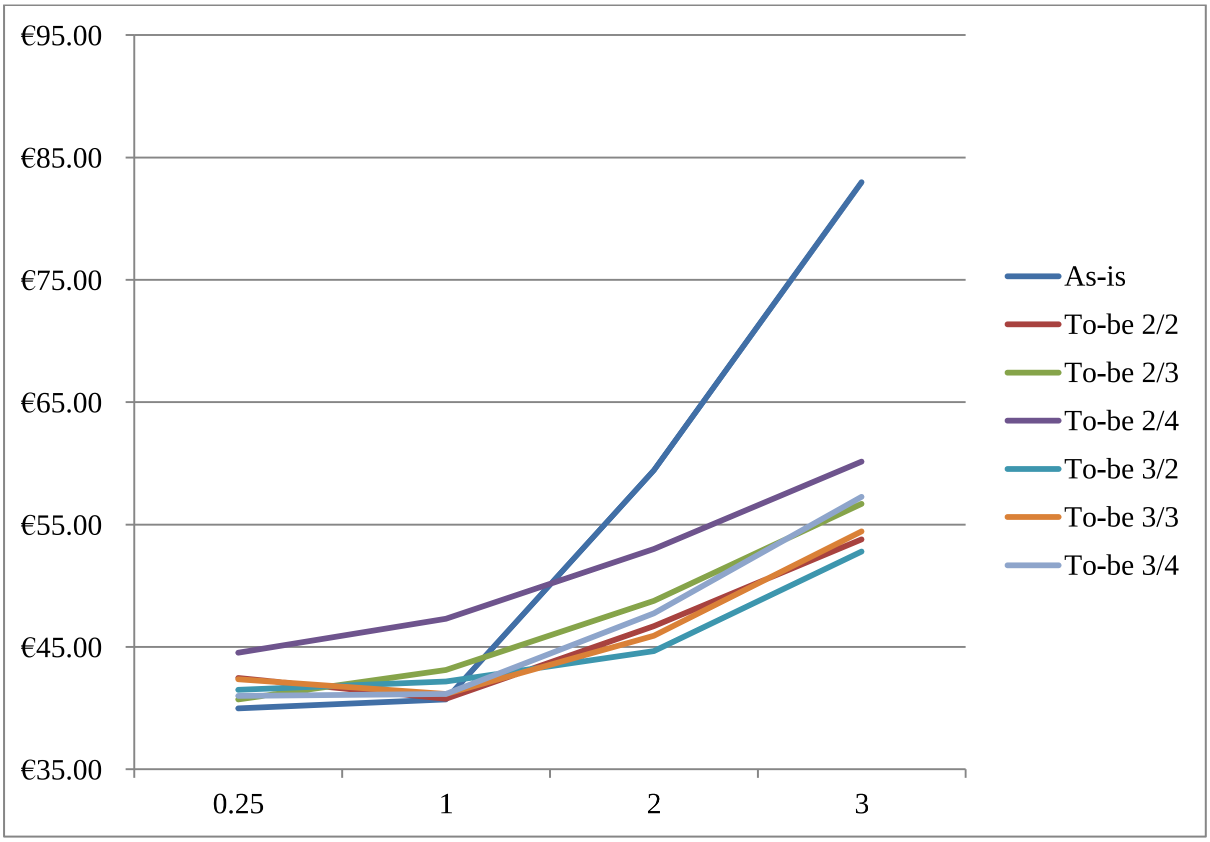

Figure 18: Costs per TEU (horizontal axis are the different delay conditions, where 1 is the reference situation) (To-be X/Y means the number of barges that can be handled at Oosterhout is X, and handling a container takes Y minutes)

7.3. Testing the hypotheses

Hypothesis 1:The to-be network is cost efficient, under the same or a better service level.
In the reference situation (i.e. the situation with delay at "1"), there is not a big difference between the to-be and as-is simulations. This is caused by the fact that the reduction in fixed costs is lower than expected. Since the exact costs for barges and late containers can slightly differ in practice, and the difference in the reference is low, the first hypothesis has to be rejected.

Hypothesis 2: There are around 6000 extra handlings at Oosterhout in the to-be network.
For the same simulations as in Section 7.2 the number of handlings was calculated, and this output can be found in Figure 19. The number of handlings is in all cases slightly higher than the expectation, but within a range of 10%. Therefore this hypothesis is accepted.

Hypothesis 3: The quay utilisation increases to around 60% in the to-be network.

In the simulation as presented in Table 34, the utilisation of the quay of Oosterhout is 57,2%, which is close to the expectation for this network. For the other simulations, with other handling times and extra handling capacity, this number differs because a lower handling time or higher handling capacity decreases the quay utilisation. Therefore this hypothesis is accepted.

Hypothesis 4: The current stack capacity is sufficient for the hub containers..
For the same simulations as in Section 7.2 we analysed what the highest number of containers on Oosterhout was during the whole simulation. This result can be found in Figure 20. As can be seen there are more hub containers on Oosterhout when delays are getting higher, and when the handling time per container is higher. For all containers, with higher delays there is a "queue" of containers waiting at the inland terminals, since there are less roundtrips. Therefore there can be less loaded at Oosterhout, and containers stay there for a longer time. However, the maximum number of 400 TEU is not extremely exceeded, and it is likely that this amount of TEU can be stored somewhere else. Therefore this hypothesis is accepted.

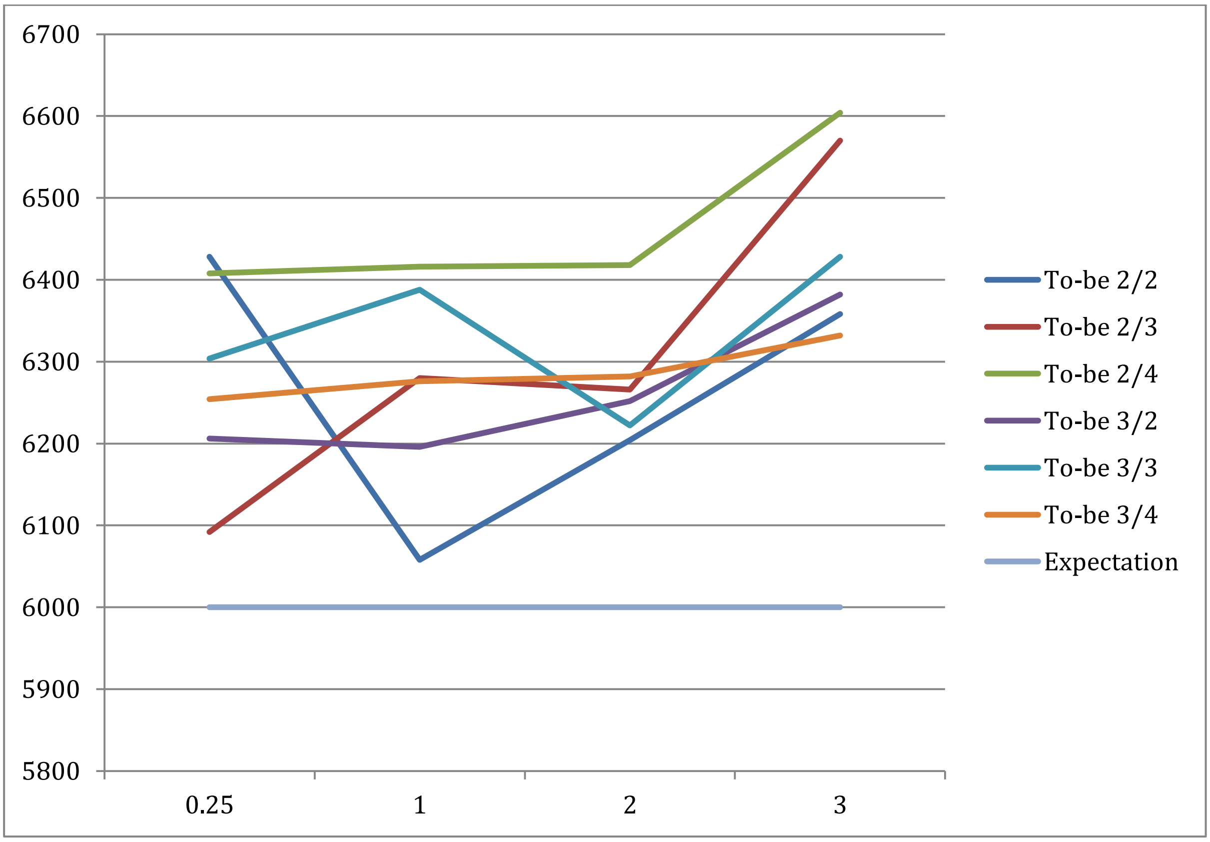

Figure 19: Number of handlings at Oosterhout (horizontal axis are the different delay conditions, where 1 is the reference situation) (To-be X/Y means the number of barges that can be handled at Oosterhout is X, and handling a container takes Y minutes)

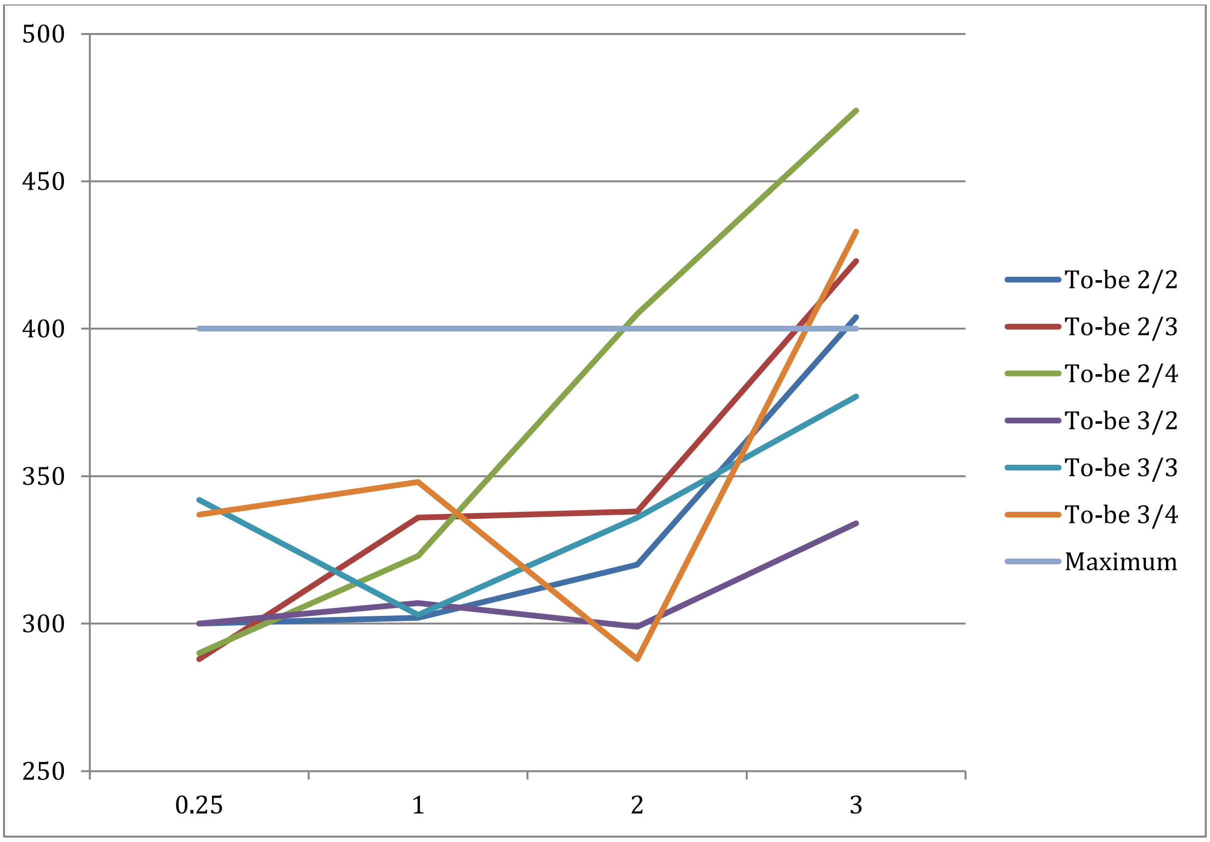

Figure 20: Highest number of hub containers (in TEU) on Oosterhout (horizontal axis are the different delay conditions, where 1 is the reference situation)
(To-be X/Y means the number of barges that can be handled at Oosterhout is X, and handling a container takes Y minutes)

7.4. Interpretation of the output

When looking at the operational feasibility of a hub network, it can be concluded that the network is feasible, under certain conditions. However, looking at the cost efficiency of such a network it cannot directly be concluded that such a network should be implemented.

The feasibility of the to-be network depends completely on the handling of barges at Oosterhout. For the reference situation, the case where no crane is added at Oosterhout, but the handling time of one container goes down to two minutes is the best when comparing it to the as-is network. In this case, the costs per TEU for the as-is network are €40,70, and there is 4,8% of the containers delivered too late. For the to-be network the costs per TEU are €40,77, and the same percentage of containers is delivered too late. This can decrease in the to-be network, when some of the barges are paid per week instead of per day. When this is implemented as proposed in Section 7.1.2, the costs per TEU decrease to €39,70. The difference is higher than the €0,55 in Section 7.1.2, since barges make more roundtrips when the handling at Oosterhout takes less time. Therefore the savings are larger when paying barges per week instead of per roundtrip.

For achieving this, a major increase in efficiency of the handling of barges has to be achieved. Four minutes per container movement leads to an undesirable high percentage of late containers, but two minutes per container movement is enough for the above-mentioned outcomes. Loading a container from the inland terminal on the barge needs at least one movement of a crane, or, when the width of the barge allows it, a reach stacker. However, when the container is not on top of the stack, one or more containers have to be moved first to be able to load the container. The row of the stack where the container is located is also important. When the container is located close to the quay, it takes less time to load this container on the barge. It can also happen that the container is out of the range of the crane. Then, a reach stacker needs to pick up the container, and loads it on the barge directly or via the crane. For the unloading of containers it also holds that the further the container is moved on to the inland terminal, the more time it takes to handle a container. Furthermore, at inland terminals the equipment is used for the (un)loading of barges and trucks at the same time. Trucks deliver or pick-up containers to and from the customers. This is an on-going process, where especially during office hours there are a lot of trucks driving to and from the customers.

For efficiently (un)loading containers at Oosterhout, two major points have to be taken into account. First, containers that will be loaded on a barge should be located at a stack that is inside the reach of the crane that will handle the barge, and the containers need to be stacked in the right order (i.e. the container that will be loaded first should be on top of the stack). This stack needs to be located as close to the quay as possible. An example of how this may look like can be found in Appendix I. Containers need to be in the right sequence for loading. For unloading, the containers should be unloaded on the inland terminal as soon as possible. This means that this dedicated stack will also be used for unloading containers. Second, the cranes should be fully dedicated to (un)loading barges whenever there is a barge docked. Whenever there are still containers not located in the dedicated stack, reach stackers should be available to relocate these containers. Furthermore, when the barge where the containers will be placed on for the second part of the trip is already docked, there should be a reach stacker available to relocate these containers.

This is all based on the base conditions regarding delays in the PoR. When looking at Figure 17 and Figure 18, it can be seen that the to-be network performs worse than the as-is network when there are low delays. This happens because the savings in delays do not compensate the time the barges spend at Oosterhout. However, when the delays are increasing, the to-be network performs better than the as-is network. Therefore the hub network is favourable when BIM expects the delays in the PoR will increase. Also when the delay at one terminal increases, other containers are almost not affected in the hub network, while in the as-is network probably containers to and from other terminals will also be delayed.

Another advantage of the to-be network is the decline in variable costs, which means less fuel is used. A summary of this can be found in Table 41, where the as-is reference situation is compared with the to-be situation with a handling time of two minutes per container and two barges that can be handled at the same time at Oosterhout. This is mainly caused by taking two Oosterhout barges out of use, which are large barges that use more fuel compared to the smaller barges.

Barge identifier	Kilometres sailed in the as-is simulation	Variables costs in the as-is simulation	Kilometres sailed in the to-be simulation	Variable costs in the to-be simulation
ITV28.1	5992	€1.138	7013	€1.333
ITV28.2	6401	€1.216	7097	€1.348
BTT32.1	5249	€3.464	5303	€3.500
BTT32.2	5092	€3.361	5050	€3.333
ROCW36	5599	€11.085	6050	€11.979
VOS44.1	4597	€2.988	5593	€3.636
VOS44.2	4876	€3.169	5562	€3.615
ROCW48.1	4988	€16.010	6173	€19.816
ROCW48.2	5157	€16.555	5913	€18.979
ITV52	5912	€1.596	6618	€1.787
VOS60.1	4543	€12.174	5373	€14.398
VOS60.2	4542	€12.172	5056	€13.549
ITV90.1	6010	€12.620	6599	€13.857
ITV90.2	5930	€12.453	6266	€13.158
OCT108.1	4785	€18.663		
OCT108.2	4876	€19.017		
OCT144	4254	€16.589	6459	€25.190
Sum	**88801**	**€164.272**	**90124**	**€149.478**

Table 41: Kilometres and variable costs for the as-is and to-be networks

With shorter roundtrips, the total number of departures per inland terminal increases. This is actually an important factor, because more departures mean the average lead time for containers will be shorter. This is important for customers of the inland terminal, since on average a container can be delivered later to the inland terminal, or will be delivered earlier at the customer. Furthermore, this can attract extra loading because the transportation time to the PoR is shorter. When the situation where the handling time is two minutes is compared with the reference situation of the as-is network, the increase in the number of roundtrips lays between 13 and 30% for the inland terminals except Oosterhout. For Oosterhout the increase is almost 500%, which is caused by the fact that all barges stop at Oosterhout. This can be found in Table 42.

Furthermore, we assumed the delays would stay the same when a hub network is introduced. In fact, the delays even got higher per call, since the simulation is modelled in such a way that the delay at a terminal increases with the number of containers (un)loaded. In practice however, port terminals favour larger calls by a lower number of barges, instead of a lot of barges that (un)load a few containers. Therefore it is reasonable to assume the delays decrease when this network is introduced. For assessing whether this leads to an advantage, the reference situation of the as-is network is compared with the to-be network with the delays set at 25% of the normal delay, and the three different handling times. Furthermore, for the three to-be simulations it is assumed that barges are paid per week instead of per roundtrip when this is favourable. With these lower delays for the hub network, a handling time of three minutes per container is enough to reach lower costs per TEU. Actually, the extra number of roundtrips created by the lower delays and handling time at two minutes leads to substantial higher fixed and variable costs for barges, while the percentage of containers delivered to late does not decrease enough to compensate this. Therefore, when we assume delays will decrease when the hub network is introduced, the costs per TEU decrease by €0,88, while the service level increases. These results can be found in Table 43. The advantage of a decline in variable costs does not hold in this situation, because the number of roundtrips is higher than the situation displayed in Table 41. However, the higher service level largely compensates this increase in variable costs.

Terminal	Number of departures and arrivals as-is	Number of departures and arrivals to-be	Increase
Oosterhout	73	437	499%
Veghel	112	127	13%
Tilburg Loven	50	58	16%
Tilburg Vossenberg	89	116	30%
Waalwijk	79	95	20%

Table 42: Departures and arrivals per inland terminal for as-is and to-be networks

Performance indicator	As-is reference situation (normal delays)	To-be (handling time at 2 minutes, delay at 25%)	To-be (handling time at 3 minutes, delay at 25%)	To-be (handling time at 4 minutes, delay at 25%)
Containers delivered too late	4,8%	3,5%	4,1%	7,0%
Costs for last-minute trucking	€159.802	€125.434	€146.951	€233.815
Variable costs barges	€164.272	€263.024	€225.738	€200.325
Variable costs handlings	-	€64.280	€60.920	€64.080
Fixed costs barges	€812.211	€687.456	€678.165	€729.688
Total costs	€1.136.285	€1.185.531	€1.136.495	€1.243.238
Costs per TEU	€40,70	€40,84	€39,82	€43,98

Table 43: Comparing the reference situation with lower delays in the to-be network

8. Conclusions

The container throughput in the PoR almost doubled in a decade. While the expectation is that this throughput will keep growing, the hinterland transportation is currently not able to keep up with this growth. Whereas the roads in the surroundings of the PoR are congested, more containers have to be transported by trains and barges. The capacity on waterways is sufficient to keep up with the growth, but the handling in the PoR forms a bottleneck. Port dwell times are not decreasing, and the number of terminals visited per roundtrip is increasing.

This thesis studies one of the solutions that is put forward to address this problem in the PoR: the hub network. In a hub network container flows are bundled, with the goal to decrease the number of calls per roundtrip, and, by visiting fewer terminals, the port dwell time. Some research has been conducted on this subject, however not on an operational level. In this thesis we addressed the performance of such a network on an operational level.

The remainder of this chapter is organised as follows. In Section 8.1 the results of this thesis are summarized, and in Section 8.2 the discussion and further research is presented.

8.1. Summary of results

In Chapter 3 three research questions and a research objective were stated. We will reiterate the questions and summarize our results.

Research question 1: How is the performance of a container barge network measured?

Inland terminal operators focus on delivering containers on time, based on customer requirements. Therefore the main focus is laid on the service level. Furthermore, the costs per TEU are an important factor, since the service level will not be 100% at all costs. Other performance indicators were also introduced to be able to analyse the performance of both networks more detailed.

Research question 2: Can the performance of the as-is network be simulated in a realistic way?

In the operational planning of container barges, it is of the upmost importance to deliver as much containers on time as possible, with the available barges. Another important part in container barge planning is that there are numerous terminals in the PoR, of which some are always open, and some are not. All these different terminals cause delays in the execution of the planning.

These parts have been included in the simulation by keeping the origins and destinations of all containers intact, and by connecting a timeframe to containers, in which the container can be picked up and delivered. Whenever the latest delivery time is exceeded, it is assumed the container would have been trucked, which incurs extra costs. Furthermore, the opening hours of the terminals where also taken into account. For the port terminals that caused delays in practice most often, a fixed delay was implemented. By simulating the container barge planning in this way, the most important parts of container barge planning have been included.

The simulation tool was developed in AIMMS, because this modelling environment allowed us to use the optimization tool CPLEX together with own-developed algorithms. For the routing of barges a new approach to the VRP was developed: the VRPPDSTW. This allowed for an optimal routing of barges, while other factors like the allocation of containers were executed by algorithms. By designing the simulation tool in this way, the problem remained solvable within a reasonable amount of time. Furthermore, the level of detail reached in this model makes that the planning is aligned with planning in practice, and therefore the outcomes are usable in practice.

Research question 3: Can a to-be network be designed that has a better performance than the as-is network?

To reach the goal of a hub network, shorter roundtrips by decreasing the number of calls per roundtrip, flows of containers will be bundled at Oosterhout. Oosterhout is the best hub location in the BIM network, because of its physical location, the fact that it has no restriction on its opening hours, and the availability of two cranes to ensure barges are handled efficiently.

After an analysis of the distribution of containers over the areas and terminals, it was concluded that the barges should sail dedicated to one of the two areas in the PoR (Stad or Maasvlakte 1). Because there is only one TEU to and from the Stad area for every four TEU to and from the Maasvlakte 1 area, while the number of terminals in the Maasvlakte 1 area is lower, the smallest barges in the network were dedicated to the Stad area (five in total), and the larger barges were dedicated to the Maasvlakte 1 area (ten in total). Two of the three Oosterhout barges were taken out of order, because a higher utilisation and more roundtrips could be accomplished for the other barges.

Furthermore, the Maasvlakte 1 barges would only call at one of the delayed terminals to decrease the total incurred delay. With this design, the two barges that are taken out of order compensate the costs for extra handlings at Oosterhout.

One of the starting points of the performance of the to-be network was that the service level could not be significantly lower. However, in a situation where the delays would stay the same and the handling at Oosterhout would not be executed more efficiently, the number of late containers almost doubled, which does not lead to a viable business case. The quay utilisation of around 60% at Oosterhout leads to queues of barges waiting to be handled at Oosterhout. There are two solutions for this problem. First, the handling time at Oosterhout, which was modelled at four minutes per container, needs to decrease. When the delays stay the same, the handling time should decrease to two minutes per container. However, it is likely that delays will decrease, since BIM gains a bargaining position towards the port terminal operators when implementing the hub network. Less BIM barges call at the port terminals, and the call sizes are higher. This is more efficient for port terminals, and therefore BIM should demand a smoother operation for call appointments, or fixed time windows should be arranged for a steady operation. Under the assumption that delays decrease by 75%, a handling time of three minutes is sufficient. In this last case the service level improves, while the costs per TEU decrease.

To decrease the handling time, the operations at Oosterhout need to be changed. When there is a barge docked at Oosterhout, the crane should be fully dedicated to this barge. Furthermore, when it is known when a barge will arrive, the containers for this barge should be moved towards the quay, so that the crane does not have to move over long distances while handling the barge. Furthermore, to reach the lower costs per TEU, some of the barge contracts have to be renegotiated. Because barges are making more roundtrips in a hub network, the costs increase for barges that are paid per single trip. Depending on the situation, it is less expensive for some barges to pay them per week.

Whenever the handling time and delays in the PoR do not decrease, there is another situation in which a hub network is favourable. This network is more responsive to high delays. Where the costs per TEU and the percentage of late containers in the current network grow exponentially with increasing delays, this is linear for the hub network. Therefore this network is favourable when delays keep increasing.

Besides the effects of lower costs per TEU and a higher service level, there are also side effects that have not been quantified in this thesis. The hub network creates more possibilities for the re-use of empty containers, since the inland terminals are better connected. Re-using containers decreases the costs, because fewer empty containers are transported from and to the PoR, and ultimately less terminals are visited. Moreover, there are more connections created for transporting Antwerpen containers by barge. Currently, a barge is sailing from Oosterhout to Antwerpen to transport BIM containers. Most of these containers are already transported by barge to Oosterhout, but when the hub network is introduced all barges stop at Oosterhout, which can decrease the lead time for Antwerpen containers, and possibly more Antwerpen containers can be transported by barge. Furthermore, the increase in roundtrips for all inland terminals decreases the lead time for containers. This can attract extra containers in the future, and containers that normally would have been trucked can now be transported by barge.

8.2. Discussion and future research

The research objective of this thesis was to design a barge network that has a better operational performance than the current network. However, implementing a hub network does not directly lead to an performance improvement, since this depends on the efficiency of handling at the hub, and the delays in the port. Decreasing the delays in the port depends heavily on the willingness of the port terminal operators, and a lower handling time incurs extra moves of containers between the stacks. These extra moves make an efficient terminal planning necessary, which leads to a need for extra man-hours. This also holds for the network planning, since the more or less standalone planning processes of inland terminals will now be integrated into one planning process. It is likely to assume a network planner is needed to coordinate this, together with the terminal operations at Oosterhout. Furthermore, there has to be an agreement about the division of savings. Oosterhout will have most benefits, while the costs will be higher for the other terminals, because extra roundtrips are made. BIM needs to consider the hub network as a strategic decision, since changing the network by introducing a hub is not something that can be changed within one day. In this strategic decision it must be considered whether this extra work and coordination is compensated by a more efficient and future-proof way of operation.

Taking a more general perspective on hub networks, we conclude that a hub network is still feasible at the operational level. The hub network did not lead to extremely high dwell times of containers at the hub. Furthermore, a hub located closely to the port can still lead to savings. However, it was important that the hub in this case also had its own supply and demand of containers. There were not only containers exchanged at the hub, but also extra loaded. By increasing the utilisation and the number of roundtrips of barges, two of the barges that were dedicated to Oosterhout in the current situation, could be taken out of order in the hub network. Whenever a hub does not have its own supply and demand, taking barges out of order can only be reached when there is a much higher increase in the number of roundtrips. Another advantage of using an existing inland terminal as hub, is that the investment costs do not have to be compensated by a more efficient operation. As was shown with the investment for a crane, this is already difficult to compensate for at an existing terminal. The investment for a new hub is much higher, and this will probably not be compensated by a more efficient operation.

In this thesis we showed that a hub network can be feasible on the operational level, something that was not yet available in academic literature. However, there is future research that can be done regarding this subject. First, it would be interesting to develop a more general model that is able to test different networks instead of one, and that is able to test different network designs instead of one. Including the re-use of empty containers, or the trucked containers to analyse whether barges will transport more containers in a hub network, would also be interesting. This could potentially lead to a more valuable business case. In such a model, the port side of the simulation could be modelled as a more dynamic environment, so that the uncertainty, and the responsiveness of networks to certain levels or uncertainty, is better represented in the model. Finally, more robust data sets can be used in the future. Currently, inland terminals are working on systems that provide more reliable data. When combining this with an implementation of D&D in a model, the process of containers in hinterland networks is better modelled, and better decisions can be made, by for example deliberately delivering an empty container one day later at a port terminal, for which the costs are lower than trucking a container.

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Appendix A – Container types

Containers can be distinguished on several specifications, namely length, height, type, and cleanliness.

A.1 – Length

The most common way to describe and measure containers is the length, which is in general divided in three categories: 20, 40, and 45 feet. The length defines the maximum number of containers on a ship or barge, which is in defined in TEUs. Furthermore, the length defines how much cargo can be stored inside the container.

Length (feet)	Length (metres)	Length (TEU)
20	6,1	1
40	12,2	2
45	13,7	2,25

Table 44: Container lengths

A.2 – Height

There is also a distinction made between the container's height, which can be described as *normal* or *high-cube*. Normal containers have a height of 2,6 metre, whereas high-cube containers have a height of 2,9 metre. These higher containers define the height of cargo that can be stored in the containers, where high-cube containers can handle, for example, higher pallets or (more) stacked pallets. However, the high-cube containers can also form a limitation for barges. Barges are almost always restricted to certain height limitations, because of bridges along the waterways. When three high-cube containers are stacked on to each other, the height of the barges is almost a metre higher compared with three layers of normal containers.

A.3 – Type

There are different types of containers, which can have different versions depending on the before-mentioned length and height. A short description of the most common types:

- Dry cargo: the most common type of containers, which is meant for non-liquid cargo that can be loaded into the container via the doors.
- Reefer: a container equipped with a refrigerating unit, that can keep the temperature of the goods at a certain temperature, in general between -25°C and 25°C.
- Open top: a container with a removable roof that can be used for goods that can only loaded vertically into the container. This roof can be soft or hard.
- Flat rack: a container without sidewalls and a roof, designed for special goods that cannot be stored in other containers.
- Tank: a tank fitted inside the frame with the size of a container, to transport liquids or gases.

A.4 – Cleanliness

Depending on the cargo a customer can demand a certain state of cleanliness of a container. In general three levels can be distinguished, which are food cargo, general cargo, and scrap cargo. Food should be stored in containers with no defects, rust, residue, and the floor should be clean and dry. In some cases this means that customers demand new containers, or reject a lot of containers because the level of cleanliness is not acceptable. General cargo is stored in containers with a clean and dry floor, and no defects like gaps, which in most cases can be (repaired) used containers. Scrap cargo, like waste paper, can be stored in containers that do not have large deviations, mainly depending on the specific cargo.

Appendix B – Source of data

Factor	Source
Barges	
Speed	BIM, Pro-Log, Ab Ovo
Capacity	BIM
Fixed costs	BIM
Variable costs	BIM
Inland terminals	
Crane and reach stacker capacity	BIM, Pro-Log, Ab Ovo
Quay length	BIM
Opening times	BIM
Fixed handling time	BIM, Pro-Log, Ab Ovo
Handling costs	BIM
Dedicated stack capacity for the hub	BIM
Port terminals	
Crane capacity	BIM, Pro-Log, Ab Ovo
Opening hours	BIM, Pro-Log, websites of port terminal operators
Fixed handling time	BIM, Pro-Log, Ab Ovo
Waiting times	BIM
Waterways	
Distances	Pro-Log (PC Navigo)
Capacity	BIM
Locks	BIM, Danser, Google Maps
Last-minute trucking	
Costs	BIM

Table 45: Sources of input

The parameters that we used as input for the model have different sources. The main source is BIM, since they are the operator of this network. In some cases multiple sources were used. In Table 46 there is a short description of who we spoke at the companies.

Company	Name	Function
BIM	Ben van Rooy	Consultant Business Development
Pro-Log	Arjen Barto	General Director
	Ruben Borremans	Barge Planner
Ab Ovo	Ard-Jan Cieremans	Senior Consultant
	Hugo de Valk	Senior Consultant

Table 46: Contact persons at the companies

Notes:

- From Danser a file with all lock locations was used;
- The satellite view of Google Maps was used to locate locks;
- Where possible we used the websites of port terminals to find out their opening hours. If this was not available, we used input from BIM and Pro-Log.

Appendix C – Analysis data set

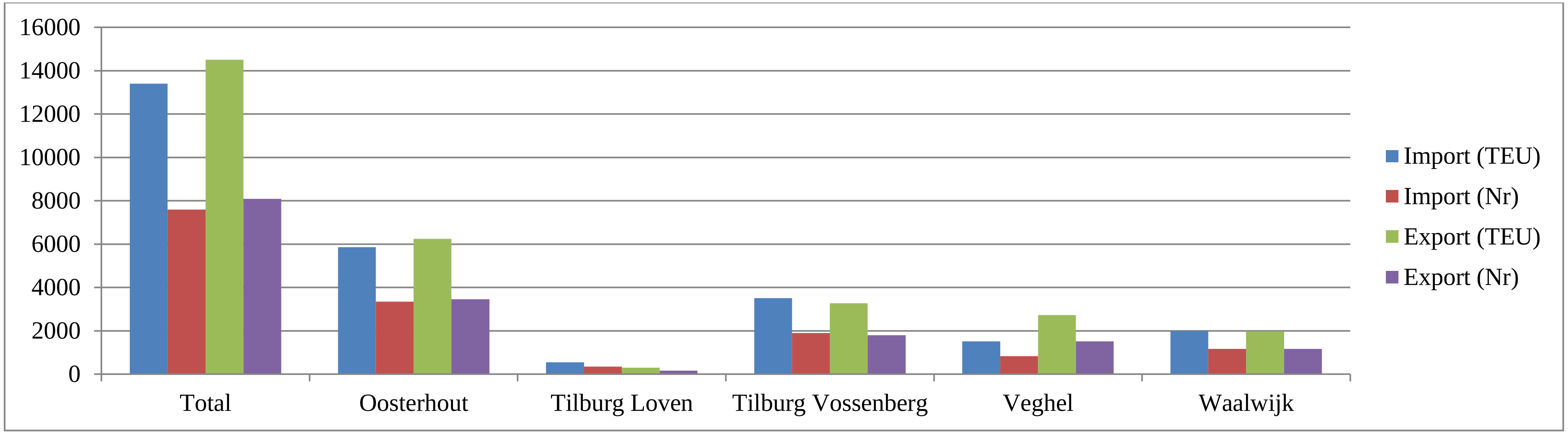


Figure 21: Distribution of containers in the data set over the inland terminals (in number and TEU)

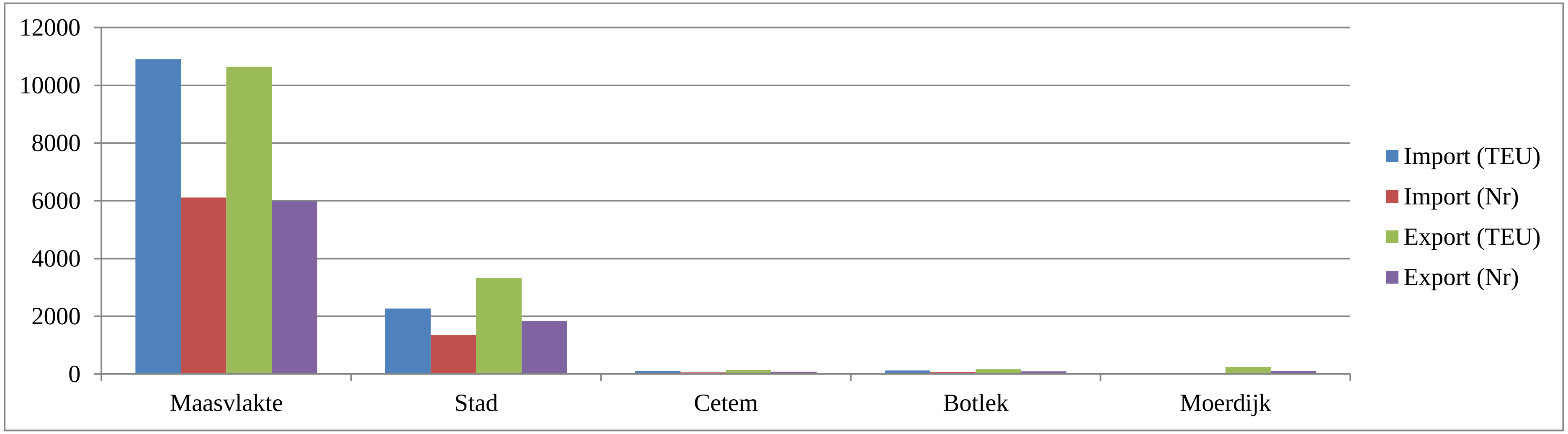


Figure 22: Distribution of containers in the data set over the sailing areas (in number and TEU)

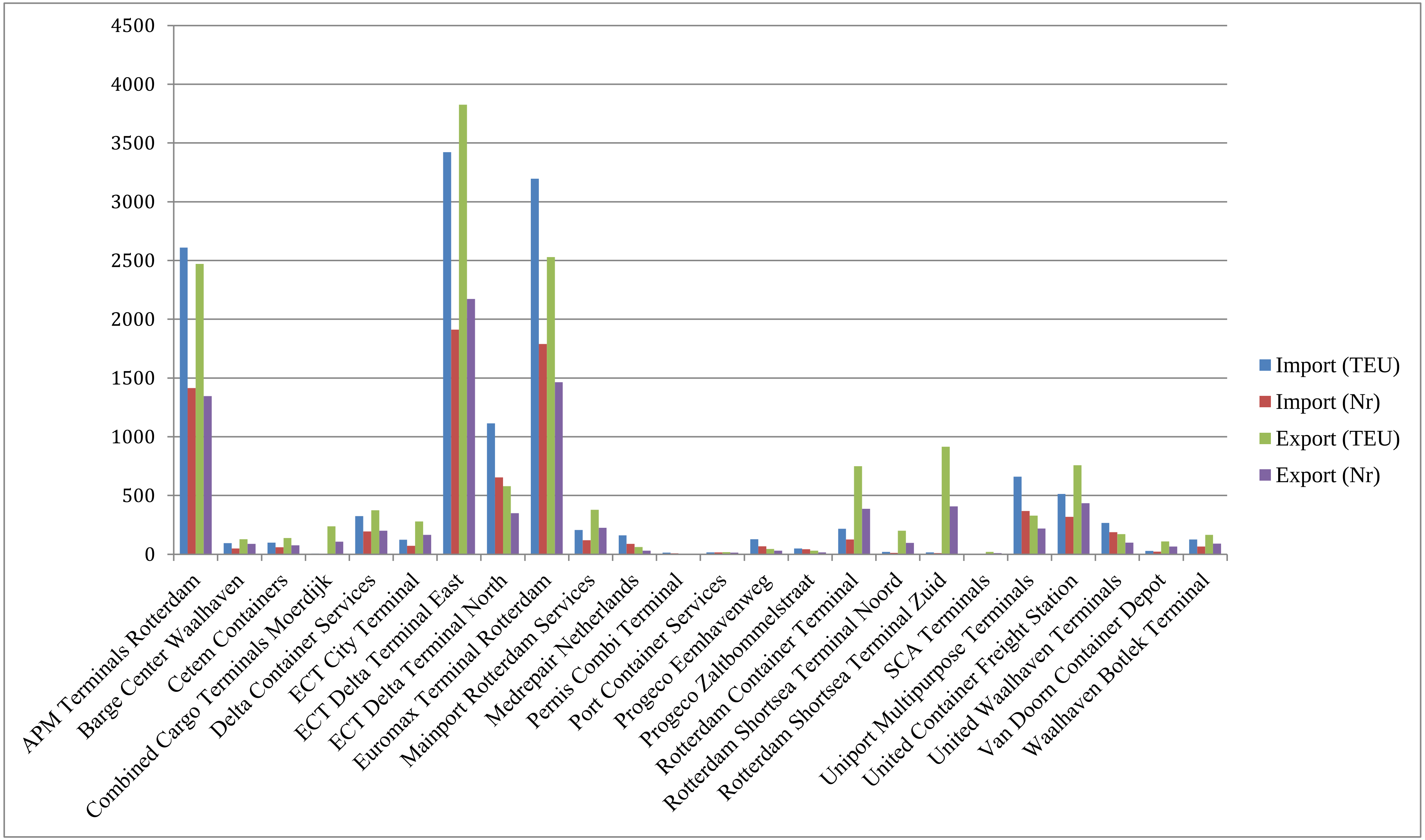


Figure 23: Distribution of containers over the port terminals (in number and TEU)

Appendix D – Decision scheme as-is network simulation tool

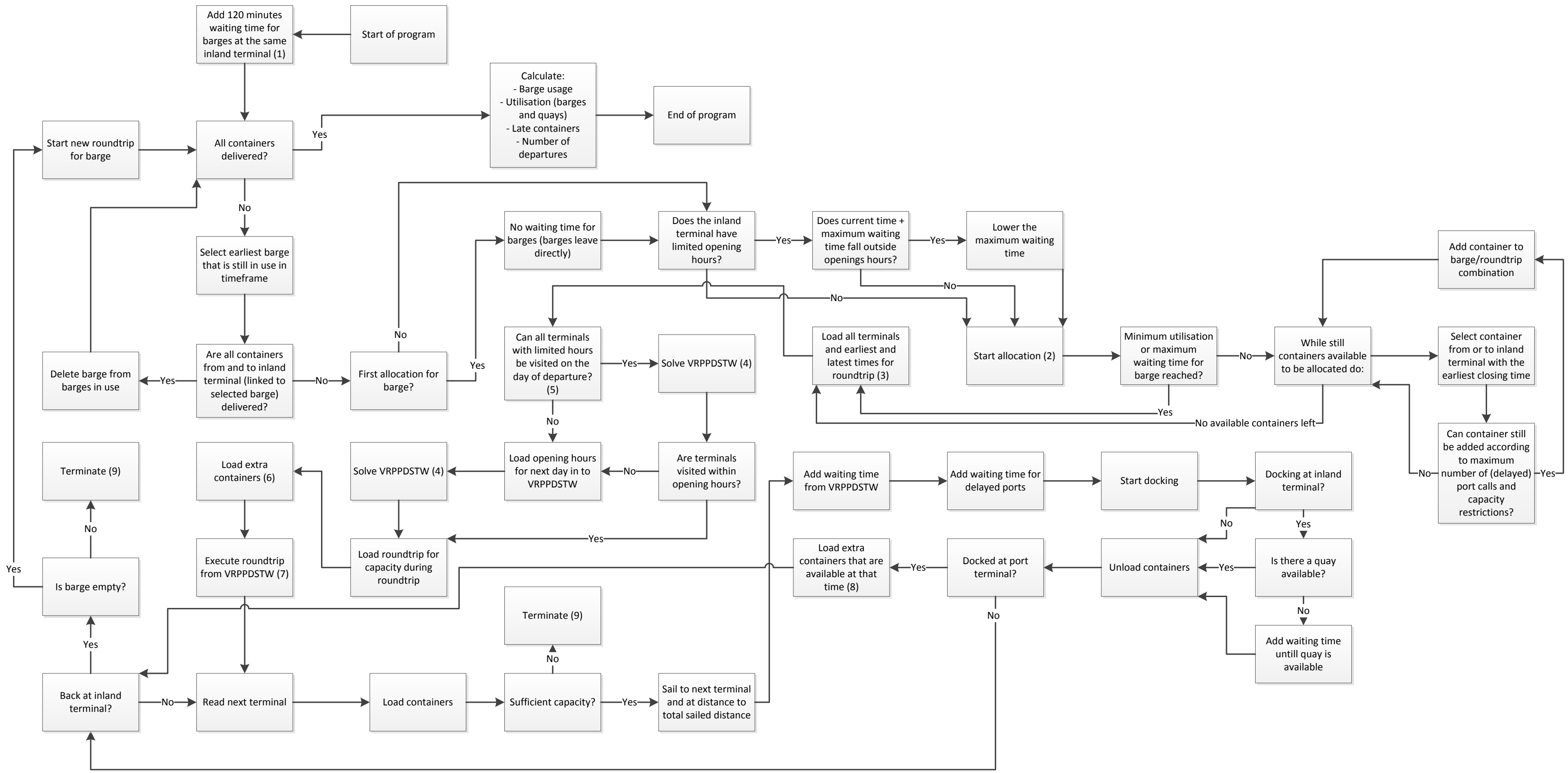


Figure 24: The decision scheme of as-is network simulation tool

Specification of Figure 24:
(1): All barges start at the inland terminals. Therefore, when starting the simulation, probably only one or two barges per inland terminal will have containers to transport, while others will depart empty. Waiting time (adjustable) will be added for every single barge according to Table 47 (an example where all barges start at 15-09-2014 00:00, four barges at this specific inland terminal). Now the allocation will start at the new times, and containers will be available for the barges.

Barge	Time available without waiting time	Waiting time (minutes)	Time available with waiting time
1	15-09-2014 00:00	0	15-09-2014 00:00
2	15-09-2014 00:00	120	15-09-2014 02:00
3	15-09-2014 00:00	240	15-09-2014 04:00
4	15-09-2014 00:00	360	15-09-2014 06:00

Table 47: An example for adding waiting time in the beginning of the simulation

(2): Allocation is based on a few (adjustable) parameters, which can be changed for every barge separately:
- Maximum number of port calls per roundtrip.
- Maximum number of port calls that are at delayed terminals.
- Minimum utilisation for trip from the inland terminal towards the port.
- Minimum utilisation for trip from the port to the inland terminal.
- Maximum waiting time for the minimum utilisation.

Then, for a selected time, containers will be added that are:
- Available right away at the inland terminal for export containers.
- Available at the earliest time that the barge will arrive at the port terminal for import containers.

Given that the maximum number of port calls, and calls at delayed ports, is not exceeded. Furthermore, the capacity will not be exceeded on both links (towards the port and towards the inland terminal). When, after this allocation, one of the utilisation bounds is not reached, and the maximum waiting time is not reached, one hour of waiting time will be added and containers will be added again.

(3): The VRPPDSTW takes time windows into account. Therefore we load the earliest time that we can arrive at a terminal (the latest time an allocated container will be available at the terminal), and the latest time that a barge should arrive at a terminal (the earliest time a container that is on board needs to be delivered) into the VRPPDSTW.

(4): The VRPPDSTW finds an optimal routing according to sailing costs, container lateness costs, waiting costs, and earliness costs. Because being too early is never possible, costs for being too early are set at €100 / minute, while lateness costs are set at €10 / minute, and waiting costs are set at 0,95 times the sailing cost (per minute) of a barge. Lateness costs are doubled for terminals with limited opening hours, so that these will not be violated.

(5): The VRPPDSTW has, besides the routing, the arrival and departures times as output. This is used to check if the visit is in between the opening and closing hours of the visited terminals.

(6): Since the VRPPDSTW has two nodes for every port terminal (load and unload), reading the output depends on quite a few things. This is not exactly displayed in the scheme, since (in general) you only load at the load node, and unload at the unload node, but sometimes a barge will load at an unload node. This is done because containers are available at the terminal, but the load node is not visited.

(7): Now that the exact roundtrip and associated calling times are known, there are more import containers that can be allocated to the roundtrip. This is done based on closing times (earliest closing time will be allocated first, when possible).

(8): When a barge is docked at a port terminal, there is a check if there are extra containers available at the selected time, according to the earliest closing times and the available capacity during the rest of the trip.

(9): There are a few checks build in the simulation, which check for mistakes made in allocation, loading, and unloading. In general this does not happen, but since allocation codes are changed constantly these checks are important to be sure the simulation works correctly. When the program is terminated an error is displayed.

Appendix E – Loan calculations for an extra crane and reach stacker

Formula for yearly annuity:

$$a = \frac{i}{(1-(1+i)^{-n}} * I$$

a:	Yearly annuity	€144.027
i:	Interest rate	4%
n:	Number of years	25
I:	Initial investment	€2.250.000

Total costs

	Costs
Annuity payment	€144,027
Costs per operator	€35,000.00
Number of operators	6
Total for operators	€ 210,000.00
Total costs	€ 354,026.92

Table 48: Costs for an extra crane

Appendix F – Screenshots of the as-is simulation tool

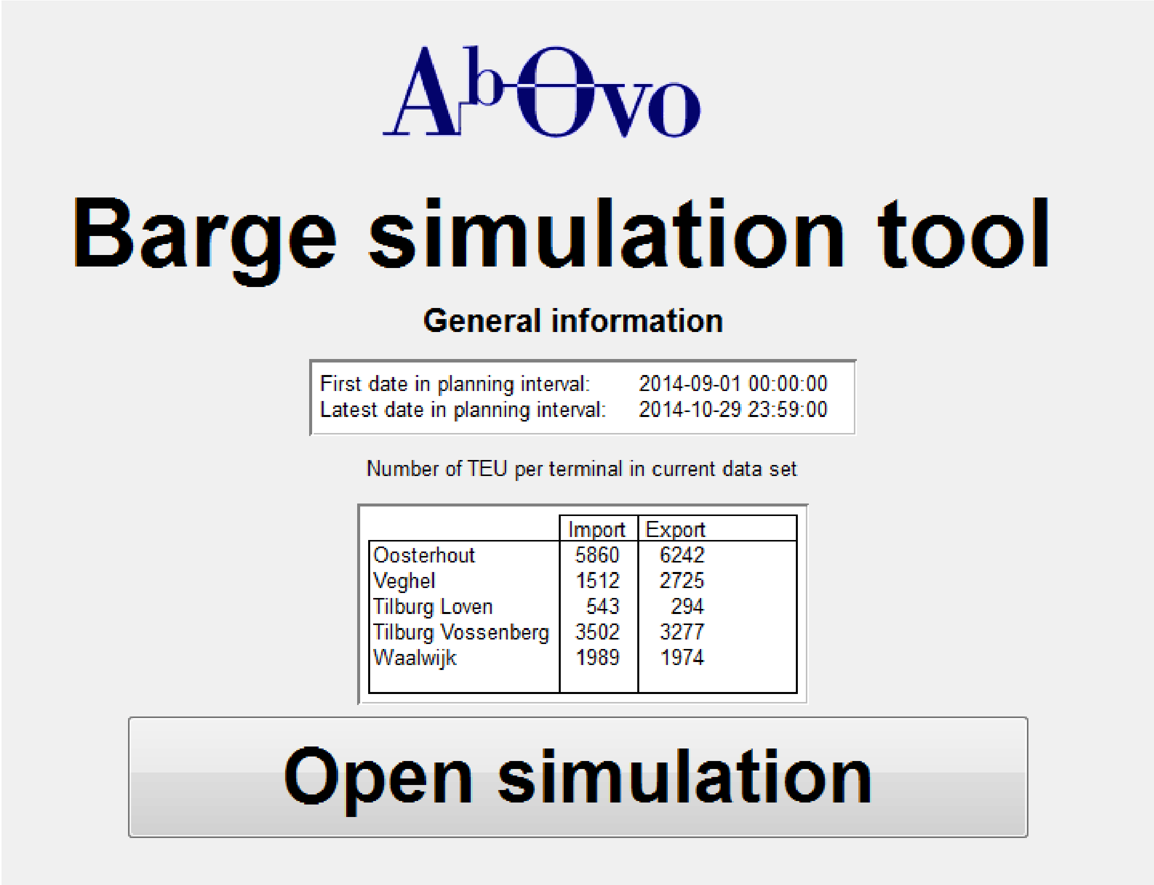
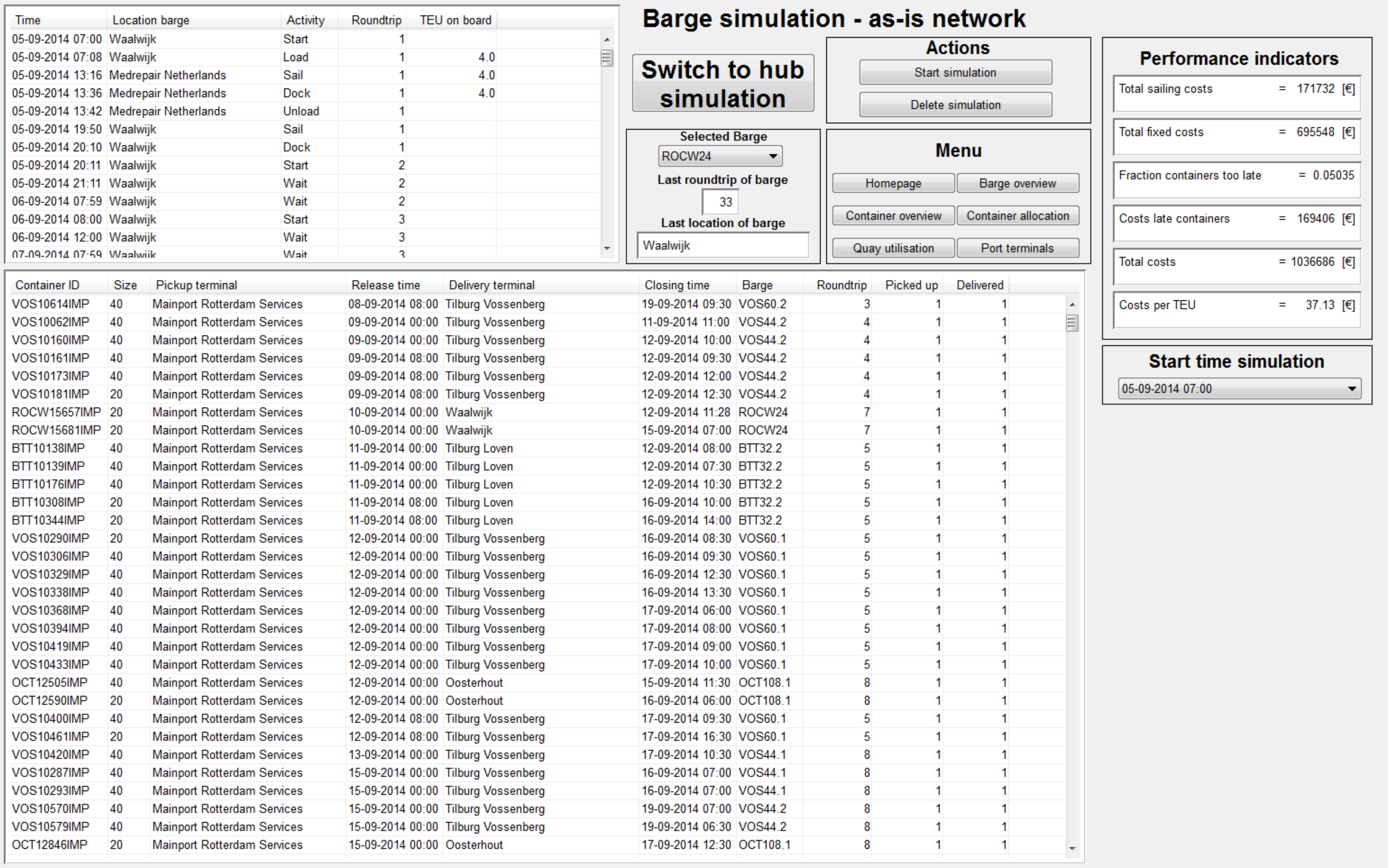


Figure 25: Homepage



Barge simulation - as-is network

Time	Location barge	Activity	Roundtrip	TEU on board
05-09-2014 07:00	Waalwijk	Start	1	
05-09-2014 07:08	Waalwijk	Load	1	4.0
05-09-2014 13:16	Medrepair Netherlands	Sail	1	4.0
05-09-2014 13:36	Medrepair Netherlands	Dock	1	4.0
05-09-2014 13:42	Medrepair Netherlands	Unload	1	
05-09-2014 19:50	Waalwijk	Sail	1	
05-09-2014 20:10	Waalwijk	Dock	1	
05-09-2014 20:11	Waalwijk	Start	2	
05-09-2014 21:11	Waalwijk	Wait	2	
06-09-2014 07:59	Waalwijk	Wait	2	
06-09-2014 08:00	Waalwijk	Start	3	
06-09-2014 12:00	Waalwijk	Wait	3	
07-09-2014 07:59	Waalwijk	Wait	3	

Switch to hub simulation

Actions

Start simulation

Delete simulation

Selected Barge

ROCW24

Last roundtrip of barge

33

Last location of barge

Waalwijk

Menu

Homepage | Barge overview

Container overview | Container allocation

Quay utilisation | Port terminals

Performance indicators

Total sailing costs = 171732 [€]

Total fixed costs = 695548 [€]

Fraction containers too late = 0.05035

Costs late containers = 169406 [€]

Total costs = 1036686 [€]

Costs per TEU = 37.13 [€]

Start time simulation

05-09-2014 07:00

Container ID	Size	Pickup terminal	Release time	Delivery terminal	Closing time	Barge	Roundtrip	Picked up	Delivered
VOS10614IMP	40	Mainport Rotterdam Services	08-09-2014 08:00	Tilburg Vossenberg	19-09-2014 09:30	VOS60.2	3	1	1
VOS10062IMP	40	Mainport Rotterdam Services	09-09-2014 00:00	Tilburg Vossenberg	11-09-2014 11:00	VOS44.2	4	1	1
VOS10160IMP	40	Mainport Rotterdam Services	09-09-2014 00:00	Tilburg Vossenberg	12-09-2014 10:00	VOS44.2	4	1	1
VOS10161IMP	40	Mainport Rotterdam Services	09-09-2014 08:00	Tilburg Vossenberg	12-09-2014 09:30	VOS44.2	4	1	1
VOS10173IMP	40	Mainport Rotterdam Services	09-09-2014 08:00	Tilburg Vossenberg	12-09-2014 12:00	VOS44.2	4	1	1
VOS10181IMP	20	Mainport Rotterdam Services	09-09-2014 08:00	Tilburg Vossenberg	12-09-2014 12:30	VOS44.2	4	1	1
ROCW15657IMP	20	Mainport Rotterdam Services	10-09-2014 00:00	Waalwijk	12-09-2014 11:28	ROCW24	7	1	1
ROCW15681IMP	20	Mainport Rotterdam Services	10-09-2014 00:00	Waalwijk	15-09-2014 07:00	ROCW24	7	1	1
BTT10138IMP	40	Mainport Rotterdam Services	11-09-2014 00:00	Tilburg Loven	12-09-2014 08:00	BTT32.2	5	1	1
BTT10139IMP	40	Mainport Rotterdam Services	11-09-2014 00:00	Tilburg Loven	12-09-2014 07:30	BTT32.2	5	1	1
BTT10176IMP	40	Mainport Rotterdam Services	11-09-2014 00:00	Tilburg Loven	12-09-2014 10:30	BTT32.2	5	1	1
BTT10308IMP	20	Mainport Rotterdam Services	11-09-2014 08:00	Tilburg Loven	16-09-2014 10:00	BTT32.2	5	1	1
BTT10344IMP	20	Mainport Rotterdam Services	11-09-2014 08:00	Tilburg Loven	16-09-2014 14:00	BTT32.2	5	1	1
VOS10290IMP	20	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	16-09-2014 08:30	VOS60.1	5	1	1
VOS10306IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	16-09-2014 09:30	VOS60.1	5	1	1
VOS10329IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	16-09-2014 12:30	VOS60.1	5	1	1
VOS10338IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	16-09-2014 13:30	VOS60.1	5	1	1
VOS10368IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	17-09-2014 06:00	VOS60.1	5	1	1
VOS10394IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	17-09-2014 08:00	VOS60.1	5	1	1
VOS10419IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	17-09-2014 09:00	VOS60.1	5	1	1
VOS10433IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Tilburg Vossenberg	17-09-2014 10:00	VOS60.1	5	1	1
OCT12505IMP	40	Mainport Rotterdam Services	12-09-2014 00:00	Oosterhout	15-09-2014 11:30	OCT108.1	8	1	1
OCT12590IMP	20	Mainport Rotterdam Services	12-09-2014 00:00	Oosterhout	16-09-2014 06:00	OCT108.1	8	1	1
VOS10400IMP	40	Mainport Rotterdam Services	12-09-2014 08:00	Tilburg Vossenberg	17-09-2014 09:30	VOS60.1	5	1	1
VOS10461IMP	20	Mainport Rotterdam Services	12-09-2014 08:00	Tilburg Vossenberg	17-09-2014 16:30	VOS60.1	5	1	1
VOS10420IMP	40	Mainport Rotterdam Services	13-09-2014 00:00	Tilburg Vossenberg	17-09-2014 10:30	VOS44.1	8	1	1
VOS10287IMP	40	Mainport Rotterdam Services	15-09-2014 00:00	Tilburg Vossenberg	16-09-2014 07:00	VOS44.1	8	1	1
VOS10293IMP	40	Mainport Rotterdam Services	15-09-2014 00:00	Tilburg Vossenberg	16-09-2014 07:00	VOS44.1	8	1	1
VOS10570IMP	40	Mainport Rotterdam Services	15-09-2014 00:00	Tilburg Vossenberg	19-09-2014 07:00	VOS44.2	8	1	1
VOS10579IMP	40	Mainport Rotterdam Services	15-09-2014 00:00	Tilburg Vossenberg	19-09-2014 06:30	VOS44.2	8	1	1
OCT12846IMP	20	Mainport Rotterdam Services	15-09-2014 00:00	Oosterhout	17-09-2014 12:30	OCT108.1	8	1	1

Figure 26: Main simulation page for the as-is network

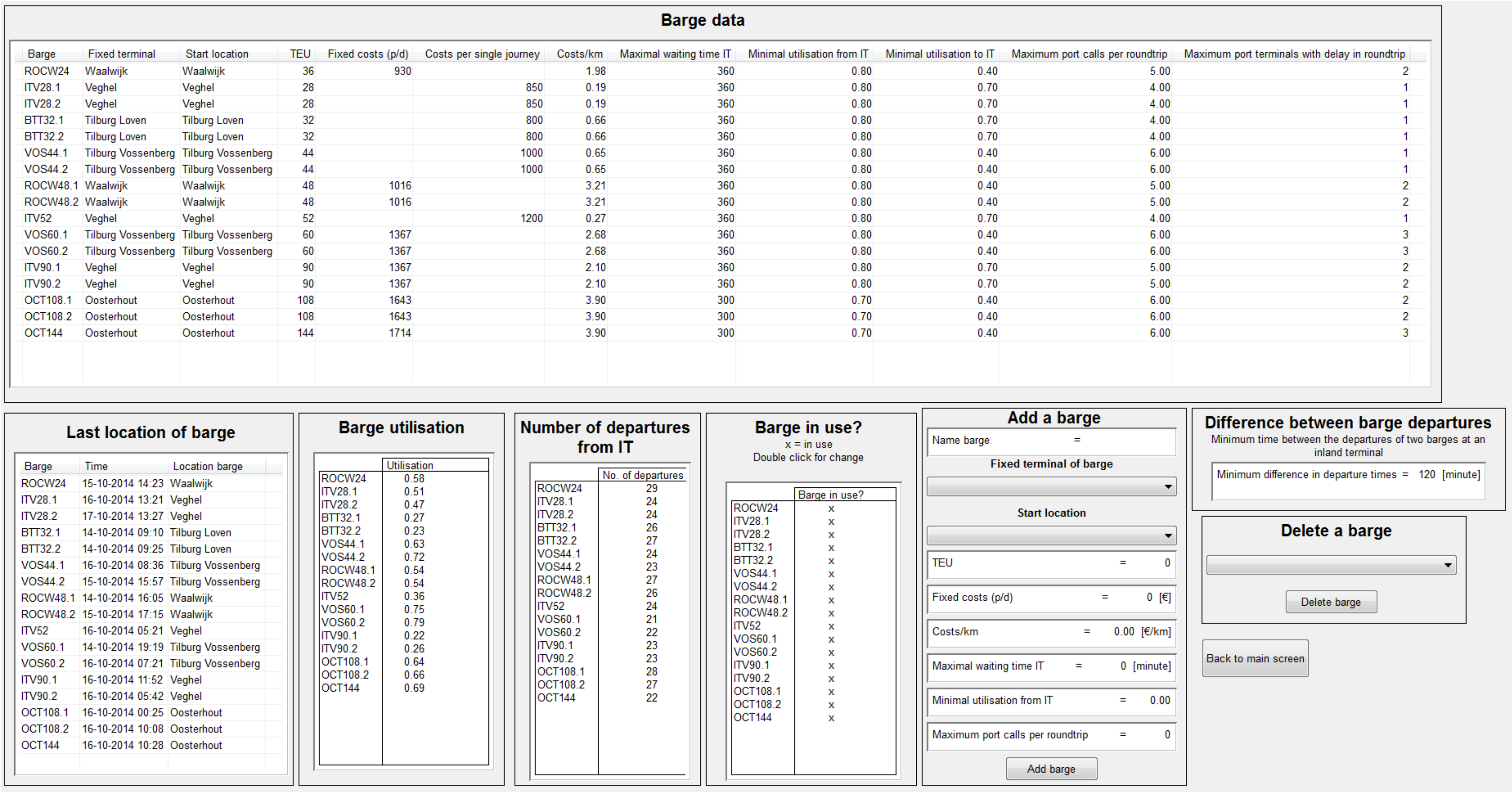
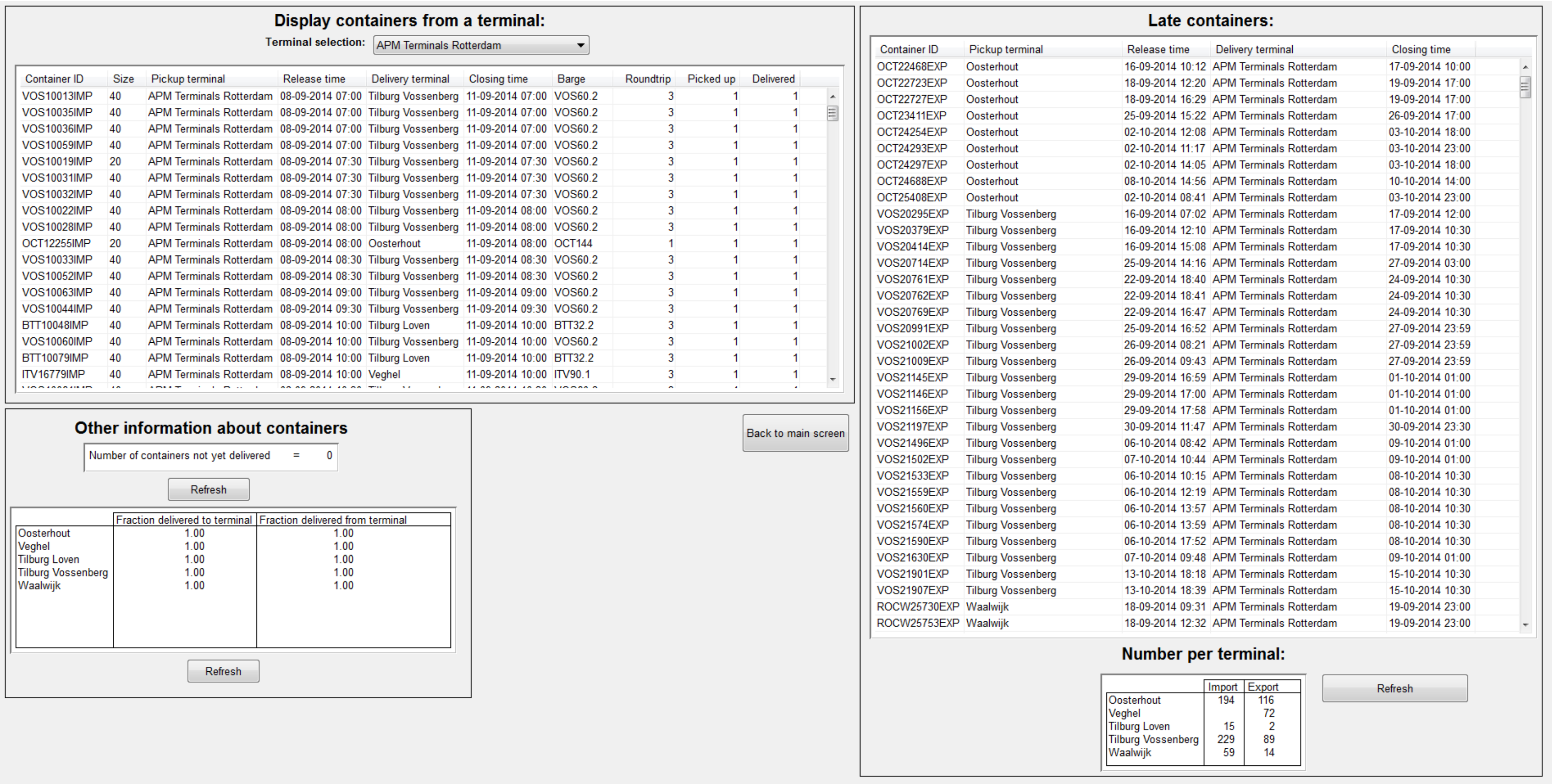


Figure 27: Page with all barge details



Display containers from a terminal:

Terminal selection: APM Terminals Rotterdam

Container ID	Size	Pickup terminal	Release time	Delivery terminal	Closing time	Barge	Roundtrip	Picked up	Delivered
VOS10013IMP	40	APM Terminals Rotterdam	08-09-2014 07:00	Tilburg Vossenberg	11-09-2014 07:00	VOS60.2	3	1	1
VOS10035IMP	40	APM Terminals Rotterdam	08-09-2014 07:00	Tilburg Vossenberg	11-09-2014 07:00	VOS60.2	3	1	1
VOS10036IMP	40	APM Terminals Rotterdam	08-09-2014 07:00	Tilburg Vossenberg	11-09-2014 07:00	VOS60.2	3	1	1
VOS10059IMP	40	APM Terminals Rotterdam	08-09-2014 07:00	Tilburg Vossenberg	11-09-2014 07:00	VOS60.2	3	1	1
VOS10019IMP	20	APM Terminals Rotterdam	08-09-2014 07:30	Tilburg Vossenberg	11-09-2014 07:30	VOS60.2	3	1	1
VOS10031IMP	40	APM Terminals Rotterdam	08-09-2014 07:30	Tilburg Vossenberg	11-09-2014 07:30	VOS60.2	3	1	1
VOS10032IMP	40	APM Terminals Rotterdam	08-09-2014 07:30	Tilburg Vossenberg	11-09-2014 07:30	VOS60.2	3	1	1
VOS10022IMP	40	APM Terminals Rotterdam	08-09-2014 08:00	Tilburg Vossenberg	11-09-2014 08:00	VOS60.2	3	1	1
VOS10028IMP	40	APM Terminals Rotterdam	08-09-2014 08:00	Tilburg Vossenberg	11-09-2014 08:00	VOS60.2	3	1	1
OCT12255IMP	20	APM Terminals Rotterdam	08-09-2014 08:00	Oosterhout	11-09-2014 08:00	OCT144	1	1	1
VOS10033IMP	40	APM Terminals Rotterdam	08-09-2014 08:30	Tilburg Vossenberg	11-09-2014 08:30	VOS60.2	3	1	1
VOS10052IMP	40	APM Terminals Rotterdam	08-09-2014 08:30	Tilburg Vossenberg	11-09-2014 08:30	VOS60.2	3	1	1
VOS10063IMP	40	APM Terminals Rotterdam	08-09-2014 09:00	Tilburg Vossenberg	11-09-2014 09:00	VOS60.2	3	1	1
VOS10044IMP	40	APM Terminals Rotterdam	08-09-2014 09:30	Tilburg Vossenberg	11-09-2014 09:30	VOS60.2	3	1	1
BTT10048IMP	40	APM Terminals Rotterdam	08-09-2014 10:00	Tilburg Loven	11-09-2014 10:00	BTT32.2	3	1	1
VOS10060IMP	40	APM Terminals Rotterdam	08-09-2014 10:00	Tilburg Vossenberg	11-09-2014 10:00	VOS60.2	3	1	1
BTT10079IMP	40	APM Terminals Rotterdam	08-09-2014 10:00	Tilburg Loven	11-09-2014 10:00	BTT32.2	3	1	1
ITV16779IMP	40	APM Terminals Rotterdam	08-09-2014 10:00	Veghel	11-09-2014 10:00	ITV90.1	3	1	1

Other information about containers

Number of containers not yet delivered = 0

Refresh

	Fraction delivered to terminal	Fraction delivered from terminal
Oosterhout	1.00	1.00
Veghel	1.00	1.00
Tilburg Loven	1.00	1.00
Tilburg Vossenberg	1.00	1.00
Waalwijk	1.00	1.00

Refresh

Back to main screen

Late containers:

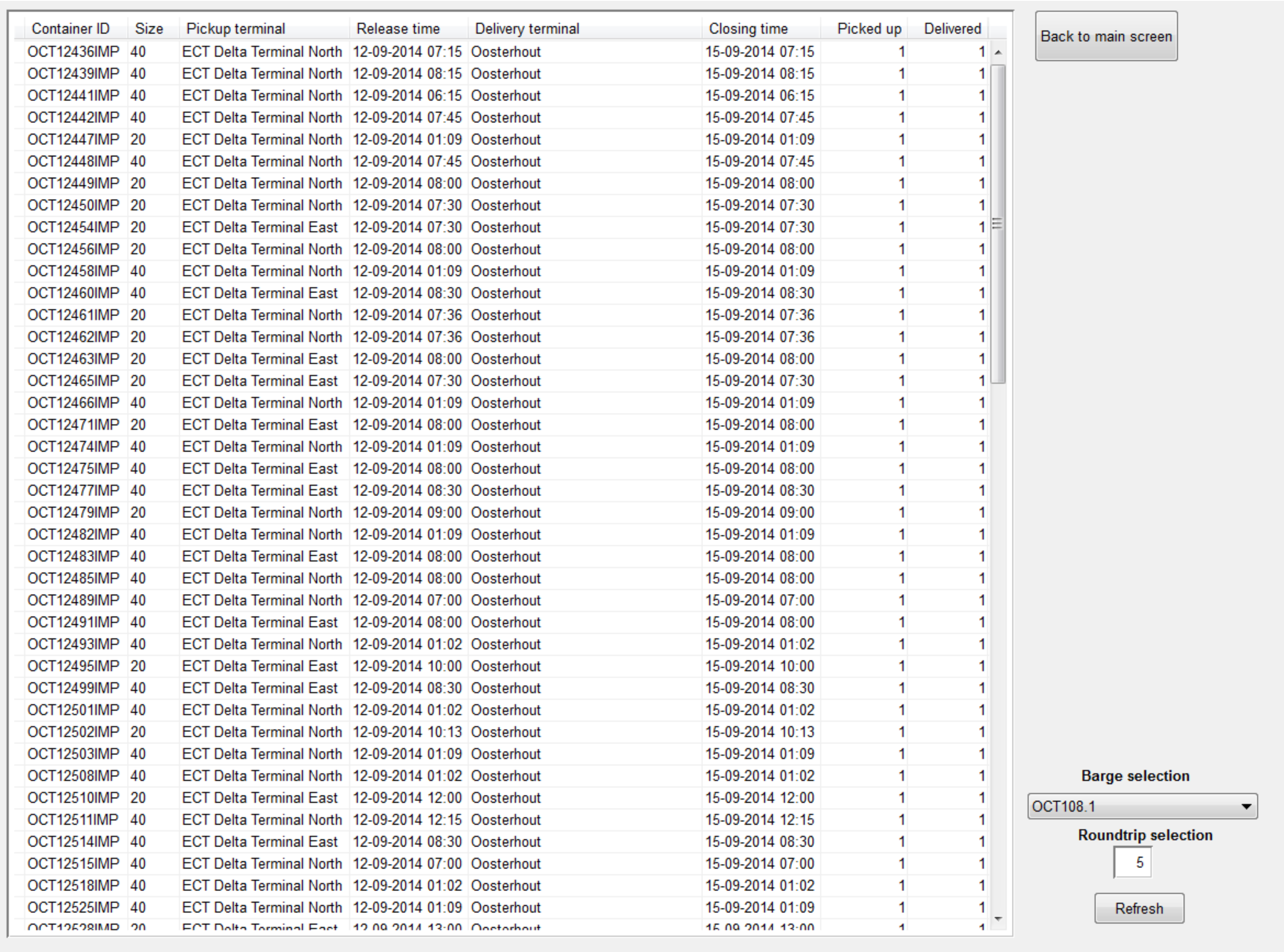
Container ID	Pickup terminal	Release time	Delivery terminal	Closing time
OCT22468EXP	Oosterhout	16-09-2014 10:12	APM Terminals Rotterdam	17-09-2014 10:00
OCT22723EXP	Oosterhout	18-09-2014 12:20	APM Terminals Rotterdam	19-09-2014 17:00
OCT22727EXP	Oosterhout	18-09-2014 16:29	APM Terminals Rotterdam	19-09-2014 17:00
OCT23411EXP	Oosterhout	25-09-2014 15:22	APM Terminals Rotterdam	26-09-2014 17:00
OCT24254EXP	Oosterhout	02-10-2014 12:08	APM Terminals Rotterdam	03-10-2014 18:00
OCT24293EXP	Oosterhout	02-10-2014 11:17	APM Terminals Rotterdam	03-10-2014 23:00
OCT24297EXP	Oosterhout	02-10-2014 14:05	APM Terminals Rotterdam	03-10-2014 18:00
OCT24688EXP	Oosterhout	08-10-2014 14:56	APM Terminals Rotterdam	10-10-2014 14:00
OCT25408EXP	Oosterhout	02-10-2014 08:41	APM Terminals Rotterdam	03-10-2014 23:00
VOS20295EXP	Tilburg Vossenberg	16-09-2014 07:02	APM Terminals Rotterdam	17-09-2014 12:00
VOS20379EXP	Tilburg Vossenberg	16-09-2014 12:10	APM Terminals Rotterdam	17-09-2014 10:30
VOS20414EXP	Tilburg Vossenberg	16-09-2014 15:08	APM Terminals Rotterdam	17-09-2014 10:30
VOS20714EXP	Tilburg Vossenberg	25-09-2014 14:16	APM Terminals Rotterdam	27-09-2014 03:00
VOS20761EXP	Tilburg Vossenberg	22-09-2014 18:40	APM Terminals Rotterdam	24-09-2014 10:30
VOS20762EXP	Tilburg Vossenberg	22-09-2014 18:41	APM Terminals Rotterdam	24-09-2014 10:30
VOS20769EXP	Tilburg Vossenberg	22-09-2014 16:47	APM Terminals Rotterdam	24-09-2014 10:30
VOS20991EXP	Tilburg Vossenberg	25-09-2014 16:52	APM Terminals Rotterdam	27-09-2014 23:59
VOS21002EXP	Tilburg Vossenberg	26-09-2014 08:21	APM Terminals Rotterdam	27-09-2014 23:59
VOS21009EXP	Tilburg Vossenberg	26-09-2014 09:43	APM Terminals Rotterdam	27-09-2014 23:59
VOS21145EXP	Tilburg Vossenberg	29-09-2014 16:59	APM Terminals Rotterdam	01-10-2014 01:00
VOS21146EXP	Tilburg Vossenberg	29-09-2014 17:00	APM Terminals Rotterdam	01-10-2014 01:00
VOS21156EXP	Tilburg Vossenberg	29-09-2014 17:58	APM Terminals Rotterdam	01-10-2014 01:00
VOS21197EXP	Tilburg Vossenberg	30-09-2014 11:47	APM Terminals Rotterdam	30-09-2014 23:30
VOS21496EXP	Tilburg Vossenberg	06-10-2014 08:42	APM Terminals Rotterdam	09-10-2014 01:00
VOS21502EXP	Tilburg Vossenberg	07-10-2014 10:44	APM Terminals Rotterdam	09-10-2014 01:00
VOS21533EXP	Tilburg Vossenberg	06-10-2014 10:15	APM Terminals Rotterdam	08-10-2014 10:30
VOS21559EXP	Tilburg Vossenberg	06-10-2014 12:19	APM Terminals Rotterdam	08-10-2014 10:30
VOS21560EXP	Tilburg Vossenberg	06-10-2014 13:57	APM Terminals Rotterdam	08-10-2014 10:30
VOS21574EXP	Tilburg Vossenberg	06-10-2014 13:59	APM Terminals Rotterdam	08-10-2014 10:30
VOS21590EXP	Tilburg Vossenberg	06-10-2014 17:52	APM Terminals Rotterdam	08-10-2014 10:30
VOS21630EXP	Tilburg Vossenberg	07-10-2014 09:48	APM Terminals Rotterdam	09-10-2014 01:00
VOS21901EXP	Tilburg Vossenberg	13-10-2014 18:18	APM Terminals Rotterdam	15-10-2014 10:30
VOS21907EXP	Tilburg Vossenberg	13-10-2014 18:39	APM Terminals Rotterdam	15-10-2014 10:30
ROCW25730EXP	Waalwijk	18-09-2014 09:31	APM Terminals Rotterdam	19-09-2014 23:00
ROCW25753EXP	Waalwijk	18-09-2014 12:32	APM Terminals Rotterdam	19-09-2014 23:00

Number per terminal:

	Import	Export
Oosterhout	194	116
Veghel		72
Tilburg Loven	15	2
Tilburg Vossenberg	229	89
Waalwijk	59	14

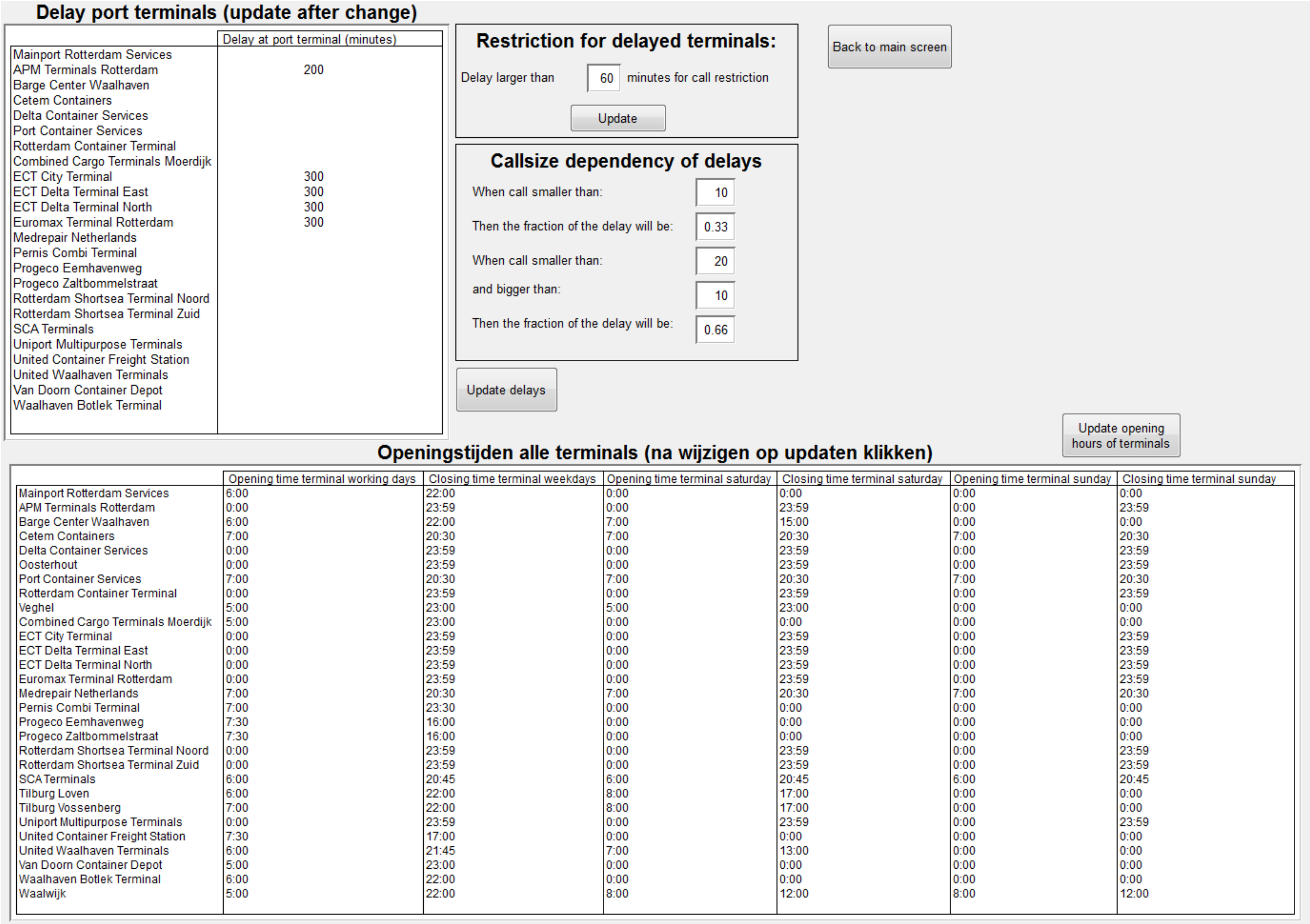
Refresh

Figure 28: Page with all container details per terminal and late containers



Container ID	Size	Pickup terminal	Release time	Delivery terminal	Closing time	Picked up	Delivered
OCT12436IMP	40	ECT Delta Terminal North	12-09-2014 07:15	Oosterhout	15-09-2014 07:15	1	1
OCT12439IMP	40	ECT Delta Terminal North	12-09-2014 08:15	Oosterhout	15-09-2014 08:15	1	1
OCT12441IMP	40	ECT Delta Terminal North	12-09-2014 06:15	Oosterhout	15-09-2014 06:15	1	1
OCT12442IMP	40	ECT Delta Terminal North	12-09-2014 07:45	Oosterhout	15-09-2014 07:45	1	1
OCT12447IMP	20	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12448IMP	40	ECT Delta Terminal North	12-09-2014 07:45	Oosterhout	15-09-2014 07:45	1	1
OCT12449IMP	20	ECT Delta Terminal North	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12450IMP	20	ECT Delta Terminal North	12-09-2014 07:30	Oosterhout	15-09-2014 07:30	1	1
OCT12454IMP	20	ECT Delta Terminal East	12-09-2014 07:30	Oosterhout	15-09-2014 07:30	1	1
OCT12456IMP	20	ECT Delta Terminal North	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12458IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12460IMP	40	ECT Delta Terminal East	12-09-2014 08:30	Oosterhout	15-09-2014 08:30	1	1
OCT12461IMP	20	ECT Delta Terminal North	12-09-2014 07:36	Oosterhout	15-09-2014 07:36	1	1
OCT12462IMP	20	ECT Delta Terminal North	12-09-2014 07:36	Oosterhout	15-09-2014 07:36	1	1
OCT12463IMP	20	ECT Delta Terminal East	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12465IMP	20	ECT Delta Terminal East	12-09-2014 07:30	Oosterhout	15-09-2014 07:30	1	1
OCT12466IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12471IMP	20	ECT Delta Terminal East	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12474IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12475IMP	40	ECT Delta Terminal East	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12477IMP	40	ECT Delta Terminal East	12-09-2014 08:30	Oosterhout	15-09-2014 08:30	1	1
OCT12479IMP	20	ECT Delta Terminal North	12-09-2014 09:00	Oosterhout	15-09-2014 09:00	1	1
OCT12482IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12483IMP	40	ECT Delta Terminal East	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12485IMP	40	ECT Delta Terminal North	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12489IMP	40	ECT Delta Terminal North	12-09-2014 07:00	Oosterhout	15-09-2014 07:00	1	1
OCT12491IMP	40	ECT Delta Terminal East	12-09-2014 08:00	Oosterhout	15-09-2014 08:00	1	1
OCT12493IMP	40	ECT Delta Terminal North	12-09-2014 01:02	Oosterhout	15-09-2014 01:02	1	1
OCT12495IMP	20	ECT Delta Terminal East	12-09-2014 10:00	Oosterhout	15-09-2014 10:00	1	1
OCT12499IMP	40	ECT Delta Terminal East	12-09-2014 08:30	Oosterhout	15-09-2014 08:30	1	1
OCT12501IMP	40	ECT Delta Terminal North	12-09-2014 01:02	Oosterhout	15-09-2014 01:02	1	1
OCT12502IMP	20	ECT Delta Terminal North	12-09-2014 10:13	Oosterhout	15-09-2014 10:13	1	1
OCT12503IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12508IMP	40	ECT Delta Terminal North	12-09-2014 01:02	Oosterhout	15-09-2014 01:02	1	1
OCT12510IMP	20	ECT Delta Terminal East	12-09-2014 12:00	Oosterhout	15-09-2014 12:00	1	1
OCT12511IMP	40	ECT Delta Terminal North	12-09-2014 12:15	Oosterhout	15-09-2014 12:15	1	1
OCT12514IMP	40	ECT Delta Terminal East	12-09-2014 08:30	Oosterhout	15-09-2014 08:30	1	1
OCT12515IMP	40	ECT Delta Terminal North	12-09-2014 07:00	Oosterhout	15-09-2014 07:00	1	1
OCT12518IMP	40	ECT Delta Terminal North	12-09-2014 01:02	Oosterhout	15-09-2014 01:02	1	1
OCT12525IMP	40	ECT Delta Terminal North	12-09-2014 01:09	Oosterhout	15-09-2014 01:09	1	1
OCT12528IMP	20	ECT Delta Terminal East	12-09-2014 13:00	Oosterhout	15-09-2014 13:00	1	1

Figure 29: Page with the allocated containers per barge



	Delay at port terminal (minutes)
Mainport Rotterdam Services	
APM Terminals Rotterdam	200
Barge Center Waalhaven	
Cetem Containers	
Delta Container Services	
Port Container Services	
Rotterdam Container Terminal	
Combined Cargo Terminals Moerdijk	
ECT City Terminal	300
ECT Delta Terminal East	300
ECT Delta Terminal North	300
Euromax Terminal Rotterdam	300
Medrepair Netherlands	
Pernis Combi Terminal	
Progeco Eemhavenweg	
Progeco Zaltbommelstraat	
Rotterdam Shortsea Terminal Noord	
Rotterdam Shortsea Terminal Zuid	
SCA Terminals	
Uniport Multipurpose Terminals	
United Container Freight Station	
United Waalhaven Terminals	
Van Doorn Container Depot	
Waalhaven Botlek Terminal	

	Opening time terminal working days	Closing time terminal weekdays	Opening time terminal saturday	Closing time terminal saturday	Opening time terminal sunday	Closing time terminal sunday
Mainport Rotterdam Services	6:00	22:00	0:00	0:00	0:00	0:00
APM Terminals Rotterdam	0:00	23:59	0:00	23:59	0:00	23:59
Barge Center Waalhaven	6:00	22:00	7:00	15:00	0:00	0:00
Cetem Containers	7:00	20:30	7:00	20:30	7:00	20:30
Delta Container Services	0:00	23:59	0:00	23:59	0:00	23:59
Oosterhout	0:00	23:59	0:00	23:59	0:00	23:59
Port Container Services	7:00	20:30	7:00	20:30	7:00	20:30
Rotterdam Container Terminal	0:00	23:59	0:00	23:59	0:00	23:59
Veghel	5:00	23:00	5:00	23:00	0:00	0:00
Combined Cargo Terminals Moerdijk	5:00	23:00	0:00	0:00	0:00	0:00
ECT City Terminal	0:00	23:59	0:00	23:59	0:00	23:59
ECT Delta Terminal East	0:00	23:59	0:00	23:59	0:00	23:59
ECT Delta Terminal North	0:00	23:59	0:00	23:59	0:00	23:59
Euromax Terminal Rotterdam	0:00	23:59	0:00	23:59	0:00	23:59
Medrepair Netherlands	7:00	20:30	7:00	20:30	7:00	20:30
Pernis Combi Terminal	7:00	23:30	0:00	0:00	0:00	0:00
Progeco Eemhavenweg	7:30	16:00	0:00	0:00	0:00	0:00
Progeco Zaltbommelstraat	7:30	16:00	0:00	0:00	0:00	0:00
Rotterdam Shortsea Terminal Noord	0:00	23:59	0:00	23:59	0:00	23:59
Rotterdam Shortsea Terminal Zuid	0:00	23:59	0:00	23:59	0:00	23:59
SCA Terminals	6:00	20:45	6:00	20:45	6:00	20:45
Tilburg Loven	6:00	22:00	8:00	17:00	0:00	0:00
Tilburg Vossenberg	7:00	22:00	8:00	17:00	0:00	0:00
Uniport Multipurpose Terminals	0:00	23:59	0:00	23:59	0:00	23:59
United Container Freight Station	7:30	17:00	0:00	0:00	0:00	0:00
United Waalhaven Terminals	6:00	21:45	7:00	13:00	0:00	0:00
Van Doorn Container Depot	5:00	23:00	0:00	0:00	0:00	0:00
Waalhaven Botlek Terminal	6:00	22:00	0:00	0:00	0:00	0:00
Waalwijk	5:00	22:00	8:00	12:00	8:00	12:00

Figure 30: Terminal overview

Appendix G – Decision scheme to-be network simulation tool

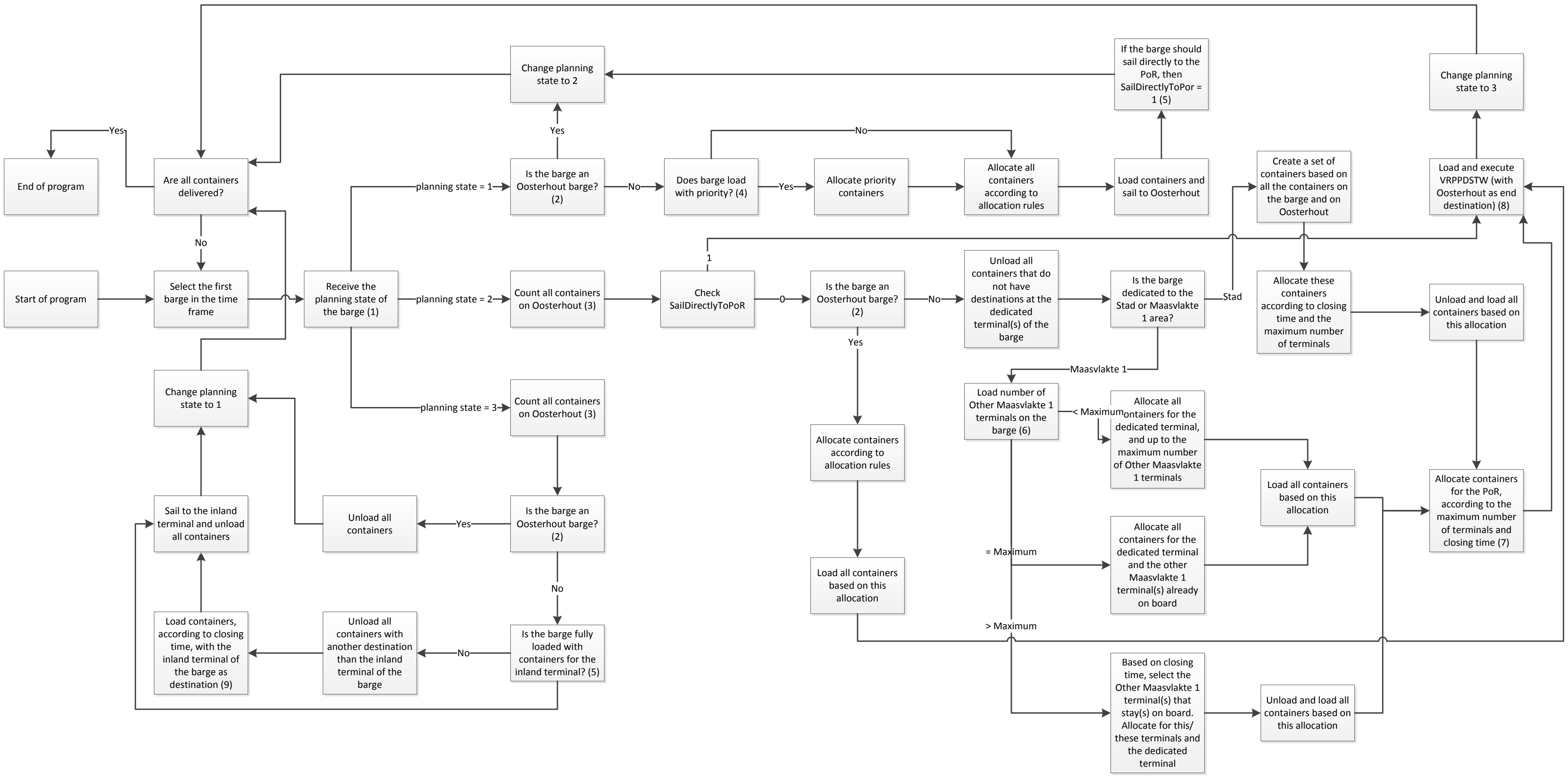


Figure 31: Decision scheme of the to-be network simulation tool

Specification of Figure 31:
(1): In this tool, barge are in a "planning state". There are three states, which are used to split the roundtrip in three parts, so that the operation at the hub is chronically correct. Therefore, whenever a barge is selected that is the earliest in the timeframe just as in the simulation of the as-is network, the planning state is received to determine which steps have to be executed.

(2): For Oosterhout barges there are other procedures executed, since these barge only sail between Oosterhout and the PoR.

(3): For planning states 2 and 3 the number of containers on Oosterhout is counted, where the containers from Oosterhout itself are not included. This is done to see what the impact of the use of Oosterhout as hub is on the stack capacity of Oosterhout.

(4): When a barge loads with priority (see Section 6.2.1 and 7.1), first the containers are loaded for its dedicated terminal(s). After this, all containers that can possibly be loaded are considered and allocated when there is capacity left on the barge.

(5): In general the barge sails as follows: Inland terminal – Oosterhout – PoR – Oosterhout – inland terminal (except for Oosterhout barges). However, in some cases a barge can be fully loaded with containers for its dedicated terminal(s) (export route), or fully loaded with containers for its inland terminal (import route). In that case the barge does not have to call at Oosterhout.

(6): When a barge loads for other Maasvlakte 1 terminals, and is also sailing to these terminals, it is checked whether the number of terminals on board is lower, the same, or higher than the maximum amount. The allocation is based on this number, since extra terminals can be loaded or not. Whenever the number of other Maasvlakte 1 terminals on board is larger than the allowed number, there are also containers unloaded.

(7): Containers that are allocated in the PoR (import containers), are based on the fact whether are barge already reached the maximum number of terminals or not. If not, a set with containers is created, based on which terminals can possibly be visited and closing times, and these are allocated as long as the maximum number of terminals or capacity is not exceeded. When this maximum number is already reached before the allocation of import containers, a set is created with containers that are on the terminals that are already on board of the barge.

(8): The VRPPDSTW is not changed, except for the fact that Oosterhout is almost always used as start and end point of the roundtrip (except for cases as discussed in point 5). A more extensive explanation of the VRPPDSTW can be found in Section 5.3.2 and Appendix D.

(9): For the import route, containers at Oosterhout are loaded for the inland terminal the barge is linked to. No difference is made in the origins of the containers; the containers are loaded according to closing times.

Appendix H – Screenshot of the to-be simulation tool

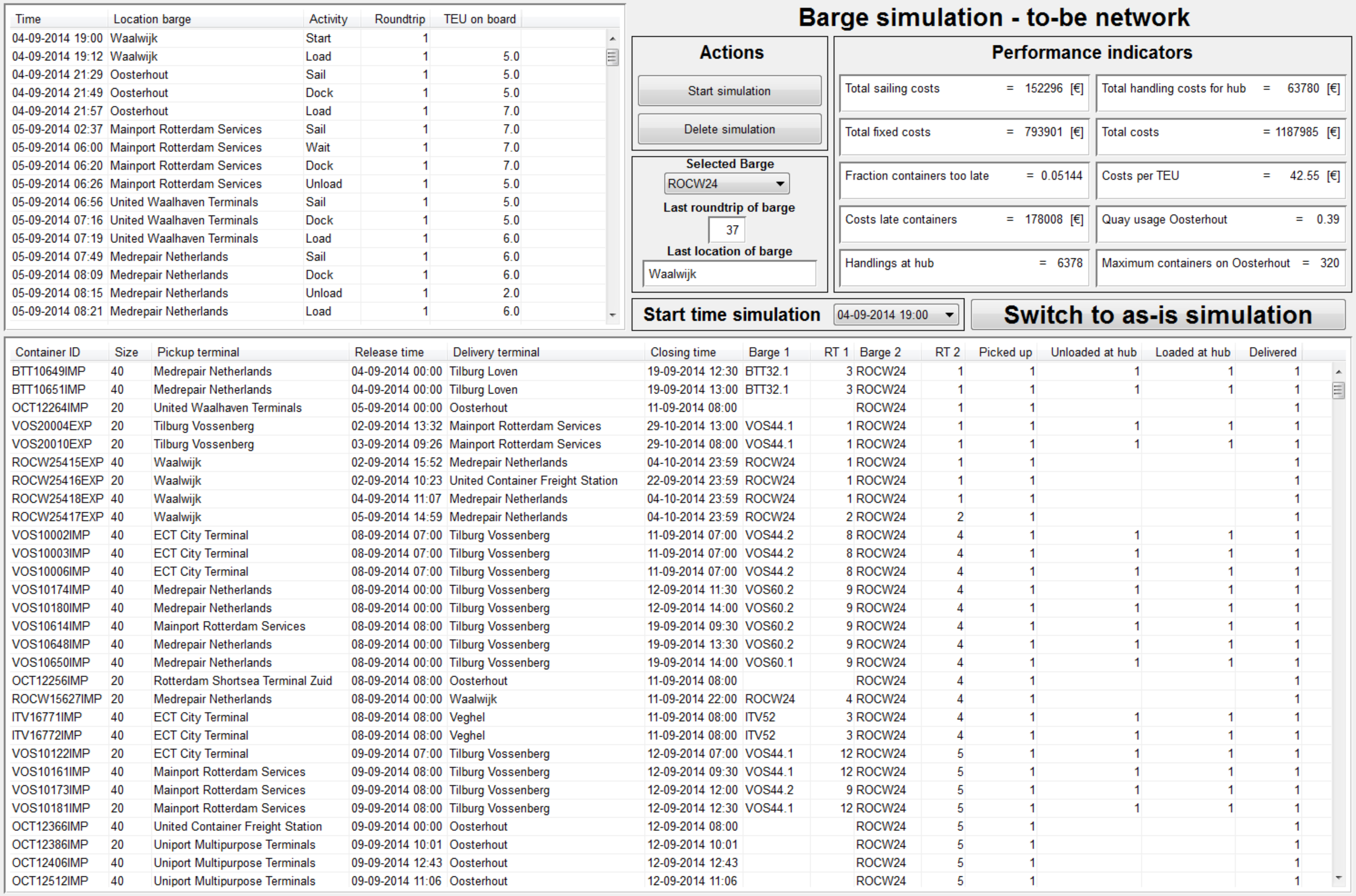


Figure 32: Main simulation page of the to-be simulation tool

Appendix I – A design for a more efficient handling of containers at the hub

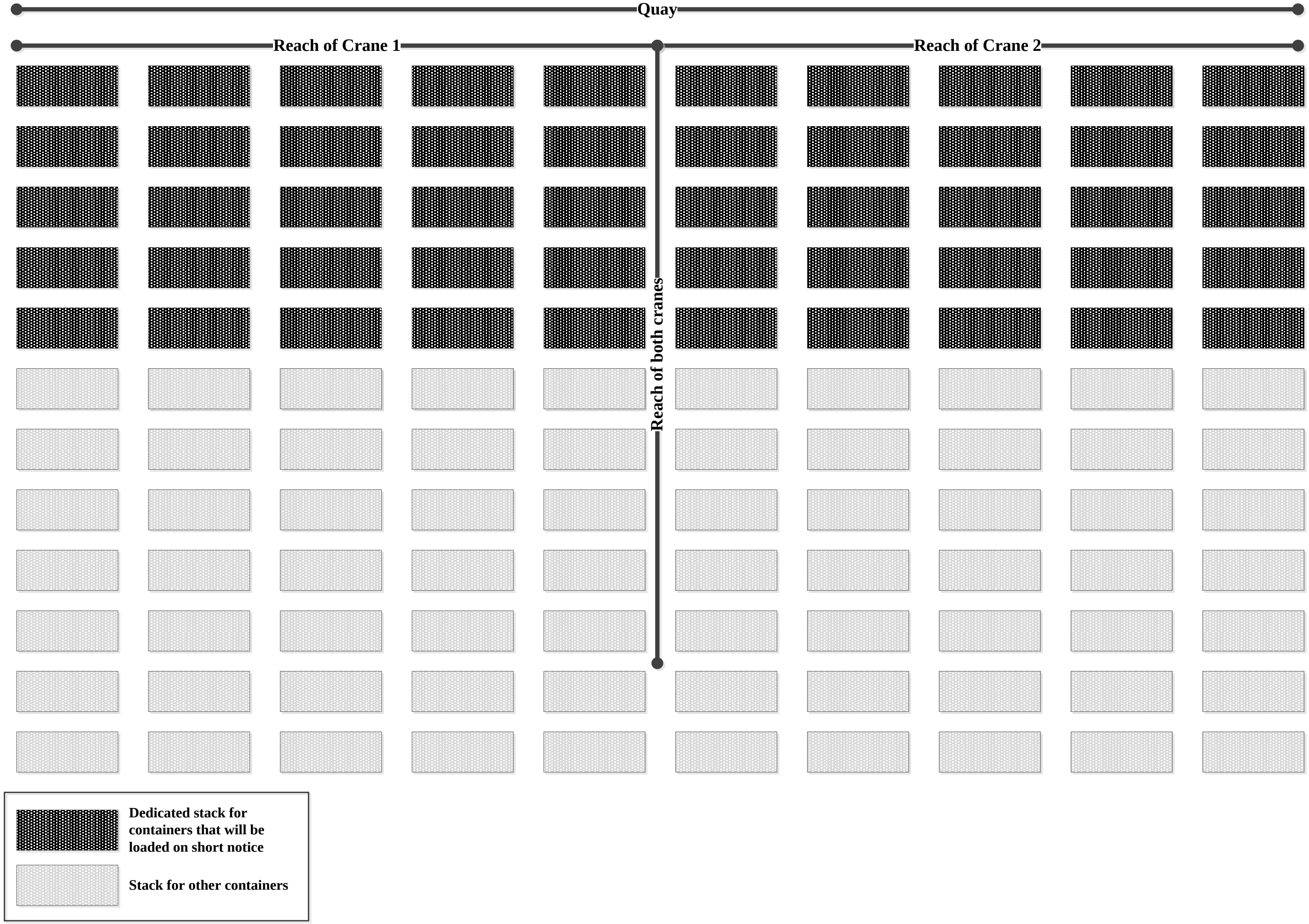


Figure 33: Dedicated stack for containers that will be loaded on short notice (one rectangle represents one pile of containers)