Master Thesis

September 20, 2013

DEVELOPMENT OF A DECISION SUPPORT TOOL FOR BARGE LOADING

Author:
Lina Baranowski *University of Twente*
Master: Industrial Engineering and Management
Track: Production and Logistics Management
s0148768

Supervisors:
Marco Schutten *University of Twente*
Martijn Mes *University of Twente*
Danny Otter *Combi Terminal Twente*
Maurice Glandrup *NexusZ*

UNIVERSITEIT TWENTE.

CTT INTERMODAAL TRANSPORT

Management Summary

Introduction Combi Terminal Twente B.V. (CTT) is a terminal operator that transports containers from the Port of Rotterdam via Hengelo to the customer and vice versa. The majority of containers that are shipped between Rotterdam and Hengelo are transported by inland barges. The number of goods that is transported by container is growing and barge planners have to deal with large amounts of data for hundreds of containers when making plans. A barge planner at CTT makes different types of decisions at different moments in the planning process of a barge. Currently, these decisions are based on experience and common sense. Planners do not make use of any structural decision support. In order to profit from the growth in transportation, CTT wants to optimize the use of their transportation means and increase the quality of transportation in terms of transportation time, frequency, flexibility, costs, and reliability. Therefore, the main research objective of this research is:

> **Design a method to support CTT's barge planners to improve the quality of CTT's transportation flows.**

Method To meet this objective we develop a decision support tool that supports planners in the planning of containers on barges. The main objective for the tool is to create plans where all containers are delivered or picked-up in time. Furthermore, we have two secondary objectives. We want to minimize the trip duration and maximize the utilization rate of the barge. The method considers information of all containers in the planning process, while planners make subproblems. We structure the model in such a way that it is easy to adjust en add different aspects of the model.

Results We test several settings of the model. We use the combination that generally performs best for the experiments we execute to determine the methods' performance. From these experiments, we conclude that the method achieves the main objective and one of the secondary objectives (avoiding lateness and maximizing the utilization of the barge, respectively). The method has a varying performance with respect to the second secondary objective (minimizing trip duration).

Conclusions We conclude that the prototype tool has the potential to become a decision support tool that assists planners in their planning. At this point it provides planners with insights on urgency of containers and terminal visits and a foundation is made to built upon. With further development, the tool will be a valuable addition to the planning process, because it initially considers all information at once, instead of making smaller subproblems. Furthermore, will planning become easier when using the tool because it also considers future planning.

Recommendations In order to make the decision support tool fully operational we recommend CTT to further develop the model:

- To extend the model to plan on hour base instead of day base.

- To create a better overview of the states of all containers, CTT should register whether import containers are ready to be picked-up, are planned to be picked-up by a barge, or are already picked-up and on their way to CTT.
- To register when original pick-up and closing dates are changed and when a container cannot be served in time, in order to measure lateness.

During this study we observed several subjects that are interesting for future research at CTT. We therefore recommend CTT to:

- To extend the model to make plans for a longer time horizon.
- Develop performance indicators for plans.
- Investigate how CTT can make use of their terminal in Rotterdam to increase transportation quality.
- Develop forecasting techniques.
- Create a preferred customer network.

Preface

In 2006, is started at the University of Twente with the Bachelor Technische Wiskunde. Now, seven years later I will complete my first Master's degree. I completed this study as a graduation requirement for my Masters degree in Industrial Engineering and Management. The end of my Master thesis does not mean the end of my student life, because I already started to study for my teachers degree for Mathematics. For coming year I will stay at the University of Twente.

I am grateful that I was allowed to do my Master Thesis at Combi Terminal Twente. Because of the open attitude, enthusiasm and collegiality of my colleges, I have had a great time. In particular I want to thank my supervisors, Danny Otter and Maurice Glandrup, who put a lot of confidence in me. Furthermore, I thank my supervisors form the University of Twente, Marco Schutten en Martijn Mes for guiding me through the process of writing my Master Thesis.

Finally, I appreciate the support of my parents, boyfriend and friends who believed in me, despite the ups and downs I passed through during the project. Your support in both the mental and the writing process, helped me to finish this work.

Lina Baranowski
Enschede, September 20, 2013

Contents

Chapter 1

Introduction

There is almost no place on earth we cannot transport goods to or from. Most goods are transported in a number of steps. In different steps, different means of transportation are used, which are coordinated by operators. For example, Timberland's shoes are, among others, produced in Zhongshan (China) and transported to Almelo with different means. The shoes are transported in a container by a truck to the nearest port, which is located in Tianjin. From here, the shoes are shipped by sea vessel to the Port of Rotterdam. Barges ship the containers from Rotterdam to the inland terminal in Hengelo. From here, the container is transported by truck to the distribution centre in Almelo. These series of consecutive steps is called a transportation chain and the steps are the links of the chain, e.g., the transportation from Zhongshan to Tianjin. Often, different means of transportation can be used for one link, e.g., the container with Timberland's shoes could have been transported by truck directly from Rotterdam to the distribution centre. Figure 1.1 shows the links in the transportation chain from Zhongshan to Almelo.

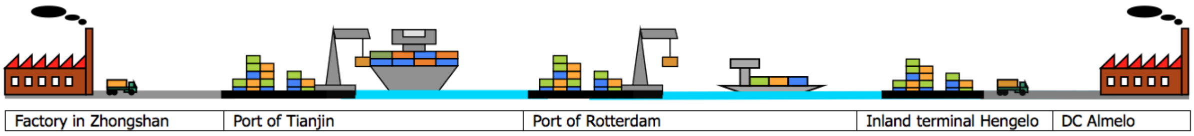


Figure 1.1: Links in the transportation chain from factory to distribution centre

In Figure 1.1, we see that in this particular case, the container is transported by truck in the first link of the transportation chain. After that, it is shipped by sea vessel and then transshipped to an inland barge in Rotterdam. The barge brings the container to the inland terminal in Hengelo, where the container is transshipped to a truck, which brings the container to Timberland's distribution centre in Almelo.

Increasing the efficiency in a transportation chain can be done on chain and link level. Optimization on chain level is, among other things, about streamlining connections between links. Optimization on link level is about streamlining the transportation within the link. An operator that operates on one or more links, has to anticipate the preceding links in the chain to manage its own links efficiently. On this level, an operator aims to minimize costs by minimizing travel time and distance, without decreasing its service level. Not only the adjacent links influence the planning and decisions an operator must make, external factors such as weather conditions can have a great impact too. These complex sets of internal and external factors challenge the planning capacities of the operators. Furthermore, plans tend to change several times, even during execution.

The Port of Rotterdam is the only non-Asian port in the top 10 of the World Port Ranking 2011. It has the fourth position in the overall ranking and the tenth position in ranking of container traffic [Amercain Association of Port Authorities, 2012]. This makes that the Port of Rotterdam plays an important role for transportation chains starting or ending in Western Europe. The Port of Rotterdam invested in Maasvlakte 2, an extension of the port, to reinforce its position by increasing their container traffic capacity.

Combi Terminal Twente B.V. (CTT) is an operator, which manages links between the Port of Rotterdam and Hengelo, in a transportation chain to and from the Western European hinterland. CTT strives for optimal use of the upcoming growth of the Port of Rotterdam. As an operator, CTT aims to manage their part of the transportation chain good as possible in order to serve its customers' needs.

CTT's main tasks are to ship and transport cargo containers from Rotterdam to Hengelo, from Hengelo to the customer, and vice versa. The majority of containers that are shipped between Rotterdam and Hengelo are transported by inland barges. The remaining part is mainly transported by truck and occasionally by train. In Hengelo, containers are transshipped from barges to trucks, which bring the containers to the customers. CTT's planners currently solve planning problems without the use of decision support. The goal of this research is to support barge planners at CTT to make more efficient plans and guide real-time decisions.

Section 1.1 describes the problem we tackle in this study. Next, Sections 1.2 and 1.3 give the motivation and the scope of the research, followed by the research objective and questions (Section 1.4).

1.1 Problem description

A barge planner at CTT makes different decisions at different moments in the planning process of a barge. These decisions are based on data, experience, common sense, and intuition. The number of bookings for transportation services keeps growing at CTT. This positive development results in a growing number of information to process by CTT's barge planners. Besides the large amount of data they also need to deal with unreliable and missing information. A lack of overview leads to inefficient decisions.

Currently, the roundtrip time of a barge, transporting containers to and from Rotterdam, is about four days. The trip can be divided into three parts. The first part is loading at CTT and sailing to Rotterdam. The second part is visiting different terminals in Rotterdam, unloading and loading containers. The third part is returning from Rotterdam and unloading at CTT.

As Figure 1.2 shows, it takes about a day to sail from CTT to Rotterdam and a barge stays, on average, in Rotterdam for two days. Currently, barges sail with an average load of 70 to 80 containers. On average, it takes 3 minutes to unload or load a container, about half an hour to moor at a terminal. Barges call at on average 7 terminals per tour, which makes that it takes 5 to 6 hours to unload and reload a barge. So, there are approximately 40 hours remaining in Rotterdam in which barges sail and wait. A tour along all terminals in the Port of Rotterdam

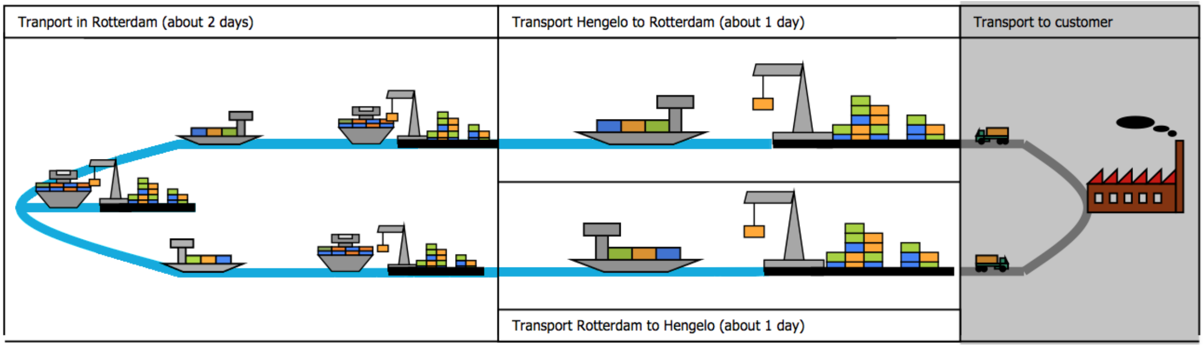


Figure 1.2: Schematic overview of the distribution of the current tour time of a barge

is about 130 km. With a average sailing speed of 10 km/h it would mean that every efficient tour takes at most 13 hours of sailing time in Rotterdam. So the total duration of an efficient trip, thus without waiting time and delay, in the Port of Rotterdam would not take longer than 19 hours. This is less than half of what it takes currently. CTT expects that by supporting barge planners in the planning process, more efficient transportation plans can be made, which thus results in lower sailing and waiting time, which increases revenues and decreases costs.

A plan of a barge tour can be divided into subproblems with several preconditions that must be met. We briefly describe these subproblems with their preconditions to give an impression of when in the process which decision must be made. Furthermore, it shows the complexity of the planning problems a barge planner has to deal with. The following sections present the subproblems in a particular order, but it is important to realize that the problems are strongly related and partly depend on each other.

1.1.1 Container information

Before containers and their content are allowed to be shipped by CTT, CTT requires certain information and several forms. CTT needs to know where to pick-up certain containers and where to deliver them. Permission forms are required because containers belong to shipping companies and the content belongs to CTT's customers and not to CTT itself. Furthermore, containers must be checked on valid customer forms and seals. This is a large amount of data, which is almost never complete when the container is booked. Missing information becomes available gradually, but the planners need to watch closely that all required information and forms are available at the moment of pick-up. Appendix H gives a list of all required information. With the changing information and its availability, it is desirable to make a plan as late as possible, because then the most up-to-date information is available. This means that many real-time decisions are made without having the time to gain the total overview of the situation.

1.1.2 Composition of cargo for one tour

The barge planner decides on the composition of the containers on the barge. The composition of containers is the set of containers that will be transported by a particular barge. At this point in time the planners have a global plan about the order of terminal visits. When assigning cargo to a barge, the barge planner needs to bear in mind the pick-up and delivery dates of import as well as export containers and turn-in dates of empty import containers. Simultaneously, the planner tries to minimize the traveling time of a barge. This can be done by minimizing the number of terminals and visiting terminals in a smart way. There are about 30 terminals that CTT visits regularly (Appendix I provides a complete list of all terminals). Most of them are located at the port of Rotterdam. There are roughly two locations with terminals in the port of Rotterdam, called Rotterdam City and Maasvlakte. Figure 1.3 shows a rough overview of the locations of terminals. Currently, containers are planned as soon as they enter the system. By speeding up the planning process, a plan can be made at a later moment, which makes it more reliable.

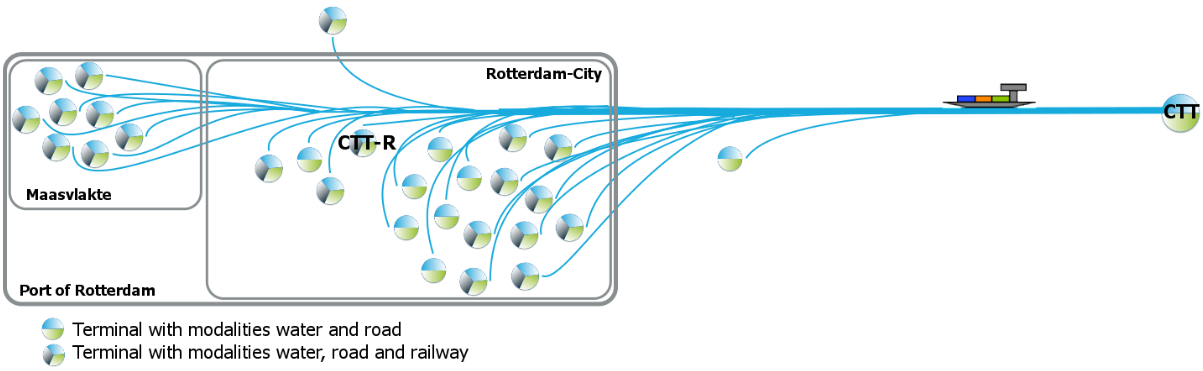


Figure 1.3: Schematic overview of terminals visited by CTT

When making a composition of containers for one barge, the barge planner has to take into account both export and import containers. Export containers are located in Hengelo and need to be in Rotterdam at a certain terminal at a certain time. Import containers arrive at terminals in the Port of Rotterdam. They have a pick-up date and need to be at the costumer before a certain time, and after that they need to be delivered at the corresponding terminal in Rotterdam within a certain number of days after pick-up. In the ideal situation, the barge visits a number of terminals where it both picks-up and delivers containers. CTT hires four barges to do container transportation, which are in service of CTT 24/7. So, some flexibility is available to assign containers to trips.

When the barge planner has a global overview of the composition of the cargo on a barge, he will contact the operators of the terminals that the barge needs to visit to make appointments. From that moment, he also has to bear in mind the preconditions such as those mentioned before.

1.1.3 Synchronization of transportation

A barge planner manages one link in the transportation chain of a container. At one end of the link, planners have to cooperate with the truck planners of CTT. They manage the transportation from CTT to the customer. This collaboration is relatively easy because the planners are located in the same room in the office of CTT. At the other end of the link, it is more difficult. Barge planners are dependent on the arrival of the sea vessel and plans made by the terminal operators. In addition, the barge planner has the possibility to let certain parts of a trip that containers make be executed by different modalities, e.g., the planner has the opportunity to let containers be delivered or picked-up by truck. In some cases this is needed because the transportation by barge takes too long. Transportation by truck is much faster but also more expensive, when comparing the price per container of a full truck and barge load. The planner can also choose to let trucks or a train do parts of the trip a container needs to make, e.g., when a batch of containers needs to be picked-up at one of the terminals at Maasvlakte, it can be transported to CTT-R by train. That could save a barge a trip to the Maasvlakte.

CTT wants to implement the concept of synchromodal transportation. CTT defines synchromodal transportation as follows:

"Synchromodality is the optimal, flexible, and sustainable usage of different transport modalities in a network under direction of a logistic service provider, such that the customer is offered an integrated solution for its transportation."

A more extensive definition is given by Tavasszy et al. [2010] in a TNO report:

"The core of the concept is that synchromodality is to coordinate within and between the three layers that form the transportation system, namely shippers, carriers/terminals, and infrastructure managers, in such a way that given aggregated transportation demand at any time the right modalities are used, in such a way that:

1. *the shipper is offered a transportation means that suits his competitive strategy.*
2. *a business economical exploitation is possible for the carrier (or terminal).*
3. *use of infrastructure and available space is maximized.*
4. *chain performance is optimized in terms of sustainability."*

The most important aspects of synchromodal transportation for CTT is the flexibility of using different means of transportation in a network to make transportation more efficient and sustainable. To do so, they want to change the perspective from a point centric view to a net-centric view, which means that information on the whole or large parts of the transportation chain are taken into account when making decisions.

To increase flexibility, CTT purchased a terminal in Rotterdam (CTT-R) recently. This was acquired to take advantage of the growth of the Port of Rotterdam. CTT opened this terminal on January 1, 2013. Since then, it serves as an intermediate terminal between the sea terminals in Rotterdam and the transshipment terminal in Hengelo. The introduction of the terminal not only opens up new opportunities, but also makes planning more complex.

1.1.4 Stowage

Until the moment of loading, the container composition may change several times, sometimes even during loading. The captain makes the stowage plan for his barge. He decides which container gets which position on the barge. He needs to take into account that the barge needs to be in balance that the containers are stacked to a maximum height, and that the barge has a maximum draught it may reach. Furthermore, to minimize loading and unloading time, containers should be stacked in such a way that no repositioning of containers is needed when loading or unloading a batch of containers.

The captain is only able to make a feasible stowage plan if the barge planner has chosen a good composition of containers for that barge.

1.1.5 Uncertainties in plan execution

When the barge is loaded, it immediately leaves Hengelo to sail to Rotterdam. As mentioned before, it takes about a day to reach the Port of Rotterdam. During this day, several factors influence the global plan made. Frequently, terminal operators in Rotterdam change appointments with and without communicating it to planners and captains, because sea vessels are late or they find other customers more important. A barge operator has hardly any influence on the decisions a terminal operator makes. The only thing they can do is to advise their customers to book at transshipment agents that do not collaborate with certain terminals. In the situation that an appointment is cancelled or moved, the captain is the first to try to make a new plan. He is the one that is on location and is able to see which terminals have available berths. He contacts the terminal operators to make new appointments and communicates this with the barge planners at CTT.

Another factor that influences sailing times is the weather. Wind and precipitation can de- and increase the shipping time. Furthermore, the barge passes several locks and bridges, where waiting time can arise. When barges are delayed, customers and terminals in question are informed about the delay as late as possible for two reasons. First, because more certain information can be given at a later time. Second, it can happen that terminals move their appointment for certain reasons, in that case no rearrangements are needed.

1.2 Research motivation

To anticipate the growing amount of information, CTT wants to increase the efficiency of their transportation streams by optimizing the deployment of their own and hired means. To do so, they want to change their point-centric view to a net-centric view. This means that they want to make decisions based on information from the whole or large parts of the transportation chain. This makes decision making based on experience, common sense, and intuition even harder.

A good plan is essential for CTT, because it decreases waiting times and thus shortens lead times. Shorter lead times mean that barges can sail more often, which result in a higher shipping capacity, which leads to increased revenue. Furthermore, when transportation time by barge decreases, more containers can be transported by barge instead of truck. This second effect results in lower transportation costs per container.

1.3 Scope of research

The background of this research is that CTT wants to optimize their transportation flows. To do so, CTT wants to implement synchromodal transport. To increase the quality of the transportation flows, transportation should be more reliable and transportation time per container should be decreased. Both can be achieved by making better transportation plans. Because of the high amount and complexity of data, which results in lack of insight for the planners, decision support for planners is needed. In this study, we investigate how to support planners in such a way that they make better plans. We only focus on the transport from CTT to the Port of Rotterdam and vice versa. Transportation from CTT to the customer in the hinterland by truck is beyond the scope of this research.

Transportation by barge is the preferable modality in this study, because it is less expensive, emits less CO_2 than transportation by truck, and is more reliable in a number of aspects. Also transportation by train emits less CO_2 than truck, but the connection from CTT to the nearby train terminal is not easily accessible yet. These are the reasons why we focus on transportation with barge in this study. Figure 1.4 shows the differences in CO_2 emission for different modalities.

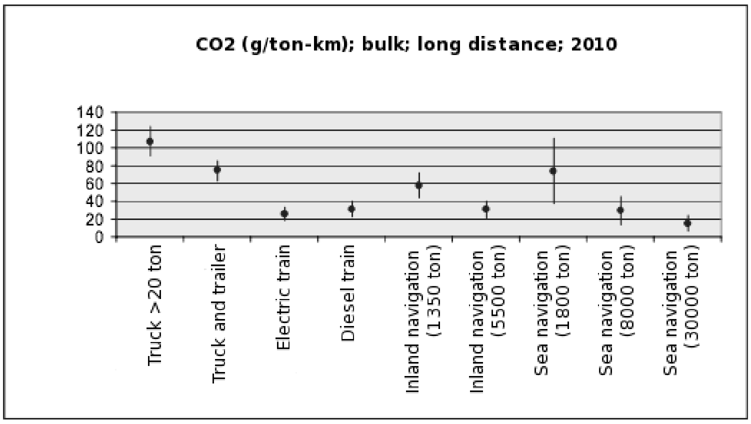


Figure 1.4: CO_2 emissions per ton-kilometer in 2010, adapted from den Boer et al. [2009]

Other modalities will only be taken into account, when barge transportation is not feasible. As described in Section 1.1, the planning of a round trip includes different optimization decisions. We focus on the real time planning of the composition of containers on the barges that enter that day. We expect to gain the largest increase in efficiency here.

1.4 Research objective, questions, and approach

As described in Section 1.1, there are a considerable number of aspects that planners must oversee. This makes it hard to meet the conditions to make a good barge plan. The goal of this research is to help barge planners to make more efficient plans and better real-time decisions. From this, we formulate the research objective:

> **Design a method to support CTT's barge planners to improve the quality of CTT's transportation flows.**

From this problem, four main research questions follow. We divide each question into sub research questions and assign it to a chapter. This division gives us the following overview of this research:

Chapter 2: What is the current situation at CTT?

2.1 What are the expectations for future development of the container sector?

2.2 What is the current situation at CTT?

   (a) What services does CTT provide?
   (b) What are CTT's networks?

2.3 What is CTT's current planning procedure?
   (a) What is the current decision making process?
   (b) Which factors influence plans and decisions?
   (c) What are current problems at planning process?

We answer these questions by the information received from CTT via documentation, observation, and interviews.

Chapter 3: What is said in academic literature about barge loading, planning and scheduling, and transportation quality?

3.1 What is known about barge loading, planning and scheduling?

3.2 What is considered as good container transportation quality?

We answer these questions by performing a literature study.

Chapter 4: What is suitable decision support for CTT's barge planners?

4.1 Which output should the solution provide?

4.2 Which requirements should the solution meet?

4.3 Which approach should be used to come to the required output?

Based on the knowledge gained from literature and CTT's current insight, we will design a suitable method for CTT.

Chapter 5: Which performance can be expected when implementing the solution method?

5.1 How can we test whether the developed method increases transportation quality?
   (a) How do we test the performance of the method?
   (b) Which key performance indicators do we use to test the performance?
   (c) How do we define successful improvement of performance?

5.2 What are the advantages and disadvantages of the solution method?

We answer these questions by testing the developed decision support method and the current method , through applying them on various datasets, evaluating the outcomes, and discussing the results.

Chapter 2

Context analysis

This chapter describes the current situation at Combi Terminal Twente. We start with an introduction to the container transportation sector in Section 2.1. The section describes the current situation and development of the sector. In Section 2.2 we give an introduction to CTT, a description of the services CTT provides, and the networks in which CTT participates. Section 2.3 describes how the planning and booking process is managed now and the system CTT uses. The chapter ends with a conclusion on the context analysis (Section 2.4).

2.1 Container sector

The worldwide volume of transported goods in containers keeps on growing. Figure 2.1 shows the growth in the past and gives an expectation of growth in the future [ESCAP, 2007]. The volumes shown in the figure are full origin-destination containers only, so empty containers are not included and each container is counted once on a roundtrip. United Nation's ESCAP [2007] expects the total number of containers shipped internationally to grow to 177.6 million TEU (twenty-foot equivalent unit) by 2015. This is based on the numbers from 1980 tot 2002, where the growth factor was 8.5% per annum.

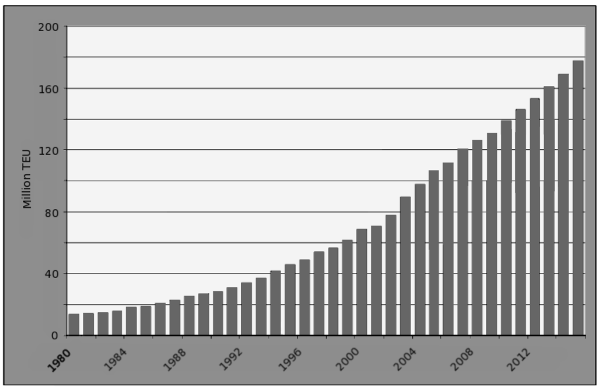


Figure 2.1: Past and forecast global TEU's (1980-2015). Adapted from ESCAP [2007]

This worldwide growth affects the growth of container transportation in Europe and hence the growth of container transportation in the Largest European port, the Port of Rotterdam. The container throughput in the Port of Rotterdam grew from 100.3 million (gross weight x metric tons) in 2009 to 112.3 millions in 2010 to 123.6 millions in 2011 [Port of Rotterdam, 2011a].

To anticipate the expected growth, the Port of Rotterdam invested in broadening of the Amazone port and the development of Maasvlakte 2. These investments enable double port capacity. The growth of transshipment leads to higher stress on the hinterland connections. The transportation to the hinterland is in 2012 mainly done by road (46.9%) which is compared to waterway and rails extra burdening for the environment and burdens the traffic flow on the road network. To counter the increase in CO_2-emission and relief the road network, the Port of Rotterdam wants to make a shift in modality for its transportation to the hinterland. This means a shift in container transportation from road transportation to less polluting transportation means, such as rail and water [Port of Rotterdam, 2012].

These developments also play a major role in Port of Rotterdam's vision for 2030. The Port of Rotterdam wants to grow into a *"leading European junction for mondial freight flows. The European global hub for containers, fuel and energy flows."* Furthermore, they want to build up *"an integrated network with the hinterland"* and become *"leader in the field of sustainable and efficient chains"* [Port of Rotterdam, 2011b].

Based on forecasts of ESCAP and visions Port of Rotterdam, we expect that future developments will influence the inland navigation in a positive way. Demand for inland navigation will continue to increase, because of the growth of container transportation and because of the shift to less polluting transportation means.

2.2 Combi Terminal Twente

Combi Terminal Twente is an inland terminal located in Hengelo. Its main activity is to transport containers from the Port of Rotterdam to customers and vice versa. The transportation from the Port of Rottedam to CTT is mainly done by inland barges. Sometimes, trucks and trains are used to transport containers along the route or parts of it. CTT is also able to transport containers from and to Amsterdam and Antwerpen. From CTT, containers continue to the customer by truck. Customers vary from local farmers that receive a container once a year to large international companies that receive multiple containers on a daily basis. The transportation from and to the customer is provided in collaboration with Bolk Transport BV. Bolk is CTT's permanent partner and provide the largest part of the trucks that drive for CTT.

CTT expands its activities to more than the normal activities of a transshipment terminal. On January 1st, 2013, CTT opened a new terminal in the Port of Rotterdam (CTT-R). This terminal serves as an intermediate terminal between the sea terminals and the transshipment terminal in Hengelo. It opens up new opportunities for CTT. The three main reasons for the acquisition of CTT-R are:

- The realization of Maasvlakte 2 means an increase in transportation, especially container transportation, which results in an increased need for depots and transshipment terminals.
- CTT-R can serve three transportation modalities: transportation by water, road, and rail. This makes it possible to switch between modalities at one trip.
- The possibilities to reposition, transship and store containers at CTT-R enables anticipation on inefficiencies in the Port of Rotterdam.

Furthermore, CTT invested to build a public warehouse next to the terminal in Hengelo. A public warehouse is a business that provides short or long-term storage to companies that need extra storage.

2.2.1 CTT in numbers

The number of TEUs transported by CTT is growing. Figure 2.2 shows that in the past five years a growth of almost 100,000 TEUs has been realized. These are incoming and outgoing containers transported by barge or truck. In the last year, the growth comes from TEUs transported by truck, while the transportation by barge even decreases. This is because of the broken lock in Eefde in the beginning of 2012. This resulted in that no barge transportation was possible for more than a month. After that, the trust in the inland navigation transportation had to be rebuild.

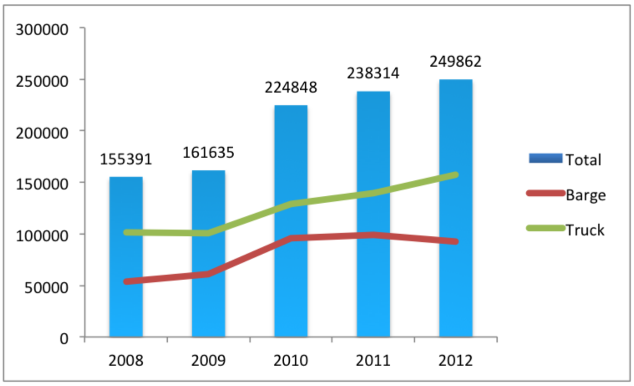


Figure 2.2: Number of incoming and outgoing TEUs at CTT

CTT transports different types of containers. The main distinction is made in the lengths of a containers. Figure 2.3 shows the distribution of the different length of container that are transported by CTT. More than half of all containers have a length of 20 foot (one TEU) and 39% have a length of 40 foot (two TEU). Only 6% are 45 foot containers, which correspond with 2.25 TEU per container.

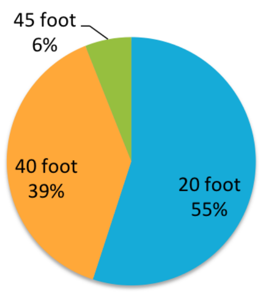


Figure 2.3: Distribution of incoming and outgoing TEUs from January 2012 to May 2013

Further general numbers on CTT, CTT-R and its barges can be found in Appendix B.

Bookings

Table 2.1 shows the number of bookings made in 2012. A difference is made between bookings that consist of one container, bookings that consist of 2 to 10 containers, bookings that consist of 11 to 99 containers, and bookings that consist of more than 99 containers. The first column signifies which group of bookings is dealt with. In the second column we see the number of booking in a certain group and the third column gives the corresponding percentage. The fourth column shows how many containers belongs to the corresponding group and the fifths column give the corresponding percentages. The last column shows the average number of containers in a booking of a certain group.

Containers per booking	number of bookings	% of all bookings	total containers	% of all containers	avg. containers per booking
1	4600	51.69	4600	15.19	1.00
2 to 10	3762	42.27	14183	46.85	3.77
10 to 99	534	6.00	11176	36.92	20.93
100 or more	3	0.03	315	1.00	105.00
Total	8899	100	30274	100	3.4

Table 2.1: Distribution of containers among bookings

We see that more than half of all bookings consists of only one container, while these are only 15% of all containers. On the other hand 6% of all bookings, are booking that are composed of 2 tot 10 containers, which are almost 47% of all containers.

Voyages

Table 2.2 shows the number of planned incoming and outgoing voyages. The data are based on the planning date. This means that the date when the voyages was executed may differ from the planned date. However, they are all executed. The table shows the number of days with 1, 2, 3, or 4 voyages in 2012.

Voyages per day	Incoming (%)	Outgoing (%)
1	245 (73)	239 (73)
2	83 (25)	83 (25)
3	7 (2)	7 (2)
4	1 (>0.5)	1 (>0.5)
Total	336(100)	330 (100)

Table 2.2: Distribution of number of voyages per day

We notice a slight difference in the number incoming and outgoing voyages. Of course, each outgoing voyage has its corresponding incoming voyage. The difference can be explained by the fact that the corresponding outgoing voyages are planned in the previous year, so they do not count for 2012. We also notice that only at 336 out of 365 days voyages have been planned in 2012. Due to the broken lock in January 2012, there has been almost no transportation by barge for more than a month.

Missing data

A problem that barge planners and workers from customer service encounter each day, is missing and incorrect data. It is hard to check whether entered data are correct, but it is possible to check absent data. Table 2.3 shows the results from a study on data from seven days, where we distinguish between five types of missing data.

Missing pick-up reference	12.89%
Missing import terminal	5.76%
Missing delivery reference	0.36%
Missing export terminal	1.90%
Missing motor vehicle	3.24%

Table 2.3: Percentage of missing relevant data for planning

For each day, we studied bookings, for which hold that the closing or pick-up date lays within a week ahead. It is striking that almost 13% of relevant import bookings miss their pick-up reference. This is not crucial for the planning but it must be available to the shipper when picking-up the container. More concerning is the fact that the import terminal is unknown for more than 5% of all containers that must be picked-up within a week. This means that these containers cannot be planned at all. Figure 2.4 shows the percentage of bookings that miss data categorized per number of days remaining to handle on time. The horizontal axis presents the number of days remaining to deal with a booking with missing data and the vertical axis the percentage of bookings with missing data. Thus, we see that approximately 1% of all export bookings that must be dealt with within a day, have incomplete information.

Figure 2.4: Distribution of missing data

Figure 2.4 shows an irregular curve of percentages of bookings with missing data as a function of days remaining to deal with the bookings in time. The peaks in the graph arise because of the different types of bookings. Some bookings are made weeks ahead while others only a few days. This explains why there is still a lot of unknown information only few days before the pick-up or delivery date of a container.

CTT's competition

InlandLinks is an organization that examines every year participating inland terminals on five quality criteria. These five criteria are: 'accessibility and connectivity', 'services', 'safety and security', 'customs', and 'ICT'. From all European inland terminals, rated by InlandLinks and located within a radius of 250 kilometers of CTT, CTT is on the shared first place with a score of 92%. InlandLink collects data from inland terminals and presents them on its webpage to give shippers and transport providers information on intermodal services and options. Figure 2.5 shows CTT's scoring on these categories. The lacks in 'accessibility and connectivity' are caused by the lack of the rail modality in Hengelo.

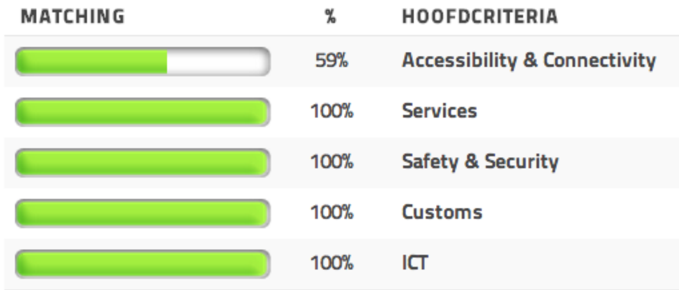


Figure 2.5: CTT's rating by InlandLinks [InlandLinks.eu]

2.2.2 Services offered by CTT

As mentioned before, CTT's main activity is to transport containers from and to Rotterdam. The different types of transportation of a container that CTT offers its customers are divided into three categories.

- Round trip
- Single trip
- Depot transportation

Note that 'a trip' in this section is different from 'a trip' in the remaining chapters. A roundtrip is a trip where a container is shipped from Rotterdam to CTT, from CTT to the customer, from the customer back to CTT, and then back to Rotterdam. Figure 2.6 shows an import round trip.

A single trip is similar to a round trip. The only difference is that the container starts or stops at CTT in Hengelo, which means that it contains one trip less to or from Rotterdam. This is possible, because CTT has its own depot where containers can be kept in stock. Figure 2.7 shows an example of an import single trip.

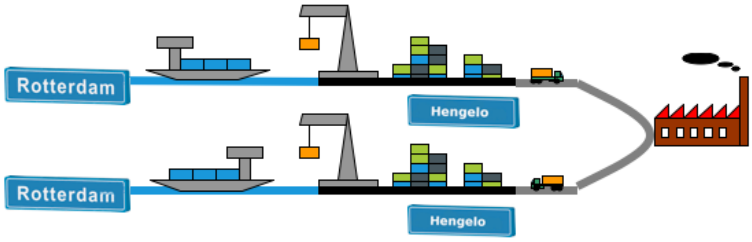


Figure 2.6: Example of an import roundtrip

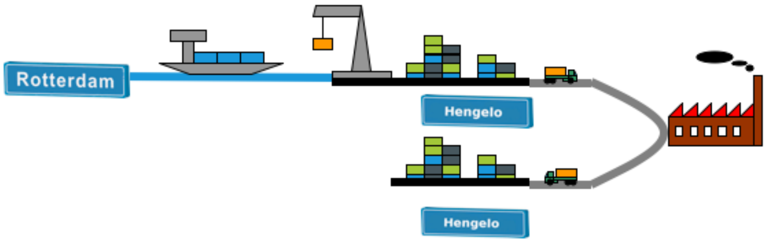


Figure 2.7: Example of a single trip

In a depot transportation, a container is just transported from Rotterdam to CTT or vice versa. Figure 2.8 shows an example of a depot transportation. This means that the container is transported from Rotterdam to CTT, where no further actions are taken. This happens in situations where customers pick-up their containers themselves.

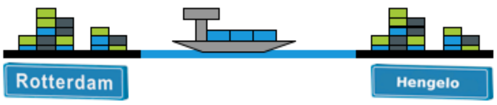


Figure 2.8: Example of a depot transportation

Besides transportation, CTT offers some other services related to the container transportation:

- Storage of containers
- Repair of containers and trucks
- Sale and lease of containers
- Gas measurement of import containers
- Care taking of customs forms for import and export containers

2.2.3 Networks

This section describes the most important networks CTT is part of. These networks show CTT's interest in development in innovation and sustainability.

Port of Twente

Port of Twente (PoT) is a collaboration between entrepreneurs, government, and research and education authorities that are concerned with the wellbeing of the Twente Region. This association has the goal to strengthen the Twente region by investing in logistics, which promotes employment at different educational levels. To reach this goal, Twente has to turn itself into a logistic hotspot [Regio Twente, 2012]. Twente already has some important ingredients for this development:

- Twente has several large inland ports including the largest in the Netherlands (CTT).
- Twente has the most modern Dutch water-related container terminal (CTT).
- Twente has a direct waterway connection with the Port of Rotterdam.
- Twente has enough space for new logistic businesses.

CTT is one of the main initiators of this collaboration.

Vereniging van Nederlandse Inland Terminal Operators (VITO)

VITO is an association for transshipment terminals in the Netherlands that are accessible by train or by barge. CTT and the other members of VITO have the common goal to increase the quality of their services, promote collaboration between members, and give meaning to a sustainable mobility policy in a commercial way. This is done by sharing knowledge and experiences between members, running a national network of inland terminals, and developing additional services to improve the transportation chain [VITO, 2013].

Nextlogic

Nextlogic is a collaboration of different parties that aim to tackle the inefficient handling of inland container shipping in the Port of Rotterdam. Together, the parties involved in the logistic chain have developed a solution that will benefit barge operators, inland terminals, deep sea terminals, and depots and shipping companies [Nextlogic, 2013]. The aims are reliable and thus predictable turnaround times, better use of the quays, cranes and barges and fewer (small) calls in the sea port [Nextlogic, 2013]. CTT has interest in these developments, because it includes several advantages for the company and is therefore part of one of the subgroups that works on one of the subjects.

2.3 Process flow

This section describes the process flow at CTT. Figure 2.9 shows that, when an order enters CTT, it passes several steps. Each step is noted by a box. The vertical arrows signify the flow through the system. The dotted boxes show that several order flow in parallel and are united in the planning part. The big planning box shows that information of multiple orders is needed to make a plan.

We explain each step of an order through the system. The first step is the creation of a booking in CTT's system. Based on the booking, a plan is made. In the planning process first a barge plan is created, after that, if necessary, a truck plan at the sea port is made, and after that a truck plan at CTT. After the planning comes the execution of the plan, followed by billing of the services. In this section, we give a more extensive description of the booking and barge planning process.

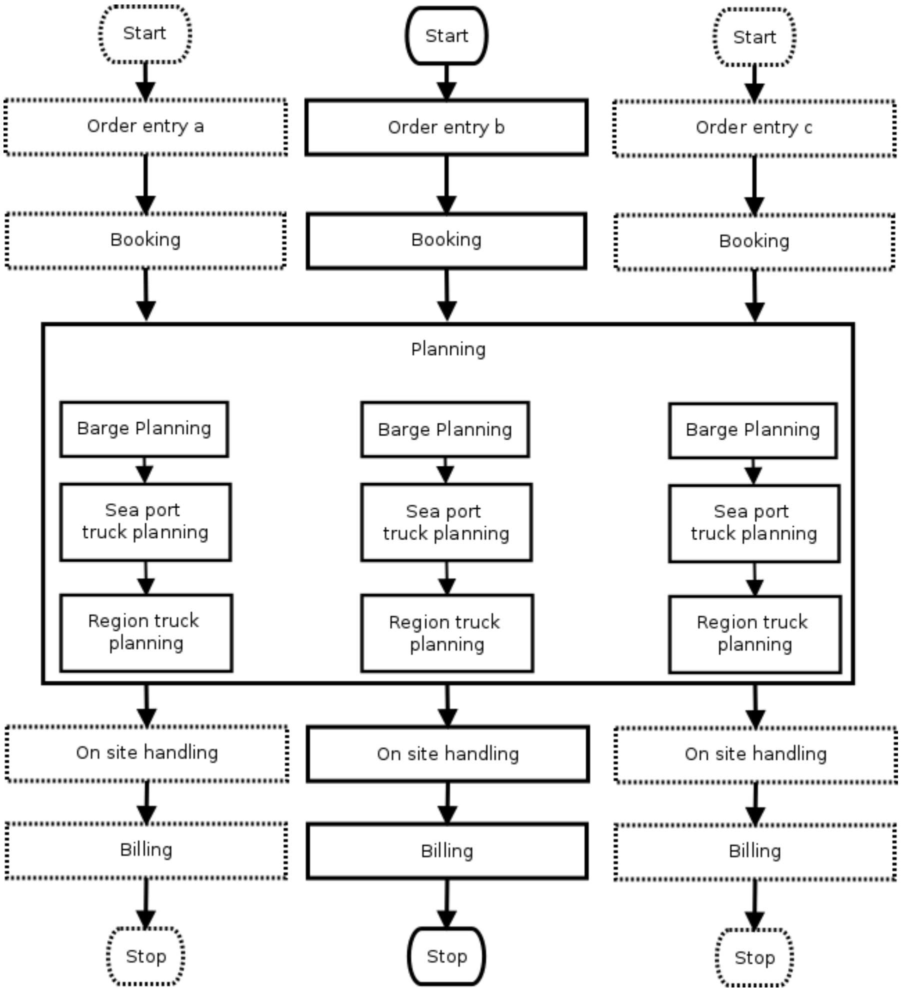


Figure 2.9: A bookings flow through CTT

2.3.1 Booking

The transportation of a container starts with a booking. This booking can enter CTT in several ways. Mainly, bookings are done by email or telephone, but also the fax is still used and sometimes customers even visit CTT to do their booking. Members of customer service take up all bookings and register them in a database called Modality. This database system is widely used by different companies in the container logistic sector. At CTT, all planners and members of customer service work with it.

One booking may consist of several containers. Strictly spoken, CTT does not transport individual containers, but it does transport cargo that is packed in one or more containers. The result is that one booking number can represent several containers. The other way around, a container number does not imply a booking because containers are reused. This makes it difficult to track individual tours of containers.

Most bookings are not complete when they are registered, because at the time of the booking not all necessary information is available. The minimum information needed to book an order is:

- customer
- shipping company
- container number
- container type
- pick-up reference (PIN-number)
- pick-up and delivery location
- pick-up date and time

When the container is shipped, more information is needed:

- customs forms
- permission forms to handle the container
- seal number
- closing time
- detention time
- demurrage time

The members of customer service report to the customer which information is missing. Sometimes customers prefer a modality for the transportation of their containers. That depends on the reliability, transportation time, and costs of the modality.

The customer service department keeps all contacts with the customer. It does the bookings, makes agreements on price, and sends invoices.

2.3.2 Barge planning

As mentioned before, planners work with Modality. This database system contains all important information of a container. All information entered by customer service can be seen by the planners.

Figure 2.10 gives an overview of the barge planning process at CTT. The oval part signify a start or stop event, the diamond denotes a decision, and the quadrangles are actions.

Appendix C gives a more detailed flowchart of the barge planning process.

Containers are assigned to trips based on their pick-up or closing date. At the moment a rough estimation of the arrival time in Hengelo of a barge can be made, a barge is assigned to an

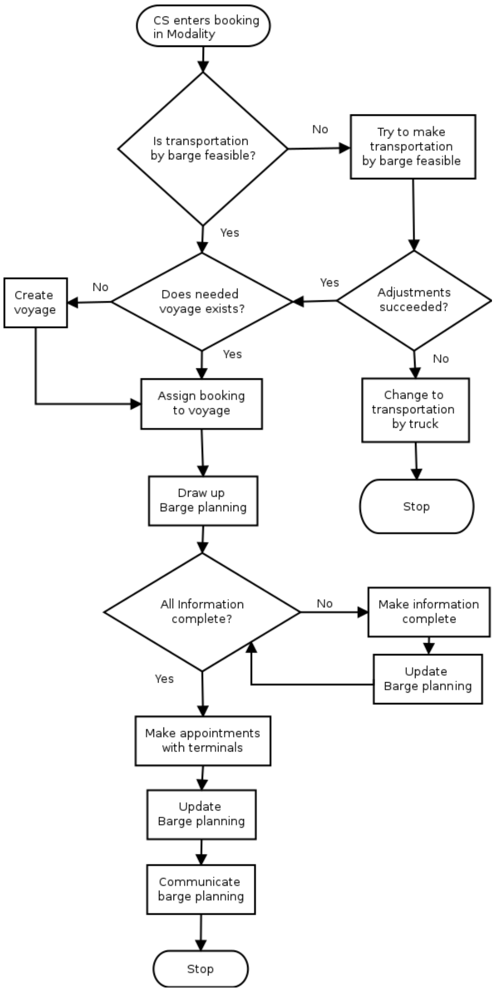


Figure 2.10: Barge planning process flow at CTT

outgoing trip. Initially, outgoing trips are put together based on the closing time of export containers. Future trips are mostly overbooked at the moment the corresponding barge enters CTT. When the barge enters CTT the number of container is decreased to a feasible number. First, all containers with missing information are moved. When, after that, the load still exceeds the barges capacity, containers are moved that have a late closing date. next, an estimation of the leaving time at CTT is made. Based on that, an estimation of the production time in Rotterdam is made. The actual composition is made based on the following characteristics:

- Dimensions of the container
- Destination terminal
- Closing time
- Completeness of information
- Contents of containers

When a container lacks information, the planner asks customer service to contact the customer to get the information needed. Some information can also be found on websites from the shipping companies, but it is preferable that planners do not have to search for information. The containers that are removed from a trip are booked on a later trip with another barge.

Three hours before the barge enters Rotterdam, the plan for import containers is made. This composition of import containers is based on the same characteristics as the export containers, but now the planner also has to take export containers into account. A preferable tour through the Port of Rotterdam is either loading roughly as many containers as unloading at a certain terminal or first visiting the unloading terminals and after that the loading terminals. These choices made by planners are based on intuition and common sense, but are not included in the planning procedure described by CTT (Figure 2.10).

When making the plan, the planners main goal is to let containers arrive in time. When this is satisfied, they try to use the capacity of the barge as good as possible and after that they try to plan in such a way that they provide the shipper with a nice route. This means that a shipper does not need to visit the same terminal twice and visit all terminals next to each other in one go, such that he does not need to ship up and down between places.

The most difficult part for the planner is to keep an overview of all factors that influence a plan. To manage the planning of hundreds of containers, the planners work with lists. Containers are categorized based on delivery/pick-up date or destination. This has the advantage that hundreds of units with information are reduced to dozens of units with information. The disadvantage is that a part of the overview gets lost. That can result in situations where the planner cannot locate the bottleneck in a plan and thus does not know how to fix it. If a planner is not able to make a plan feasible with respect to meeting closing and pick-up dates, the most common action is to call the customer and ask to move the corresponding closing or pick-up date. If the customer does not agree with that, the container is transported by truck and CTT has to pay for additional costs. If the barge cannot be filled or the shipper has to visit the same terminal twice to make a plan feasible, no actions are taken to change that. Examples of available means that a planner can use to make a plan feasible or better are:

- Using truck from Hengelo to Rotterdam
- Moving to later trip

- Repositioning in CTT-R
- Transporting with other means from CTT-R
- Delivering to other terminal

2.4 Conclusions

Based on the sketched situation in the container sector and the planning situation at CTT, we conclude that there are several reasons to support barge planners in the planning process. First, because the sector is growing, especially for inland navigation. Second, the amount of data and information that planners need to manage is already extensive. This will only become worse when the demand for container transport grows.

Currently, planners are not structurally supported in their decisions to optimize barge loading and routing. They make plans based on intuition and common sense.

Chapter 3

Literature overview

A good start to tackle a problem is to investigate existing knowledge in the field. To do so, we describe relevant literature in this chapter. It consists of three parts. The first part describe literature that discuss container logistics with focus on container loading, planning and scheduling. In this first part we start with a brief overview of planning and scheduling techniques (Section 3.1) followed by a section on ship routing and scheduling (Section 3.2). Section 3.3 focusses on container loading problems that largely can be translated to barge loading problems and Section 3.4 gives an overview of terminal operations in general discussed in literature. The second part of this literature overview (Section 3.5) focusses on the definition of transportation quality. This is discussed to be able to judge whether or not this study contributes to increase in transportation quality. The third and last part (Section 3.6) describes a way of structuring programming, which we use to structure our solution method.

3.1 Planning and Scheduling

This section gives an overview of methods to make plans and schedules. The goal is to position the method used in this study in existing methods from literature. Planning and scheduling is a topic extensively discussed several fields, such as health care and production. The methods can be divided into nine categories.

- Mathematical Programming
- Constructive Heuristics
- Meta-heuristics
- Simulations
- Constraint programming
- Queuing
- Artificial Intelligence
- Hybrid-methods
- Other

The full list of all methods, which is composed based on the findings of Cardoen et al. [2010] and Van den Bergh et al. [2013], can be found in Appendix E.

The priority method that we use in this study is a combination of Constructive Heuristics and Decision Rules, which is positioned under Other. Constructive Heuristics start with an empty solution, which is extended repeatedly to a complete solution. If necessary the solution can be improved after constructing it.

From the overview provided in Section 3.1 and Appendix E we conclude that no type of planning method, as used in this study, is found in literature.

3.2 Ship routing and scheduling

This part of the literature overview presents several models that make relevant contributions to ship routing and scheduling. Furthermore, this section discusses some heuristics to solve routing and scheduling problems. We review this literature to give an overview of problems related to barge loading and planning problems. The backbone of this part of the literature review about ship routing and scheduling is the review paper of Christiansen et al. [2012]. They review ship routing and scheduling and related problems published between 1999 and 2012. All literature discussed in this section is also discussed in Christiansen et al. [2012].

The review executed by Christiansen et al. [2012] is divided into four parts:

- Liner shipping
- Industrial and tramp shipping
- Sailing speed, bunkering and emissions
- Offshore logistics, lightering and stowage

The part about 'Industrial and tramp shipping' is interesting for this research, because it presents a basic model for ship routing and scheduling and several extensions for this or similar models. 'Liner shipping' is beyond our scope, because it is comparable to public bus services that have a fixed route and a fixed schedule according to which they operate [Christiansen et al., 2012]. This is not applicable to CTT because the route is not fixed but depends on available containers. Furthermore, the paper discusses several papers that discuss heuristics to solve the basic problem and extended problems. From the review, it follows that user experience and interaction of planning and decision supporting tools play a major role. We pay attention to this topic too.

First, we introduce the basic model and some extensions in Section 3.2.1. Next, Section 3.2.1 introduces several heuristics and their performance. Finally, we deal with user experience and interaction in Section 3.2.2.

3.2.1 Ship routing and scheduling methods

This section consists of three parts. First we describe the basic model that is used, adjusted, and extended in several studies. After that, we discuss the extensions and finally, the last part deals with heuristics that are developed to find solutions for different models.

Basic model The basic cargo routing model discussed by Christiansen et al. [2012] is introduced by Christiansen and Ronen [2007]. Specified cargoes are the input for the planning process. Routing becomes a scheduling problem when the time-aspect is taken into account. This model is a routing and scheduling model for tramp shipping, which is a more advanced version of the industrial shipping problem.

Christiansen and Ronen [2007] formulate a model to maximize profit gained by operating a fleet. The model includes different types of loading (mandatory and spot cargo), vessel capacity, and time windows. A considerable amount of problems faced in reality are not included in this model. One important extension is the variability in cargo size. The paragraph below discusses this extension.

Extensions When considering variable cargo, a routing and scheduling problem also includes optimizing the size of cargo. This problem is studied by Brønmo et al. [2006] and Korsvik and Fagerholt [2008]. Brønmo et al. [2006] present a mathematical programming model and a set partitioning approach with a priori column generation to tackle the tramp problem extended with flexible cargo sizes. Brønmo et al. [2006] states that the results of the study show that it has an positive economical effect to use flexible cargo sizes.

In order to be able to save computation time and solve larger problems, Korsvik and Fagerholt [2008] develop a tabu search algorithm with an embedded specialized heuristic for determining optimal cargo quantities in each route. Korsvik and Fagerholt [2008] state that the heuristic is able to give optimal and near-optimal solutions to real-life cases within reasonable time. Furthermore, they also found that using flexible cargoes increases the quality of solutions.

Brø nmo et al. [2010] extend their previous approach with a static column generation to an approach with dynamic column generation in which ship routes are generated when needed. In this approach no optimal solutions are guaranteed, but more extensive problems can be solved faster than in the static column generation case. Real world cases are solved optimal or near-optimal.

Heuristics Different heuristics can be used to find solutions to the problems mentioned above. As mentioned before, Brø nmo et al. [2010] use column generation to solve the mathematical programming model. Earlier, Brø nmo et al. [2007] used a multi-start local search, but this was outperformed by the tabu search heuristics by Korsvik and Fagerholt [2008] and Korsvik et al. [2009]. Malliappi et al. [2011] present a variable neighborhood search metaheuristic for this problem. Compared to the multi-start and tabu search heuristics, this heuristic gives better solutions with respect to the quality of the solutions and the computation time.

3.2.2 Decision support

Decision support tools (DST) *'are computational systems with the purpose of helping decision makers by analyzing information and identifying solutions'* [Perimenis et al., 2011]. A DST consists of a database that can store and manage internal and external information, algorithms necessary for the analysis, and an interface for communication with the user [Perimenis et al., 2011]. A DST aims to analyze the problem, evaluate the performance of alternatives based on criteria, and express the priorities of the decision makers [Shim et al., 2002]. When Fagerholt et al. [2009] implemented and tested a DST at a shipping company, they experienced that there are constraints and secondary objectives that are hard to model in a proper way. From this experience and from discussion with the planners, they conclude that it is desirable for a DST to provide several high quality solutions that planners can analyze and choose from.

3.2.3 Conclusions on ship routing and scheduling

We see that barge planning and loading only plays a minor role in the literature discussed in this section, while in practice it is an important part of ship routing and scheduling problems. Loading, planning and routing are problems dependent on each other, which makes it too complex to analyze them in total and thus are split into subproblems.

From the part on decision support, we learn that it is desirable to provide planners with a number of solutions from which they can choose and adjust to plans they want to execute.

3.3 Constraints on loading problems

An extensively discussed topic in the literature is the container loading problem. This problem is easily translated into other problems such as loading a truck, a pallet, or a barge. Bortfeldt and Wäscher [2013] define a container loading problem formally as a three-dimensional geometric assignment problem. In these types of problems, three-dimensional items are assigned to a bigger cube such that a given objective function is optimized and two basic geometric feasibility conditions hold:

- all small items lie entirely within the bigger cube
- the small items do not overlap

In our situation, we interpret the bigger cube as a barge, because a barge also is limited in three dimensions. We see small items as container that must be loaded in barges. In this literature review, we use the term ‘cargo’ for the small items and for the bigger cube the term ‘container’, because that is terminology mainly used in literature.

Bortfeldt and Wäscher [2013] did a recent literature review on this topic. The review goes from 1980 to the end of 2011 and makes a difference between problems where the number of containers to load all cargo is minimized and problems where the amount of cargo loaded in a fixed number of containers is maximized. We focus on the second type of problem, because in this study the number of barges is limited. Within this problem type, Bortfeldt and Wäscher [2013] distinguish between seven problems. The problems relevant for this study are:

- *Single Large Object Placement Problem (SLOPP): Loading a single container with a selection from a weakly heterogeneous set of cargo such that the value of the loaded items is maximized.*

- *Multiple Identical Large Object Placement Problem (MILOPP): Loading a set of identical containers with a selection from a weakly heterogeneous set of cargo such that the value of the loaded items is maximized.*

In our study, we deal with barges that are almost identical. That is why it can be translated into problems with one or multiple identical barges (containers in terms of container loading problems). The containers (small items in terms of container loading problems) we load, are considered to be weakly heterogeneous, because they can be grouped into few classes, where each container type is available in relatively large quantities.

Within these problems, literature focusses on different constraints related to container items and cargo. The difference between item- and cargo-constraints is that item-constraints are related to single items and cargo-constraints to groups of items. Bortfeldt and Wäscher [2013] divide the constraints into ten categories. We only discuss eight out of the ten because these are relevant for our study. For the complete list we refer to Bortfeldt and Wäscher [2013].

3.3.1 Container-related constraints

This section discusses constraints related to the container. A container is, among others, restricted by carrying weight and stability. In the context of our study these can be translated to constraints that are imposed by the characteristics of a barge.

Weight limits The load of a container must not exceed a certain weight. This may have different reasons such as the capacity of a container or the carrying capacity of handling means. Bortfeldt and Wäscher [2013] state that weight limits can be modeled as linear Knapsack constraints, where the sum of the weights of the loaded items must be smaller than or equal to the weight capacity of the container. For literature discussing this topic we refer to Bortfeldt and Wäscher [2013].

Weight distribution Weight distribution constraints require that the weight of the cargo is spread evenly across the container floor. This is useful because balanced loads reduce the risk that the cargo shifts when moved, reduce the wear of axles in truck transportation, and makes it easier to handle containers [Bortfeldt and Wäscher, 2013].

Bortfeldt and Wäscher [2013] found two common ways to achieve an even distribution of weight: the centre of gravity should be close to the geometrical midpoint of the container floor or should not exceed a certain distance. They also found more simple ways to implement weight distribution constraints, e.g., one-dimensional distribution of weight along the container height or width, which are commonly used in aircraft loading [Martin-vega, 1985, Davies and Bischo, 1999]. Bortfeldt and Wäscher [2013] report that in all cases they found, literature requires that the centre of gravity is located as low as possible, to get more stable containers. All found methods try to minimize distances. For the distribution of literature among these topics we refer to Bortfeldt and Wäscher [2013].

3.3.2 Item-related constraints

This section discusses the constraints related to items. The positioning or orientation of an item can be limited. In the context of our study this type of constraints can be translated to constraints related to containers.

Loading priorities constraints This constraint type is a typical constraint that belongs to maximization type problems, which means that there are a limited set of containers and the number of items loaded must be maximized. Available container space is insufficient to load all small items, so a decision must be made which items to load and which to leave behind. In practice, the loading of some items may be more desirable than the loading of others, which results in priorities [Bortfeldt and Wäscher, 2013]. Loading priorities can be translated into multiple hard and soft constraints. Even though loading priorities are characterized as important constraints, by e.g., Junqueira et al. [2012], Bortfeldt and Wäscher [2013] only found little literature that discusses this type of constraints. Ren et al. [2011a] and Ren et al. [2011b] introduce algorithms for problems where allocation constraints are combined with priority constraints. Ren et al. [2011b] give big items higher priorities than smaller items, because they are more difficult to load. Bischoff and Ratcliff [1995] mention that the case of relative priorities could be modeled as objective function coefficients which define or adjust the value ratings of the items. However, Bortfeldt and Wäscher [2013] state that no one introduces a corresponding algorithm.

Orientation constraints This type of constraints are needed when items need to have a specific orientation within the container. For example boxes with one side labeled with "This side up!". Containers do also have the restriction that they must be positioned with their top side up. Bortfeldt and Wäscher [2013] distinguish five cases, from these two are interesting for our case:

- One single orientation is permitted for each item (type) in both vertical and horizontal direction.
- One single vertical orientation is permitted for each item (type). No restriction is given to their horizontal direction.

For the division of literature among all five types we refer to Bortfeldt and Wäscher [2013].

3.3.3 Cargo-related constraints

Constraints discussed in this section can, in the context of our study, be translated into order or booking constraints. Items belonging to one cargo or containers belonging to one order may not be separated in some situations. Furthermore, it can be preferable to have items belonging to one cargo located near to each other.

Complete-shipment constraints Sometimes items are related to each other because together they are one cargo. These cargoes can be restricted to be shipped as one in a container or as one in a shipment. If this is not possible, the consequence is that total cargo is left behind. Bortfeldt and Wäscher [2013] states that Eley [2003] is the only one to consider this type of constraints.

Allocation constraints Allocation constraints are divided into two different types of constraints. First, separation constraints, where cargo that cannot be shipped in the same container, must be separated (e.g., food and perfumery articles). Second, connectivity constraints, where specific cargo needs to be shipped in one container. Bortfeldt and Wäscher [2013] states that most literature refers to connectivity constraints. These types of problems are often used in pallet-stacking problems where a pallet with just one type of items is more preferable than mixed pallets. Bortfeldt and Wäscher [2013] find that in area of pallet loading, allocation constraints are often treated as soft constraints. However, allocation constraints discussed in papers that also concern vehicle routing, often consider them as hard constrains. For more literature that discuss these constraints we refer to Bortfeldt and Wäscher [2013].

Positioning constraints Positioning constraints restrict the location of items within the container, either in absolute terms (i.e., where items are to be located or not to be located within the container) or in relative terms (i.e., where items are to be located or not to be located relative to each other). Position of items within a container are often related to the items size, weight, or content. Haessler and Talbot [1990] describe a problem where handling means have limited access to the container so positioning of some items is restricted. Bortfeldt and Gehring [1999] divide containers into different zones (front, middle, back) and link specific item types to zones in the container.

In relative positioning constraints, Bortfeldt and Wäscher [2013] found a separation in constraints that require items to be placed closely to each other (grouping) and constraints that separate items from each other. In multi-drop situations, combinations of these two types are made [Bischoff and Ratcliff, 1995]. Items of the same customer should be grouped and the positioning within the container should correspond to the sequence of customer visits.

Bortfeldt and Wäscher [2013] state that literature addressing combined container loading and vehicle routing problems typically introduce a specific multi-drop condition which aims at facilitating the unloading operations. More literature that discusses position constraints can be found in Bortfeldt and Wäscher [2013].

3.3.4 Conclusions on constraints for container loading problems

There is extensive literature available on the topic of container loading constraints and several constraints described are relevant for this study. When dealing with barge loading, restrictions such as weight capacity, loading priorities, orientation constraints, and complete-shipment constraints must be dealt with. Constraints such as positioning, weight distribution, and allocation constraints are constraints that must be considered when making stowage plans.

3.4 Container Terminal Operations

The purpose of this part of the literature review is to give an overview of container terminal operations. Voß et al. [2004] provide an overview of literature (1983-2004) discussing the main logistic processes and operations at container terminals. They classify these processes and provide a literature review concerning operation research models and applications in this logistic field. They describe possible means of handling equipment used in container terminals and the different types of container terminals. The subjects discussed in the sections about terminal logistics and optimization methods are:

- Berth allocation
- Stowage planning
- Crane split
- Storage and stacking logistics
- The quayside transportation optimization
- The landside transportation optimization
- Crane transportation optimization
- Simulation systems

For a detailed description of the subjects and corresponding methods we refer to Voß et al. [2004]. Although, the titles of some subjects may suggest that part of the review discusses barge or truck loading, no attention is paid to this topic. Note that this is a gap in the literature, because barge loading and planning problems do belong to the operations of most container terminals.

3.5 Transportation Quality

In this section, we discuss quality measures of transportation. This is required because we want to be able to analyze transport quality within this study. Literature about freight transportation quality is scarce while literature on passenger services quality, especially on public transportation, is extensive. In this section, we present one paper on freight transportation quality and a literature review on public transportation quality. We think useful information can also be obtained too from the study on public transportation, because there are many factors that are similar or can be translated into a situation with freight transportation.

3.5.1 Freight transportation quality measures

Zamparini et al. [2011] collected a number of measures to evaluate the quality of freight transportation. The goal of their survey was to determine the relative importance, as well as financial values of the freight transportation quality seen from Tanzanian shippers perspectives. Zamparini et al. [2011] determined the following six attributes to be the most important:

- Travel Time is the freight transit time and includes the loading and unloading procedures.
- Travel Cost include all costs that are made to transport the freight.

- Frequency is related to the number of shipments offered by a transportation company, or any freight forwarding agent, in a given period of time.
- Flexibility considers the number of unexpected shipments that is dealt with, without excessive delay.
- Loss and damage may refer to the percentage of the commercial value of shipped goods that is lost because of theft, damages, or losses.
- Reliability has been defined in several heterogeneous ways. It has been defined as the absolute variation in transit times, as the relative variation (measured as the coefficient of variation), or as the percentage orders that arrive within scheduled time.

Zamparini et al. [2011] conclude that improvements in travel time, loss and damage, and frequency have a higher economic value than the upgrading of flexibility and of reliability.

3.5.2 Public transportation quality measures

Carse [2011] assesses an evaluation tool for the impact of public transportation projects. Part of this research is about the evaluation of the quality measures of transportation. Carse [2011] divides the measurements into five categories: access and availability, environment, sustainable transportation, personal safety and transportation costs. Within these categories the measurements are categorized as follows:

- Access and availability

  Availability
  Reliability
  Transportation diversity
  Services access

- Environment

  Noise pollution
  Climate change
  Air quality

- Sustainable transportation

  Sustainable transportation infrastructure investment
  Walking and cycling quality

- Personal safety

  Passenger behaviour
  Safety on public transportation

- Transportation costs

  Travel costs
  Personal costs

Translating these quality measures to freight transportation quality measures we end up with ‘Access and availability’, which can directly be copied and includes ‘Frequency’. ’Sustainable transportation’ where we skip ’Walking and cycling quality’ and include the measurements from ‘Environment’. ’Personal safety’ is translated to ’Cargo safety’, which includes loss and damage of cargo. Finally, we have ‘Costs’ that only consists of the costs for transporting freight. Carse [2011] concludes that an equal distribution between the five categories is a good distribution of the importance between the categories.

3.5.3 Conclusions on transportation quality

The six quality measures for freight transportation discussed in Section 3.5.1 share similarities with the quality measures for public transportation discussed in Section 3.5.2. The conclusions drawn by Zamparini et al. [2011] for Tanzanian freight transportation may not be directly relevant for freight transportation in Europe. We expect that reliability plays a more important role than travel time, because it is easier to plan longer travel times than it is to take into account uncertainties. The complete set of quality measures considered in this study is: ‘Travel Time’, ‘Frequency’, ‘Flexibility’, ‘Costs’, ‘Safety’ and ‘Reliability’.

3.6 Method Architecture

To structure the heuristics and decision rules that together form the solution design, we use an architecture from Computer Science. This is the Pipes and Filters architecture.

Buschmann et al. [2007] describes this architecture for data stream as follows: data flows through pipes and is processed by filters. Each processing or transformation step is integrated in a filter component. The output of one filter is the input of another filter. Translated to our situation, this means that a filter executes a heuristics that processes the data. Filters receive data from other filters or the source via its inbound pipe, process it, and send the transformed data via the outbound pipe to a successive filter. Data producing filters write data to a pipe, data consuming filters receive data from a pipe. Filters can be both producing and consuming. The first filter of a system is called source filter and is responsible for the transformation of external data to fit into the system. The last component of a system is the sink filter that consumes the data.

Pipes are used to pass data between adjacent filters, it connects one filter to the next. Pipes are also able to buffer information, when a filter is not ready to process the information. Data flow only one way. When data need to flow to preceding filters, a pipe will loop back to that filter.

Filters can be sequenced in parallel or series. For filters sequenced in parallel holds that a choice must be made between the filters. Filters sequenced in series must all be executed in the order they are sequenced in.

3.7 Conclusions

A considerable amount of studies and literature reviews are available on different topics of container shipping and container terminal operation. However, no direct literature on barge loading and planning is found, while an extensive amount of literature is found on container loading, and planning and scheduling in the health care sector. From these studies, many results can easily be translated into results for barge loading problems.

From the small intermezzo about decision support we learn that the optimal solution according to a heuristic may deviate from the optimal solution for a planner. To satisfy planners, several solutions must be given.

We discussed transportation quality. Although little literature is available on freight transportation quality, we can draw some important conclusions. Frequency, travel time, flexibility, costs, safety and reliability of transportation are considered as important. These results are also confirmed by literature concerning public transportation.

Finally, we introduce the Pipes and Filters architecture, which we will use to structure the solution method in Chapter 4

Chapter 4

Solution design

Recall that the goal of this study is to provide CTT's planners with decision support. Decision rules and planning methods could do a part of the planners work, such that the planner can concentrate on crucial parts of the planning. By developing a decision support tool, the goal is to make the planning process faster and the output better. This chapter answers the research question *"What is suitable decision support for CTT's barge planners?"* In this chapter, we start with a description of the model designed to support planners in making their plans. We describe the characteristics of the model, such as the basic functionalities and the structure of the model in Section 4.1 and the heuristics used in the method in Section 4.2. After that, we continue with the description of the tool in Section 4.3. First, we discuss the goal and requirements, after that we describe the usage and implementation of the tool.

4.1 Solution method

In this section, we map out how we reach the research goal, by developing a decision support tool. The tool should provide the barge planner with more than one plan that tells the planner which containers i to pick-up and deliver on the current day d with barge j. Decisions variable $x_{i,j,d} = 1$ when container i is transported by barge j on day d. Each container is provided with a pick-up P_i and/or delivery terminal D_i in Rotterdam and a pick-up p_i and/or closing date c_i. Containers do not need to be picked-up or delivered directly at their pick-up date p_i or closing date c_i. We denote this margin by s. This means that import containers can be picked-up s days after their pick-up date p_i and that export containers can be delivered s days before their closing date c_i. The date that we pick-up an import container is signified by f_i (fetching date) and the date we deliver an export container is signified by d_i. The lateness of a container i is denoted with K_i. For import containers it holds that if the fetching date $f_i > p_i + s$ then $K_i = 1$. For export containers it holds that if the turn-in date $t_i > c_i$ then $K_i = 1$. In all other cases $K_i = 0$. Note that K_i only record if lateness occur, not how much lateness occur.

The input of the model is a set of import and export containers i with a corresponding pick-up date p_i and terminal P_i or closing date c_i and destination terminal D_i. Within the model pick-up dates and closing dates are substituted by pick-up priorities PP_i and/or delivery priorities DP_i. We explain this in more detail in Section 4.2.1

A barge j arrives at date A_j in the Port of Rotterdam and leaves at date L_j. In between these two dates, it can pick-up and deliver containers at terminals. The container terminals in the Port of Rotterdam that are served by CTT are divided into four groups $\mathcal{T}_h$ with $h = 1...4$ based on their location. Each group is a proper subset of all terminals $\mathcal{T}_h$ and all groups are disjunct, thus $\mathcal{T}_h \subset \mathcal{T}$ and $\mathcal{T}_h \cap \mathcal{T}_{h'} = \emptyset$ if $h \neq h'$. Terminals located in the Waalhaven belong to $\mathcal{T}_1$, terminals located in the Eemhaven belong to $\mathcal{T}_2$, terminals located in the Botlek belong to $\mathcal{T}_3$, and terminals located at the Maasvlakte belong to $\mathcal{T}_4$, which we also denote as $\mathcal{M}$. The distribution of terminals is as follows:

$$\mathcal{T}_1 = \{BCW, GEVELCO, GROERID, JCMERO, MEDREP, MRSTRO, UP6, WHT\} \subset \mathcal{T}$$
$$\mathcal{T}_2 = \{HMU, INTERO, MEDEEM, PCSA, PROGRO, RSTN, RSTZ, STEIRO, UCTEEM\} \subset \mathcal{T}$$
$$\mathcal{T}_3 = \{CETEM, COBELRO, CTTROT, WBT\} \subset \mathcal{T}$$
$$\mathcal{T}_4 = \{APM, DBF, DCSROT, DDE, DDN, DDW, DRB, EMX, RCTROT\} \subset \mathcal{T}$$

Figure 4.1 shows the location of the groups on a map of the Port of Rotterdam.

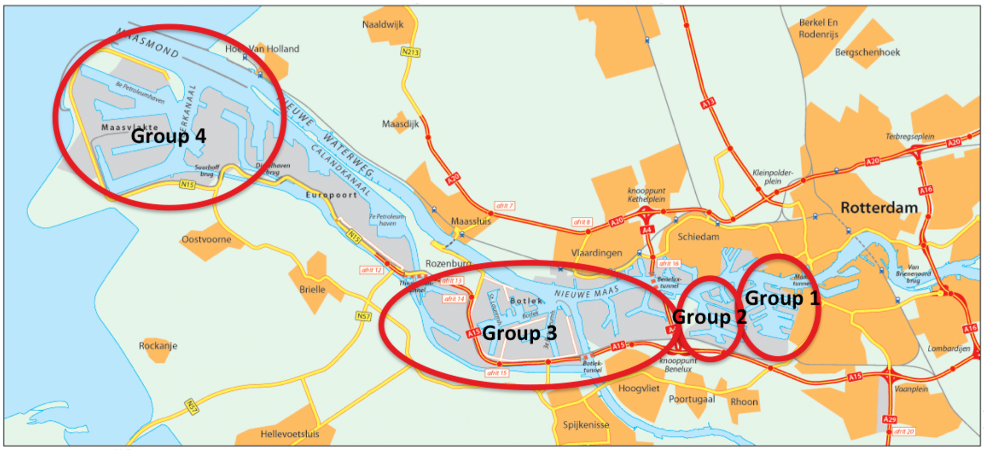


Figure 4.1: Grouping of terminals

Appendix I contains the full list of terminals and the corresponding abbreviations used in this study. Terminals not included in Appendix I are beyond the scope of this research.

Each barge j has a capacity C_j in TEU and a utilization rate $U_{j,k}$ on trip k. The utilization rate is defined as follows: $U_{j,k} = \frac{\text{number of containers on barge } j}{C_j}$. Furthermore, the trip duration of trip k is denoted by S_k. The full list of parameters and variables can be found in Appendix D.

We have three objective variables that depend on decision variables, listed later on. One main objective variable and two secondary objective variables. The difference between the main objective that is that its value is more important than the values of the secondary objectives. If there are multiple solution that belong to one objective value the secondary objective value indicates which solutions are better. We come back to this in Section 4.1.1. The list below shows the objective values.

$$K_i \in \{0,1\} \quad \text{Lateness of container } i \tag{4.1}$$
$$U_{j,k} \quad \text{Utilization rate of barge } j \text{ on trip } k \tag{4.2}$$
$$S_k \quad \text{Duration of trip } k \tag{4.3}$$

This is the list of all parameters in this study.

$$P_i \in \mathcal{T} \qquad \text{Pick-up terminal of container } i \tag{4.4}$$
$$D_i \in \mathcal{T} \qquad \text{Destination terminal of container } i \tag{4.5}$$
$$p_i \qquad \text{Pick-up date of container } i \tag{4.6}$$
$$c_i \qquad \text{Closing date of container } i \tag{4.7}$$
$$s \qquad \text{Margin for pick-up and closing} \tag{4.8}$$
$$\mathcal{M} \subset \mathcal{T} \qquad \text{Terminals located at the Maasvlakte} \tag{4.9}$$
$$\mathcal{T}_h \subset \mathcal{T} \qquad \text{Terminal groups with } h = 1...4 \tag{4.10}$$
$$A_j \qquad \text{Arrival date of barge } j \text{ in Rotterdam} \tag{4.11}$$
$$C_j \qquad \text{Capacity of barge } j \tag{4.12}$$

This list gives an overview of the decision variables.

$$x_{i,j,d} \in \{0,1\} \qquad x_{i,j,d} = 1 \text{ if container } i \text{ is transported by barge } j \text{ on day } d, \tag{4.13}$$
$$x_{i,j,d} = 0 \text{ otherwise.} \tag{4.14}$$
$$PP_i \in \{0,1,2,...\} \qquad \text{Pick-up priority of container } i \tag{4.15}$$
$$DP_i \in \{0,1,2,...\} \qquad \text{Delivery priority of container } i \tag{4.16}$$
$$f_i \qquad \text{The day import container } i \text{ is picked-up} \tag{4.17}$$
$$t_i \qquad \text{The day export container } i \text{ is turned in} \tag{4.18}$$
$$L_j \qquad \text{Departure date of barge } j \text{ in Rotterdam} \tag{4.19}$$

4.1.1 Basic functionalities

The main goal of this study is to support barge planners at CTT with planning decisions as described in Section 1.4. To make plans on a given day d for barge j, the planner needs to keep an overview of a large amount of data, which is a difficult task. In order to help the barge planner, we design a method for decision support. This section describes the objective and constraints of the model and the assumptions we made to develop it.

Objectives

As mentioned in Section 4.1 the most important factor in barge planning is the on-time delivery of export containers and pick-up of import containers. From this we develop the objective function, which minimizes late arrival or pick-up:

$$\min \sum_i K_i \tag{4.20}$$

Recall that $K_i = 1$ if container i is late and $K_i = 0$ otherwise. This means that a lateness of container i of three days counts equally in the objective value as a lateness of one day. If Equation 4.20 is minimized, two secondary objectives indicate which solutions with the same main objective value are more preferable. The utilization rate U_j of barge j must be maximized and the duration S_k of trip k must be minimized. We write this as $\max U_j$ and $\min S_k$.

Constraints

As mentioned before, we want that the decision support tool to provide a planner with more than one plan. Furthermore, CTT wants that CTT-R is visited at least once every day, because they use CTT-R as a hub, which means it is used a depot and containers can be transshiped to other barges or other modalities. This results in the following to constraints:

- *Number of plans*: The tool should provide the planner with more than one plan per barge j per day d.
- *CTT-R*: Each day d at least one barge j should pass CTT-R.

Assumptions

It is hard to precisely represent the real situations in a model, because not all requirements and restriction can be taken into account, and sometimes it is hard to model all of them. Therefore, we simplify real situation by making assumptions. The assumptions made for this study are listed below:

- Every operational day, there is at least one barge available at CTT.
- All barges have a capacity of 104 TEU.
- Sailing time is deterministic.
- A shipper can always make a feasible stowage plan with the planned composition of containers.
- All information on containers is available and correct.
- A barge is always within two days in Rotterdam. This does not mean 48 hours, but is based on two dates. So S_k can still be influenced.
- A container can be delivered up to two days before its delivery date at the destination terminal.
- A container can be picked-up up to two days after its pick-up date at the pick-up terminal without penalties.
- Serving and waiting time at terminals are deterministic. The service time depends on the number of containers.
- Terminals, locks and bridges have a 24/7 service.

4.1.2 Structure of method

For the solution method we want to test several heuristics, because different heuristics may perform different in different situations. Furthermore, it gives the opportunity to develop several plans. For different steps in the solution design we develop different heuristics. To structure them, we use an architecture. The architecture we use is known as the "Pipe and Filter architecture" in Software Engineering. An extensive description can be found in Section 3.6. In our situation, data are processed in a filter by a heuristic or a rule. Figure 4.2 gives and schematic overview of a filter.

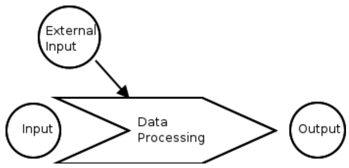


Figure 4.2: Example of a filter

The circle on the left side of the arrow signifies the input of a filter. The arrow, which denotes the filter, processes the data and gives an output. The circle at the right side of the arrow. When the filter changes something in the input data, the input datasets differ from the output datasets. Some filters need additional input, which is shown as the circle above the arrow.

Figure 4.3 gives a more specific overview of most of the filters we use in this study. The source filter is different from other filters. We return to that in Section 4.2.1.

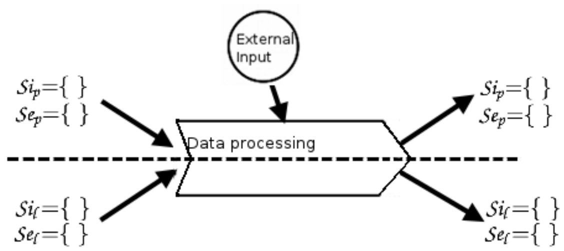


Figure 4.3: Example of a filter

The input data consist of four data sets. Si_p and Se_p contain the export and import containers that are planned to be picked-up and delivered. In Figure 4.3 these datasets are positioned above the dotted line. Si_ℓ and Se_ℓ stand for the datasets with the unplanned import and export containers and are positioned below the dotted line in Figure 4.3. The additional input that some filters need to execute the heuristic or routine are, e.g., a decision of a planner, information on capacity, or number of barges.

Filters can be connected in parallel and in series. In this study, filters that are connected in parallel, have the same function but use different heuristics. We call this a group of filters. Filters connected in series process data sequentially. Figure 4.4 gives an example of an pipes and filters system. The first pentagon of the system represents the source filter of the system, where

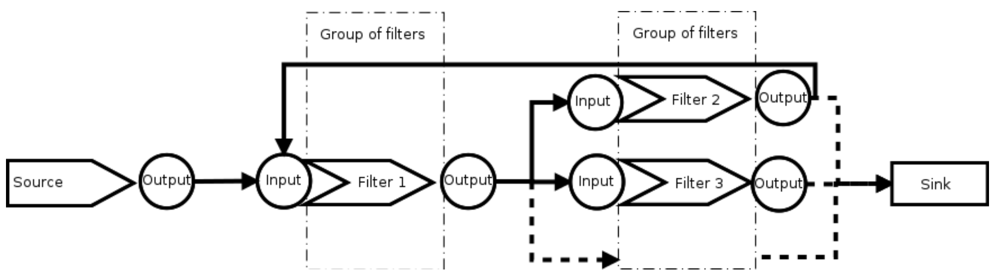


Figure 4.4: Example architecture of pipes and filters system

data are transformed, such that it fits into the system. The circle with 'output' symbolizes the output data from the source filter, which flows via the pipe, denoted by black arrows, to the next filter (big arrow with name) where they serve as input data. Note that the output data at the beginning of a pipe are equal to the input data at the end of the same pipe. A pipe does not process data.

Several pipes and filters can follow after one filter or be positioned before one filter, which is shown after *Filter 1*. The boxes with dotted lines denote that filters belong to one group. After *Filter 1* the data can flow along different pipes to several filters of the second filter group. After the filter from the second filter group, data flow into the sink or is led back to the first filter. The dotted black arrows denote the generic character of the pipes and filters.

An important feature of the pipes and filters system is that the sequence of groups of filters is interchangeable. Filters are dependent on a certain sequence and can thus be placed in different sequences which may result in different outputs. In the example shown in Figure 4.4, the second group of filters could be placed before the first group. A system may also contain loops of filters, which can be used as feedback systems. The example of Figure 4.4 shows that data may run several times through *Filter 1* and *Filter 2*.

Architecture algebra

To describe the configurations of a pipes and filters systems, we develop an algebra. When a system can be captured in an algebra it is easy to translate it to programming language, which is useful for automation of tooling software. This section describes the notation of the pipes and filters algebra.

A "name" describes a filter, e.g., *Filter 1*.

A "$\oplus$" describes a sequential connection, e.g., *Filter 1* $\oplus$ *Filter 2*. *Filter 1* is followed by *Filter 2*.

A "$||$" describes a parallel connection, e.g., *Filter 1* $||$ *Filter 2*. *Filter 1* is connected in parallel with *Filter 2*.

A "$\ominus$" describes a feedback loop, e.g., *Filter 2* $\ominus$ *Filter 1*. There is a connection from *Filter 2* back to *Filter 1*.

Example 4.1 The system shown in Figure 4.5 is noted as follows:

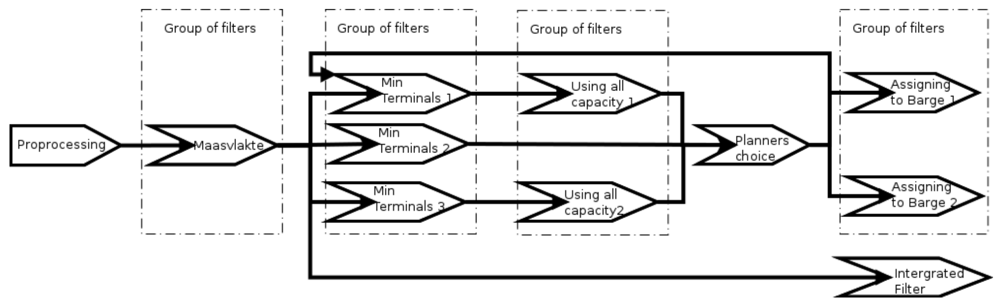


Figure 4.5: Example architecture of pipes and filters system

$$
\begin{aligned}
&Preprocessing \oplus Maasvlakte \oplus \\
&((Min\ Terminals\_1 \oplus Using\ all\ capacity)||Min\ Terminals\_2||(Min\ Terminals\_3 \oplus Using\ all\ capacity\_2)) \oplus \\
&(Planners\ choice \ominus Min\ terminals\_1) \oplus \\
&(Assign\_1||Assign\_2)
\end{aligned} \tag{4.21}
$$

4.1.3 Summary and Conclusions on Solution Method

In Section 4.1, we describe that we develop a decision support tool for barge planners that provides them with plans that suggest which containers to transport with which barges. The goal hereby is to minimize late arrivals, while maximizing the utilization rate U_j and minimizing the trip duration S_k. To do so, we use several heuristics and routines, which are structured in a 'Pipes and Filters' architecture. By using this structure, it becomes easy to extend the method in a later stadium. Other filters with the same function or filters with new functionalities can be added in parallel or series. Furthermore, it is simple to test the performance of parts of the method by using different filters which have the same goal. When filters do not perform well, they can be substituted by others.

4.2 Description of heuristics and routines

This section describes the different filters and their heuristics and routines. Based on the purposes of the filters, they are divided into six groups:

- *Preprocessing*
- *Maasvlakte*
- *Planners Choice*
- *Minimizing Number of Terminal Visits*
- *Filling capacity*
- *Assigning to barges*

Furthermore, we introduce one integrated filter that combines functionalities of several filter groups. The section is subdivided as follows: First, we discuss *Preprocessing*, which in its structure differs from other filters (Section 4.2.1). Section 4.2.2 describes *Maasvlakte* filters and Section 4.2.3 describes one *Planners choice* filter. After that, we discuss all filters from *Minimizing Number of Terminal Visits (Min Terminals)* , *Filling capacity*, and *Assigning to barges* in Section 4.2.4, because filters from these three groups can contain similar heuristics and routines. Section 4.2.4 also includes a description of the integrated filter.

4.2.1 Preprocessing

As mentioned before, the structure of filters in the *Preprocessing* group differs from the other filters. This is because these filters are source filters. In order to process data in a pipes and filters system, data must be delivered in a proper format. The process to do so is called preprocessing and is explained in this section. The corresponding filter is called a source filter, because it transforms data from an external source to fit into the system. The difference between this filter and others is that its input is of a different format than for other filters.

In this section we first describe what a data warehouse (Section 4.2.1) and datamining (Section 4.2.1) is. After that, we describe a general approach for a pre-processing filter in terms of priority determination in Section 4.2.1 followed by a description of the filter used in this study in Section 4.2.1

Data warehouse

A data warehouse consists of structured data used for reporting and analysis. Data warehouses store current as well as historical data and are used for analyze trends. CTT uses *Modality* for this purpose. Data in *Modality* can be exported to Excel-files. These Excel-files contain one line per container per booking. All available information is presented in 90 columns. One line contains information such as information on containers, transportation from/to Rotterdam, transportation from/to client, and information on billing.

Datamining

In order to make plans, we want to know where containers are located, where they need to go, when they need to be there, and what kind of containers they are. All other information on containers and bookings such as information on billing is unnecessary.

The Excel-sheet used for our study is generated based on booking-dates. When exporting an Excel-file from *Modality*, a large range of booking-dates must be taken into account to be sure that all relevant bookings are included. This means that the file also contains many unimportant bookings, e.g., settled bookings, which results in a excel-sheet with thousands of lines. Figure 4.6 shows a part of such a file.

To make the sheet easier to manage, we remove unimportant rows and columns. Lines are removed if:

- Transportation is not from or to Hengelo
- Booking concerns waste transportation
- Booking only includes transportation from CTT to customer
- Booking is already executed
- Pick-up and closing date are after the time-interval a barge is in Rotterdam

We end up with data that are relevant for the particular day on which the model is executed. So for each day the preprocessing must be executed, to make the data up to date.

Priority Determination Prioritizing containers is a way of indicating the importance of the containers. This will help to decide which containers should be transported first. The

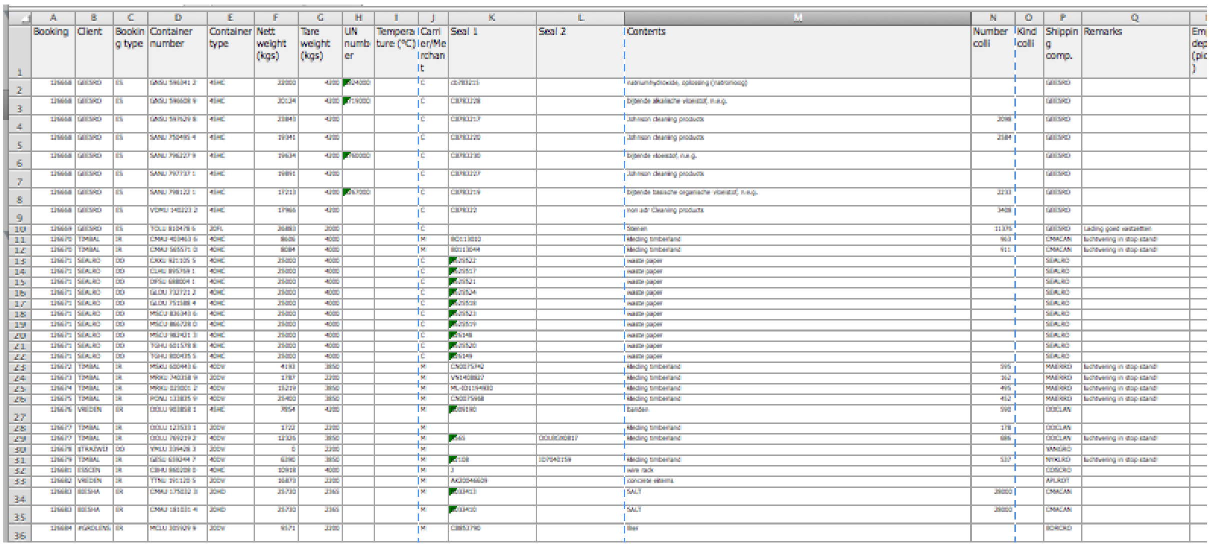


Figure 4.6: Example of excel sheet exported from Modality

assignment of priorities can be based on different criteria, such as quality of service at the destination or pick-up terminal, whether or not the client is a preferred customer, and shipment urgency. We advice to use a method that is based on the multi criteria analysis method *Saaty's Analytic Hierarchy Process* (AHP) [Saaty and Shang, 2011]. Appendix J gives an adjusted version of AHP which can be used for multi criteria priority determination of containers.

Priority Determination in this study In this study we do not use the method described in Section J to determine the priorities of containers. The priorities in this study are based on delivery and pick-up dates. We distinguish between import and export containers. Each container gets a priority per import and export trip. Recall that each container can be deliver s days before its closing date c_i and can be picked-up s days before its pick-up date. In this study we consider s to be two days. Furthermore, a barge j arrives at date A_j in Rotterdam and leaves at date L_j. As mentioned earlier, we assume that each barge is within two days in the Port of Rotterdam. This does not necessarily mean that the barge spends 48 hours in the port, but that it is in the port at two consecutive days, on which the barge can deliver and pick-up containers. We assign priorities two export containers based on the following rules:

$$\begin{array}{lll} \text{If} & c_i = A_j & \text{then } PD_i = 1 \qquad (4.22) \\ \text{elseif} & c_i = L_j & \text{then } PD_i = 2 \qquad (4.23) \\ \text{elseif} & c_i - s = A_j & \text{then } PD_i = 3 \qquad (4.24) \\ \text{elseif} & c_i - s = L_j & \text{then } PD_i = 4 \qquad (4.25) \\ \text{else} & & \text{container } i \text{ is not interesting for the plan at day } d \qquad (4.26) \end{array}$$

Similarly, we assign priorities to import containers. Here, we take into account that import containers can be picked-up two days after their pick-up date without getting penalties. This results in the following priority rules, where p_i is the pick-up date of container i:

If	$p_i + s = A_j$	then $PP_i = 1$	(4.27)
elseif	$p_i + s = L_j$	then $PP_i = 2$	(4.28)
elseif	$p_i = A_j$	then $PP_i = 3$	(4.29)
elseif	$p_i = L_j$	then $PP_i = 4$	(4.30)
else		container i is not interesting for the plan at day d	(4.31)

Now each container that is relevant for that day has a destination or pick-up terminal and an priority between 1 and 4, where 1 is most important. The next step is to sort the containers with a priority per terminal. We end up with two matrices, one for export and one for import. An example of such a matrix:

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	...
Priority 1	5	0	0	0	5	...
Priority 2	12	1	0	0	5	...
Priority 3	6	0	0	0	15	...
Priority 4	18	0	0	0	0	...

These matrices give an overview of how many containers with a certain priority need to be delivered/picked-up at a certain terminal. These matrices are used as input datasets $\mathcal{S}e_\ell$ and $\mathcal{S}i_\ell$ at the first regular filter after the *Pre-processing* filter. $\mathcal{S}e_\ell$ stand for the dataset with unplanned export containers. Similarly, $\mathcal{S}i_\ell$ stands for unplanned import containers. The input $\mathcal{S}e_p$ and $\mathcal{S}i_p$ are similar matrices. They present the planned containers, which are none at the first regular filter, so it is filled with zero's.

4.2.2 Maasvlakte Filter

The *Maasvlakte Filter* is a decision filter, which means that the filter needs additional input, namely, the planner's decision whether or not to go to the Maasvlakte. This decision will normally be based on the number of containers i with $DP_i = 1$ or $PP_i = 1$ and $D_i \in \mathcal{M}$ or $P_i \in \mathcal{M}$, which means that priority 1 containers are located at terminals at the Maasvlakte. The decision can also be based on weather conditions or other factors.

There are two types of *Maasvlakte* filters. The first filter deletes the set of containers with pick-up or destination location at the Maasvlakte from $\mathcal{S}e_\ell$ and $\mathcal{S}i_\ell$. In this case containers must be transported by other means from CTT. The second type of the Maasvlakte filters changes the destination and pick-up terminal from Maasvlakte to CTT-R. From here the containers must be transported by other means to the Maasvlakte. For simplicity reasons, the second type of *Maasvlakte* filter is not further considered in this study, so CTT-R operate as the other considered terminals.

If the planner decides to visit the Maasvlakte, all containers will be re-prioritized. Containers located at the Maasvlakte get a higher priority than containers not located at the Maasvlakte. In this way as many as possible containers are transported to and from the Maasvlakte, which makes it easier to avoid the Maasvlakte in the future. When assigning new priorities to containers we still consider priority 1 containers located at other terminals to be important. The rules for re-prioritizing are formulated as follows:

- If a container i has priority 1 with its destination or pick-up terminal located at the Maasvlakte it remains a priority 1 container.

- If a container i has priority 1 with its destination and pick-up terminal not located at the Maasvlakte it becomes a priority 2 container. It is still a important container, but less important than the priority 1 containers located at the Maasvlakte.

- All containers that are located at the Maasvlakte and originally had a priority > 1 get a priority that is 1 higher (less important) than their original priority. This is because these containers are less important than the containers with a priority of 1 that are not located at the Maasvlakte. Thus priority 2 becomes priority 3 etc.

- All containers that are not located at the Maasvlakte and originally had a priority > 1 get a priority that is 4 higher (less important) than their original priority. This is because these containers are less important than the containers with a priorities > 1 that are located at the Maasvlakte. Thus priority 2 become priority 6 etc.

We give an example to clarify the rules.

Example 4.2 *APM* is a terminal located at the Maasvlakte and *BCW* is a terminal in Rotterdam city. This is the dataset $\mathcal{S}e_\ell$ before it enters the 'Maasvlakte Filter':

	APM	BCW	...
Priority 1	5	3	...
Priority 2	12	1	...
Priority 3	6	0	...
Priority 4	18	0	...
Priority 5	0	0	...
Priority 6	0	0	...
Priority 7	0	0	...
Priority 8	0	0	...

If the planner decides to avoid the Maasvlakte, $\mathcal{S}e_\ell$ becomes $\mathcal{S}e_{\ell,1}$ and if he decides to go to the Maasvlakte, $\mathcal{S}e_\ell$ becomes $\mathcal{S}e_{\ell,2}$.

$\mathcal{S}e_{\ell,1} =$

	APM	BCW	...
Priority 1	0	3	...
Priority 2	0	1	...
Priority 3	0	0	...
Priority 4	0	0	...
Priority 5	0	0	...
Priority 6	0	0	...
Priority 7	0	0	...
Priority 8	0	0	...

$\mathcal{S}e_{\ell,2} =$

	APM	BCW	...
Priority 1	5	0	...
Priority 2	0	3	...
Priority 3	12	0	...
Priority 4	6	0	...
Priority 5	18	0	...
Priority 6	0	1	...
Priority 7	0	0	...
Priority 8	0	0	...

We notice that in $\mathcal{S}e_{\ell,1}$, all containers i located at $\mathcal{M}$ are removed, while the priorities for containers located at terminals outside the Maasvlakte remain the same. $\mathcal{S}e_{\ell,2}$ shows that priorities are redistributed and that containers located at the Maasvlakte get higher priorities than other containers.

4.2.3 Planners Choice

The *Planners Choice* filter simply removes the containers from $\mathcal{S}e_\ell$ and $\mathcal{S}i_\ell$ that are located at the terminals the planners wants to exclude. This filter needs additional input of the planner, as which terminals to remove.

4.2.4 Other Filters

In this section, we describe three groups of filters: 'Minimizing Terminal Visits', 'Filling capacity', and 'Assigning to barges'. Each group has another role in the total model. First, we describe the goal of each filter group in Section 4.2.4. After that, we deal with the different heuristics, give examples, and discuss the pros and cons in Section 4.2.4

Groups of filters

As mentioned before, we discuss three groups of filters. The 'Minimizing Terminal Visits' group consists of filters that have as goal to minimize the number of terminal visits per trip. Minimizing the number of visits minimizes trip duration S_k, because adding a new terminal visit results in additional sailing and waiting time.

The filters in this group need additional input. To execute the filter-process the total capacity of barges entering that day at CTT is needed. The common starting point of all filters in this group is that all containers i with $DP_i = 1$ or $PP_i = 1$ must be loaded. Not loading them means that they have to be transported by other means or the containers will not be in time at their destination, which affects the objective function negatively.

The 'Filling capacity' group of filters is used to fill up the available capacity such that the barges sail with filled capacity. This is required to meet one of the secondary objectives about the utilization rate U_j. The more we make use of a barge j's capacity the higher the U_j will be. If necessary new terminals will be added to visit.

The last group of filters 'Assigning to Barges' is only needed when multiple barges must be loaded the same day. This filter decides which containers are assigned to which barge.

Heuristics and routines

This section describes five heuristics and routines that are partly used by several filters from different groups. Each heuristic or routine has its own section, which contains an explanation, the pros and cons of it and, an example if needed.

Priority based This heuristic is purely based on priorities. This means that containers with higher priorities will be served before containers with lower priorities. In this study the priorities are only based on pick-up and closing dates, so this heuristic similar to *Earliest Due Date* heuristic. The sequential steps for this heuristic are shown below:

Step 1: Move container i for which holds that $DP_i = 1$ or $PP_i = 1$ from $\mathcal{S}e_\ell$ or $\mathcal{S}i_\ell$ to $\mathcal{S}e_p$ or $\mathcal{S}i_p$. Repeat until no capacity is left or no suitable containers are left.

Step 2: Repeat Step 1 for $DP_i = 2$ or $PP_i = 2$, $DP_i = 3$ or $PP_i = 3$ etc.

This is a very simple heuristic, which ensures that containers with higher priorities are loaded before containers with lower priorities. Especially, when containers i with $PP_i = 2$ or $DP_i = 2$ are dealt with, it becomes easier to make plans the day after, because those containers become priority 1 containers, which must be served that day. The disadvantage is that more terminals are visited than strictly necessary, because it is more likely that terminals are visited that do not have containers i with $PP_i = 1$ or $DP_i = 1$ but do have containers i with $PP_i = 2$ or $DP_i = 2$, which increases trip duration S_k. We give an example to clarify the heuristic.

Example 4.3 When we have $\mathcal{S}e_\ell$ and $\mathcal{S}i_\ell$ as shown below and we assume that the capacity of the barge arriving today is 60 TEU. Furthermore, no container are planned yet so $\mathcal{S}e_p$ and $\mathcal{S}i_p$ are filled with zero's.

$\mathcal{S}e_\ell$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	5	0	0	0	5	8	0
Priority 2	12	1	0	0	5	0	4
Priority 3	6	0	0	0	15	0	4
Priority 4	18	0	0	0	0	1	1

$\mathcal{S}i_\ell$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	0	0	1	0	3	0	6
Priority 2	1	0	0	0	0	0	5
Priority 3	0	2	1	0	6	0	0
Priority 4	26	0	0	0	0	0	13

After execution of the heuristic we the following $\mathcal{S}e_p$ and $\mathcal{S}i_p$:

$\mathcal{S}e_p$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	5	0	0	0	5	8	0
Priority 2	12	1	0	0	5	0	4
Priority 3	6	0	0	0	14	0	0
Priority 4	0	0	0	0	0	0	0

$\mathcal{S}e_p$ exists no longer of zero's because there are containers planned now. There is no remaining capacity.

$\mathcal{S}i_p$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	0	0	1	0	3	0	6
Priority 2	1	0	0	0	0	0	5
Priority 3	0	2	1	0	6	0	0
Priority 4	22	0	0	0	0	0	13

$\mathcal{S}i_p$ exists no longer of zero's because there are containers planned now. There is no remaining capacity.

Note that we do load all import containers, because the capacity allows it. For export containers hold that we do unload all priority 1 and 2 containers but only a part of priority 3 containers and no priority 4 containers, because no more capacity is available.

Priority and location based This heuristic chooses the containers in such a way that only containers located at terminals for which we have a container i with $DP_i = 1$ or $PP_i = 1$ are collected. The corresponding heuristic can be described as follows:

Step 1: Move container i for which holds that $DP_i = 1$ or $PP_i = 1$ from $\mathcal{S}e_\ell$ or $\mathcal{S}i_\ell$ to $\mathcal{S}e_p$ or $\mathcal{S}i_p$. Repeat until no capacity is left or no suitable containers are left.

Step 2: Move container i from $\mathcal{S}e_\ell$ or $\mathcal{S}i_\ell$ to $\mathcal{S}e_p$ or $\mathcal{S}i_p$ if holds that $DP_i = 2$ or $PP_i = 2$ and D_i or P_i is already planned to be visited. Repeat until no capacity is left or no suitable containers are left.

Step 3: Repeat 'Step 2' for $DP_i = 3$ or $PP_i = 3$ and $DP_i = 4$ or $PP_i = 4$.

With this heuristic only containers that are located at terminals with priority 1 containers are taken into consideration. This results in a minimum number of terminal visits, while meeting the objective function. The disadvantage is that containers located at other terminals, despite their priorities, do not play any role, while they might be important too, based on other considerations. The following example shows how the heuristics works.

Example 4.4 We consider the same $\mathcal{S}e_\ell$, $\mathcal{S}i_\ell$, $\mathcal{S}e_p$, and $\mathcal{S}i_p$ as in example 4.3. Furthermore, we assume that the capacity of the barge arriving today is 60 TEU. After execution of the heuristic we get the following $\mathcal{S}e_p$ and $\mathcal{S}i_p$:

$\mathcal{S}e_p$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	5	0	0	0	5	8	0
Priority 2	12	0	0	0	5	0	4
Priority 3	6	0	0	0	15	0	0
Priority 4	0	0	0	0	0	0	0

All export capacity is used.

$\mathcal{S}i_p$

	APM	*BCW*	*CETEM*	*COBELRO*	*CTTROT*	*DDW*	*DDN*
Priority 1	0	0	1	0	3	0	6
Priority 2	1	0	0	0	0	0	5
Priority 3	0	0	1	0	6	0	0
Priority 4	24	0	0	0	0	0	13

All import capacity is used.

Note that we do not load any container i with $DP_i = 4$, because they do not fit within the capacity and we do not load the container i with $PP_i = 3$ at BCW because there are no containers i with $DP_i = 1$ or $PP_i = 1$ at that terminal, while we do load containers i with $PP_i = 4$ from other terminals.

Priority and distance based This heuristic looks at groups of terminals discussed in Section 4.1.1. Recall the the distribution of terminals among the groups is as follows:

$$\mathcal{T}_1 = \{BCW, GEVELCO, GROERID, JCMERO, MEDREP, MRSTRO, UP6, WHT\}$$
$$\mathcal{T}_2 = \{HMU, INTERO, MEDEEM, PCSA, PROGRO, RSTN, RSTZ, STEIRO, UCTEEM\}$$
$$\mathcal{T}_3 = \{CETEM, COBELRO, CTTROT, WBT\}$$
$$\mathcal{T}_4 = \{APM, DBF, DCSROT, DDE, DDN, DDW, DRB, EMX, RCTROT\}$$

The corresponding heuristic can be written schematically as follows:

Step 1: Move container i for which holds that $DP_i = 1$ or $PP_i = 1$ from $\mathcal{S}e_\ell$ or $\mathcal{S}i_\ell$ to $\mathcal{S}e_p$ or $\mathcal{S}i_p$. Repeat until no capacity is left or no suitable containers are left.

Step 2: Move container i for which holds that $DP_i = 2$ or $PP_i = 2$ from $\mathcal{S}e_\ell$ or $\mathcal{S}i_\ell$ to $\mathcal{S}e_p$ or $\mathcal{S}i_p$ if container i is located at T_i from a group that is already visited. Repeat until no capacity is left or no suitable containers are left.

Step 3: Repeat 'Step 2' for $DP_i = 3$ or $PP_i = 3$ and $DP_i = 4$ or $PP_i = 4$.

This heuristic takes the neighborhood of a terminal with priority 1 containers in consideration. This means that when a terminal is visited terminals within the same group will also be visited as long as needed and there is enough capacity. This makes it less likely that part of the Port of Rotterdam must be visited the next day. If the focus is on one part of the port it is easier to make plans. Furthermore, a shorter travel distance is needed, because certain parts are not visited, which again affects the trip duration S_k. The disadvantage of this heuristic is that containers with an original high priority are left out of consideration if they are located in another group of terminals. Furthermore, the number of terminal visits is not minimized as much as possible, which effects the trip duration S_k negatively. We give an example to clarify the heuristic.

Example 4.5 We use the same $\mathcal{S}e_\ell$, $\mathcal{S}i_\ell$, $\mathcal{S}e_p$, and $\mathcal{S}i_p$ as in Example 4.3 and the capacity of the barge arriving today is 60 TEU. This results in $\mathcal{S}e_p$ and $\mathcal{S}i_p$ shown below.

	APM	BCW	$CETEM$	$COBELRO$	$CTTROT$	DDW	DDN	...
Priority 1	5	0	0	0	5	8	0	...
Priority 2	12	0	0	0	5	0	4	...
Priority 3	6	0	0	0	15	0	0	...
Priority 4	0	0	0	0	0	0	0	...

All import capacity is used.

$\mathcal{S}i_p$

	APM	BCW	$CETEM$	$COBELRO$	$CTTROT$	DDW	DDN	...
Priority 1	0	0	1	0	3	0	6	...
Priority 2	1	0	0	0	0	0	5	...
Priority 3	0	0	1	0	6	0	0	...
Priority 4	24	0	0	0	0	0	13	...

All export capacity is used.

Note that we do not visit BCW, although it has priority 2 containers, while we also loaded priority 3 containers, because we the terminal is located at the Waalhaven ($\mathcal{T}_1$) and we do only visit the Botlek ($\mathcal{T}_3$) and the Maasvlakte ($\mathcal{T}_4$).

Quantity based This heuristic sums up all containers available at unplanned terminals and chooses containers i from the terminal with the highest number of containers to move from $\mathcal{S}e_{\ell}$ or $\mathcal{S}i_{\ell}$ to $\mathcal{S}e_p$ or $\mathcal{S}e_p$. We can write is as a heuristic in the following way:

Step 1: Sum all containers i from $\mathcal{S}e_{\ell}$ or $\mathcal{S}i_{\ell}$ per terminal.

Step 2: Sort from many containers to few.

Step 3: Choose containers i from the terminal with the highest number of containers and move from $\mathcal{S}e_{\ell}$ or $\mathcal{S}i_{\ell}$ to $\mathcal{S}e_p$ or $\mathcal{S}e_p$.

Step 4: Repeat 'Step 3' until capacity is filled.

Visiting terminals with high numbers of containers means that the capacity is filled quickly and only few terminals need to be served, so the trip duration S_k is influenced positively. However, priority 1 containers are not taken into account, so this heuristic alone does not meet the objective. An example clarifies the heuristic.

Example 4.6 We use the same $\mathcal{S}e_{\ell}$, $\mathcal{S}i_{\ell}$, $\mathcal{S}e_p$, and $\mathcal{S}i_p$ as in Example 4.3 and the capacity of the barge arriving today is 60 TEU. This results in $\mathcal{S}e_p$ and $\mathcal{S}i_p$ shown below.

	APM	BCW	$CETEM$	$COBELRO$	$CTTROT$	DDW	DDN	...
Priority 1	5	0	0	0	5	0	0	...
Priority 2	12	0	0	0	5	0	0	...
Priority 3	6	0	0	0	9	0	0	...
Priority 4	18	0	0	0	0	0	0	...

There is no capacity remaining.

$\mathcal{S}i_p$

	APM	BCW	$CETEM$	$COBELRO$	$CTTROT$	DDW	DDN	...
Priority 1	0	0	0	0	3	0	6	...
Priority 2	1	0	0	0	0	0	5	...
Priority 3	0	0	0	0	6	0	0	...
Priority 4	26	0	0	0	0	0	13	...

There is no capacity remaining.

Note that we do not visit $CETEM$ while it has priority 1 containers. This is because the total number of containers is smaller than at other terminals.

Randomness based The last heuristic we introduce is planning containers based on randomness until all capacity is filled. This heuristic does not take any priorities, locations or distances into consideration and is used as a comparison to the other heuristics.

Overview Now we know all filter groups and heuristics, we show which heuristics we use in which groups. Recall that filters from 'Minimizing Terminal visits' are used to minimize the number of terminal visits, filters from 'Filling capacity' are used to make use of the total capacity available and filters from 'Assigning to barges' are used to assign planned containers to available barges. Table 4.1 shows, which heuristics are used in which filter groups in a schematic way.

Heuristic \ Filter Groups	Min Terminal Visits	Filling capacity	Assigning to barges
Priority based	x	x	-
Priority and location based	x	-	-
Priority and distance based	x	x	x
Quantity based	-	x	-
Random	-	-	x

Table 4.1: Overview of heuristics used in different filter groups

The columns present the filter groups and the lines present the heuristic. An 'x' notes that the corresponding heuristic is used in one of the filters in that group.

Integrated Filter In this paragraph, we describe the integrated filter that does several things in one filter. The goals that earlier were divided into groups of filters are now combined in one filter. The heuristics for the integrated filter are divided into three scenarios, namely whether one, two, or three barges are available on a day. The scenario that four barges are available is not taken into consideration because it hardly ever occurs that all four barges depart from CTT at the same day. We now discuss the three different scenarios. Before we are able to use the integrated filter in any scenario, we need to execute the *Preprocessing* filter first.

Scenario 1: With one barge available at CTT, the heuristic used is similar to *Maasvlakte* filter, the priority and location based heuristics for *Minimizing Terminal Visits*, and the quantity based heuristic for *Filling capacity*. Filters from *Assigning to barges* are not needed because we only deal with one barge.

Scenario 2: With two barges available, we first use the *Maasvlakte* filter. Based on the decision to serve terminals at the Maasvlakte, different heuristics are used. When we go to Maasvlakte, the integrated filter uses priority and distance based heuristic focussing only on the Maasvlakte to fill one barge and uses the priority and location based heuristic to serve all other terminals. If we do not serve terminals at the Maasvlakte we use the priority and distance based heuristic starting with $\mathcal{T}_1$, $\mathcal{T}_2$ etc. to fill one barge, so one barge returns as quickly as possible. We use the priority and location based heuristic to fill the other barge. In all situation unused capacity is filled by the quantity heuristic.

Scenario 3: In the situation, where we have three barges available we want one barge to serve the Maasvlakte, one to return as quickly as possible to CTT and one to serve all other terminals needing service. So the barge that goes to the Maasvlakte is filled by the priority and distance based heuristic focussing only on the Maasvlakte. The barge that has to return as quickly as possible is filled by the priority and distance based heuristic starting with $\mathcal{T}_1$, $\mathcal{T}_2$ etc. The last barge is filled by the priority and location based heuristic. If needed, the remaining capacity of all barges j is filled by the quantity based heuristic.

4.2.5 Summary of Heuristics description

To summarize, we use six different groups of filters, each containing one or more filters that have the same goal. We use different heuristics in different filters. Furthermore, we have one integrated filter that uses different filters in different situations. In total we deal with twelve filters.

An example of a pipes and filters systems used for this study is shown in Figure 4.7:

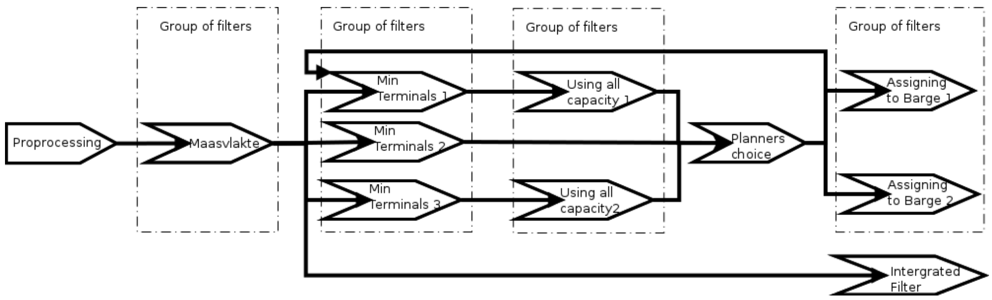


Figure 4.7: Example architecture of pipes and filter system

4.3 Tool description

In this section we present the tool that executes the model discussed in Section 4.2. First we discuss the requirements the tool should meet and how the tool fulfill these requirements in section 4.3.1. After that, we present the user interface of the tool in Section 4.3.2, which is followed by a Section discussing the implementation plan (Section 4.3.3).

4.3.1 Goal and Requirements

The goal of the decision support tool is to provide planners with a number of plans that assign containers to barges and results in shorter trip durations for barges. As Kjetil Fagerholt & Haakon Lindstad [2007] conclude, it is hard to model all planning objectives and requirements in a proper way, and thus impossible to come up with a single optimal plan. So, it is desirable to provide planners with several plans they can choose from. Additionally, the planner must be able to decide to visit or to avoid specific terminals, which is taken into account when coming up with a plan.

From this goal, some requirements follow for the prototype of the decision support tool. These requirements are listed below.

- *Time*: The planning procedure with the tool should not exceed a certain time.
- *# of actions*: The number of manual actions that must be done to come up with a plan should be limited.
- *Data*: The tool should use data from *Modality*.
- *Applicable*: The planner should be able to use the tool in his normal planning environment.

- *Interaction*: The planner should be able to adjust certain parameters (terminals, capacity, number of barges).

With the prototype, it takes about 15 minutes and 8 steps to make a plan for the day. Especially the export of data from *Modality* and the preprocessing needs some time. Once the preprocessing is done, several plans can be made with the same pre-processed data. This steps takes hardly any time. In a final product it is preferable that a plan can be made by one press on a button that takes into account the most actual information. The software used for the prototype is *Modality*, Excel and an executable, which can be executed on each Windows computer, which makes it accessible for planners at CTT. The executable has a number of components where interaction of the planners is required. In Section 4.3.2 we describe the user interface into more detail.

4.3.2 User Interface

The user interface consits of seven components that allow the planner to influence the plan. Figure 4.8 shows the user interface and each component is numbered with a blue number.

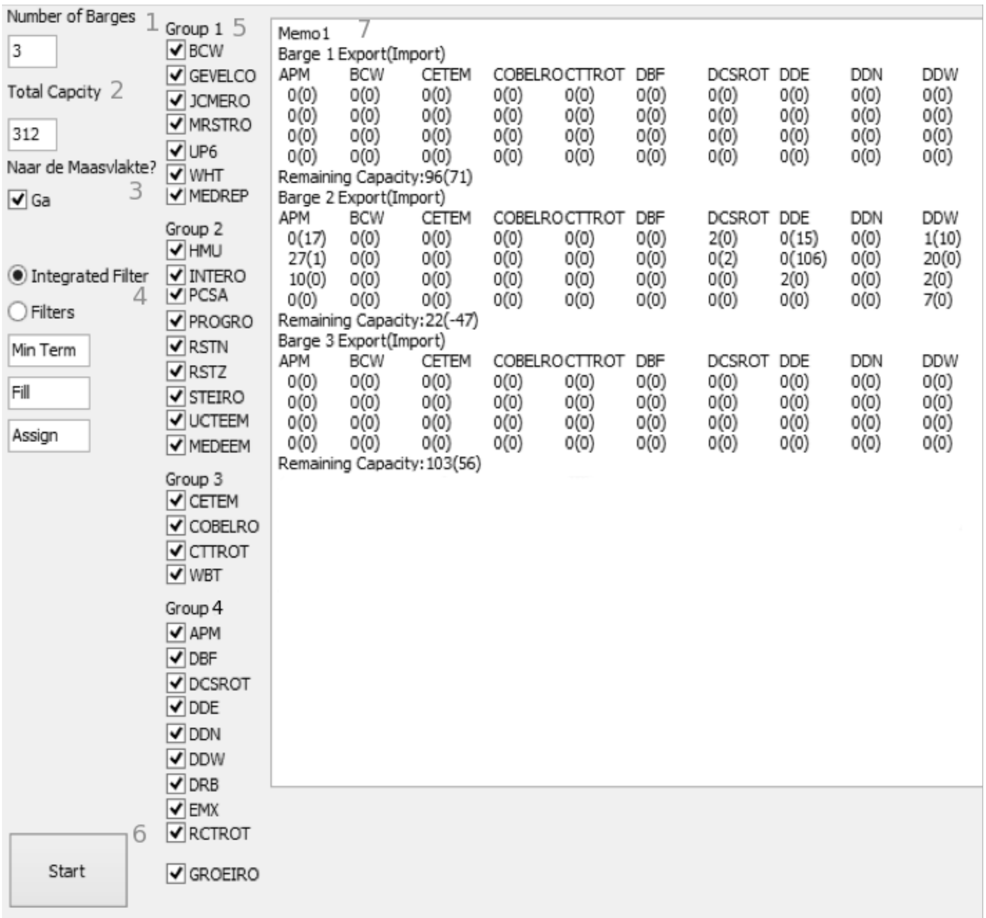


Figure 4.8: User interface of the tool

1. Here the number of barges that depart that day from CTT must be entered.

2. Here the total capacity of barges that depart that day from CTT must be entered.
3. Activation of *Maasvlakte* filter. Decision whether or no to visit the Maasvlakte with the barges leaving that day.
4. Activation of filters *Minimizing Terminal Visits*, *Filling capacity*, and *Assigning to barges* or the integrated filter (radio buttons). When using a combination of filters, the corresponding number per filter must be entered into the fields under the radio button 'Filters'.
5. Executing of *Planners Choice* filter, which gives the possibility for the barge planner to exclude terminals in the plan.
6. Is the Start-button that starts the heuristics
7. Shows the actual plan made by the heuristics. For each barge, it shows how many containers of a certain priority must be picked-up and delivered at a certain terminal.

4.3.3 Implementation

As mentioned earlier in this study, the information overflow is an issue at CTT. Developing a decision support tool for barge planning is not the only project they work on to tackle the problem.

CTT is working on a platform that bundles all relevant information from different sources and visualizes them in a surveyable way, such that users can make decisions based on intuitive visualization of complex data. The platform, called *InSight*, is a web-based platform that is easy to access for all types of relevant users. The model we present in this study is a prototype. To develop plans, several actions must be taken in different software programs. We recommend to reduce these steps to one action that provides the planner with one plan. Furthermore, integrating the model into the platform means that more insight is provided. A totally integrated decision tool is able to show the impact of certain decisions, such that it will be even easier for planners to foresee consequences of certain plans and make decisions.

To reach that goal, we suggest some implementation steps for further development and implementation.

Further development of prototype. This means programming the most important remaining releases and iterations discussed in Section 6.3.

Test new additions. Testing the tool, as is it now is done. However, the new added parts must be tested too.

Convince management and users. Support from the management is very important to successfully implement the tool. This support is needed to get resources and support for the rest of the implementation. Management should be convinced that the tool has enough advantages for the company.

Create urgency. Currently, planners plan without support, which works to a certain extend. Learning to use new software costs effort, thus planners must be motivated and supported to use the new software.

Integrate tool in platform. When the tool is developed to an extend where it is a valuable tool for the planners, it should be added to the online platform *InSight*. This makes it possible to bundle all information at one spot.

Extend tool. Integrating the decision tool in *InSight* means that new opportunities arise. These opportunities allow to develop plans that take more aspects into account, when making plans.

Monitoring. After the implementation of the tool, the project is still not complete. The final step is monitoring. During this step problems in the usage of the tool should be solved. It also should be monitored that everyone uses the tool in the right way. Finally the tool should continuously be evaluated and improved if needed.

4.3.4 Conclusion on Tool description

A first attempt is made to develop a decisions support tool for barge planners at CTT. It is build to satisfy the goal to provide the planner with plans that can be made within limited time and a number of limited actions. The planners can use data from *Modality*, set various variables, and use it in their own planning environment. Furthermore, an implementation plan is given to integrate an extended version of the decision support tool in the platform suggested by CTT.

4.4 Conclusions on Solution design

A first version of a decision support tool is developed that meets the formulated goals and requirements both for the model and the tool itself. We provide planners with a plan that suggests which container to ship on which day with which barge. The method aims to ship all containers in time while the utilization of the barge is maximized and the trip duration is minimized. The setup of priority determination and the ‘Pipes and Filters’ architecture provides the method with flexibility, which makes it easy to test separated parts of the method and to further extend the method and the tool. Furthermore, the flexibility of the model gives opportunities to come up with plans for special situations. Predefined filter combinations can be developed for special situations, depending on certain weather condition, or avoiding obstructions on the trip.

The tool that is based on our model is developed in such a way that the planner has the possibility to choose the filters the planner wants to work with and adjust certain setting to come up with plans that fit the situation of that day.

Chapter 5

Solution Test

This chapter answers the fourth research question *Which performance can be expected when implementing the solution method?*. First, we recapitulate the goal of this study in Section 5.1. Second, we determine the best settings for the solution method in Section 5.2. Sections 5.3, 5.4, and 5.5 determine the results of three experiments. Section 5.6 concludes what the performance, advantages and disadvantages are.

5.1 Testing Setup

Recall that in Section 3.5 we determine six performance measures for the quality of transportation. These performance measures are:

- Travel time
- Frequency
- Flexibility
- Costs
- Safety
- Reliability

We use these measures to test the performance of the developed method. The performance measure 'Safety' is not taken into consideration to examine the quality of the outcomes. In the experiments we focus on the number of terminals visited. Less terminals visited means less possible uncertainties and a lower trip duration. Less uncertainty means that transportation becomes more reliable. A shorter trip duration results in an increase of capacity, which results in an increased frequency of transportation, increased number of containers that are transported per week, and an increase in flexibility of transportation. Transportation of more containers with the same means results in lower transportation costs per container, which is positive for the performance measure 'Costs'.

To examine the method proposed in Chapter 4, we first determine the order of filters that gives the best outcome in Section 5.2 based on dummy data. After that, we execute the method on data from two separate days (Section 5.3), and compare the performance of the method with historic data. One day with one barge available and one with two barges available. The data used, are historic data and the outcomes are compared to the actual execution of that day. In Section 5.4 we test what the influences are of using the method's solutions on seven consecutive days. For this experiment we use dummy data that are based on historic data and we compare the methods with a First-In/First-Out system, which is a very simple method that in some way represents the tendency of how a planner plans. The last experiment we execute is a real-time experiment where we execute the method with real-time data and compare the outcome with the planning of CTT's barge planners. We discuss the differences and similarities of the outcome with the barge planners and present the outcome in Section 5.5.

5.2 Filter performance testing

This section determines, which filters and combinations of filters give the best results in terms of number of terminal visits and sailing time. First, we look at the order of filters in Section 5.2.1. Second, we test the performance of the different filters in Section 5.2.2.

5.2.1 Order of filters

Recall that we deal with six types of filters: *Pre-processing*, *Maasvlakte*, *Planners choice*, *Min Terminals*, *Fill up*, and *Assigning barges*. The position of *Pre-processing* is set, because this filter puts the information in the correct form. The filters *Maasvlakte* and *Planners choice* can be positioned everywhere after the *Pre-processing* filter, but after execution of one of them the total process must be restarted. The *Fill up* filter must follow after the *Min Terminals* filter because it is designed to fill the remaining unused capacity. The *Assigning barges* filter must follow after the *Fill up*, because the *Assigning barges* filter assigns number of containers to barges based on all planned containers. We include a manual feedbackloop in the system, because the outcome of one run may provide the planner with information on which the planners base their decisions for filter *Planners Choice* and *Maasvlakte*. If a planner notices that a terminal is visited to only deliver or pick-up one container, he is able to decide to avoid that terminal, by using *Planners Choice* and run the model once more.

Although we state in Section 4.1.2 that the sequence of filters is interchangeable, in this study the sequence is almost fixed. We choose to put *Maasvlakte* and *Planners choice* directly after *Pre-processing*, because the choices are taken into account from the beginning of the process. The order of *Maasvlakte* and *Planners choice* is interchangeable, so there is no specific reason to place *Maasvlakte* before *Planners choice*. Figure 5.1 shows the order of groups of filters we work with in this study.

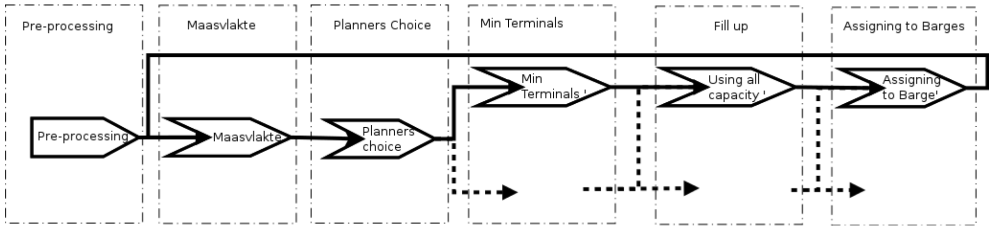


Figure 5.1: Sequence of filter types

5.2.2 Filter Performance

Per group of filters we have different filters. We want to know which filters and combinations of filters perform best in terms of minimizing number of terminals and traveling time. To do so, we develop sets of dummy data to test different types of configurations. In the following three paragraphs we discuss the selection of dummy data, selection of experiment configurations and the results. In this part of the study we leave out the pre-processing step and the filters *Planners choice* and *Maasvlakte*, because they only remove terminals and do not further influence the other filters.

Selection of dummy data

To test the performance of filters, we consider several situations. To simulate these situations, we develop different sets of dummy data. The goal of creating a variety of sets is to test the filters on their strengths and weaknesses. A detailed description of the sets can be found in Appendix F.

Set 1: A set in which terminals with priority 1 containers are located in two groups. On the terminals with priority 1 containers only few other containers are located. This makes that the *Fill* filters come into action and we can test the performance.

Set 2: A set in which terminals with priority 1 containers are located in one group. On the terminals with priority 1 containers many other containers are located. This means that the *Min Terminal* filters are the main determinant of the outcome.

Set 3: A set in which terminals with priority 1 containers are located in one group. There are plenty of other containers located on all terminals. This makes that a second barge can come into action and the *Assign* filter is used.

Set 4: Containers are distributed more equally among terminals. So each terminal has at least one import and one export container. The container are distributed in such a way that all terminals must be visited, so the *Assign* filters will have the main influence on the performance. There are enough containers to fill three barges.

Settings of experiments

There are different ways to test different filter combinations for *Min Terminals*, *Fill*, and *Assign*. The most straightforward way would be to test all different combinations of filters. This type of experiment is called a *Full factorial* experiment. A big advantage of this *Full factorial* experiment is that all interactions of the different filters are known after the experiment. However, this would be a time-consuming task because then $3 * 3 * 2 * 4 = 72$ experiments should be performed if we use four dummy datasets. To save time and effort this amount of experiments is lowered at the cost of not knowing the precise interactions of the different combinations of filters. However, the experiment is set up in a clever way and a lot of information is derived from the results. The design we use is called an *Orthogonal array*. An *Orthogonal array* is a combinatorial design, which uses the lowest amount of experiments in which every experiment provides unique information. The *Orthogonal array* allows the study of the simultaneous effect of the different filter combination efficiently [Bolboaca and Jantschi, 2007].

Figure 5.1 shows the designs of the experiments. The columns represent the type of filters and the rows are the experiment number. The numbers in the matrix represent the specific filter that is used. The 'Min T' and 'Fill' filters both have 3 different filters, the 'Assign' filter only 2. For example in experiment 7, 'Min T' uses its #3 filter, 'Fill' uses its #2 and 'Assign' uses its #1. In experiment 10 we use the integrated filter.

	Min T	Fill	Assign
Experiment 1	1	1	1
Experiment 2	1	2	2
Experiment 3	1	3	1
Experiment 4	2	1	2
Experiment 5	2	2	1
Experiment 6	2	3	2
Experiment 7	3	1	2
Experiment 8	3	2	1
Experiment 9	3	3	2
Experiment 10	-	-	-

Table 5.1: Setups for filter comparison testing

5.2.3 Results of filter comparison

As mentioned earlier, we perform four experiments with dummy data. Table 5.2 shows the results of experiments 1, 2, and 3 and Table 5.3 of experiment 4. Table 5.2 contains information on how many terminals a barge visits or several barges visit, the kilometers, and the duration (S_k) of the trip.

The *Assign* Filters do not have any effect on the results of experiment 1 and 2, because assigning an amount of containers to one barge will always result in the same container on that one barge. Furthermore, we note that the *Fill* Filters do not have any effect on the results, when they follow after *Min Terminal_2*. In the corresponding three tests (test 4, 5, and 6) the terminals visited and the trip duration are equal. This is due to the fact that the *Min Terminals_2* filter always uses full capacity, when enough containers are available. In the situations where the *Fill* filter clearly comes into action (test 1, 2, and 3 in experiment 1 and tests 1, 2, 3, 7, 8, and 9 in experiment 2) we notice that *Fill_2* outperforms *Fill_1* and that *Fill_3* outperforms *Fill_2*. In both experiment 1 and 2 the combination of *Min Terminals_1* with *Fill_3* is the combination that results in the smallest amount of terminals to be visited and the integrated filter performs equally to this combination.

	Experiment 1		Experiment 2		Experiment 3	
Test	# visits	trip distance (S_k)	# visits	trip distance (S_k)	# visits	trip distance (S_k)
1	12	500.5 km (39.5h)	13	503 km (40h)	19	941.5 km (72.5h)
2	8	504.5 km (37.5h)	10	503 km (38.5h)	16	989 km (74h)
3	7	488.5 km (36h)	9	503 km (38h)	14	933 km (69h)
4	8	504.5 km (37.5h)	17	516 km (43h)	20	938.5 km (72.5h)
5	8	504.5 km (37.5h)	17	516 km (43h)	22	1016 km (79h)
6	8	504.5 km (37.5h)	17	516 km (43h)	20	938.5 km (72.5h)
7	11	505 km (39h)	13	503 km (40h)	22	999 km (77.5h)
8	11	505 km (39h)	12	504 km (39.5h)	18	939.5 km (71.5h)
9	11	505 km (39h)	11	491 km (38h)	17	933 km (96.5h)
10	7	488.5 km (36h)	9	503 km (38h)	15	932.5 km (70h)

Table 5.2: Results of experiment 1, 2, and 3

In experiment 3, the number of terminals visited include terminals that are visited multiple times. So when barge 1 and barge 2 both visit the same terminals it counts double. We notice once more that *Fill_2* outperforms *Fill_1* and that *Fill_3* outperforms *Fill_2*. Again, the *Fill* filters have no influence on the number of terminals, when using the *Min Terminals_2* filter. The reason why the trip duration in test 7 is lower than in test 4 is due the fact that in test 4 both barges visit terminals from all groups and in test 7 one barge only visits terminals from three groups. In experiment 3 we observe that *Assign_1* outperforms *Assign_2*. This is because of the fact that when we use *Assign_2* more terminals are visited by both barges. We note that the combination of *Min Terminals_1*, *Fill_3*, and *Assign_1* performs the best and is followed by the integrated filter.

Table 5.3 shows the results of experiment 4. It contains the total number of visits at terminals for al barges and it shows which barges visit which groups.

Test	# visits	$\mathcal{T}_h$'s on 1	$\mathcal{T}_h$'s on 2	$\mathcal{T}_h$'s on 3	total distance of trips (S_k)
1	33	1 and 2	2, 3, and 4	3 and 4	1427.5 km (111.5h)
2	31	1, 2, 3, and 4	1, 2, 3, and 4	1, 2, 3, and 4	1503 km (115.5h)
3	33	1 and 2	2, 3, and 4	3 and 4	1427.5 km (111.5h)
4	33	1 and 2	2, 3, and 4	3 and 4	1427.5 km (111.5h)
5	33	1, 2, 3, and 4	1, 2, 3, and 4	1, 2, and 4	1513.5 km (117.5h)
6	33	1 and 2	2, 3, and 4	3 and 4	1427.5 km (111.5h)
7	35	1, 2, 3, and 4	1, 2, 3, and 4	1, 2, and 4	1504 km (118h)
8	33	1 and 2	2, 3, and 4	3 and 4	1427.5 km (111.5h)
9	39	1, 2, 3, and 4	1, 2, 3, and 4	1, 2, 3, and 4	1537.5 km (122h)
10	29	1 and 2	4	2 and 3	1398 km (107,5h)

Table 5.3: Results of experiment 4

Experiment 4 uses 3 barges. The dummy dataset for this experiment is chosen in such a way that all terminals always need to be visited to fill the available capacity. We notice that the distribution of groups in general is better when using the *Assign_1* filter. In most cases the number of visits at terminals is lower when we use this filter. However, in test 2 the number of visits is lower. This is because of the randomness off the *Assign_2* filter. In this experiment the integrated filter outperforms all test settings with combinations of filters.

Conclusion on filter performance testing

In Section 5.2.1, we determine the sequence of groups of filters: 'Pre-processing', 'Planners Choice', 'Maasvlakte', 'Min Terminals', 'Fill', and 'Assign'. From the tests in Section 5.2.3 we conclude that *Min Terminals_1*, *Fill_3*, and *Assign_1* is the combination of filters that perform best on minimizing the number of terminals visited and the trip duration S_k. In most cases the integrated filter performs equally or slightly better or worse. With these outcomes we set the order and selection of filters to: *Pre-processing*, *Planners Choice*, *Maasvlakte*, *Min Terminals_1*, *Fill_3*, and *Assign_1*. Because the outcome of one run provides the planner with information, on which the planners based their decisions for filter *Planners Choice* and *Maasvlakte*, we include a feedback-loop in the system. Figure 5.2 shows the order of filters in a schematic way.

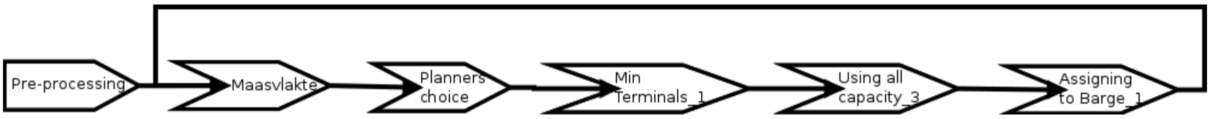


Figure 5.2: The filters and order of filters used in study

In the filter algebra we write this as:

$$Preprocessing \oplus Maasvlakte \oplus Planner\ choice \oplus MinT\_1 \oplus Fill_3 \oplus Assign\_1 \ominus Maasvlakte \quad (5.1)$$

This is the combination of filters we use in all further experiments.

5.3 Model output comparison with historical data

In this section we compare the output of the model with historical data in two situations: Situation 1 with one barge available and Situation 2 with two barges available. Recall that we use the order of filters *Pre-processing*, *Planners Choice*, *Maasvlakte*, *Min Terminals_1*, *Fill_3*, and *Assign_1*. If the total TEU of priority 1 containers located at the Maasvlakte is lower than 10 TEU and the total number of priority 1 containers that have their destination terminal at the Maasvlakte is lower than 10 TEU we choose to avoid the Maasvlakte because all containers i with $PP_i = 1$ or $DP_i = 1$ that go to or from the Maasvlakte will be transported by truck. Furthermore, we transport containers by truck as long as the total TEU of priority 1 containers is lower than 5 TEU and additional terminal visits can be avoided.

5.3.1 Situation 1

In Situation 1 we deal with a dataset of a day where one barge was available. The solution the tool produced and the solution that was executed are presented in Table 5.4. The first number in a cell represents the number of TEU of export containers shipped to the corresponding terminal and the number in the brackets represents the number of TEU of import containers picked-up at that terminal. The first row of Table 5.4 gives our plan, the second row the planners plan, and in the third row shows the number of priority 1 containers on that day at for that particular terminal.

	APM	CTT-R	DDE	DDN	DDW	EMX	MED-E	RCT-R
Our solution (ex(in))	11(34)	22(10)	0(14)	3(7)	0(22)	9(17)	4(0)	55(0)
Planners solution (ex(in))	63(0)	10(0)	0(28)	0(6)	0(56)	8(14)	0(0)	10(0)
Priority 1 (ex(in))	11(34)	2(10)	0(14)	3(7)	0(22)	9(17)	4(0)	10(0)

Table 5.4: Comparison of result of tool and what was executed

As mentioned before, we choose to transport some containers by truck, to avoid additional terminal visits. The planner did the same. Table 5.5 shows the choices made by the planner and by us. The number before the bracket is the number of export container transported by truck and the number in the bracket the number of import containers transported by truck.

	HMU	UCTEEM
Our choice (ex(in))	1(0)	1(0)
Planners choice (ex(in))	1(0)	0(0)

Table 5.5: Priority 1 containers transported per truck

Some containers have moved closing and pick-up dates. This may have several reasons, e.g., the sea vessel is late, new appointments are made with clients, wrong data, etc. Table 5.6 gives an overview of containers with moved dates. Note that the numbers in Table 5.4 represent TEU, while the numbers in Table 5.5 and Table 5.6 represent number of containers.

	CTT-R	DDN	EMX	MED-E	RCT-R	UCT-E
Planners choice (ex(in))	13(0)	0(1)	2(3)	2(0)	3(0)	1(0)

Table 5.6: Number of containers with moved pick-up or closing date

We notice that the solution given by the tool visits one terminal more than the solution executed by the barge planners. This can be explained by the fact that containers are transported by truck or that their closing or pick-up dates are changed. Striking is that in the solution made by the barge planners only one terminal is visited where both export and import containers are unloaded and loaded.

5.3.2 Situation 2

In this situation there are two barges available. Table 5.7 contains the number of TEU transported by the first barge and Table 5.8 contains the number of TEU transported by the second barge. The first row of Table 5.7 and Table 5.8 give our plan, the second row the planners plan, and in the third rows show the number of priority 1 containers on that day at for that particular terminal.

Table 5.9 shows the number of container transported by truck.

Table 5.10 shows the number of priority 1 containers with moved dates.

Once more we notice that the tool makes a plan to visit more terminals than the planners did and that the first barge in the solution executed by the planners only visits one terminal where it both picks-up and delivers containers. However, there are similarities too. In both plans, both barges visit the Maasvlakte and they both visit CTT-R. In the plans made by the tool, additional terminals are visited by both barges. This can be explained by the number of

	APM	CTT-R	DDE	DDN	DDW	EMX	HMU	RCT-R
Our solution (ex(in))	41(60)	0(0)	10(21)	15(23)	14(0)	24(0)	0(0)	0(0)
Planners solution (ex(in))	21(38)	0(34)	0(0)	0(0)	0(0)	0(0)	0(33)	36(0)
Priority 1 (ex(in))	10(0)	6(6)	4(21)	10(13)	0(11)	30(15)	0(4)	19(0)

Table 5.7: Result of tool and what was executed of first barge

	DDE	DDN	DDW	EMX	RCT-R	CTT-R	HMU	PROG	UCT-E	RSTZ
Our solution (ex(in))	0(0)	0(14)	0(11)	31(17)	34(2)	12(12)	0(36)	2(6)	12(0)	13(6)
Planners solution (ex(in))	10(29)	11(39)	9(6)	58(36)	0(0)	12(6)	0(0)	0(0)	0(0)	19(0)
Priority 1 (ex(in))	4(21)	10(13)	0(11)	30(15)	19(0)	6(6)	0(4)	2(6)	12(0)	0(6)

Table 5.8: Result of tool and what was executed of second barge

containers that are transported by truck and containers for which the pick-up or closing date has been postponed. Making use of these opportunities saves the planner two visits compared to our plan.

5.3.3 Conclusions on model output testing

A comparison of the model based on two separated days is not a very strong comparison. First, because we only take two days into consideration. Second, because when comparing separated days it is not possible to measure future effects of the model. For time and effort reasons no further comparison is done during this experiment. However, we are still able to recognize some trends based on the comparison on the two days.

In the experiment we notice that the suggested plan by the model differs from the executed plan. This is because the planner takes much more factors into account, such as appointments, sequence of visits, etc., when making plans. Furthermore, the method does not come up with solutions that visits a smaller number of terminals than the executed plan, which again can be explained by the fact that the planner takes more factors into account than the method.

It is striking that the executed plans only have few terminals where they both deliver and pick-up containers, which seems inefficient. If possible, it is more efficient to both unload and load container at the same terminal at the same time because less visits are needed. For a planner it is easier to first plan terminals to unload and after that terminals to load containers. It is hard for the planners to tune the plan in such a way that there is enough capacity to to both unload and load at the same terminal.

	APM	EMX	MEDREP	MRSTRO	RCT-R	UCTEEM	WBT
Our choice (ex(in))	0(0)	0(0)	0(1)	0(1)	0(0)	0(0)	0(1)
Planners choice (ex(in))	1(0)	0(1)	0(1)	0(1)	1(0)	1(1)	0(0)

Table 5.9: Priority 1 containers transported per truck

	APM	DDE	DDW	EMX	PROGRO	UCTEEM	WBT
Planners choice (ex(in))	1(0)	0(1)	1(1)	0(2)	1(0)	5(0)	0(1)

Table 5.10: Number of containers with moved pick-up or closing date

5.4 One week of testing

In this section, we discuss the outcome of testing one week of dummy data that are based on historic data. The goal of this experiment is to show the effect of methods on future decisions and on late arrivals. In this setting we test the method with the filter setting discussed in Section 5.2.1 and compare it with a First-in/First-out method (FiFo). This means that orders that are booked first are served first, independent of their closing or pick-up date. We choose this approach, because when planners plan with the idea of "first things first" in a wrong way it can easily begin to look like FiFo. In this experiment we use are very simple form of FiFo, by looking at the booking dates of the containers that are relevant that day. A smarter way would be to always transport priority 1 containers and choose the remaining containers with FiFo. This version is not further studied, we consider the simple FiFo method in this experiment. Furthermore, we assume that all data are known from the beginning, so no new bookings are made during the week.

Tables 5.11a and 5.11b show which terminals are planned to be visited each day when using FiFo and the model. The first column notes the day, the second which method is used, the third how many terminals are planned to be visited, and the fourth column gives the number of containers that will be delivered and picked-up late. The first number signifies numbers of export containers late and the number in the brackets signify the number of import containers late. All remaining columns show which terminals are visited. An 'x' means the terminal is visited for delivering containers and an 'x' in brackets means the terminal is visited for pick-up containers.

In the fourth column of Table 5.11a we notice that lateness occurs immediately when using the FiFo method. This means that there are relevant bookings that could have waited at least a day to be dealt with, which are dealt with now, because the have an older booking date. The number of late containers increases in the beginning of the week and decreases later in the week. No lateness occurs when using the model, because that is the objective of that model.

The number of terminals planned to be visited are generally lower when using our model compared to FiFo. On average 9.9 terminals are visited when using our model and 13.3 when using FiFo. Figure 5.3 shows the number of terminals visited during the week.

We notice that the number of terminals planned to be visited with the model starts higher than with the FiFo method but decreases during the week. This can be explained with the fact that the model tries to make future planning easy, which results in less terminals that need to be visited thus a lower trip duration S_k. The increase in number of terminals at the end of the week can be explained by the composition of data. When not enough terminals with large amounts of containers are available, several terminals must be visited to fill the capacity.

Day		# of T	Lateness	APM	BCW	CETEM	DCS-R	DDE	DDN	DDW	EMX	GROE	HMU
1	FiFo	12	9(19)	x(x)	x(-)	-(-)	-(-)	x(x)	-(x)	x(x)	x(x)	x(-)	-(-)
	Model	14	0(0)	x(x)	x(-)	-(-)	-(x)	x(x)	x(x)	x(x)	x(x)	-(-)	-(-)
2	FiFo	13	62(82)	x(x)	x(-)	x(-)	-(x)	x(x)	x(-)	x(x)	x(x)	-(-)	x(x)
	Model	10	0(0)	x(-)	x(-)	-(-)	-(-)	x(x)	-(-)	x(x)	x(x)	-(-)	-(-)
3	FiFo	13	63(147)	x(x)	x(-)	-(-)	-(-)	-(x)	-(-)	x(x)	x(x)	-(-)	x(-)
	Model	9	0(0)	x(x)	x(x)	-(-)	-(-)	x(x)	x(x)	x(x)	x(x)	x(-)	-(x)
4	FiFo	13	31(159)	x(x)	x(-)	-(-)	-(-)	x(x)	x(x)	x(x)	x(x)	-(-)	-(-)
	Model	9	0(0)	x(x)	x(-)	-(-)	-(-)	x(x)	-(-)	x(x)	-(-)	-(-)	x(-)
5	FiFo	14	4(169)	x(x)	x(-)	-(-)	x(-)	x(x)	x(-)	x(x)	x(x)	-(-)	x(-)
	Model	7	0(0)	-(x)	-(-)	-(-)	-(-)	-(x)	x(-)	-(-)	x(x)	-(-)	-(-)
6	FiFo	15	20(155)	x(-)	x(-)	-(-)	x(-)	x(-)	x(-)	x(-)	x(-)	x(-)	x(-)
	Model	6	0(0)	-(-)	-(-)	-(-)	-(-)	-(-)	x(x)	-(-)	x(x)	-(-)	-(-)
7	FiFo	13	12(118)	x(x)	x(-)	-(-)	-(x)	-(x)	x(x)	x(x)	x(x)	-(-)	x(x)
	Model	14	0(0)	x(x)	x(-)	-(-)	x(-)	x(x)	-(-)	x(x)	x(-)	x(-)	-(-)

(a) Data of one week of testing with FiFo and model. Part 1

Day	MRSTRO	PCSA	PROGRO	RCT-R	RSTN	RSTZ	STEIRO	UCT-E	UP6	WBT	WHT
1	-(-)	-(x)	-(x)	-(x)	-(-)	-(-)	-(-)	x(x)	x(-)	-(-)	-(-)
	-(-)	-(x)	-(-)	-(x)	x(-)	x(x)	-(-)	x(x)	x(x)	-(x)	-(-)
2	-(-)	x(-)	-(-)	-(-)	x(-)	-(-)	-(-)	x(-)	-(x)	-(-)	-(-)
	-(-)	x(-)	-(x)	-(-)	-(-)	x(-)	-(-)	x(x)	-(-)	-(-)	x(-)
3	-(x)	-(-)	-(-)	-(-)	x(-)	x(x)	-(x)	-(x)	-(x)	-(x)	-(-)
	-(-)	-(-)	-(x)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
4	x(-)	x(-)	-(-)	-(-)	-(-)	x(-)	-(-)	x(x)	x(-)	x(x)	x(-)
	-(-)	-(-)	x(x)	x(-)	-(-)	-(-)	-(-)	-(-)	-(x)	x(x)	-(-)
5	-(-)	-(x)	-(-)	-(-)	x(-)	x(-)	-(-)	x(x)	x(-)	x(-)	x(x)
	x(-)	x(-)	-(-)	x(x)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)	-(-)
6	-(-)	-(-)	x(-)	x(-)	x(-)	x(-)	-(-)	x(x)	-(-)	-(-)	-(x)
	-(-)	x(-)	-(-)	-(-)	-(-)	x(-)	-(-)	x(-)	x(-)	-(-)	-(-)
7	-(-)	x(-)	-(-)	x(-)	-(-)	-(x)	-(-)	-(-)	x(x)	-(x)	-(-)
	-(-)	-(-)	x(x)	x(-)	x(-)	-(x)	-(-)	-(x)	-(-)	x(x)	x(x)

(b) Data of one week of testing with FiFo and model. Part 2

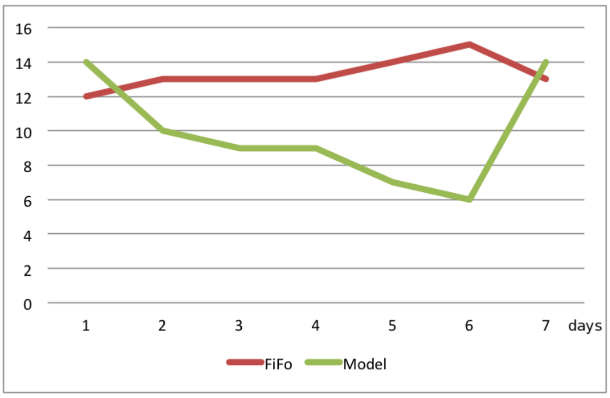


Figure 5.3: Number of terminals visited with two different models

5.4.1 Conclusions on one week of testing

Compared to the FiFo method, the model performs better on lateness and trip duration. No containers are planned to be late and the average number of terminals visited is lower than with the FiFo method.

5.5 Comparison in practice

The goal of this experiment is to discover the strength and weaknesses of the decision support tool. Furthermore, it gives us insight in what the next important steps of development of the tool should be.

5.5.1 Setup of experiment

This experiment has an execution duration of five days. In the morning of each day, the decision support tool gives a proposal for a composition of containers to be shipped that day, based on current data. The proposal plan is compared with the plan made by the barge planners. The plans are compared based on the following points:

Which terminals are planned by barge planners and not by the tool? What is the planners motivation?

Which terminals are avoided by barge planners but planned by the tool? What is the planners motivation?

What is the planners motivation to assign terminals to barges?

Based on differences in the plans more questions will be asked. Furthermore, we let the planner judge the plans made by the model.

5.5.2 Findings

The main reasons why the executed plan differs from the suggested plan are listed below. Appendix G gives the actual data belonging to this experiment.

- Terminals that CTT normally does not serve were served because of a broken lock, which made it impossible for other operators to reach these terminals.
- Barges partly shipped three layers of containers instead of two (156 TEU instead of 104 TEU), which is possible when the total freight is heavy enough.
- Waste containers were transported to increase the total weight and enable an extra layer of containers.
- Some containers were transported by truck from Rotterdam to CTT or vice versa.

- Some containers were transported by truck directly from Rotterdam to the client or vice versa.
- Some containers were transported within the Port of Rotterdam.
- There is a big variation in the numbers of import containers, because of containers which are already picked-up by other barges but not processed in the system.
- Some containers where not ready for transportation.
- Some transportations where moved to a later date for several reasons.
- When appointments are made at certain terminals, it is preferable to deal with as much containers as possible, because appointments are hard to make.
- Some terminals do not serve in the weekend, thus must be planned during the week.

From the data in Appendix G we learn that in this experiment period we could have avoided one to three terminal visits per day, if we had made the same decision about moving dates or transporting containers by truck. This means that we most times would have less visits than when the planners plans.

When assuming that the data considered are correct, the planners find most of our plans executable. Points of concern are unbalanced amounts of import and export containers at one terminal. When a lot of containers have to be unloaded at one terminal while only a few have to be loaded that terminal needs to be visited at the beginning of a trip. If it is the other way around, thus a large amount of import containers and only few export containers that terminal has to be visited at the end of a trip. This makes a trip less flexible. Another concern is to visit too many terminals in one trip. Each terminal visit brings uncertainty, so a long trip is more likely to change than a short trip.

5.5.3 Conclusions on practice comparison

From the results of the practical experiment we notice three striking things. First, closing and pick-up dates are not always as strict as it might seem. For some container and terminal combinations it is easy to move them back and forth in time. Second, the status of import containers is registered in such a way that it is difficult to know whether an import container is ready to be picked-up, is planned to be picked-up by another barge, or is located on another barge and is on its way to CTT. Third, we notice that even within a week a lot of exceptions to the normal course of events are made. Non-standard terminals are visited, waste containers are served, capacity is extended, etc. This makes it difficult to compare the outcome of the model with the executed plan.

Leaving the three points out of consideration, the plans made by our model look promising. However, the concern mentioned by the planners about unbalanced loading and unloading containers should be taken into consideration in further development. The concern about too many terminal visits can be solved by taking into account that some dates can be moved and some containers can be transported by truck.

5.6 Conclusions on model testing

In all experiments we executed we see that the main objective, delivering and picking-up containers in time, is always met. The secondary objective to maximize utilization is achieved too. The performance on minimizing trip duration is varying strongly.

When comparing the method with real plan, we notice strong deviations in the terminals that are visited and the number of containers delivered and picked-up. The main reason for this is that planners have more information they take into consideration than the method does. This is also the reason why the method results in more terminal visits. Compared to a simple FiFo rule, the method performs better on minimizing the number of terminal visits and we even notice that the rules of the method influence future plans.

A flaw in the data is that the method uses a number of import containers with priority 1 that is larger than it actually is. That is because it is hard to tell the difference between import containers that are ready to be picked-up, are planned to be picked-up by another barge, or are located on another barge and are on their way to CTT.

An advantage of our method compared to plans made by CTT's barge planners and by methods such as FiFo, is the fact that the method tries to combine loading import containers with unloading export containers at the same terminal.

Chapter 6

Conclusions and Recommendations

This chapter states the conclusions of this study in Section 6.1. Section 6.2 discusses the value and limitations of the study and Section 6.3 the recommendations for further research.

6.1 Conclusions

The main goal of this study is to:

> **Design a method to support CTT's barge planners to improve the quality of CTT's transportation flows.**

In order to reach our research goal we study the current situation at CTT and the container sector. We describe the planning and decision process of the planners at CTT to find the bottleneck where we were able to help. After that, we studied literature to learn more on loading, planning and scheduling in the container sector and other fields. With the gathered knowledge a decision method was developed which is incorporated in a decision support tool. Finally, we tested the tool on different sets of data to determine the performance compared to more simple methods and the CTT's planners.

From this study, we learned that the container sector is a growing sector and that CTT recognizes that in the growing number of bookings. We also learned that planners have a hard time with data management. A lot of data must be obtained from different sources that vary in reliability. The large amount of data must not only be collected but also taken into consideration when making plans. The amount of data grows with the growing number of bookings. The most important problem of a planner is to keep an overview of all important data.

The literature review shows that a lot of research is done in the field of planning and scheduling. Less literature is found on the topic of container barge loading and scheduling problems. Furthermore, we searched for performance measures that indicate the quality of transportation. Little literature was found that discussed this as a main topic. From our literature research we learn that decision support is an effective way of supporting planners in their planning process.

To support planners in their planning process we propose a model in Chapter 4. The output of the model provides planners with a plan that suggests which container to ship with which barge. We use a combination of heuristics that makes sure that containers are picked-up and delivered in time and minimizes the number of terminals visits. We use an architecture for the combination of heuristics, which ensures that flexibility is provided. New heuristics are easily added and new combination are easily made.

When testing the combination of heuristics, we learn which combination give the best results. The integrated combination of heuristics performs similar to the best setting when concerning one barge and it performs better when concerning several barges. Comparing the method with more simple methods and what CTT's planners execute, we discovered that the two strengths of the method are that the method combines loading and unloading containers at the same terminals and it takes future planning into account by trying to avoid visits a the same terminals multiple days after each other. The disadvantage is that the model still misses some crucial factors to be able to compare it with the plans made by barge planners plans.

Overall, we conclude that the prototype tool has the potential to become a decision support tool that assists planners in their planning. At this point it provides planners with insights and a foundation is made to built upon. With further development, the tool will be a valuable addition to the planners insights and common sense, because it initially considers all information at once, instead of making smaller subproblems. Furthermore, planning becomes easier when using the tool because it also considers future planning.

6.2 Limitations

This study has some limitations. We discuss these limitations in this section.

A hurdle was the data provided and needed. The dataset provided by CTT was not complete. Not all data are available and available data contain imperfections and are unreliable. CTT should improve the quality of their dataset to retrieve better plans from the model.

There are multiple factors that the model does not consider in the planning process, but which the planners does. Some are more crucial than others. The most crucial is that the model considers pick-up and closing dates, while the pick-up and delivery of containers must by planned on hour-level.

The testing of the model is limited. We execute a limited amount of experiments and run them a limited number of times. Doing more runs of the executed experiments gives more reliable data and outcomes. Furthermore, running additional experiments that, e.g., test the impact of missing and incorrect data or how well it performs when it is used on future data are valuable to test the model performance.

The model is developed for CTT. The model at this point is still in such a basic development stage that it would be easy to adjust it for other container terminals or even companies or organizations in other fields. Whether it is easy to adjust the model for other container terminals must be concluded in further research.

6.3 Recommendations

We divide this section into two parts. The first part gives recommendations that directly follow from the research and the second part discusses recommendations for further research.

6.3.1 Recommendations from this study

We expect that further development of the tool will result in a more useful decision support tool for barge planners at CTT. It may not make plans that can be *copied one on one*, but enough insight is created to help to inprove the plans made by barge planners.

To increase the performance of the current decision support tool, more data are needed. At this point in time it is impossible to see, solely based on the data, whether an import container is ready to be picked-up, is planned to be picked-up by a barge, or is picked-up by a barge and is on its way to CTT. A variable that signifies the moment that an import container is actually picked-up, would solve that problem.

Finally we recommend CTT to keep track on how often data changes. Especially when pick-up and closing dates are moved ahead in time. Moving often implies that CTT is not able to meet the deadline, so new arrangements or appointments are made and new dates are registered. The original dates are deleted, so it is not possible to see whether a date is original. Currently, CTT does not know how many pick-ups and deliveries are on time and how many are late. So while CTT's main goal is to serve all containers on time, they are not able to quantify how well they are doing. If CTT is able to quantify this performance measure, it is possible to determine how well certain approaches or methods are working and CTT is able to show an eventual impact of the weather or technical dysfunctions on this performance measure.

6.3.2 Recommendations for further research

During this study we observed several subjects that are interesting for future research at CTT.

In order to improve the current tool further, additional filters must be developed. To examine which containers to pick-up and deliver and to assign containers to barges, we recommend meta-heuristics such as search algorithms. A method to find an optimal solution is to use mathematical programming. These methods often are more complex, but are able to give optimal solutions, which give good insight of the performances of other methods.

Another extension of the method would be to take more information into consideration. Examples of useful extensions are, capacity dependent of location and the weight of the freight, because with a certain weight, barges are able to ship more containers through the Twente canal. Another example is to enable temporary adding of terminals or containers. An examples is that CTT's barges sometimes sail to Antwerpen via Rotterdam. Currently it is not possible to take this into account in the model.

The current tool is built to give realtime decision support, but planners start their planning days before the day the barge arrives. This has several reasons. As mentioned before, information on containers must be available and checked. Furthermore, preparation, such as making containers easily accessible, must be done, when they are planned to be moved. Therefore, we recommend to extend the tool in that way that it incorporates decisions made earlier. This means that the tool has to deal with a lot of uncertainty, because not all information is known. Not extending the tool means that the actual planning becomes less flexible, because it has to consider several decision made earlier.

While executing the study, we noticed other points of improvement. We think CTT can improve on planning and execution of plans when investing on four aspects:

- Performance indicators
- Use of CTT-R
- Forecasting
- Preferred customers

Performance indicators can be used in several different ways, in different departments and layers of the organization, and in different planning levels (strategic, tactical or operational level). We recommend to introduce a set of performance indicators that especially can be used on an operational level by barge planners. A set of performance indicators that are visualized and indicates the quality of a plan made by the planners or by the tool, assist planners in making decisions.

When CTT purchased CTT-R, their aim was to use it differently from ordinary terminals. In Section 4.2.2 we briefly introduce the filter that changes the destination and pick-up terminals from Maasvlakte containers to CTT-R. This is just a first step of using CTT-R to improve transport quality. Further research should be done to discover if and how CTT can use CTT-R to:

- Decrease travel time of transportation
- Decrease transportation costs
- Increase transportation frequency
- Increase transportation flexibility
- Increase transportation reliability

Furthermore, we recommend CTT to make use of forecasting techniques. One of the issues in planning is to deal with a the large amount of certain and uncertain factors, which influence the planning. A planner has to deal with them without often knowing what the consequences will be. For both, the certain and uncertain factors, it is possible to make forecasts. CTT has experienced an unpredictable event such as a broken lock several times, so to a certain extend they are able to predict what the consequences will be. In the same way, they can make a forecast based on predictable factors such as weather, traffic fluctuations due to weekends and holidays, and more. If it is clear what the impact of such an event is and how to react on it in terms of planning, it would be possible to develop filters or combinations of filters that come up with plans for that specific situation.

The last point is that a barge operator currently has little to no influence on how they are treated at terminals. Even if appointments at one terminal are always moved or cancelled, it is hard for CTT to stop doing business with such a terminal, because CTT's clients make the choice for a certain terminal. We recommend to rank terminal operators based on factors that are important for CTT. Terminal operator A that often cancels an appointment would for example get a lower rank than a terminal operator B never cancels an appointment. In this way, CTT can clearly communicate to their customers, which terminal operators CTT prefers to work with. CTT prefers to work with terminals that keep their appointments and therefore make CTT's transportation more reliable, which again is preferable for the clients, because they get their containers on time.

Bibliography

. Amercain Association of Port Authorities. World Port Ranking 2011. Technical report, 2012. URL http://aapa.files.cms-plus.com/PDFs/WORLDPORTRANKINGS2011.pdf.

E.E. Bischoff and M.S.W. Ratcliff. Issues in the development of approaches to container loading. *Omega*, 23(4):377–390, August 1995. ISSN 03050483. doi: 10.1016/0305-0483(95)00015-G. URL http://linkinghub.elsevier.com/retrieve/pii/030504839500015G.

Sorana Bolboaca and Lorentz Jantschi. Design of Experiments: Useful Orthogonal Arrays for Number of Experiments from 4 to 16. pages 198–232, 2007.

Andreas Bortfeldt and Hermann Gehring. Zur Behandlung von Restriktionen bei der Stauraumoptimierung am Beispiel eines genetischen Algorithmus für das Containerbeladeproblem. *Logistik Management - Intelligente I+K Technologien*, 1999.

Andreas Bortfeldt and Gerhard Wäscher. Constraints in container loading A state-of-the-art review. *European Journal of Operational Research*, 229(1):1–20, August 2013. ISSN 03772217. doi: 10.1016/j.ejor.2012.12.006. URL http://linkinghub.elsevier.com/retrieve/pii/S037722171200937X.

Geir Brø nmo, Marielle Christiansen, Kjetil Fagerholt, and Bjø rn Nygreen. A multi-start local search heuristic for ship schedulinga computational study. *Computers & Operations Research*, 34(3):900–917, March 2007. ISSN 03050548. doi: 10.1016/j.cor.2005.05.017. URL http://linkinghub.elsevier.com/retrieve/pii/S0305054805001644.

Geir Brø nmo, Bjø rn Nygreen, and Jens Lysgaard. Column generation approaches to ship scheduling with flexible cargo sizes. *European Journal of Operational Research*, 200(1): 139–150, January 2010. ISSN 03772217. doi: 10.1016/j.ejor.2008.12.028. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221708010643.

G Brønmo, M Christiansen, and B Nygreen. Ship routing and scheduling with flexible cargo sizes. *Journal of the Operational Research Society*, 58(9):1167–1177, August 2006. ISSN 0160-5682. doi: 10.1057/palgrave.jors.2602263. URL http://www.palgrave-journals.com/doifinder/10.1057/palgrave.jors.2602263.

Frank Buschmann, Kevlin Henney, and Douglas C. Schmidt. *Pattern-Oriented Software Architecture, A Pattern Language for Distributed Computing(Google eBook)*. John Wiley & Sons, 2007. ISBN 0470065303. URL http://books.google.com/books?id=WVQF2PK2tlgC\&pgis=1.

Brecht Cardoen, Erik Demeulemeester, and Jeroen Beliën. Operating room planning and scheduling: A literature review. *European Journal of Operational Research*, 201(3):921–932, March 2010. ISSN 03772217. doi: 10.1016/j.ejor.2009.04.011. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221709002616.

Andrew Carse. Assessment of transport quality of life as an alternative transport appraisal technique. *Journal of Transport Geography*, 19(5):1037–1045, September 2011. ISSN 09666923. doi: 10.1016/j.jtrangeo.2010.10.009. URL http://linkinghub.elsevier.com/retrieve/

pii/S0966692310001675.

Marielle Christiansen and David Ronen. Maritime Transportation. 14(06), 2007. doi: 10.1016/S0927-0507(06)14004-9.

Marielle Christiansen, Kjetil Fagerholt, Bjø rn Nygreen, and David Ronen. Ship routing and scheduling in the new millennium. *European Journal of Operational Research*, In Press, December 2012. ISSN 03772217. doi: 10.1016/j.ejor.2012.12.002. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221712009125.

A Paul Davies and Eberhard E Bischo. Weight distribution considerations in container loading. 114, 1999.

Eelco den Boer, Jan Anne Annema, and Huib van Essen. Actueel beeld van emissies van vervoerswijzen. Technical report, 2009.

Michael Eley. A bottleneck assignment approach to the multiple container loading problem. pages 45–60, 2003.

ESCAP. Container Traffic Forecast 2007 Update. Technical report, 2007.

Kjetil Fagerholt, Jarl Eirik Korsvik, and Arne Lø kketangen. Ship Routing and Scheduling with Persistence and Distance Objecives. *Innovations in Distribution Logistics*, pages 89–107, 2009. doi: 10.1007/978-3-540-92944-4_6. URL http://www.springerlink.com/index/t706h756164j7q37.pdf.

Robert Haessler and Brian Talbot. Load planning for shipments of low density products. 44: 289–299, 1990.

InlandLinks.eu. InlandLinks. URL http://www.inlandlinks.eu/nl.

Leonardo Junqueira, Reinaldo Morabito, and Denise Sato Yamashita. Three-dimensional container loading models with cargo stability and load bearing constraints. *Computers & Operations Research*, 39(1):74–85, January 2012. ISSN 03050548. doi: 10.1016/j.cor.2010.07.017. URL http://linkinghub.elsevier.com/retrieve/pii/S0305054810001486.

Kjetil Fagerholt & Haakon Lindstad. TurboRouter: An Interactive Optimisation-Based Decision Support System for Ship Routing and Scheduling. *Maritime Economics & Logistics*, pages 214–233, 2007. doi: doi:10.1057/palgrave.mel.9100180.

J E Korsvik, K Fagerholt, and G Laporte. A tabu search heuristic for ship routing and scheduling. *Journal of the Operational Research Society*, 61(4):594–603, 2009. ISSN 01605682. doi: 10.1057/jors.2008.192. URL http://www.palgrave-journals.com/doifinder/10.1057/jors.2008.192.

Jarl Eirik Korsvik and Kjetil Fagerholt. A tabu search heuristic for ship routing and scheduling with flexible cargo quantities. *Journal of Heuristics*, 16(2):117–137, August 2008. ISSN 1381-1231. doi: 10.1007/s10732-008-9092-0. URL http://www.springerlink.com/index/10.1007/s10732-008-9092-0.

Fotini Malliappi, Julia A Bennell, and Chris N Potts. A Variable Neighborhood Search Heuristic for Tramp Ship Scheduling. pages 273–285, 2011.

Louis A Martin-vega. AIRCRAFT LOAD PLANNING AND THE COMPUTER DESCRIPTION AND REVIEWt Louis A. MARTIN-VEGA. 9(4):357–369, 1985.

Nextlogic. Nextlogic, 2013. URL http://www.nextlogic.nl/uk/.

Anastasios Perimenis, Hartley Walimwipi, Sergey Zinoviev, Franziska Müller-Langer, and Stanislav Miertus. Development of a decision support tool for the assessment of biofuels. *Energy Policy*, 39(3):1782–1793, March 2011. ISSN 03014215. doi: 10.1016/j.enpol.2011.01.011. URL http://linkinghub.elsevier.com/retrieve/pii/S0301421511000218.

Port of Rotterdam. Port statistics 2009 - 2010 - 2011. Technical report, 2011a.

Port of Rotterdam. Uitvoering Havenvisie 2013. Technical report, Port of Rotterdam, 2011b. URL http://www.portofrotterdam.com/nl/Over-de-haven/haven-rotterdam/havenvisie2030/Documents/ConvenantUitvoeringHavenvisie2030.pdf.

Port of Rotterdam. Port of Rotterdan Jaarverslag 2012. Technical report, 2012.

Regio Twente. Ecomoische Motor Twente. Technical report, 2012.

Jidong Ren, Yajie Tian, and Tetsuo Sawaragi. A tree search method for the container loading problem with shipment priority. *European Journal of Operational Research*, 214(3):526–535, November 2011a. ISSN 03772217. doi: 10.1016/j.ejor.2011.04.025. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221711003699.

Jidong Ren, Yajie Tian, and Tetsuo Sawaragi. A priority-considering approach for the multiple container loading problem. *International Journal of Metaheuristics*, 1(4):298–316, 2011b.

Thomas L. Saaty and Jennifer S. Shang. An innovative orders-of-magnitude approach to AHP-based mutli-criteria decision making: Prioritizing divergent intangible humane acts. *European Journal of Operational Research*, 214(3):703–715, November 2011. ISSN 03772217. doi: 10.1016/j.ejor.2011.05.019. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221711004449.

J.P. Shim, Merrill Warkentin, James F. Courtney, Daniel J. Power, Ramesh Sharda, and Christer Carlsson. Past, present, and future of decision support technology. *Decision Support Systems*, 33(2):111–126, June 2002. ISSN 01679236. doi: 10.1016/S0167-9236(01)00139-7. URL http://linkinghub.elsevier.com/retrieve/pii/S0167923601001397.

Lóri Tavasszy, Robbert Janssen, Larissa van der Lugt, and Lorike Hagdorn. Verkenning synchromodaal transportsysteem-Eindrapportage. Technical report, TNO, 2010.

Jorne Van den Bergh, Jeroen Beliën, Philippe De Bruecker, Erik Demeulemeester, and Liesje De Boeck. Personnel scheduling: A literature review. *European Journal of Operational Research*, 226(3):367–385, May 2013. ISSN 03772217. doi: 10.1016/j.ejor.2012.11.029. URL http://linkinghub.elsevier.com/retrieve/pii/S0377221712008776.

VITO. VITO. 2013. URL http://www.vito-nederland.nl/.

Stefan Voß, Robert Stahlbock, and Dirk Steenken. Container terminal operation and operations research - a classification and literature review. *OR Spectrum*, 26(1):3–49, January 2004. ISSN 0171-6468. doi: 10.1007/s00291-003-0157-z. URL http://link.springer.com/10.1007/s00291-003-0157-z.

Luca Zamparini, John Layaa, and Wout Dullaert. Monetary values of freight transport quality attributes : A sample of Tanzanian firms. *Journal of Transport Geography*, 19(6):1222–1234, 2011. ISSN 0966-6923. doi: 10.1016/j.jtrangeo.2011.01.002. URL http://dx.doi.org/10.1016/j.jtrangeo.2011.01.002.

Appendix A

List of definitions

A call is a visit at a terminal

A cargo is a set of goods shipped together from a single origin to a single destination.

Demurrage is the time a empty container has to be turned in at its origin port

Detention time is the time a full container has to be moved from its origin port to the customer.

Export containers are containers that need to be transported from CTT to a terminal in the Port of Rotterdam.

Import containers are containers that need to be transported from a terminal in the Port of Rotterdam to CTT.

A loading port is a pickup location.

Routing is the assignment of a sequence of ports to a vessel.

Shipping refers to moving cargoes by ships

Shipper is the owner of the transported cargo

A shipment is a specified amount of cargo that must be shipped together from a single origin to a single destination.

Scheduling is assigning times (or time windows) to the various events on a shipments route.

A trip consists of a sequence of port calls, starting with the port where the ship loads its first cargo and ending in the same port. A trip may include multiple loading ports and multiple unloading ports.

TEU is a representation of twenty-foot equivalent unit.

An unloading port is a delivery location.

Appendix B

Numbers in terminals and barges

This Appendix gives some information on CTT and CTT-R.

B.1 CTT

Employees	58
Total area	13 ha.
Quay length	380 m.
Canal depth	2,8 m.
Container cranes	2
Reach stacker	2
Empty stacker	3
Trucks (incl. charters)	55
Barges (incl. charters)	7
Containerchassis	125

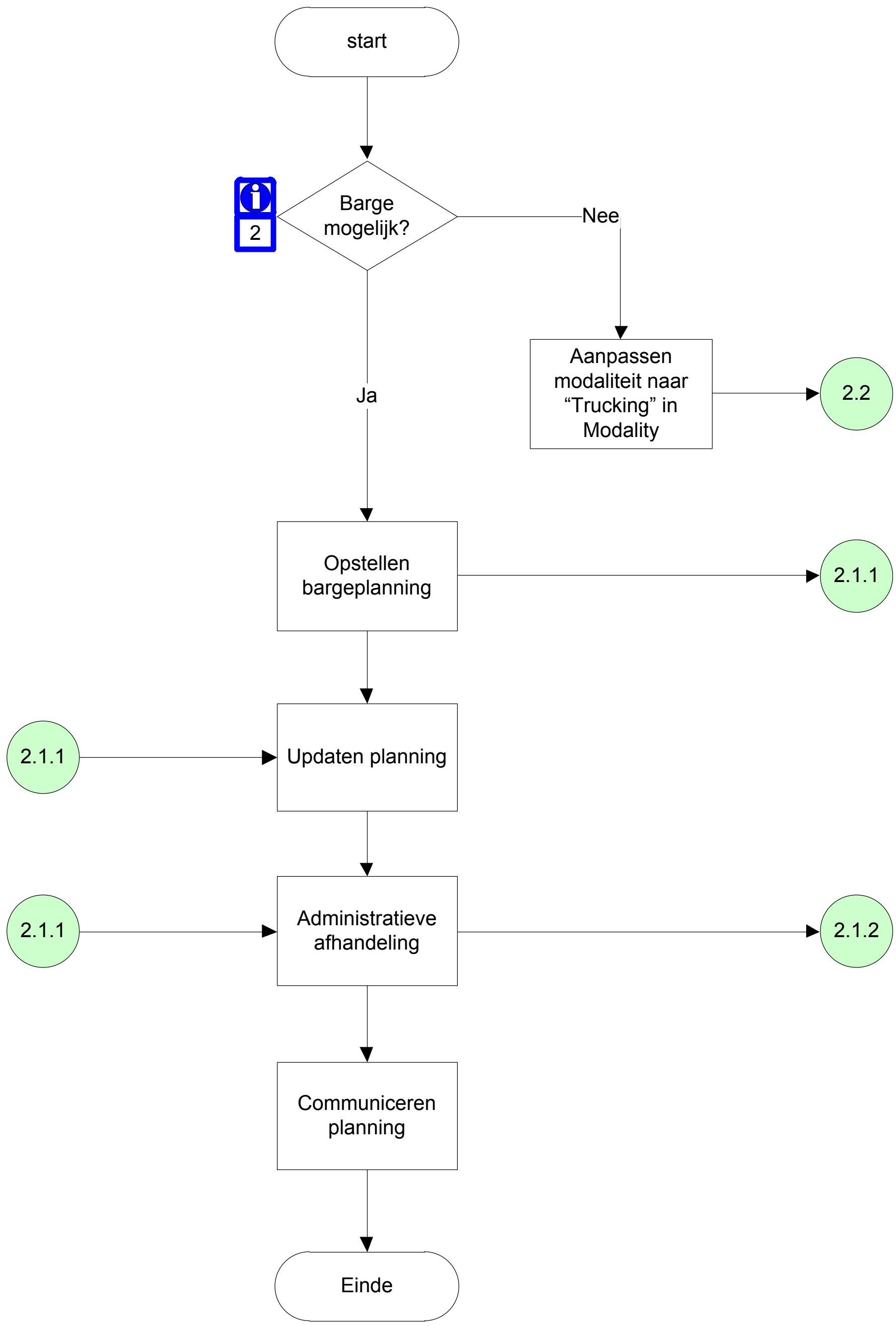
B.2 CTT-R

Employees	9
Total area	4.2 ha.
Quay length	150 m.
Canal depth	8 m.
Container cranes	1
Reach stacker	2
Railway connections	3 x 200 m.

Appendix C

Flow Barge Planning

The Appendix presents the flowcharts that are developed by CTT, to explain the barge planning process.



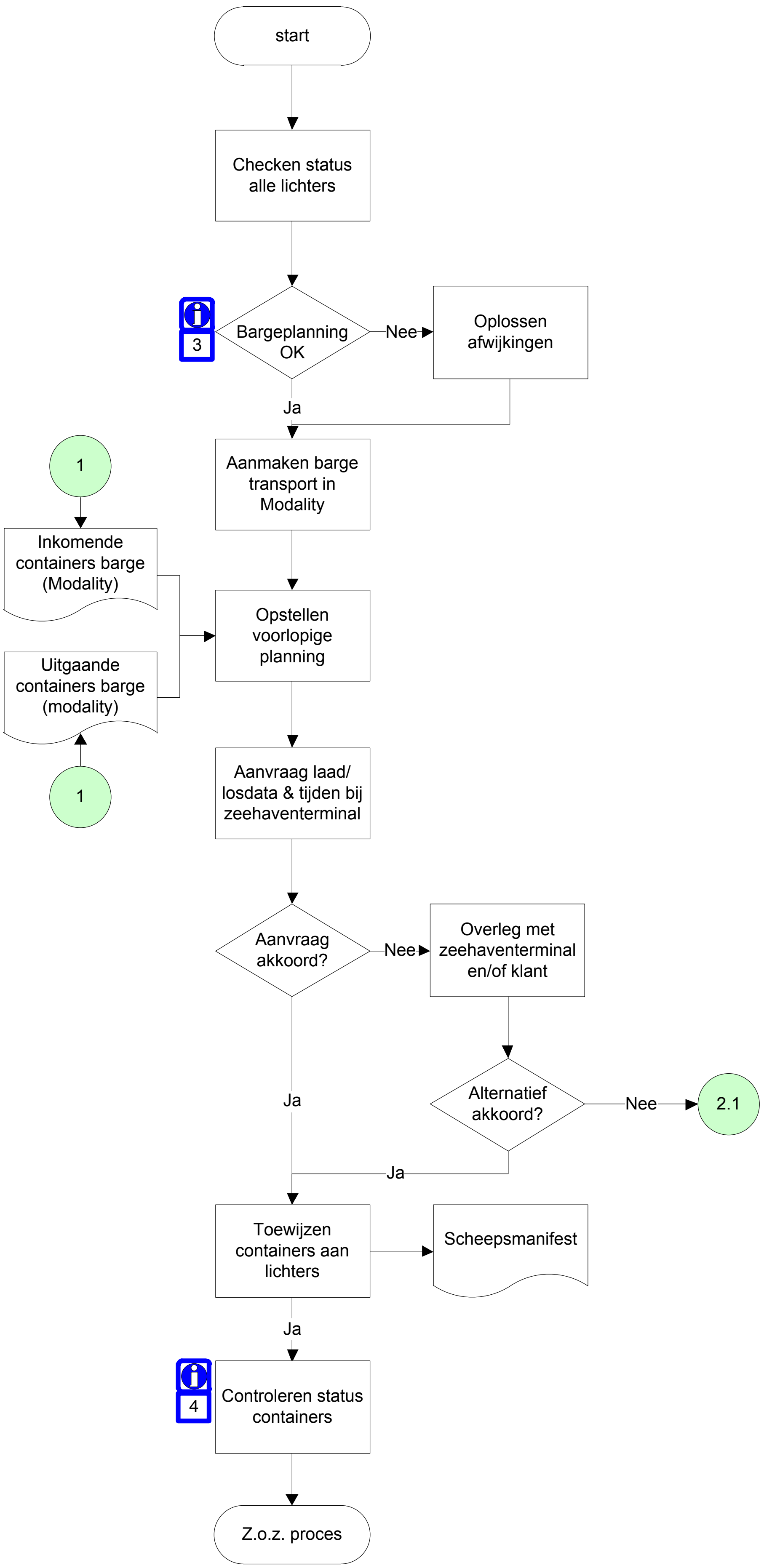
Previous step: 2

Functie	Omschrijving
Bargeplanner	Bepaald of trucking noodzakelijk vanwege spoed of vanwege capaciteitstekort barges
Truckplanner	Verandert de modaliteit in "Trucking" in Modality na overleg met de bargeplanner.
Bargeplanner	Stelt de bargeplanning op, zie proces 2.1.1
Bargeplanner	Updaten planning t.o.v. de reeds eerder gemaakte planning
Bargeplanner	Zorgt voor de administratieve afhandeling van de gemaakte planning, zie proces 2.1.2
Bargeplanner	Communiceert de planning met de schipper en zeehaven terminal. Eventueel al voor aankomst van de lichter (voor opstellen stuwplan)

Next Step: 3

2.1.1 Opstellen Bargeplanning

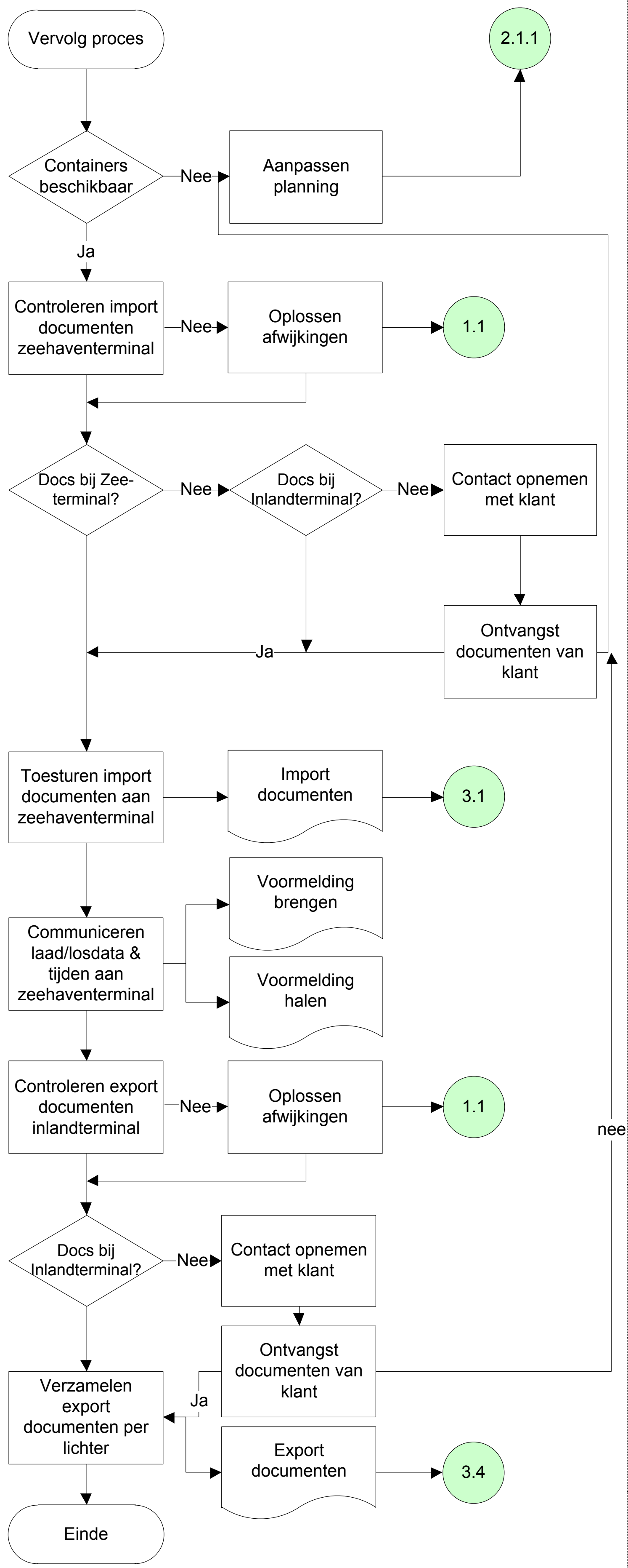
Pagina	
Hoofdstuk	
Versie	
Datum	
Auteur	CPvision



Previous step: 2.1

Functie	Omschrijving
Bargeplanner	Controleert de status van de lichters aan de hand van de planning
Customer Service/ Bargeplanner	Lost eventueel geconstateerde afwijkingen op
Bargeplanner	Maakt per lichter een reis aan in modality
Bargeplanner	Stelt een voorlopige planning op aan de hand van de in- en uitgaande containers die zichtbaar zijn in Modality.
Bargeplanner	Vraagt op basis van de voorlopige planning laad / losdata & tijden aan bij terminals
Bargeplanner	Overlegt nieuw laad/ losdata & tijden met terminals
Bargeplanner	Ontvangt van de diverse terminals een bevestiging / afwijzing van de aangevraagde laad / losdata & tijden
Bargeplanner	Wijst orders (containers) toe aan de lichters op basis van de bevestigde laad / losdata & tijden en stelt het scheepsmanifest op
Bargeplanner	Controleert de status van de containers (of deze beschikbaar zijn bij inlandterminal en/of overige terminals)

Next Step:



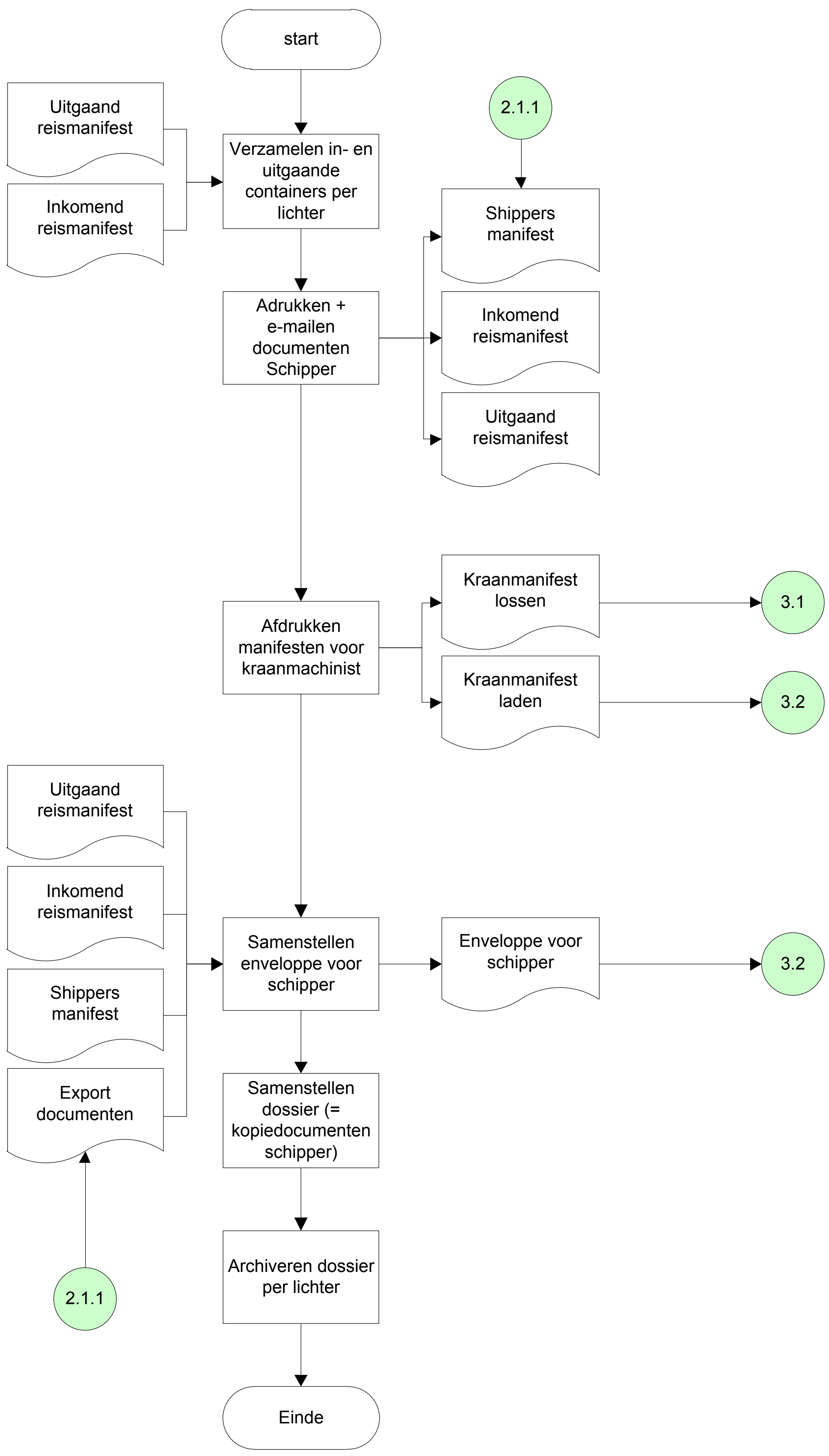
Previous step:

Functie	Omschrijving
Bargeplanner	Past de bargeplanning aan indien een of meerdere containers niet beschikbaar zijn en informeert de inland terminal hierover.
Bargeplanner	Controleren import documenten bij zeehaventerminal (zonder geldige documenten wordt container niet vrijgegeven)
Customer Service	Neemt contact op met de klant indien import documenten niet aanwezig zijn
Bargeplanner	Ontvangt alsnog de gevraagde importdocumenten
Bargeplanner	Stuurt de importdocumenten naar de desbetreffende terminal
Bargeplanner	Communiceert laad/ losdata & tijden aan de terminals ter bevestiging van de overeengekomen laad / losdata & tijden
Customer Service	Controleren export documenten bij inlandterminal (zonder geldige documenten kan container niet verscheept worden)
Customer Service	Neemt contact op met de klant indien export documenten niet aanwezig zijn op de terminal
Customer Service	Verzamelt de export documenten per uitgaande reis voor elke lichter.

Next Step: 2.1

2.1.2 Administratieve afhandeling

Pagina	
Hoofdstuk	
Versie	
Datum	
Auteur	CPvision



Previous step: 2.1

Functie	Omschrijving
Bargeplanner	Verzamelt de in- en uitgaande containers in Modality
Bargeplanner	Drukt documenten af vanuit modality en e-mailt deze documenten naar de schipper (BICS)
Customer Service	Drukt de kraanmanifesten af vanuit Modality en overhandigt deze aan de kraanmachinist
Customer Service	Voegt alle documenten per reis samen in een enveloppe
Customer Service	Maakt een fysiek hard-copy dossier aan voor intern gebruik (per reis)
Customer Service	Archiveert het dossier per reis per lichter in de daarvoor bestemde map

Next Step: 2.1

Appendix D

Parameters and variables

This Appendix gives all variables and parameters used in this study.

We have three objective variables, that depend on decision variables, listed later on. One main objective variable and two secondary objective variables. If the main objective is met the secondary objective variables, guide decisions to come up with better results. We come back to this in Section 4.1.1

$$K_i \in \{0,1\} \quad \text{Lateness of container } i \tag{D.1}$$
$$U_{j,k} \quad \text{Utilization rate of barge } j \text{ on trip } k \tag{D.2}$$
$$S_k \quad \text{Duration of trip } k \tag{D.3}$$

This list give a set of parameters, which is set information:

$$P_i \in \mathcal{T} \quad \text{Pick-up terminal of container } i \tag{D.4}$$
$$D_i \in \mathcal{T} \quad \text{Destination terminal of container } i \tag{D.5}$$
$$p_i \quad \text{Pick-up date of container } i \tag{D.6}$$
$$c_i \quad \text{Closing date of container } i \tag{D.7}$$
$$s \quad \text{Margin for pick-up and closing} \tag{D.8}$$
$$\mathcal{M} \subset \mathcal{T} \quad \text{Terminals located at the Maasvlakte} \tag{D.9}$$
$$\mathcal{T}_h \subset \mathcal{T} \quad \text{Terminals in group } h \text{ with } h = 1 \ldots 4 \tag{D.10}$$
$$A_j \quad \text{Arrival date of barge } j \text{ in Rotterdam} \tag{D.11}$$
$$L_j \quad \text{Departure time of barge } j \text{ in Rotterdam} \tag{D.12}$$
$$C_j \quad \text{Capacity of barge } j \tag{D.13}$$

This list gives an overview of the decision variables. We are able to change these data, based on decision we make:

$PP_i \in \{0, 1, 2, ...\}$	Pick-up priority of container i	(D.14)
$DP_i \in \{0, 1, 2, ...\}$	Delivery priority of container i	(D.15)
f_i	The day import container i is picked-up	(D.16)
t_i	The day export container i is turned in	(D.17)
$\mathcal{S}i_p$	Set of import containers that are planned, with corresponding terminal and priority	(D.18)
$\mathcal{S}i_\ell$	Set of import containers that are not planned yet, with corresponding terminal and priority	(D.19)
$\mathcal{S}e_p$	Set of export containers that are planned, with corresponding terminal and priority	(D.20)
$\mathcal{S}e_\ell$	Set of export containers that are not planned yet, with corresponding terminal and priority	(D.21)

Appendix E

List of scheduling and planning method

Mathematical Programming

- Linear Programming
- Goal Programming
- Integer (Linear) Programming
- Mixed (Linear) Programming
- Mixed Integer Non-Linear Programming
- Column Generation
- Branch and Bound
- Branch and Price
- Langrange relaxation
- Quadratic Programming
- Dynamic Programming

Constructive Heuristics

- Adaptive Search
- List scheduling
- Shifting Bottleneck
- Greedy methods
- Beam Search

Meta-heuristic

- Simulated Annealing
- Tabu Search
- Local Search
- Genetic Algorithm
- Other

Simulation

- Discrete-event
- Monte Carlo

Constraint programming
Queuing
Other

- Visualization
- Spreadsheet calculation
- Analytical Statistical Model
- Qualitative schedule generation
- Decision rules

Artificial Intelligence

- Rule-based methods
- Agent based methods
- Expert systems

Hybrid-methods

- Exact methods + Constraint Programming
- Exact methods + Heuristics
- Meta-heuristics + Heuristics

Appendix F

Dummy Data

This Appendix describes the dummy data sets used in Section 5.2

Type	Priority	APM	BCW	CET	COB	CTT-R	DBF	DCS-R	DDE	DDN	DDW	DRB	EMX	GEV	GROE	HMU	INT	JCM	MEDE	MEDR	MRS	PCS	PRO	RCT-R	RSTN	RSTZ	STE	UCT	UP6	WBT	WHT
Import	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	6	0	7	0	0	0
	2	0	0	0	0	6	0	0	6	24	11	0	5	0	0	4	0	0	0	1	1	0	6	0	0	6	0	0	0	1	0
	3	20	0	0	0	6	0	0	21	24	0	0	2	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	10	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Export	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	2	10	0	0	0	6	0	0	4	10	0	0	3	0	0	0	0	0	0	0	0	0	2	19	0	0	0	2	0	0	0
	3	31	2	0	0	6	0	0	6	5	14	0	5	0	0	0	0	0	0	0	0	0	0	15	0	5	0	8	0	0	6
	4	15	0	0	0	0	0	0	0	0	12	0	2	0	0	3	0	0	0	0	0	0	9	8	0	0	0	7	0	1	0

Table F.1: Dummy data set 1

Type	Priority	APM	BCW	CET	COB	CTT-R	DBF	DCS-R	DDE	DDN	DDW	DRB	EMX	GEV	GROE	HMU	INT	JCM	MEDE	MEDR	MRS	PCS	PRO	RCT-R	RSTN	RSTZ	STE	UCT	UP6	WBT	WHT
Import	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	0	0	10	0	0	1	0	0	6	0	7	0	0	2
	2	0	0	4	0	0	0	0	0	0	2	0	5	0	0	4	0	0	0	2	1	0	6	0	0	6	0	0	0	0	12
	3	2	2	5	0	0	0	0	0	4	0	0	2	0	0	13	0	0	0	3	0	1	7	2	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Export	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	5	11	0	0	0	0	10	0	0	0
	2	5	0	0	0	0	0	0	4	3	0	0	3	0	0	0	0	0	0	0	0	0	2	9	0	0	0	0	0	0	0
	3	3	2	0	0	0	0	0	6	5	5	0	5	0	0	0	0	0	0	16	0	0	0	0	0	2	0	3	0	0	6
	4	7	0	0	0	0	0	0	0	0	3	0	2	0	0	7	0	0	0	0	0	0	9	8	0	0	0	14	0	1	0

Table F.2: Dummy data set 2

Type	Priority	APM	BCW	CET	COB	CTT-R	DBF	DCS-R	DDE	DDN	DDW	DRB	EMX	GEV	GROE	HMU	INT	JCM	MEDE	MEDR	MRS	PCS	PRO	RCT-R	RSTN	RSTZ	STE	UCT	UP6	WBT	WHT
Import	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	24	0	0	11	0	0	12	0	0	7	0	8	0	0	10
	2	0	0	4	0	16	0	0	0	0	2	0	25	0	0	4	0	0	0	12	1	0	6	0	0	6	0	10	0	0	12
	3	2	2	5	0	6	0	0	0	4	0	0	2	0	0	32	0	0	0	3	0	1	7	2	0	0	0 v0	0	0	0	
	4	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
Export	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	5	11	0	0	0	0	10	0	0	0
	2	5	0	0	0	6	0	0	4	3	0	0	3	0	0	0	0	0	0	0	0	0	2	19	0	0	0	0	0	0	0
	3	3	2	0	0	6	0	0	6	5	5	0	25	0	0	0	0	0	0	16	0	0	0	0	0	10	0	3	0	0	6
	4	7	0	0	0	0	0	0	0	0	3	0	2	0	0	7	0	0	0	0	0	0	9	8	0	0	0	14	0	1	0

Table F.3: Dummy data set 3

Type	Priority	APM	BCW	CET	COB	CTT-R	DBF	DCS-R	DDE	DDN	DDW	DRB	EMX	GEV	GROE	HMU	INT	JCM	MEDE	MEDR	MRS	PCS	PRO	RCT-R	RSTN	RSTZ	STE	UCT	UP6	WBT	WHT
Import	1	0	15	14	0	6	0	0	0	2	0	0	0	0	0	2	0	0	0	1	0	0	0	2	0	6	0	8	0	0	3
	2	0	0	0	26	0	0	5	0	0	11	11	16	0	0	4	0	8	0	11	1	15	6	0	21	6	0	0	9	22	0
	3	9	2	0	6	0	0	7	0	4	0	0	2	0	0	0	15	0	0	0	0	0	0	2	0	0	18	0	0	0	0
	4	0	0	0	0	0	15	0	15	0	0	0	0	7	0	0	0	0	0	0	15	0	0	6	0	0	0	0	18	0	0
Export	1	0	2	2	0	2	0	0	0	6	0	0	4	0	0	9	0	0	0	2	0	0	2	7	0	3	0	0	0	0	11
	2	5	0	0	0	0	8	5	0	0	15	11	0	9	0	0	13	0	0	13	10	0	7	0	8	0	11	0	0	10	0
	3	3	0	0	16	0	0	0	6	4	0	0	4	0	15	0	0	9	0	0	0	5	4	0	0	10	0	0	5	0	6
	4	7	4	0	0	6	0	6	2	5	4	0	3	0	0	4	0	0	0	0	0	0	1	0	0	0	0	18	3	2	0

Table F.4: Dummy data set 4

Appendix G

Practical test data

This appendix contains all data used for the practice test in Section 5.5. There are five days of data, that are presented per day. Note that the data in the tables are TEU and not number of containers. We also show how many containers, which we consider as priority 1 containers are transported by truck or have a moved pick-up or delivery date. We only give these dat for export containers, because we have seen before that the numbers on import containers does not represent reality, because it is hard to tell from the data provided whether a import container is ready to be picked-up, is planned to be picked-up by another barge, or is located on another barge and is on its way to CTT.

For the part of the test that is executed on day 1, we have no additional data, because of loss of data.

	Moerdijk	CTT-R	DDE	DDN	DDW	WHT	EMX	MEDREP	UCT-E	APM
Model (ex(in))	0(0)	0(0)	0(0)	5(10)	3(70)	0(0)	3(22)	0(0)	0(0)	93(2)
Executed (ex(in))	96(40)	6(0)	1(0)	0(0)	1(37)	0(3)	0(24)	0(2)	0(10)	0(12)
Priority 1 (ex(in))	-(-)	4(0)	0(8)	5(0)	0(10)	0(6)	0(3)	0(0)	0(0)	10(1)

Table G.1: Data from barge 1 on day 1

	GROE	BCW	HMU	CTT-R	PROGRO	UP6	RSTZ	WHT	DDE	EMX	CETEM
Model (ex(in))	0(0)	0(0)	7(0)	16(12)	0(0)	7(38)	37(16)	0(6)	0(30)	35(2)	2(0)
Executed (ex(in))	6(0)	2(2)	0(10)	109(33)	12(1)	7(0)	11(56)	0(8)	0(0)	0(0)	0(0)
Priority 1 (ex(in))	0(0)	2(2)	7(0)	4(0)	0(0)	1(0)	6(0)	0(6)	0(8)	0(3)	2(0)

Table G.2: Data from barge 2 on day 1

One priority 1 container from CETEM, DDN, DDW and UCT-E were transported by truck in solution made by the planner. This results in three terminals visits less in the planners solution than in the models solution.

For three priority 1 containers at CTT-R the closing date was moved further to the future, so they did not needed to be transported that day.

Eight priority 1 containers with destination CTT-R on the fourth day got a later closing data such that did not need to be transported that day. The same holds for three containers with destination WHT and one container from WHT was transported by truck, which results in, that WHT was not visited that day. The containers with destination RCT-R were wrongly booked,

	CTT-R	RSTZ	UCT-E	APM	DDE	DDN	DDW	EMX	RCT-R
Model (ex(in))	20(16)	9(3)	1(2)	4(12)	4(6)	1(0)	4(10)	39(20)	20(1)
Executed (ex(in))	0(0)	27(0)	0(0)	65(12)	14(1)	8(7)	9(30)	41(10)	17(14)
Priority 1 (ex(in))	0(16)	9(3)	1(2)	4(12)	4(6)	1(0)	4(10)	39(20)	0(1)

(a) Data on day 2 Part 1

	WHT	HMU	BCW	CETEM	MED-E	PROGRO	UP6	WBT
Model (ex(in))	0(0)	0(10)	0(2)	2(0)	0(2)	0(1)	0(38)	0(1)
Executed (ex(in))	7(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Proirity (ex(in))	0(0)	0(10)	0(2)	2(0)	0(2)	0(1)	0(38)	0(1)

(b) Data on day 2 Part 2

	CTT-R	RSTZ	UCT-E	APM	DDE	DDN	DDW	EMX	RCT-R	MRSTRO	HMU
Model (ex(in))	20(6)	0(23)	8(0)	29(5)	8(0)	15(2)	0(44)	6(18)	18(14)	0(0)	0(0)
Executed (ex(in))	5(6)	16(0)	19(4)	30(27)	9(19)	24(1)	1(4)	13(7)	22(0)	6(6)	0(40)
Priority 1 (ex(in))	6(6)	0(23)	8(0)	29(5)	8(0)	15(2)	0(44)	6(18)	8(14)	0(0)	0(0)

Table G.3: Data on day 3

no further transportation were needed.

	DDE	DDW	APM	DDN	RSTZ	BCW	CTT-R	CETEM	RCT-R	UCT-E	WHT	HMU	UP6
Model (ex(in))	6(24)	0(0)	0(10)	0(8)	48(0)	4(0)	5(7)	0(0)	33(4)	0(3)	8(0)	0(48)	0(0)
Executed (ex(in))	0(6)	6(13)	0(0)	0(28)	55(0)	27(0)	12(16)	3(0)	0(0)	0(0)	0(0)	2(4)	0(36)
Priority 1 (ex(in))	6(24)	16(23)	25(10)	0(8)	48(0)	4(0)	16(7)	0(0)	6(0)	0(3)	8(0)	0(48)	0(0)

Table G.4: Data on day 4

	DDE	DDW	EMX	APM	DDN	RSTZ	CTT-R	PCSA	WBT
Model (ex(in))	0(0)	16(39)	45(23)	32(10)	0(0)	0(0)	11(0)	0(22)	0(3)
Executed (ex(in))	9(18)	17(0)	24(0)	52(16)	0(1)	0(47)	0(0)	0(0)	0(0)
Priority 1 (ex(in))	6(24)	16(23)	20(12)	25(10)	0(8)	0(23)	16(7)	0(22)	0(3)

Table G.5: Data on day 4

On the fifth day several closing dates were moved. Three with destination PROGRO, one with destination UCT-E, and two with destination WHT. This results in three terminal visits less in the planners solution than in the models solution.

	RCT-R	DDN	DDE	DDW	APM	CTT-R	EMX	HMU	PROGRO	UCT-E	WHT
Model (ex(in))	19(0)	23(10)	14(34)	0(0)	12(21)	16(10)	11(7)	0(30)	6(0)	1(0)	2(0)
Executed (ex(in))	44(1)	26(0)	61(0)	1(0)	26(38)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Model (ex(in))	2(0)	0(10)	0(34)	0(0)	12(21)	0(10)	0(7)	0(30)	6(0)	1(0)	2(0)

Table G.6: Data on day 5

Appendix H

Required Bookings Information

This Appendix describes the data needed at different points in the bookings flow at CTT.

The minimum information needed to book an order is:

- customer
- shipping company
- container number
- container type
- pick-up reference (PIN-number)
- pick-up and delivery location
- pick-up date and time

The minimum information needed to plan a container is:

- customer
- container type
- container dimensions
- container weight
- pick-up and delivery location
- pick-up and delivery date and time

The minimum information needed to ship is:

- customs forms
- permission forms to handle the container
- seal number
- closing time
- detention time
- demurrage time

Appendix I

List of Terminals

Naam	Port	Abbreviation 1	Abbreviation 2
APM Terminal	Maasvlakte	APM	-
BCW Waalhaven	Waalhaven	BCW	-
CETEM III	Botlek	CETEM	-
Cobelfret Ferries	Botlek	COBELRO	-
CTT Rotterdam B.V.	Botlek	CTTROT	CTT-R
Delta Barge Feeder	Maasvlakte	DBF	-
DCS Delta	Maasvlkate	DCSROT	DCS-R
DDE Delta	Maasvlakte	DDE	-
DDN Delta	Maasvlakte	DDN	-
DDW Delta	Maasvlakte	DDW	-
DRB Hartelhaven	Maasvlakte	DRB	-
ECT Euromax Terminal	Maasvlakte	EMX	-
Broekman Project Service	Waalhaven	GEVELCO	-
Groeneboom Ridderkerk Containertransferium	-	GROERID	GROE
ECT City Terminal Rotterdam	Eemhaven	HMU	-
Interforest Terminal Rotterdam B.V.	Eemhaven	INTERO	-
J.C. Meijers	Waalhaven	JCMERO	-
Medrepair	Waalhaven	MEDREP	-
Medrepair Eemhaven	Eemhaven	MEDEEM	MED-E
Mainport Rotterdam Service B.V.	Waalhaven	MRSTRO	-
PCS Depot A	Eemhaven	PCSA	-
Progeco	Eemhaven	PROGRO	-
RCT Hartelhaven	Waalhaven	RCTROT	RCT-R
RST Noordzijde	Eemhaven	RSTNOORD	RSTN
RST Zuidzijde	Eemhaven	RSTZUID	RSTZ
Steinweg	Eemhaven	STEIRO	-
UCT Eemhaven	Eemhaven	UCTEEM	UCT-E
Uniport 6	Waalhaven	UP6	-
Waalhaven Botlek Terminal	Botlek	WBT	-
Waalhaven terminal	Waalhaven	WHT	-

Table I.1: All terminals used in this study

Appendix J

Multi Criteria Priority Determination for Containers

This Appendix describes a method to determine priorities of container based on multiple criteria.

It is important to determine to which extent certain criteria are important. A hierarchy for the criteria is desirable. A possible method to do so, is an adjusted form of *Saaty's Analytic Hierarchy Process* (AHP) [Saaty and Shang, 2011]. This method is developed to make a comparative assessment between two options. In this study, parts of AHP are used to determine priorities of containers.

Within the AHP method all criteria are weighted generally, by doing pairwise comparison of all combinations of criteria. In our case we rate criteria related to containers. This means that for every two criteria (*Criterion a* and *Criterion b*), a relative preference must be given on a scale from -3 tot 3. -3 means that *Criterion a* is of more importance than *Criterion b* and vice versa. 0 means that both criteria are of equal importance. This comparison can be executed by multiple persons, chosen by CTT. From these comparisons, a hierarchy of criteria is given, e.g.,:

Criterion a: 70%

Criterion b: 25%

Criterion c: 5%

So *Criterion a* is generally more important than *Criterion b*. The next step is to assign a score to each container based on the criteria. Each container is weighted per criterion on a scale from 1 to 5. 5 means that a containers scores high on that criterion and 1 means low. A container that has its closing tomorrow will score higher on shipment urgency than a container that has its closing next week. The total score of container is calculated as follows:

$$\text{Total score of container} = \sum_{Criteria\ i} Weight\ of\ criteria\ i * score\ of\ container\ c\ on\ criteria\ i \tag{J.1}$$

The container with the highest score gets priority 1 (most important), the container with the second highest score gets priority 2 (second important) and so on. Containers with the same score get the same priority. It is also possible to group scores and ascribe a priority to it.

Figure J.1 gives an schematic overview of the priority determination process. First all criteria are ranked, after that all containers are ranked per criterion, which results in a score. Based on the score, priorities are assigned.

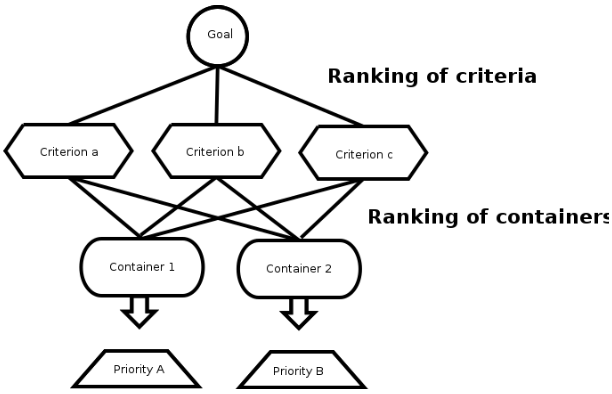


Figure J.1: Overview of priority determination based on AHP