Master Thesis of Industrial Engineering and Management

Track: Production and Logistics Management

Decision support for matching import and export flows of hinterland container transportation

TEUbooker hinterland

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MANAGEMENT SUMMARY

The total growth in throughput of the Port of Rotterdam is still increasing, which requires improved performance of hinterland transportation. Hinterland container logistics is becoming increasingly important since it is the most costly part of container transportation, covering 40-70% of the total transport costs. Additionally, arising problems related to congestion and pollution, due to excessive truck use, and new environmental regulations force the transport world to a modal shift.

TEUbooker wants to contribute to this sustainable transportation and developed an online booking platform where supply and demand of the container logistics come together, TEUbooker hinterland. Their aim is to reduce truck transportation between deep-sea terminals and the European hinterland and stimulate re-use and better planning of equipment by matching import and export flows. These objectives overlap in the fact that the matching of import and export flows reduces the empty movements between deep-sea terminals and the European hinterland. Additionally, matching can result in improved turnaround time and capacity utilization of barge operators, decreasing the overall cost of transport and making barge transportation more attractive. This might result in a modal shift away from truck transportation.

The main research question addressed in this report is: *How can we add decision support to TEUbooker for the matching of import and export flows, improving the performance of hinterland container transportation?*

The proposed solution algorithm matches import and export flows based on transport reference, container type, container owner, release location, loading location and date, and return location. The objective of the algorithm is to minimize the total cost of fulfilling all requests, by reducing empty movements and matching import and export flows. The total costs consist of transport costs, relocating costs, storage costs and detention costs. This research only considers street turns, which is the direct transportation between import and export clients, and no container substitution is allowed.

Performance of the algorithm is checked based on travel costs, travel distance (km), empty distance (km), and cost savings, with a time window of zero. The matching algorithm results in an 3.07% and 14.59% decrease in total and empty distance respectively, compared to the total and empty distance without matching. Additionally, the matching algorithm results in a 2.70% decrease in total cost of fulfilling all requests.

A sensitivity analysis on the solution algorithm demonstrate how different input values influence the performance of the matching algorithm. Experiments related to distance show that matches are generally made between import and export clients closely located to each other, and not a lot of distance is covered

for relocating an empty import container. Experiments related to time windows demonstrate that the larger the reuse time window, the more savings can be achieved. However, detention costs are incurred after three days and are relatively high. Experiments demonstrate that increasing the time window even more than 3 does not have a significant impact on the total cost of fulfilling all requests. This indicates, that even though increasing the time window more than 3 should result in a higher probability of matching import and export requests, the additional cost savings are not higher than the detention costs which are incurred after three days, and the number of matches made do not increase. The percentage decrease in total distance and empty distance due to matching with a time window of 3 is 10.75% and 42.23% respectively. The percentage decrease in total cost of fulfilling all requests is 8.83%.

On the other hand, experiments show that the reuse premium, which need to be paid for every match made between an import and an export request, does not influence the performance of the matching algorithm. However, container restrictions, which container types can be matched, do influence the performance of the matching algorithm. Experiments show that in general, less container restrictions lead to more matches made and increased cost savings. Finally, the highest savings are achieved when the import/export ratio decreases, because in a perfect world each export request is fulfilled using an empty import container. Experiments with a time window of zero demonstrate that an import/export ratio of 50:50 results a 6.75% and 22.13% decrease in total and empty distance respectively. The percentage decrease in total cost of fulfilling all requests is 6.75%.

The current algorithm needs several improvements the make it useful for TEUbooker. One of the biggest limitations of this research is that the algorithm is tested only using truck transportation and input values provided by one deep-sea carrier. Before implementation in TEUbooker hinterland, the algorithm should be able to deal with all three modalities and cost structures of multiple operators.

Further research is needed to gain insight into the possibility of container substitution and the use of depot direct, where inland depots are used for temporary storing. However, in reality data changes continuously and the matching algorithm should run every once in a while, to be able to deal with changed data. Additional research must be conducted to check what planning horizon results in an optimal performance.

This research demonstrates that the proposed matching algorithm has the potential to become a decision support tool that assist TEUbooker in planning and scheduling the import/export requests at several operators. This research is interesting for all deep-sea carriers, operators and other transport companies, who need to transport several import and export requests between deep-sea terminals and the European hinterland. The proposed solution algorithm provides insight in which request to match to achieve cost savings and minimize empty container movements, improving turnaround time, total costs and performance of hinterland container transportation.

PREFACE

In 2012, I started as a student at the University of Twente with the Bachelor of International Business Administration. During my bachelor, I made a lot of new friends, not only in my study program but also with sports, work and being a board member at T.C. Ludica. After three years, I finished my bachelor and decided to do the master Industrial Engineering and Management. During my masters, I choose to go a semester abroad at Lappeenranta University of Technology in Finland, Lappeenranta. One of the best decisions I made. I experienced some amazing trips and met friends for a lifetime. However, coming back, I had to face reality and start with my master graduation assignment.

Before I started my graduation assignment my knowledge about hinterland transportation was quite limited and throughout the process I learned a lot. I am grateful that I could do my Master Thesis at Cofano. Because of their attitude, enthusiasm and collegiality I have had a great time.

In my years at the university, I have always struggled with doing scientific research and I was always more interested into the practical side of problems. With my research at Cofano and TEUbooker, I believe I got to combine both sides. I want to thank the people who made it possible for me to finish this thesis, and thank them for their trust, patience and enthusiasm. In particular I want to thank by supervisors for their guidance and advice. Martijn Mes for helping me with the scientific aspects and supporting me throughout the process. Marco Schutten, for checking the final paper and helping me improving it to the next level. I would like to thank my supervisor at Cofano, Leon de Vries, for helping me setting the right direction of the research.

Finally, I would like to thank my roommate for helping with my thesis and listening to all of my complaints. Furthermore, friends, fellow students and family: thanks for encouraging me and being there during my student life.

Anna Kim Hiddinga

CONTENT

DEFINITIONS

Cargo rotation	The container is taken full to the client during the import journey, then it is taken empty to the export client, refilled and returned full to the port or the inland port.
Client/consignee	The person to whom the goods are supposed to be delivered. In most cases the consignee is the buyer of the goods but could also be the agent nominated by the buyer or the buyer’s bank.
Depot direct	An empty container can be stored, maintained and interchanged at off dock container depots before transported to the export client.
Hinterland transport	The movement of containers from a sea port to the hinterland (inbound) and vice versa (outbound).
Intermodal transport	The movement of goods in one and the same loading unit or vehicle by successively using various modes of transport (road, rail, water) without any handling of the goods themselves during transhipment between modes (Zhang & Pel, 2016).
Operator/carrier	The company transporting containers.
Round trip (RT)	For import flows, the container is unloaded from the vessel and taken full to the consignee, unloaded and then returned empty to a depot in the port where it was unloaded or vice versa for export flows.
Single trip (OW)	For import flows, one-way transportation to the hinterland or vice versa for export flows. Where an inland depot serves as a hub from where an empty container is taken and to which it is returned.
Street turn	An empty container is directly moved from local consignee to local shipper.
Synchromodality	Improvement of intermodal transportation, aiming at the integration and cooperation among transport services and modes, in order to give the service operators more possibilities to provide better transport alternatives to the shippers by utilising multiple services of multiple modes (Zhang & Pel, 2016).
TEU	Twenty-feet Equivalent Unit. Refers to the capacity of a container ship (barge and sea), where one TEU is a container with a length of 20 feet

CHAPTER 1

INTRODUCTION

The traffic of containers has grown exponentially in the last decades, therefore it is crucial to make effective decisions regarding the container transport (Fazi, Fransoo, & Van Woensel, 2015). This growth has put increasing pressure on hinterland transportation. Currently, shippers and freight forwarders lack time to map all transportation possibilities in detail and do not have the possibility to make bookings online. The goal of TEUbooker is to simplify the booking of container transportation, making it more transparent, efficient and less time consuming. They believe that the easier the booking process for shippers, the more cargo a port will attract. Therefore, they developed an online booking platform to match demand of shippers with available capacity of truck, barge and train operators. This online booking platform can also be seen as an electronic transportation marketplace; *'an internet-based mechanism that matches buyers and sellers of transportation services, with claims of reducing the administrative costs of transportation procurement to virtually nothing'* (Golsby & Eckert, 2003).

The electronic platform provided by TEUbooker represents an online distribution channel, where supply and demand come together, utilizing unused capacities of all transport modes to maximize exchange possibilities and reduce transportation costs. The online platform links supply and demand in an innovative way and supports TEUbooker in the further optimization of transportation between deep-sea terminals and the European hinterland, providing a synchromodal solution for the container logistics.

Figure 1.1 shows an example of synchromodal transportation from the Port of Rotterdam to the hinterland. As can be seen, there are three different options to get the container from A to B: 1) complete truck transportation from the Port of Rotterdam to the import client, 2) barge transportation to the inland terminal and truck transportation to cover the final miles to the import client and 3) train transportation to the inland terminal and again truck transportation to the import client. However, option 2 and 3 are only possible when the inland terminal contains a water- or rail connection with the Port of Rotterdam, since it depends on existing water- and railways. The online platform provided by TEUbooker shows all possible transportation options from A to B provided by different operators. Shippers, who want to transport a container, can see all possible transportation options offered by operators to the preferred destination, including modality, costs and delivery time.

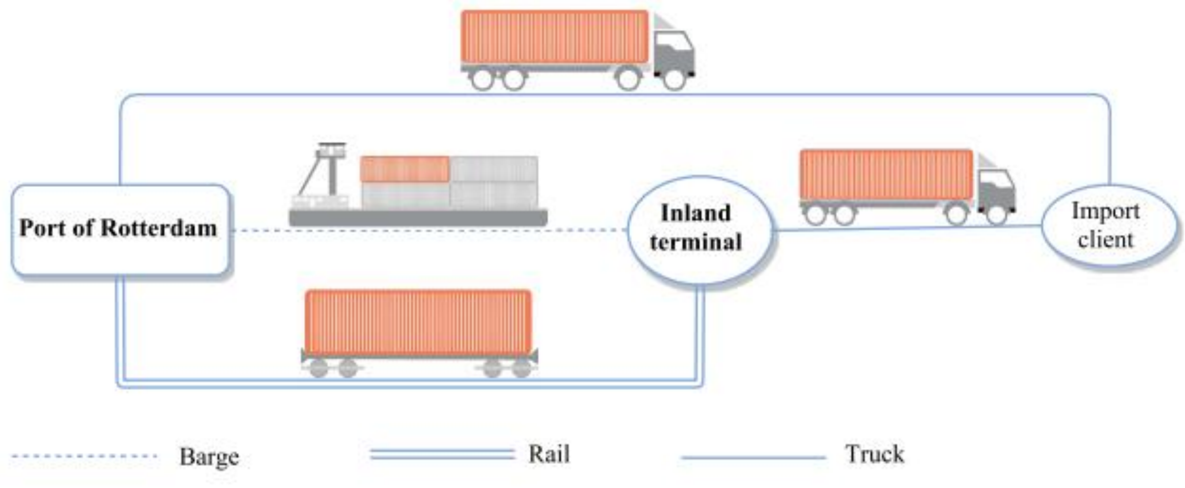

Figure 1.1 - Synchromodal transportation

In 2016, TEUbooker was introduced within the Port of Rotterdam for transhipment, and barge and train operators responded positive to this solution. The ambition of TEUbooker is to continuously improve the booking of container transportation for all concerned parties. The Port of Rotterdam is the largest of Europe and ranked in the top 10 largest ports in the world. To remain competitive and be able to deal with the anticipated growth, it is important for the Port of Rotterdam to improve its hinterland accessibility. Requirements of a successful and competitive hinterland transportation service are the ability to be cost-effective and reliable, and have a short transit time (Visser, Kronings, Pielage, & Wiegmans, 2007).

Once a container arrives at a deep-sea terminal, it most often still has a long journey ahead to the hinterland by barge, truck or train (as explained in Figure 1.1). Hinterland transportation is becoming increasingly important and is gaining interest due to its high costs and the increasing issues regarding pollution and congestion, caused by the excessive use of truck transportation (Van Schijndel & Dinwoodie, 2000). TEUbooker hinterland focusses on this part of the container logistics, the transportation of containers between the Port of Rotterdam to the European hinterland.

With TEUbooker hinterland the focus is on further optimizing the hinterland container logistics, making it more sustainable while minimizing the total costs of hinterland transportation. TEUbooker's aim is to reduce truck transportation between deep-sea terminals and the European hinterland and stimulate re-use and better planning of equipment by matching import and export request, considering empty container reuse and reducing the amount of empty container movements in TEUkm. In this thesis, a research is conducted on how to achieve these objectives and improve the online booking platform provided by TEUbooker.

Section 1.1 describes the problems tackled in this research. Section 1.2 discusses the research question contributing to the overall research goal.

1.1 Problem statement

The problems related to hinterland transportation and the motivation for this research are described in Section 1.1.1. The goal and scope of the research are described in Section 1.1.2 and Section 1.1.3 respectively.

1.1.1 Problem description

This section introduces the objectives of TEUbooker and the motivation for this research.

The exponential growth of the container logistics comes with several problems. First of all, due to excessive use of truck transportation, problems related to pollution and traffic congestion arise (Van Schijndel & Dinwoodie, 2000). New environmental regulations force the transport world to a modal shift from truck transportation towards barge or train transportation. This modal split is necessary to be able to deal with the growing container logistics. The Port of Rotterdam aims to achieve a modal split of 45% barge, 35% truck and 20% train transportation in 2035 (Port Authority Rotterdam, 2011). According to Konings, Kreutzberger, & Maras (2013), achieving such a modal split requires consistently high performance from barge services transporting containers to the hinterland.

TEUbooker wants to contribute to this sustainable transportation and developed an online booking platform where supply and demand of the container logistics come together. Shippers can make booking requests and operators can accept and schedule the requests themselves. With this online platform, TEUbooker aims to reduce truck transportation between deep-sea terminals and the European hinterland. Additionally, TEUbooker also aims to stimulate re-use and better planning of equipment by matching import and export request and considering empty container reuse. Figure 1.2 shows that when no matching occurs between import and export requests, a lot of empty container movements arise between the deep-sea terminal and inland clients. However, when considering empty container reuse and matching import and export requests, the number of empty movements decreases.

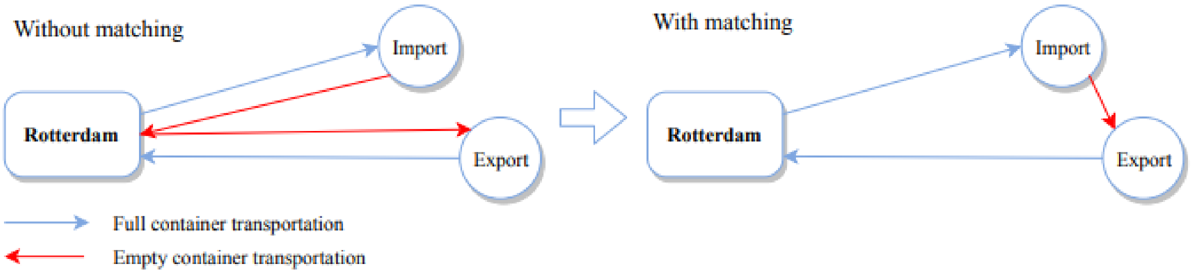

Figure 1.2: Matching of import and export request

According to Shintani, Imai, Nishimura, & Papadimitriou (2007), 40% of the hinterland transportation consists of empty container movements. Additionally, Jula, Chassiakos, & Ioannou (2006) state that barge capacity is best utilized when carrying loaded containers. TEUbooker's objectives overlap in the fact that the matching of import and export flows, reduces the empty movements between deep-sea terminals and the European hinterland. Additionally, matching can result in improved turnaround time and capacity utilization of barge operators, decreasing the overall cost of transport and making barge transportation more attractive. This might result in a modal shift away from truck transportation.

Figure 1.3 contains the amount of loaded and empty containers transported in the Netherlands per year in millions TEUkm. Table 1.1 shows the amount in numbers and as can be seen, the percentage of empty container movements in TEUkm stays relatively the same throughout the years (Eurostat, 2016).

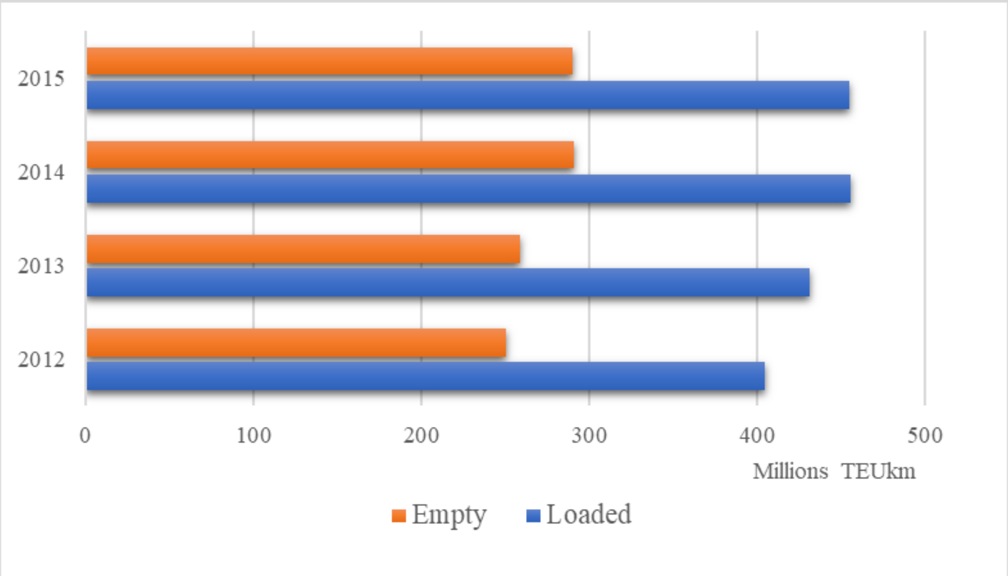

Figure 1.3: Statistics on container transport in the Netherlands (Eurostat, 2016).

	2012	2013	2014	2015
Loaded (x1000 TEUkm)	404,508	430,748	455,370	454,718
Empty (x1000 TEUkm)	250,119	258,690	290,955	290,255
Total (x1000 TEUkm)	654,627	689,438	746,325	744,973
% Empty movements	38.21%	37.52%	38.99%	38.96%

Table 1.1: Statistics on container transport flows in the Netherlands (Eurostat, 2016).

Concluding from Table 1.1, the share of empty container movements in TEUkm of the total movements is around 40%. Considering this large share of hinterland empty container movements, container reuse would be a cost-effective solution. Additionally, the huge amount of empty container transportation contributes to congestion and pollution problems. A small percentage of reduction in empty container movements can result in improved operational costs and a significant reduction related to congestion and pollution. Supporting this, Chang, Jula, Chassiakos, & Ioannou (2008) state that empty container reuse can lead to a significant decrease in the number of truck trips and the associated costs.

To optimize their platform, TEUbooker wants to match import and export flows by reusing empty import containers. Keeping the modal shift in mind and the objective to improve capacity utilization of barge operators, the focus of this research is on improving hinterland transportation, by reducing unnecessary transport movements of empty containers, creating shorter turnaround, optimizing equipment utilization and consequently improve environmental sustainability and reduce cost of hinterland transport.

Different types of trips are important to consider when matching import and export flows and multiple issues need to be taken into account concerning empty container reuse: import/export timing, location mismatch, ownership mismatch, container type mismatch and legal issues (Jula et al., 2006). Additionally, the cost of container repositioning and storing need to be considered, as well as detention and demurrage[1], which is explained later in more detail.

To goal of this research is to provide decision support to TEUbooker in the matching of import and export flows to further optimize the hinterland container logistics. The provided solution should take all relevant issues related to import and export matching into consideration and reduce unnecessary empty container movements. Therefore, the core problem addressed in this research is:

How can TEUbooker optimize their online platform and improve overall performance of hinterland container transportation, adding decision support regarding the matching of import and export flows.

[1] Detention and demurrage are the "penalty" costs for late return and late pickup of a container at the deep-sea terminal, charged by the container owner to the client/consignee.

1.1.2 Research goal

To contribute to an improved performance and increased environmental sustainability of the hinterland container logistics, TEUbooker aims to reduce truck transportation between deep-sea terminals and the European hinterland and stimulate re-use and better planning of equipment by reusing empty containers and matching import and export flows. These objectives overlap in the fact that empty container reuse provides a mean to reduce truck transportation between deep-sea terminals and the European hinterland. Additionally, reusing empty import containers can result in improved capacity utilization of barge operators, since capacity is best utilized when carrying loaded containers. making the container logistic more environmental sustainable while minimizing overall costs. This report focusses on the empty container movements and how the matching of import and export flows can improve performance of hinterland transportation. Therefore, the goal of this research is to add decision support to TEUbooker for matching import and export flows of hinterland transportation movements, improving the performance of hinterland container transportation.

1.1.3 Scope

The port of Rotterdam has an extensive intermodal network of rail, road and waterways. These ensure that cargo can easily and efficiently flow from the port of Rotterdam to the European hinterland. Barge and train operators transporting to the European hinterland have fixed routes, time schedules, and capacities. In this research, the focus is on the operational level, since the strategic decisions regarding the hinterland transportation, such as terminal and depot locations cannot be influenced. TEUbooker is not involved in the decision making of operators and shippers, but only provides a service for matching supply and demand regarding the hinterland container logistics as efficiently and effectively as possible.

The decision support model consists of an algorithm for matching supply and demand in such a way that it minimizes total cost of transport, both by maximizing capacity utilization and minimizing travelling distance.

For this research and the implementation of the solution method in the TEUbooker platform, the assumption is made that the long-haul decision is fixed. This means that transport from the port of Rotterdam to the inland terminal is done using barge transportation. The focus in this research is on the unnecessary movements of empty containers, related to import and export flows. The reason for the focus on the unnecessary movements of empty containers is that it can improve the performance of hinterland transportation relating to turnaround time, equipment utilization and environmental sustainability.

Minimizing the empty container movements, in terms of distance, can be achieved by matching import and export request and considering empty container reuse. This matching is generally done within in the first and last miles, between inland terminals and clients, and vice versa.

Truck transportation and/or barge transportation can be used to relocate empty containers from the inland depot to the pick-up destination, depending on the distance to travel. However, it should be considered that barges are not as fast and flexible as trucks since barges need waterways to move and terminals for docking. Truck transportation is the fastest and most flexible transportation modality, compared to barge and train transportation. Where barges and trains need existing water- and railways, trucks do not. Additionally, the departure times of barges and trains are more or less fixed.

Therefore, this research assumes that relocating an empty container from an import client to an export client is done using truck transportation.

1.2 Research questions

To achieve the goal of this research as described in Section 1.1.2, the main research question addressed in this report is:

How can we add decision support to TEUbooker for the matching of import and export flows, improving the performance of hinterland container transportation?

To be able to answer this main question, five research question are constructed. The first question, discussed in Chapter 2, focuses on the current situation of hinterland transportation and describing how hinterland transportation is currently organized. Chapter 3 discusses the second research question and is related to academic literature, to gain insight into different hinterland transportation scheduling processes and to help set up a model. Additionally, a solution method for the problem should be defined and knowledge about the implementation of the methodology should be gained. Based on the literature review, the next step is to set up a solution method that supports TEUbooker in matching import and export flows of containers. This is done with the help of the third research question and is discussed in Chapter 4. The fourth research question, addressed in Chapter 5, is related to the testing of the solution method and performing experiments to evaluate the solution method.

The final chapter, Chapter 6, includes the discussion and recommendations for implementation of the solution method in the TEUbooker platform and further research. The appendices contain the additional background information, which might be referred to throughout the thesis.

Chapter 2: Describing the current situation of hinterland container logistics.

1. *What is the current process for hinterland container logistics and how does TEUbooker influence this?*
   1.1. *What is the current and expected situation of hinterland transportation?*
   1.2. *What is the current booking and scheduling process of hinterland transportation?*
   1.3. *What is the concept of TEUbooker and how does it improve the hinterland container logistics?*
   1.4. *Which situation (use cases) of hinterland transportation should be supported?*
   1.5. *What key performance indicators are relevant to assess the performance of hinterland container logistics?*

Chapter 3: Describing what is known from literature about hinterland container logistics.

2. *What is already known from the literature about hinterland transportation?*
   2.1. *What is known about empty container management?*
   2.2. *What aspects need to be considered when implementing empty container reuse?*
   2.3. *Which solution methods can be used to solve the empty container allocation problem?*

Chapter 4: Suitable decision support algorithm for matching import and export requests within the hinterland container logistics (related to planning/assigning request).

3. *How can the online booking platform be supported?*
   3.1. *Which output, and requirements should the solution method have?*
   3.2. *What approach can be used to come to the required output/proposed solution?*
   3.3. *What is a suitable model for import/export matching in hinterland container logistics?*

Chapter 5: Testing and evaluating the solution method.

4. *Which settings should be used to optimize performance of the decision support algorithm?*
   4.1. *What experimental setup can be used to verify performance of the proposed solution?*
   4.2. *Which experiments can be used to test the quality of the solution method?*
   4.3. *How does the proposed solution method perform in terms of key performance indicators?*
   4.4. *What are the advantages and disadvantages of the solution method?*

CHAPTER 2

CURRENT SITUATION

This chapter discusses the current situation of the hinterland container logistics and introduces the concept of TEUbooker hinterland. First an introduction of hinterland container transportation and the current booking and scheduling process with respect to hinterland transportation is discussed in Section 2.1. The platform created by TEUbooker and how it influences the process of hinterland container logistics is discussed in Section 2.2. Section 2.3 discusses several use situations which often occur within hinterland container transportation. Finally, Section 2.4 describes the key performance indicators relevant for the evaluation of the solutions method.

2.1 Hinterland transportation of containers

The Netherlands can be seen as a trading company, since a lot of goods are transported through the country to the European hinterland. The Netherlands has an extensive network of inland waterways and railways, and together with Belgium it is one of the countries with the highest share of barge transportation (CBS Statistics Netherlands, 2015). This supports the importance of having major transit ports, such as Rotterdam and Antwerp nearby. According to Eurostat (2016), in 2015 Belgium, Germany and the Netherlands together represented over 93% of the total loaded movements and 95% of the total empty movements of containers in the EU. According to the progress report of Port Authority Rotterdam (2016), the volumes moving from the Port of Rotterdam to the European hinterland in 2015 were as follows: 4,481 km truck transportation, 3,042 km barge transportation & 884 km train transportation (x1000 TEU) (Port Authority Rotterdam, 2016).

Figure 2.1 shows the volumes moving from the Port of Rotterdam to the European hinterland over the years 2010-2015.

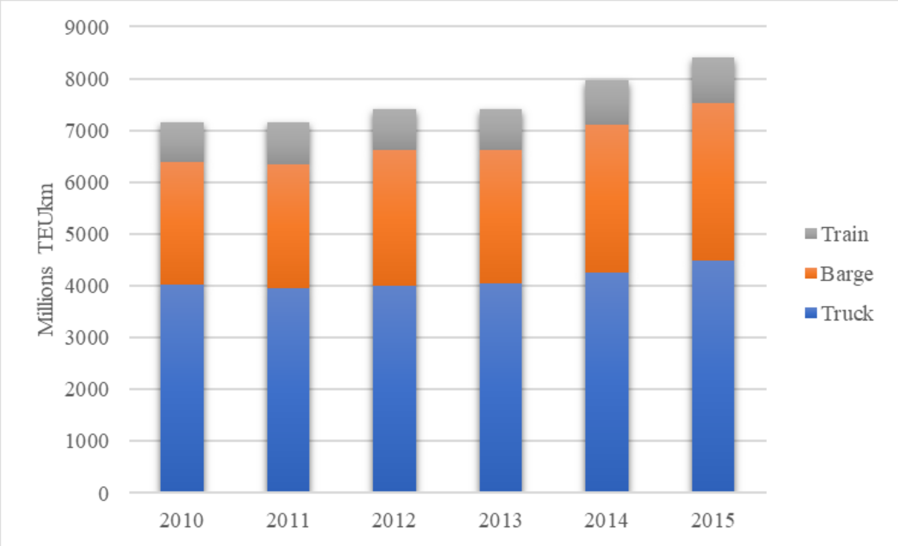

Figure 2.1: Modal split hinterland container transport (Port Authority Rotterdam, 2016).

	2010	2011	2012	2013	2014	2015	Increase
Truck (x1000 TEUkm)	4,030	3,951	3,998	4,039	4,262	4,481	10%
	56%	*55%*	*54%*	*55%*	*53%*	*53%*	
Barge (x1000 TEUkm)	2,361	2,393	2,613	2,572	2,846	3,042	22%
	33%	*33%*	*35%*	*35%*	*36%*	*36%*	
Train (x1000 TEUkm)	759	818	794	790	870	884	14%
	11%	*11%*	*11%*	*11%*	*11%*	*11%*	
Total (x1000 TEUkm)	7,150	7,162	7,405	7,401	7,978	8,407	15%

Table 2.1: Modal split hinterland container transport (Port Authority Rotterdam, 2016).

Table 2.1 shows the amount of TEU transported from the Port of Rotterdam to the hinterland per year, for each modality. From 2010-2015 the transport volumes slowly changed with 22% increase of barge transportation, 14% increase of train transportation and 10% increase of truck transportation. The total growth in throughput of the Port of Rotterdam towards the European hinterland is approximately 15%. This continuous growth in throughput (Figure 2.1) of the Port of Rotterdam, requires improved performance of the hinterland transportation. Table 2.1 shows that the percentage of truck transportation slowly decreases, whereas the percentage of barge transportation slowly increases.

Fazi et al. (2015) define hinterland transportation as *'the movement of containers from a sea port to the hinterland (inbound) and vice versa (outbound)'*. When a container arrives at the deep-sea terminal, it typically has to continue to the European hinterland, where inland terminals connect the Port of Rotterdam and the shippers through truck, barge and train connections. The process of this hinterland transportation is usually that the container is loaded on a truck, barge or train, and transported to the hinterland terminal, unloaded and returned to the deep-sea terminal or an inland depot. This transportation process can be done by one modality or a combination of modalities.

Hinterland transportation is becoming increasingly important for several reasons. First of all, it is considered to be the most costly part, covering 40-70% of the total container transportation costs (Fazi et al., 2015). Additionally, the excessive use of truck transportation between deep-sea terminals and the hinterland result in congestion and pollution problems. These drawbacks and new environmental regulations encourage authorities to promote the use of alternative modalities, such as barge and/or train transportation, to improve the environmental sustainability and generate economies of scale. The goal for 2035 is to achieve a modal split where 35% is transported by truck, 45% by barge and 20% by train (Port Authority Rotterdam, 2011).

Achieving this modal shift towards alternative transportation modes requires increased performance from barge and train services. According to Caris, Macharis, & Janssens (2013), intermodal transportation can result in a shift towards more environmental sustainable transportation modes and consequently lead to less congestion, pollution and improved accessibility of deep-sea terminals. Intermodal transportation is *'the movement of goods in one and the same loading unit or vehicle by successively using various modes of transport (road, rail, water) without any handling of the goods themselves during transhipment between modes'* (Zhang & Pel, 2016). However, intermodal transportation is not able to react to dynamics related to time-varying capacities and varying compositions of freight. Additionally, intermodal transportation is not preferable when destinations are within a 300 km transport distance, which is often the case for the Netherlands. According to Zhang & Pel (2016), at shorter distances intermodal transportation cannot compete with truck transportation, because cost savings from train and barge transportation cannot compensate the extra handling cost incurred with intermodal transportation. As response, increased attention is now on the design of services and the cooperation of multiple service providers at operational level, aiming at synchronizing intermodal transportation services.

According to Zhang & Pel (2016), *'synchromodal transportation aims at the integration and cooperation among transport services and modes, in order to give the service operators more possibilities to provide better transport alternatives to the shippers by utilising multiple services of multiple modes'*. The aim of synchromodal transportation is to make more transportation decisions by service operators, resulting in decision being made real-time. Additionally, Behdani, Fan, Wiegmans, & Zuidwijk (2016) state that this increased level of integration is expected to improve the performance of the whole transportation system and result in increased utilization of transportation services.

Synchromodality aims to define an integrated service, considering the complementary characteristics of available transportation modes, combining the schedules of multiple transportation modes in such a way, that at least one transportation service is available to transport requests on time, without violating time constraints (Behdani et al., 2016).

Efficient planning methods for transportation are needed to achieve the earlier described modal split, while still meeting customer requirements for synchronizing the container supply chain and further reduction of delivery time, costs and emissions. These trends motivate the use of inland container transportation networks, with multiple transportation modalities (Van Riessen, Negenborn, & Dekker, 2013). Increasing attention is now on the design of different services and the cooperation between multiple operators at operational level, aiming at synchronizing the intermodal transport services (Zhang & Pel, 2016). However, combining multiple transportation modes increases the complexity and requires an increased level of coordination to organize the transportation flows.

Besides the focus on synchromodal transportation to achieve the modal shift, there are other options to shift the hinterland container transportation towards more environmental friendly transportation modes. As already mentioned before, such a shift is achieved by continuously high performance of barge and/or train operators. Transport performance needs to be cost-effective, reliable and have a short transit time[2].

2.1.1 Demurrage and detention

Deep-sea carriers often offer a number of free rental days, in which the container should be picked up at the deep-sea terminal, unloaded at the client, and returned to the selected empty depot (vice versa for export request) without charging. Demurrage costs are the “penalty” costs for late pick-up at the deep-sea terminal. Detention costs are the “penalty” costs for late return, charging the client for every day the container is in custody of the client or shipper outside the time frame of free rental days. Deep-sea carriers charge clients for demurrage and detention because containers only make money when they are in circulation. So, when a container is empty at the client or a nearby inland depot for several days, it will not yield any revenue for deep-sea carriers. However, when the empty container gets “assigned” to a new job, it will yield revenue.

2.1.2 Transportation modalities

Within the hinterland container logistics and the focus towards synchromodal transportation, there are several modalities to consider. This section describes the different transportation modalities, which can be used for hinterland transportation and their related benefits and drawbacks.

[2] Planned travelling time from port to port (start to end location). Depending on the transportation mode.

In general, movements from the deep-sea terminal to the inland terminal are done by barge and train, and movements from the inland terminal to the client are made by truck. However, when time is limited, truck transportation can be used to directly transport the container from the deep-sea terminal to the hinterland client, or vice versa. It is possible to have multiple movements per day, such that a container is transported multiple times per day.

For hinterland transportation, there are three modalities to consider: barge, truck and train. Truck transportation is considered to be the most flexible and quickest transportation mode (Van Riessen et al., 2013). The downside of truck transportation are issues related to pollution and congestion problems. Traffic congestion reduces mobility and system reliability and increases transportation costs (Chang et al., 2008). Additionally, congestion problems are a major source of air pollution and drivers' inefficiency.

On the other hand, barge and train transportation have much larger capacities and can create economies of scale when capacity utilization is maximized. Therefore, barge and train transportation are overall less costly. However, barge and train transportation are depending on existing waterways and rail connections, where trucks are not. This result in the fact that barge and train schedules are more or less fixed and predefined.

A longer planning horizon can encourage the use of inexpensive, slow transportation modes, such as barges (Choong, Cole, & Kutanoglu, 2002). The relatively slow speed of barge transportation requires careful consideration of the planning horizon length. If logistics managers use long enough planning horizons, barge transportation can become a viable alternative to train and truck transportation.

When looking at the current situation of hinterland container transportation, governmental regulations are forcing companies to focus on synchromodal transportation in order to achieve the modal split. The long haul of the journey, from deep-sea terminal to inland terminal, is generally done by barge or train transportation, and the final miles from inland terminal to client by truck transportation. Because of that, truck schedules are often depending on the schedule of barges and trains. This makes sense since it is the most flexible modality and thus can easily adjust to changes in barge and/or train schedules. Therefore, decision related to barge and train schedules influence the truck schedule. Table 2.2 shows an overview of the advantages and disadvantages of each modality.

	Truck	***Barge***	***Train***
Pros	Fast & Flexible	Less costly	Less costly
	Short planning	Economies of scale	Economies of scale
Cons	Costly	Slow	Slow
	Pollution & congestion problems	Depending on existing waterways	Depending on existing rail connections
		Need for longer planning	Need for longer planning

Table 2.2: Pros and cons of hinterland transportation modalities.

Concluding, truck transportation is the most expensive modality, but also the most flexible and fastest option to transport cargo between deep-sea terminals and the hinterland. On the other hand, barge transportation is the cheapest, but also the slowest transportation modality. Train transportation is somewhere in the middle, between truck and barge transportation.

2.1.3 Current booking and scheduling tools

The current booking and scheduling process with respect to hinterland container transportation is as follows: the booker has to search for different operators and call or contact them to check whether they have available capacity and time. This is often done by phone or e-mail, meaning that it takes a lot of time. Usually the booker has to wait a while for a response and when the answer is no, the process starts again.

In the current situation, shippers spend a lot of time searching and waiting, and operators spend a lot of time responding and answering all the shippers. Therefore, the administrative and procurement costs are high. To improve the container logistics, TEUbooker is developing a platform that makes this process less time consuming and more efficient, resulting in cost and time savings.

Information needed when booking an import/export request are the following:

- Pick-up and delivery location: the location where to pick up and deliver the container.
- Pick-up and delivery date:
    - Import date: the time at which the container should be picked up at the deep-sea terminal or empty depot and transported to the inland client.
    - Loading/discharge date: the time at which the container should be at the client for unloading.
    - Export date: the time at which the container should be picked up and be transported from the client to the deep-sea terminal or empty depot.
- Booking ID: number of the booking request
- Container type and number
- Client/consignee: the person to whom the goods are supposed to be delivered.
- Preferred modality: type of transport mode used (considering the long and short haul).
- Detention and demurrage time: the number of free rental days offered by the deep-sea carrier.
- Closing time: time at which the container should be returned to the selected depot.

Each operator can make his own schedule based on the bookings being made and all the information provided during the bookings. Containers are generally assigned based on pick-up or closing date, where barges and trains are first scheduled, followed by trucks. There are three different types of schedules:

1. Offline schedule: which is an initial schedule for a day, with information about resources and demand at that moment.
2. Online schedule: updated version of the offline schedule, containing the newest information.
3. Synchromodal schedule: where the schedules of truck, barge and train are depending on each other.

In general, planners first make an offline schedule (the initial schedule per day) and later the online schedule.

2.2 TEUbooker

The goal of TEUbooker is to simplify the booking of containers, increasing the ease of doing business by providing a synchromodal solution for hinterland container transportation. Unused capacity of all modalities is used, such that exchange opportunities are maximized and transport costs can decrease.

They aim to exploit the unused capacity of barge, train and truck operators, making a match between market demand and capacity of individual operators. TEUbooker aims to ensure that shippers no longer have to search for available capacity, resulting in direct and indirect savings. Direct savings are achieved by minimizing the exchange costs and indirect savings due to the more efficient booking and search process.

TEUbooker operates as third party, being the man in the middle between the shipper and the operator. Benefits for the shippers are related to time and cost savings since they do not have to contact several operators and wait for their responses. Additionally, the supply of different operators is larger. For the operator the benefits are also related to time and cost savings since they do not have to communicate with all the different shippers. Furthermore, TEUbooker creates the possibility to increase capacity utilization, because unused capacity is readily available for shippers.

2.2.1 TEUbooker hinterland

TEUbooker hinterland is an online booking platform where supply and demand for the hinterland container logistics come together. On the platform, operators can select the modality they use (truck, barge or train) and declare their available capacity, transport costs and delivery time for each one-time trip. Additionally, the operators can add several services such as cleaning. When a booker wants to transport a container from location A to location B, he can see all possible transportation options offered by different operators to the preferred destination on the online booking platform, including modality, transport costs and delivery time. The booker can select an operator and place a request. Once the booker places the request, he has to declare the type of container, including the dimensions (TEU and length) and whether the container needs cooling or heating systems during transport (e.g. reefer[3]).

The request is then accepted automatically, assuming the operator has the declared capacity and time. The operator gets a notification of this request and can schedule it himself, as long as the container is picked up and delivered in time. With TEUbooker hinterland the focus is mainly on the smaller shippers, since they usually do not have fixed contracts with operators and their cost of procurement is relatively high (Golsby & Eckert, 2003).

TEUbooker does not own any containers or modalities. They only provide an online booking platform where operators and shippers can get in touch with each other. Different partners of TEUbooker are providing the modalities and transportation possibilities.

Concluding, the goal is to simplify the booking process of containers, making it more transparent, efficient and less time consuming. TEUbooker hinterland matches supply and demand of different transport modalities, reducing the administration cost of procurement. However, TEUbooker hinterland can be improved even further when looking at capacity utilization of different modalities and the amount of unnecessary empty container movements.

2.2.2 Different type of trips

To optimize the overall performance of hinterland container logistics and decrease the amount of unnecessary empty container movements, it is important to look at the different type of trips. This section describes the difference between several types of trips.

It should be noted that inland terminals are often used as hubs to consolidate flows of containers from the hinterland to the deep-sea terminals, where shipping lines take care of the further transport. The Port of Rotterdam is used here as the deep-sea terminal, in which the containers arrive and depart to the rest of the world.

Frémont & Franc (2010) define three different types of hinterland services: roundtrips, single trips and cargo rotation. A roundtrip is defined as follows: *'for import flows, the container is unloaded from the vessel and taken full to the consignee, unstuffed and then returned empty to a depot in the port where it was unloaded or vice versa for export flows'* (Frémont & Franc, 2010). However, this results in a lot of

[3] Refrigerated container, having its own stand-alone (self-powered) cooling system

unnecessary empty container movements from and to the hinterland. Figure 2.2[4] shows an example of a roundtrip for an import request, where the container is taken full to the import client and returned empty to the deep-sea terminal, vice versa for an export request.

In reality, it can be possible that a container is taken full to the client, unloaded and refilled with new products and returned to the Port of Rotterdam or hinterland. In this situation, single trips are used instead of roundtrips. Frémont & Franc (2010) state that: *'a single trip differs from a roundtrip in that an inland depot (in the hinterland) serves as a hub from where empty containers are taken and to which they are returned'*. The distance covered by empty containers are smaller for single trips, because the distance between the client and depot is shorter. Figure 2.2 also shows an example of a single trip, where the empty container is stored in an inland depot instead of returned to the deep-sea terminal.

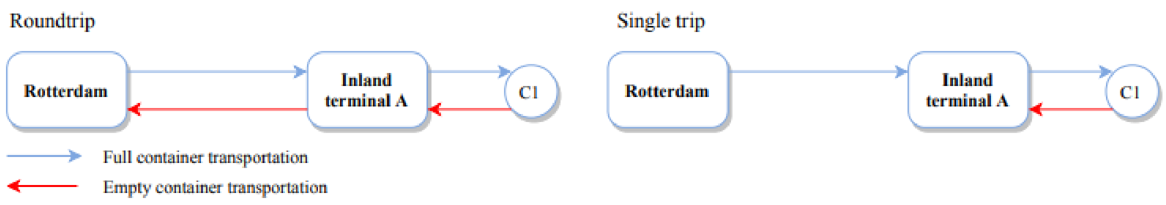

Figure 2.2: Roundtrip and single trip

Additionally, Frémont & Franc (2010) define the concept of cargo rotation where *'the container is taken full to the client during the import journey, then it is taken empty to the export client, refilled and returned full to the port or inland port'* (Frémont & Franc, 2010). Figure 2.3 shows an example of cargo rotation, where C1 represents an import client and C2 an export client. The container is taken full from the deep-sea terminal to the import client C1, unloaded and transported empty to the export client C2. At the export client C2, the container is loaded and returned full to the deep-sea terminal.

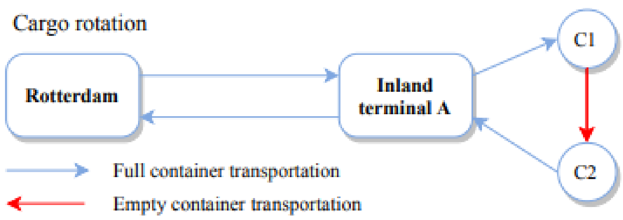

Figure 2.3: Cargo rotation

Concluding, the described types of trips influence the planning and scheduling decision of operators and are important to consider when optimizing the hinterland container logistics.

[4] Ci are the clients in the network, representing an import or export client

2.3 Empty vs loaded container flows

Finke & Kotzab (2017) state that every full container movement is generally followed by an empty container movement, where the transportation of empty containers is often unavoidable. A unique characteristic of the container logistics is, that both loaded and empty containers have to be moved and stored within the same network, using the same resources, which implies that these two supply chains are interwoven and difficult to separate (Song & Dong, 2015).

To explain the container flows in more detail, Figure 2.4 shows several cases of transport trips used for the hinterland container logistics. First, situations of a network with inland terminals and import/export clients located near the deep-sea terminal are described.

Situation 1: This situation describes intermodal transportation, where C1 represents an import client. The loaded container is transported to the import client using a roundtrip. The full container is transported from the Port of Rotterdam to the import client C1. In this situation, a barge is used to transport the container between the deep-sea terminal and inland terminal, and a truck is used for the final miles between the inland terminal and import client. Once the container is unloaded/discharged, it is returned empty to the Port of Rotterdam, or vice versa for an export request.

Situation 2: C1 represents an export client. When time is limited, or the client is within a certain distance of the deep-sea terminal, direct trucking is used to transport an empty container from the Port of Rotterdam to the export client C1. At the export client's location, the container is loaded and transported full back to the Port of Rotterdam.

Situation 3: C1 represents an import and export client within a certain time window. For both, the import request and the export request, a roundtrip is used. A full container is transported from the Port of Rotterdam to the import client C1. After unloading/discharging, the empty container is returned to the Port of Rotterdam. When the same client, C1, later files for an export request, an empty container must be transported from the Port of Rotterdam to the export client C1. Once the container is loaded, the container is transported full back to the Port of Rotterdam.

Situation 4: There are two clients in the network, an import client C1 and an export client C2, which are at different locations. The full container is transported from the Port of Rotterdam to the import client C1. At the import client's location, the full container is unloaded/discharged and returned empty to the Port of Rotterdam. On the other hand, for the export client C2, an empty container is transported from the Port of Rotterdam to the export client's location for loading and returned full to the Port of Rotterdam.

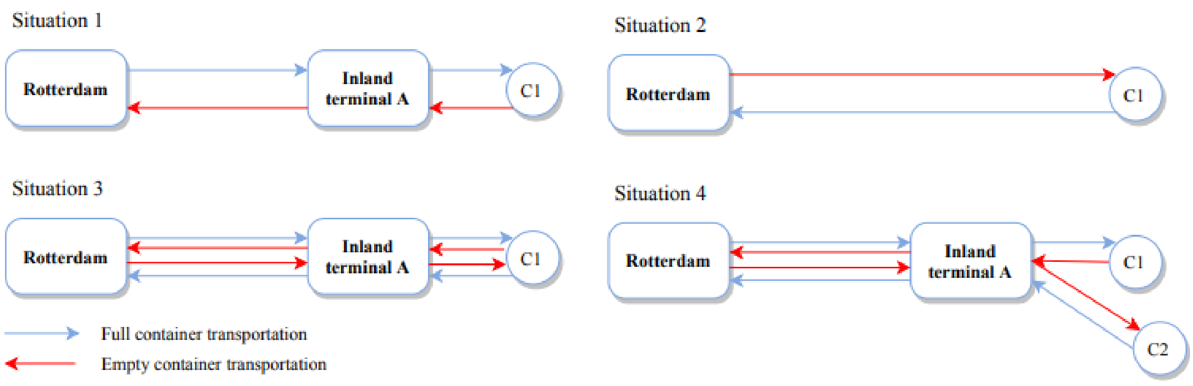

Figure 2.4: Situations before matching and empty container reuse

When looking at the described situations and considering empty container reuse and matching import and export requests, the situations change in the following ways (Figure 2.5):

Situation 1: C1 represents an import client. Again, the full container is transported from the Port of Rotterdam to the import client C1. However, once the container is unloaded/discharged, it is not returned empty to the Port of Rotterdam, but to an inland depot for temporary storage, so it can be used for a future export request. This situation describes a single trip.

Situation 2: C1 represents an export client. However, instead of using a truck to directly transport an empty container from the Port of Rotterdam to the export client C1, an empty container stored in an inland depot is used. This empty container might result from the import request described in situation 1. At the export client's location, the container is loaded and then transported full back to the Port of Rotterdam.

Situation 3: C1 represents an import and export client within a certain time window. When considering empty container reuse and matching the import and export request, there are two options.

- *Situation 3.1:* A full container is transported from the Port of Rotterdam to the import client. When the import unloading/discharging date is similar to the export loading date, the empty container resulting from the import request can directly be reused for the export request. However, this is only possible if container type match and reuse of the container is approved by the container's owner. Once the container is loaded at the export client's location, the container is transported full back to the Port of Rotterdam.
- *Situation 3.2:* A full container is transported from the Port of Rotterdam to the import client. When the import unloading/discharging data is however not similar or within a certain time window, the empty container resulting from the import request is transported to an inland depot for temporary storage, after unloading/discharging at the import client's location. For the export

request, the empty container is transported from the inland depot to the export client C1. Once the container is loaded, the container is transported full back to the Port of Rotterdam.

Situation 4: There are two clients in the network, an import client C1 and an export client C2, which are at different locations. Again, when considering empty container reuse and matching the import and export request, there are two options.

- *Situation 4.1:* A full container is transported from the Port of Rotterdam to the import client C1. When the import unloading/discharging date is similar to the export loading date, the empty container resulting from the import request can directly be reused for the export request and transported to export client C2. However, this is only possible if container type match and reuse of the container is approved by the container's owner. Once the container is loaded at the export client's location, the container is transported full back to the Port of Rotterdam.
- *Situation 4.2:* A full container is transported from the Port of Rotterdam to the import client C1. When the import unloading/discharging data is however not similar or within a certain time window, the empty container resulting from the import request is transported to an inland depot for temporary storage, after unloading/discharging at the import client's location. For the export request, the empty container is transported from the inland depot to the export client C2. Once the container is loaded, the container is transported full back to the Port of Rotterdam.

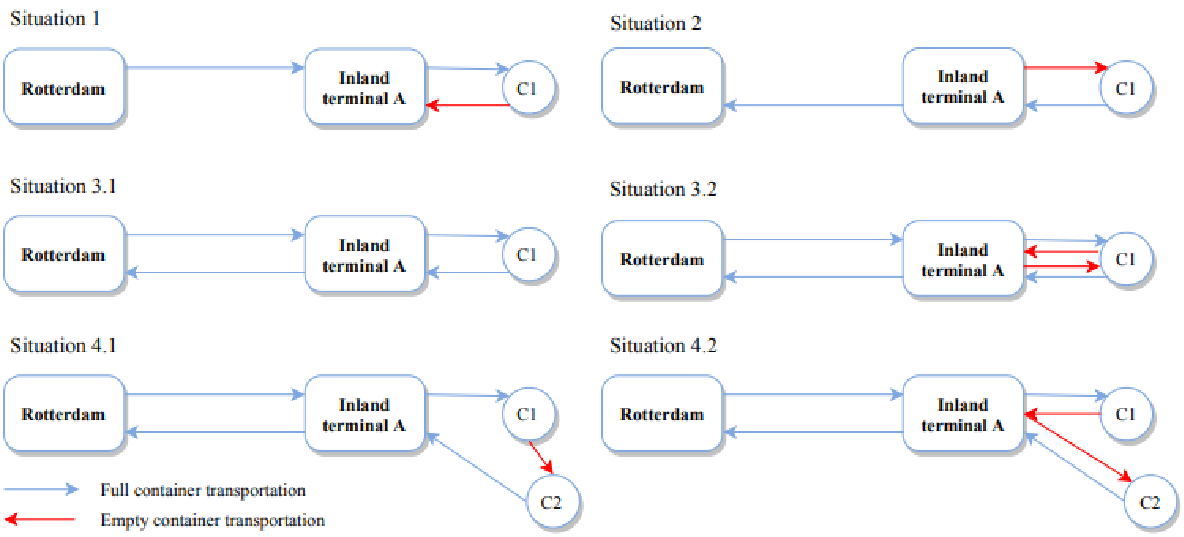

Figure 2.5: Situations with matching and empty container reuse

As can be seen, the matching of import and export requests is done in the hinterland, between inland terminals and the clients. In these situations, all repositioning of the empty container is done using truck transportation, since the geographical area between inland terminals and clients are relatively small.

When looking at a larger geographical area with multiple inland terminals and import/export clients, the network usually becomes more complex. Therefore, the situations also become more complex.

- Based on different characteristics of a request, a decision needs to be made which import and export request to match.
- Once it is decided which requests to match, a decision needs to be made whether to use cargo rotation and directly transport and empty container from the import client to the export client or use multiple single trips and temporarily store the empty container in an inland depot before transporting it to the export client.
- And if the decision is to use multiple single trips, the question remains in which inland depot to temporarily store the empty container to be efficient.

Figure 2.6 explains the situation of two inland terminals, one import client C1 and one export client C2. When not considering empty container reuse and matching the import and export request, the situations look as follows: a full container is transported to the import client C1, via inland terminal A. Once the container is unloaded/discharged at the import client's location, it is returned empty to the Port of Rotterdam. On the other hand, for the export request, an empty container is transported to the export client C2, via inland terminal B. Once the container is loaded at the export client's location, the container is transported full back to the Port of Rotterdam (Figure 2.6).

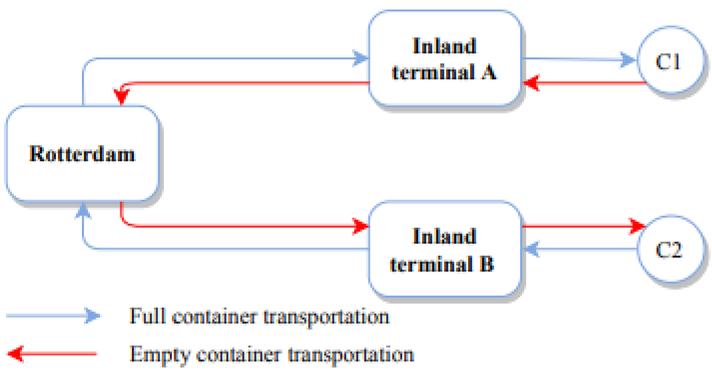

Figure 2.6: Multi-depot, multi-client transportation

When empty container reuse is considered and matches between the import and export request are made, the situation described change in the following way (Figure 2.7). The empty container resulting from the import request of C1 is reused for the export request op C2.

1: The empty container is first relocated to inland terminal A and then transported to inland terminal B, so it can later be reused for the export request of C2. This situation describes multiple single trips.

2: The empty container is first relocated to inland terminal A and then directly transported to C2 for the export request. Again, using multiple single trips.

3: The empty container is directly relocated to inland terminal B and is later reused for the export request of C2. This situation describes multiple single trips.

4: The empty container is directly transported from import client C1 to the export client C2 using cargo rotation. This situation is only possible when the time between unloading/discharging at import client C1 and loading at export client C2 is within a certain time window.

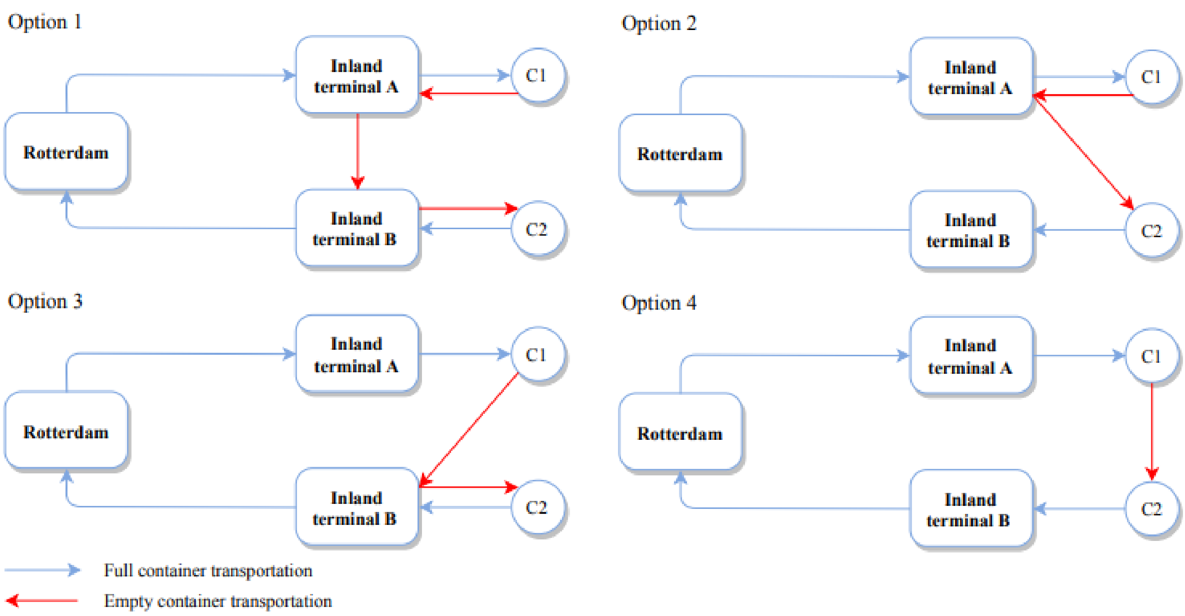

Figure 2.7: Multi-depot, multi-client with matching and empty container reuse

Again, the matching of import and export requests is done in the hinterland, between inland terminals and clients. In this situation, the repositioning of the empty containers can be done either by truck or barge, depending on the distance and locations to transport to/from. Truck transportation is a fast, flexible and suitable modality to relocate the empty container between clients or between clients and inland terminals. On the other hand, barge transportation can be used to relocate the empty container between two inland terminals.

Concluding, both import and export requests result in empty container movements. These movements contribute to congestion and pollution problems, and a small percentage of reduction in empty container movements can result in significant congestion reduction and improved operational cost (Chang et al., 2008). Additionally Jula et al. (2006) state that capacity is best utilized when carrying loaded containers.

Therefore, the matching of import and export requests and empty container reuse can provide a cost-effective solution for improving hinterland container transportation.

2.4 Performance indicators

This section discusses the key performance indicators that are relevant for hinterland container logistics. These KPIs are important to measure and demonstrate the final outcome of the actions performed.

Zamparini, Layaa, & Dullaert (2011) discuss the quality of container transport using six different performance indicators:

1. **Travel costs:** all cost associated to transport a container.
2. **Transit time:** planned travel time from port to port, including loading and unloading procedures.
3. **Frequency:** the number of shipments offered by an operator (transportation company) in a given period of time.
4. **Flexibility:** the number of unexpected shipments that is dealt with, without excessive delay. Measured as the percentage of unplanned shipments that is dealt with in respect to the total ones.
5. **Loss and damage:** the percentage of the commercial value of shipped goods that is lost because of theft, damages or losses.
6. **Reliability:** the number of shipments that are delivered in time, without any delay. Measured as the percentage of timely deliveries.

Besides the six KPIs identified by Zamparini et al. (2011), TEUbooker also defined some KPIs for hinterland container logistics at the Port of Rotterdam. In collaboration with the Port of Rotterdam, TEUbooker aims to contribute to:

- **Modal shift (%):** with a target value of shifting 5-10% of container transportation from sea terminal to hinterland (warehouse) and vice versa, from truck to barge/train.
- **Improvement of occupancy rate (%):** with a target value of 2.5-5% of occupancy rate improvement of barge/train utilization to transport cargo from sea terminal to hinterland (warehouse) and vice versa.
- **CO2 reduction (%):** with a target value of 5-10% CO2 emissions (reduction) to transport cargo from sea terminal to hinterland (warehouse) and vice versa. Based on modalities used, fuel type, distance, delays and capacity utilization, comparing current modality mix and occupancy rates with synchromodal route results and occupancy rates.

The sea terminal represents the Port of Rotterdam. The TEUbooker platform is a project which aims to contribute to these KPIs within the Port of Rotterdam. Even though these KPIs are not directly related to the solution method, they should be evaluated on and taken into consideration when designing the solution method.

2.5 Conclusion

This chapter answers the first research question related to the current situation of the hinterland container logistics.

Section 2.1 describes the hinterland container logistics. Due to the growing volumes of containers moving between the Port of Rotterdam and the European hinterland, there is a need for increased performance of hinterland container logistics. In the past years, the percentage of truck transportation slowly decreases, whereas the percentage of barge transportation slowly increases. The goal of 2035 is a modal split of 35% truck, 45% barge and 20% train transportation (Port Authority Rotterdam, 2011), which requires increased performance of barge and train transportation.

Section 2.2 describes the concept of TEUbooker hinterland. TEUbooker aims to simplify the booking process of containers to the hinterland and improve the overall cost of hinterland container transportation. Relevant aspects to consider for the further optimization of the hinterland container logistics are the different type of trips.

Section 2.3 discusses the current situations occurring in hinterland container transportation, describing full and empty container flows. Based on these situations, it can be concluded that empty container movements contribute significant to the total transportation distance and are an important issue to consider when optimizing hinterland container logistics.

Section 2.4 discusses the key performance indicators (KPIs) that are important for accessing the quality and performance of hinterland container logistics. These KPIs need to be taken into consideration when designing and testing the solution method in chapter 5. Important KPIs are: travel costs, transit time, frequency, flexibility, loss and damages, and reliability. Additionally, important KPIs TEUbooker aims to contribute to are:

1. Modal shift
2. Improved occupancy rate
3. Reduced CO2

CHAPTER 3

LITERATURE REVIEW

This chapter discusses relevant literature related to hinterland container logistics, empty container management and the possibility for empty container reuse. It evaluates the aspects that need to be considered when implementing empty container reuse and matching import and export flows between the Port of Rotterdam and the European hinterland. First Section 3.1 describes the concept of empty container management. Section 3.2 evaluates on different solution methods and decision support methods, which can be used to solve the container allocation problem. Section 3.3 discusses the solution method on which this research will built upon.

3.1 Empty container management

In a perfect world, empty movements would not exist, because there would always be cargo to fill a container when it is emptied at a certain location. However, commercial traffic never seems to be in balance, neither in volume nor in value. Therefore, carriers must relocate empty containers on a local, national and global scale in such a way that empty containers will be positioned to take advantage of future transportation opportunities (Olivo, Zuddas, Francesco, & Manca, 2005).

As already mentioned before in Section 1.1.1, the movement of empty container flows account for 40% of the total hinterland container flows. Considering this large share of hinterland empty container movements, container reuse would be a cost effective solution (Shintani et al., 2007). Additionally, the large amount of empty container movements contribute to the congestion and pollution problems, and a small percentage decrease in empty container movements can result in significant congestion reduction and improved operational costs (Shintani et al., 2007). In line with that, Chang et al. (2008) state that the reuse of empty containers can significantly decrease in the number of truck trips and the associated costs.

Empty container management deals with making empty containers available for export requests, while minimizing transportation cost and maximizing benefits (Finke & Kotzab, 2017). When a ship arrives at a deep-sea terminal, loaded containers must generally be delivered to the hinterland. After unloading/discharging these containers at the client's location, there are three options for the empty container:

1. The empty container can be returned to the deep-sea terminal

2. The empty container can be transported to an inland depot for an expected export request
3. The empty container can directly be transported to export client's location, who demands an empty container.

Figure 3.1 explains the situation for an import request. When there is an import request for C1, the container is transported full from the Port of Rotterdam to the import client C1. This is often done, using a barge to transport the container to an inland terminal and transport the final miles, from inland terminal to import client, by truck. After the container is unloaded, there are several options for the empty container: A) return the empty container to the deep-sea terminal Rotterdam, B) store the empty container in an inland depot, such that it later can be used for an export request from C2, C) directly transport the empty container from import client C1 to export client C2 or D) leave the container at the customers site when the customer owns the container or the customer needs it for an export request in the near future. However, the question remains whether there is a need to store the container at the customers site, since the right equipment and available space is needed.

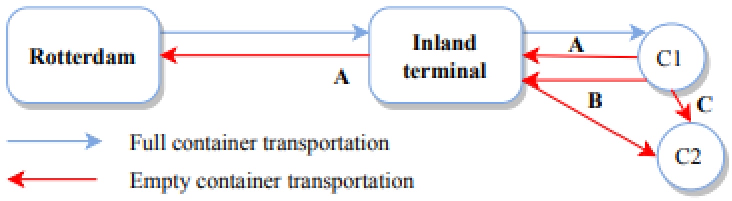

Figure 3.1: Situation for an import request

Option B is only possible when the import request of C1 and the export request of C2 are matched beforehand. An empty container cannot be randomly stored in an inland hub without knowing it is used within the near future. Additionally, temporally storage of an empty container at an inland terminal needs to be approved by the owner of the container, the deep-sea carrier. If this is not approved, the empty container must be returned to the Port of Rotterdam within a certain time window to avoid detention costs. When import and export request are matched and approved, an empty container can be stored in a selected inland depot for a limited (pre-defined) amount of time, without incurring detention costs, since the container is already "assigned" to an export request. Within the pre-defined amount of time, planners can play a bit with the time left after the import request and use it for the next export request.

Concluding from Section 2.3, empty container movements have a significant contribution to the total transportation distance of containers and therefore the overall costs. In comparison with loaded container movements, empty container movements do not generate revenues. Even though they cannot be avoided completely, minimizing them leads to reduced operational costs for transportation companies (Braekers, Janssens, & Caris, 2011). According to Braekers et al. (2011), opportunities for optimizing the empty container management can be found in preventing some empty containers to be moved back to the deep-sea terminal immediately.

The matching of import and export flows between the Port of Rotterdam and the European hinterland is an interesting feature to further optimize the hinterland container logistics. The most important concepts for the matching of import and export flows are empty container reuse and empty container repositioning, which is discussed in more detail in the following sections.

3.1.1 Empty container repositioning

Empty container repositioning is understood as the transfer of a discharged container to a place where it can be loaded again (Finke & Kotzab, 2017). Crainic, Gendreau, & Dejax (1993) state that empty containers are often repositioned between depots to overcome regional imbalances. The empty container repositioning on regional level is defined as *"repositioning empty containers between importers, exporters, inland depots and deep-sea terminals within a small geographical area"* (Song & Dong, 2015). They also state that container utilization can be improved when empty containers are effectively repositioned.

According to Olivo et al. (2005), the repositioning of empty containers does not directly contribute to profit margins and involves important logistics costs for carriers. Within the container logistics, the focus is mainly on the loaded containers and generally have priority. However, empty containers are needed for future shipments and can therefore not stay idle (Bandeira, Becker, & Borenstein, 2009).

For empty repositioning on regional level, several decisions need to be made on strategic, tactical and operational level. This research only focuses on the operational level, which is concerned with the scheduling of services and the routing and dispatching of resources, making sure demand for empty containers are satisfied at all locations and the best routes and transportation modes are used (Braekers et al., 2011).

3.1.2 Empty container reuse

An operator's willingness to exchange or share resources with others can provide opportunities for container reuse and reduce empty container repositioning. Empty container reuse consist of *"using empty import containers for export loads without first returning them to the deep-sea terminal"* (Jula et al., 2006). It provides a means for reducing empty container repositioning around ports. Therefore, empty container reuse will not only have economic effects, but also environmental and sustainability effects, since the reduction of empty container movements reduces fuel consumption, congestion and pollution problems (Song & Dong, 2015).

Additionally, empty container reuse avoids waiting times at depots and terminals and eliminate unnecessary movements and thus reduces CO2 emissions. Benefits of empty container reuse are (Song & Dong, 2015):

- It optimizes the planning of trucks, since truck trips to and from the port can be saved
- It can help avoiding congested areas around ports
- It can be more effective by avoiding waiting times at depots and terminals
- Environmental impact can be reduced (traffic, congestion, noise & CO2 emissions)
- Export clients can get the empty container sooner

Besides these benefits, empty container reuse leads to shorter transit time and possible decreased costs since it minimizes unnecessary empty container movements.

There are multiple issues to take into account when reusing empty containers and link import and export flows. Song & Dong (2015) define some issues with respect to empty container reuse: 1) the opportunity for reuse should be identified and communicated, 2) the location of the emptied import container should be within reasonable distance of the next export client and its available time should match the loading time window of the export request, and 3) the empty container should be in good condition and suitable for the export load and the container/chassis combination should be acceptable at the terminal used by the export vessel.

According to Jula et al. (2006), several operational issues also need to be taken into account to achieve empty container reuse: import/export timing, location mismatch, ownership mismatch, container type mismatch and legal issues. When there is an empty import container available for reuse for an export client, permission should be requested from the owner of the container. The container is owned by the one transporting it from its origin to its destination (e.g. from China to Enschede), the deep-sea carrier.

Before empty container reuse can be implemented successfully, all relevant issues must be addressed and a reliable, fast, and efficient system for empty container reuse should be created (Jula et al., 2006).

Jula et al. (2006) also state that there are two important empty container reuse methodologies: street turn and depot direct. Street turn is defined as the movement where "*an empty container is directly moved from local consignee to local shipper"*, and depot direct as the movement where *"an empty container can be stored, maintained and interchanged at off dock container depots"* (Jula et al., 2006). Street turn is preferred when the costs of transport and environmental factors are important because it provides a direct match between supply and demand of empty containers. On the other hand, depot direct minimizes the overall waiting time and is preferred when time is a critical factor.

Interesting to consider is the availability of barge transport for addressing the empty container management problem. According to (Choong et al., 2002), empty containers can be “piggy-backed”, within barge capacity limits, onto existing barge trip at very low costs. Therefore, the costs of moving empty containers can be negligible in a network with barge links.

3.2 Container allocation models

According to Braekers et al. (2011), the regional empty container management problem on an operational level can be divided into the container allocation problem and the vehicle routing problem.

- Container allocation problem: determining the best distribution for empty containers, while satisfying both known and unknown future demand.
- Vehicle routing problem: minimizing overall transportation costs of both loaded and empty containers for their origin to their destination.

These two problems are often considered separately to decrease complexity. The focus in this research is on the container allocation problem. Several decisions and assumptions should be made, when modelling the empty container allocation problem at regional level (Braekers et al., 2011):

- Is it a deterministic or stochastic model?
- Is it a static or dynamic model?
- Is it a single or multi-commodity model?
- Which aspects are allowed, related to container substitution, container leasing and/or street turns

These decisions and assumptions affect the model complexity, and therefore also whether the problem can be solved to optimality or not. According to Braekers et al. (2011), the most realistic model is when it is stochastic, dynamic, multi-commodity and including container substitution, container leasing and street turns. However, according to Braekers et al. (2011), such a model has not yet been described in literature and many models contain some but not all of these elements .

Crainic et al. (1993) introduce a general framework for the empty allocation problem, describing a dynamic deterministic mathematical model for single- and multi-commodity cases. Closely related to the model of Crainic et al. (1993) is the model described by Wang & Wang (2007). Wang & Wang

(2007) consider all three transportation modalities and storage limits at depots, using a small numerical experiment.

Olivo et al. (2005) develop a two-commodity deterministic model for the empty allocation problem, by formulating it as a minimum cost flow problem. A dynamic network of depots is considered using hourly timesteps, which offers the possibility for adjusting decisions based on unexpected new information.

Jula et al. (2006) describe a model and optimization technique for dynamic allocation of empty containers in the Los Angeles and Long Beach port area. Their model solves the problem in two stages; first transforming the model into a classical transportation problem and later solving it with linear programming. Within their model, Jula et al. (2006) describe several options for modelling depot direct and street turn approaches. Chang et al. (2008) continues this work, using a heuristic to solve the multi-commodity empty container substitution model. Where multi-commodity refers to the substitution of different container types.

Additionally, Braekers, Caris, & Janssens (2013) describe in their paper an empty container allocation model in which they determine the optimal repositioning of empty containers based on the locations of demand and supply in the region. The model aims to reposition empty containers, while minimizing the total distance travelled by empty containers, without taking vehicle routing decisions into account.

Bandeira et al. (2009) describe a single-type empty container substitution model. Their focus is on the reuse and allocation of containers, while considering the movement of all empty and full containers. To solve the problem, they first defined it as a multi-depot vehicle scheduling problem, which is NP-hard. Therefore, the proposed model for solving the multi-depot vehicle scheduling problem consists of heuristics.

Shintani et al. (2007) define the problem as a Knapsack problem, where the problem faces decisions regarding which ports to visit, in which sequence. Since this problem is NP-complete, they did not provide an exact algorithm for solving the problem.

On the other hand, Zhang, Yun, & Kopfer (2010) state that empty containers can be seen as resources for transportation, which need to be delivered to the right locations. In their research, they describe the problem as a traveling salesman problem with time window (TSPTW).

3.3 Solution method

As mentioned in Section 3.2, the problem can be defined as container allocation problem. The proposed models described in literature can be distinguished in exact methods and approximations models/heuristics. Exact methods solve problems to optimality, often requiring a lot of computation time. Heuristics on the other hand determine a feasible solution that is as good as possible, in as little time as possible, but does not guarantee to find the optimal solution.

Solution methods can be divided into several categories:

- Exacts methods
    - Mathematical programming:
        - Linear programming (LP)
        - Integer linear programming (ILP or IP)
        - Mixed integer LP (MILP)
- Approximation methods
    - Constructive heuristics: repeatedly adding a building block to the solution
        - Adaptive search
        - Nearest neighbour
        - List scheduling
        - Greedy
    - Local search/improvement heuristics: within a solution space, there are a number of feasible solutions (neighbourhood).
        - Local search
        - Steepest descent
        - Simulated annealing
        - Tabu search

Heuristics are useful to solve realistic problems and give feasible solutions in an acceptable amount of time, but not always the optimal solutions. To get an indication of the difference in the objective value between the heuristic solution and the optimal solution, lower bounds of ILP or LP solutions for the reduced problem can be used.

3.4 Conclusion on the literature review

This chapter answers the second research question, discussing the literature related to hinterland container transportation, focusing on empty container management.

Section 3.1 describes the concept of empty container management and the different decisions regarding empty import containers. Two relevant concepts are introduced related to empty container management; empty container repositioning and empty container reuse. The concept of empty container repositioning is understood as the transportation of a discharged container to place where it can be used for future export requests. The concept of empty container reuse refers to the use of empty import containers for export loads without first returning them to a deep-sea terminal. Both concepts can create opportunities for improved hinterland container logistics. For empty container reuse several aspects need to be considered such as: import/export timing, location mismatch, ownership mismatch, container type mismatch and legal issues.

Additionally, two reuse methodologies are described: street turn and depot direct. Street turn refers to directly relocating the empty import container to the export client's location. Depot direct describes a transport trip, where an empty import container is first stored in a nearby hinterland depot, so it can later be used for an export request.

Section 3.2 discusses several container allocation models found in literature. The empty container management problem on a regional level is generally split into the container allocation problem and the vehicle routing problem. The focus in this research is on the container allocation problem, deciding what to do with empty containers resulting from import requests. The most realistic model for the empty container allocation problem is when it is stochastic, dynamic, multi-commodity and including container substitution, container leasing and street turns. However, this is hard to achieve all at once and can often not be solved to optimality. Therefore, most models do not contain all aspects. The model of Jula et al. (2006) corresponds the most with the described problem. Discussing a dynamic allocation model of empty containers, using both street turns and depot direct trips and not considering empty container substitution or leasing.

As described in Section 3.3, the problem addressed in this research is complex and therefore it is hard to find an exact solution which solves the problem to optimality. A heuristic method is designed to find a solution out of a number of feasible solutions, close to optimality, in a reasonable amount of time.

CHAPTER 4

SOLUTION METHOD

This chapter discusses a suitable decision support algorithm for the matching of import and export flows within the hinterland container logistics, proposing an algorithm for empty container reuse. Therefore, it answers the third research question 'How can the online booking platform be supported?'. First, the provided dataset that is used for the designing of the solution methods is described in Section 4.1. Section 4.2 discusses the output and requirements that the proposed algorithm should meet. The approach used to come to the required output is discussed in Section 4.3. Section 4.4 discusses the proposed algorithm for matching import and export flows. Section 4.5 discusses the validation and verification of the proposed algorithm and Section 4.6 discusses several advantages and disadvantages of the proposed matching algorithm. Finally, the chapter ends with a conclusion in Section 4.7

4.1 Use cases

For the design of a solution method, data is provided by Cofano. For simplicity, data of one month is considered, to design and test the algorithm. Data from February 2018 is used since it is the first complete month in the dataset.

The provided dataset (Appendix B) contains information of a deep-sea carrier, who schedules multiple inland requests to the European hinterland (The Netherlands, Belgium and Germany). Freight arrives generally in the Port of Rotterdam and on occasion in the Port of Antwerp. To transport it to the hinterland, the company has partnerships with several truck, barge and train operators. The dataset shows import and export requests, their pick-up location, loading/unloading location and date, return location and demanded container type. The dataset contains 737 requests to fulfil, from which 553 are inbound (import), 180 outbound (export) and 4 reload (both import and export). These reload trips can be eliminated from the dataset since those requests cannot be matched, which results in a total of 733 request to be fulfilled. The import to export ratio is 553:180, which suggests that every export request can be fulfilled using an empty import container. However, geographical spread between import and export clients and the difference in loading date and container type makes the matching more complex. Figure 4.1 shows a visualization of the loading/unloading locations. All loading/unloading locations, and the release and return locations of February can be found in Appendix C.

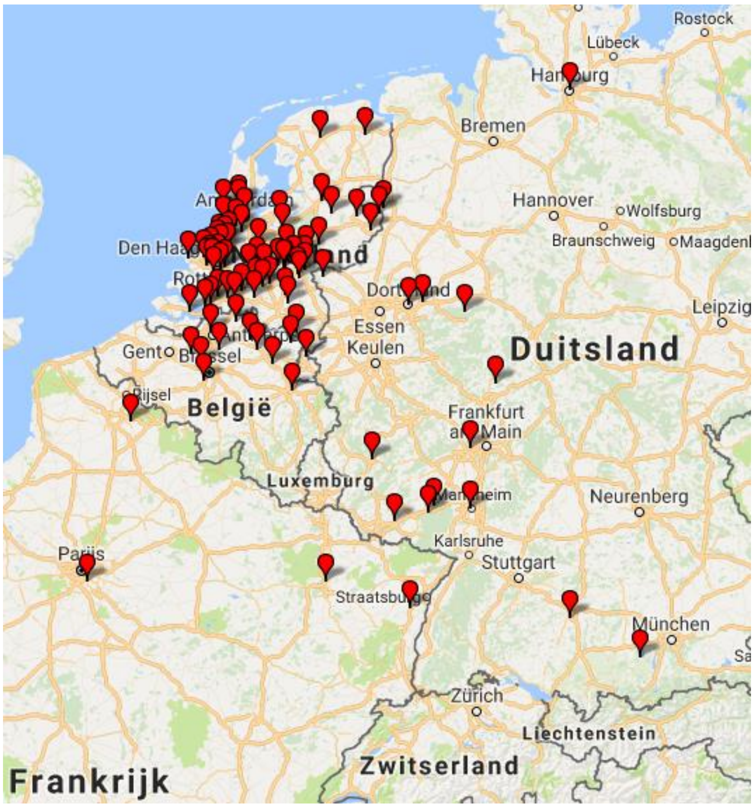

Figure 4.1: Loading/unloading locations of February 2018

The dataset contains historical data; therefore, the requests have already been handled. All requests are fulfilled using truck transportation and there is an existing schedule. Based on this schedule, the frequency of the situations described in Section 2.3 is found. Data shows that in February only 8 times import and export request where matched using reloading, unloading and loading on the same location (Figure 2.5, situation 3.1), and 17 times matched with the concept of reusing, unloading and loading on different locations (Figure 2.5, situation 4.1). However, most import and export requests are fulfilled using roundtrips (Table 4.1), resulting in a lot of empty container movements.

Type	***Number***	***Percentage***
Reuse	17	2.88%
Reload	8	1.36%
Roundtrip	565	95.76%
Total	590	

Table 4.1: Number and type of trips in February

Data also shows that matching only occurs when unloading and loading of the import and export container are on the same day, and not considering a certain reuse time window[5]. Matches are only made using street turns, direct transport from the import to the export client, for the following reason. Before every week, an initial schedule is made for all requests. This schedule is later adjusted when changes or unexpected events occur. The matching of import and export requests is done by human planners. Based on experience and common sense, the person responsible for the schedules decides to reuse or reload an import container for an export request or not. This takes a lot of time and several options for matching are generally missed.

4.2 Output and requirements

The proposed solution should provide decision support for finding the optimal decision to be made for an empty import container: whether it can be matched to an export request or should be returned to the predefined depot. The model should consider: import/export timing, client's location, ownership, container type and legal issues. The model is assumed to be feasible if the empty container is reused for an export request or returned to the depot within a predefined reuse time window. This reuse time window should be defined and represents the time between unloading of the import container and its return time to the deep-sea terminal.

The objective is to minimize the total cost of fulfilling all requests. The total costs consist of:

1. Transport costs: transporting the full container (including loading/unloading costs). For import requests, this is the cost of transporting a full container from the deep-sea terminal to the import client's location. For export requests, this is the cost of transporting a full container from an export client's location to the deep-sea terminal.
2. Relocating costs: ensuring the empty container is at the right location at the right time. When matched, relocating an empty import container to the export client's location, and if not matched, returning the empty container to the predefined depot.
3. Storage costs: cost of storing an empty container at an inland depot. Only incurred when unloading and loading time is not on the same day. In general, the first 5 days of storage is for free and only handling cost should be paid.
4. Detention costs: cost for late return of an empty import container at the deep-sea terminal.

Minimizing the total costs can be achieved by empty container reuse, matching import and export requests and minimizing the total empty container movements. Additionally, matching can result in

[5] Time between unloading of the import container and return date

improved turnaround time and capacity utilization of barge operators, decreasing the overall cost of transport and making barge transportation more attractive. This might result in a modal shift away from truck transportation.

4.2.1 Constraints and assumptions

For designing an algorithm, several constraints and assumptions need to be considered. The constraints in this research are:

- All requests must be fulfilled in time (all containers must be picked up and delivered in time).
- Empty import containers must be returned or reused within the reuse time window.
- Export (demand) clients do not receive more empty containers than requested.
- Import container becomes available for export after unloading/discharging.
- Container type of supply and demand of empty containers should match (dimensions and other characteristics must match).
- The cost of matching should lead to lower cost/distance compared to without matching (only reuse when it leads to lower overall costs).

Additionally, in this research it is assumed that:

- No container substitution is allowed, meaning that a container type cannot be replaced by another container type. This because it is not known whether all operators can transport all container types, and if all cargo can be transported in every container type.
- Requests supplying/demanding reefer containers cannot be matched. Due to governmental regulations, this is not yet allowed.
- Only street turns, directly transporting empty import containers to the export client, are considered in this research.
- All requests (containers) are owned by the same deep-sea carrier, no ownership mismatch.
- No orders/requests before the start of the planning horizon. Only the requests in the dataset are used for the algorithm.
- Cost of transport depends on the distance to cover.
- Storing costs are only incurred when time between unloading at the import client’s location and loading at the export client’s location is larger than 24hours. When unloading and loading is within this time window, only waiting costs are incurred.
- The dataset does not contain information related to the return date of containers. Therefore, an estimate of three days is used. This means that an empty import container should be returned to

the deep-sea terminal on the third day after unloading at the import client's location. Otherwise the booker will incur detention costs.

4.2.2 Input values for the algorithm

Several input values related to costs and time are needed in the matching algorithm. These input values differ for each operator and deep-sea carrier. Input values in this research are based on the provided data by the deep-sea carrier. The return time window is assumed to be 0. A return time window of zero, implies that the container must be reused or returned on the same day.

In this research, only truck transportation is used since all data provided by the deep-sea carrier is based on truck transportation. Used cost for truck transportation is based on data (tariffs) from the deep-sea carrier, where the truck transportation cost depends on the distance to cover (Appendix D).

Other input values are related to truck speed, waiting costs, storing costs, detention costs and reuse costs.

- The average truck speed is assumed to be 65 km/h.
- The cost of waiting is €45.- per hour, with 2 free hours for loading per request.
- When loading time between import and export clients is larger than 24 hours, the empty container will be temporary stored in an inland depot.
- Storing cost for the first 4 to 5 days is zero, and only handling costs need to be paid. These handling costs per request are €60.-.
- Detention costs are incurred three days after unloading the import container and are €80.- per day.
- The reuse premium incurred when matching import and export requests is €80.- per match made.

4.3 Approach

The idea is to match import and export requests, looking at unloading and loading dates at the client's site. The model does allow for street turns, but not container substitution[6]. Meaning that an empty import container can only be reused for an export request when the characteristics of the demanded export container are the same. The loading and unloading times during a day are slightly negotiable, therefore import and export requests with the same loading/unloading date are matched first. All matches are assumed to be made using truck transportation, where a truck transports the empty import container

[6] Container substitution occurs when one container type can be replaced by another container type.

directly, on the same day, to the export client for loading. However, this is only possible within a small geographical area, so no time constraints are violated.

The dataset contains import and export requests handled by one deep-sea carrier, therefore the issue related to ownership mismatch does not have to be considered when designing the algorithm for import and export matching. Once the deep-sea carrier knows which requests can be matched, they can contact operators and make schedules for transportation accordingly.

Cofano also provided a distance matrix, containing the distance between different import and export clients and deep-sea terminal(s). Because only street turns are considered in this research, the distance matrix does not provide information regarding inland terminals.

Overall, the algorithm should match different requests based on: container type, location (distance between clients and/or deep-sea terminal) and loading/unloading date. Each match made between import and export requests results in a considerable cost reduction for the deep-sea carrier.

4.3.1 Heuristics

The solution algorithm is based on a constructive heuristic. Constructive heuristics start with an empty solution and repeatedly extend the solution until the complete solution is reached. This research uses the greedy approach, based on common sense. The goal is to find an initial feasible solution where import and export request are matched and costs are minimized, in a limited amount of time. Improvements are used to find the best possible solution out of a number of feasible solutions.

Within the dataset, for every import request and decision needs to be made, whether to return or reuse the empty import container. To be able to make this decision, it is checked whether the empty import container can be reused for an export request, resulting in overall cost decrease.

To describe the process in more detail, the first step is to sort the list, containing all requests, in ascending order based on loading date. Requests with the earliest loading date are generally scheduled first to ensure requested containers are in the right place at the right time.

For each import request, it should be checked whether the empty import container can be reused for an export request on the same day (or in the near future), based on container characteristics and location. If the empty import container can be reused for an export request, the associated cost of reuse should be computed. The next step is to check if the reuse results in an overall cost decrease, compared to transporting the empty import container back to the return depot and transporting an empty container to the export client. If it leads to a cost decease, the import and export requests are matched. If not, the empty container is returned to the deep-sea terminal. The best export match for each empty import container, related to highest cost savings, is assigned to that import request.

If no possible match is found for the empty import container within the time window, the container must always be returned to the deep-sea terminal, since empty containers are not allowed to be stored in inland depots when they are not assigned to a future export request.

Concluding, the steps are as follows:

1. Create a table including all requests, containing the following information: import/export, transport reference, container type, container owner, release location, loading location and date, return location.
2. Sort the table on loading date in ascending order for both import and export requests
3. Loop over all requests. If request is import, then
    - o Loop over all requests: If request is export then
        - If container types match (of import and export request) and import unloading/export loading date is within the reuse time window, then
            - Calculate reuse costs and cost savings generated by this match
            - If savings are larger than best savings so far then
                - Remember new match
4. If there is a best match for reuse, implement the match set as best match.
    - o Else, return the empty import container to a predefined return location.

The flowcharts (Figure 4.2 and Figure 4.3) represent the process for matching per week, taking into account container type, loading time, location and owner. Since the data provided by Cofano is from one deep-sea carrier, the ownership mismatch is not an issue.

Figure 4.2 shows the process of decision making for an import request. For every import request found in the dataset, a decision must be made what to do with the resulting empty container. This decision-making process for each independent import request is described in Figure 4.3. For each import request, all export requests are checked on a possible match (the decision to reuse or not). When there are multiple options for reuse, the best export match (related to highest cost savings) is assigned, and when there is no possible match, the empty import container is returned to the deep-sea terminal.

The objective is to minimize cost of hinterland transportation and empty container movements, finding a feasible solution for matching import and export flows and showing which import and export requests to match. Every match made, represents a decrease in total distance travelled and as consequence a decrease in overall transport costs, improving performance of hinterland container logistics.

To check the performance of the solution, the number of matches, as well as the total distance needed to fulfil all requests is evaluated. This is done by comparing the total distance travelled to fulfil all requests with and without matching.

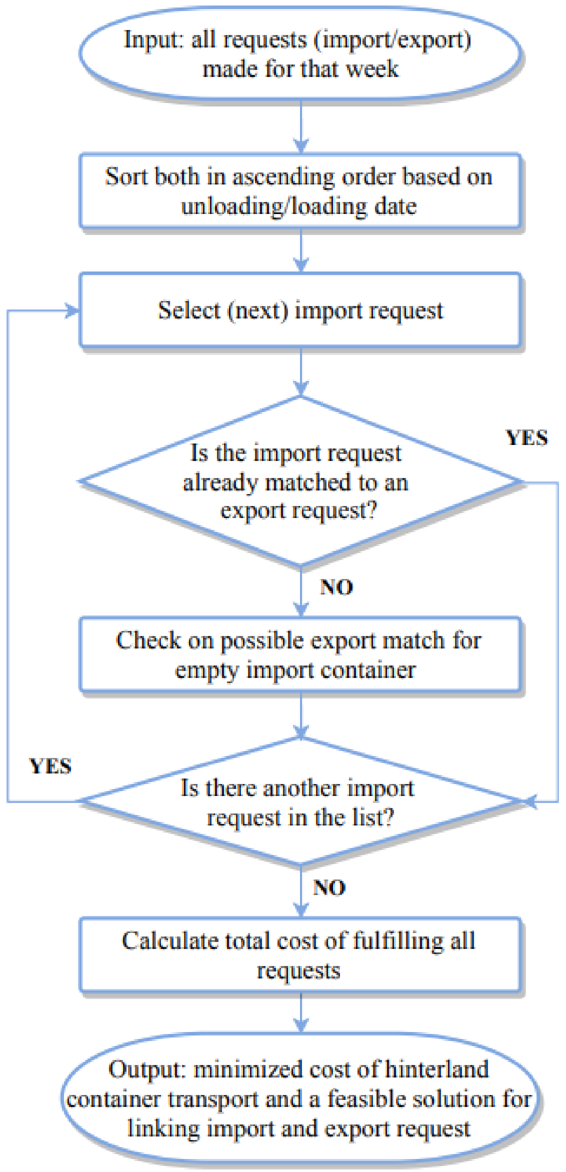

Figure 4.2: Loop over all import requests for which a decision must be made

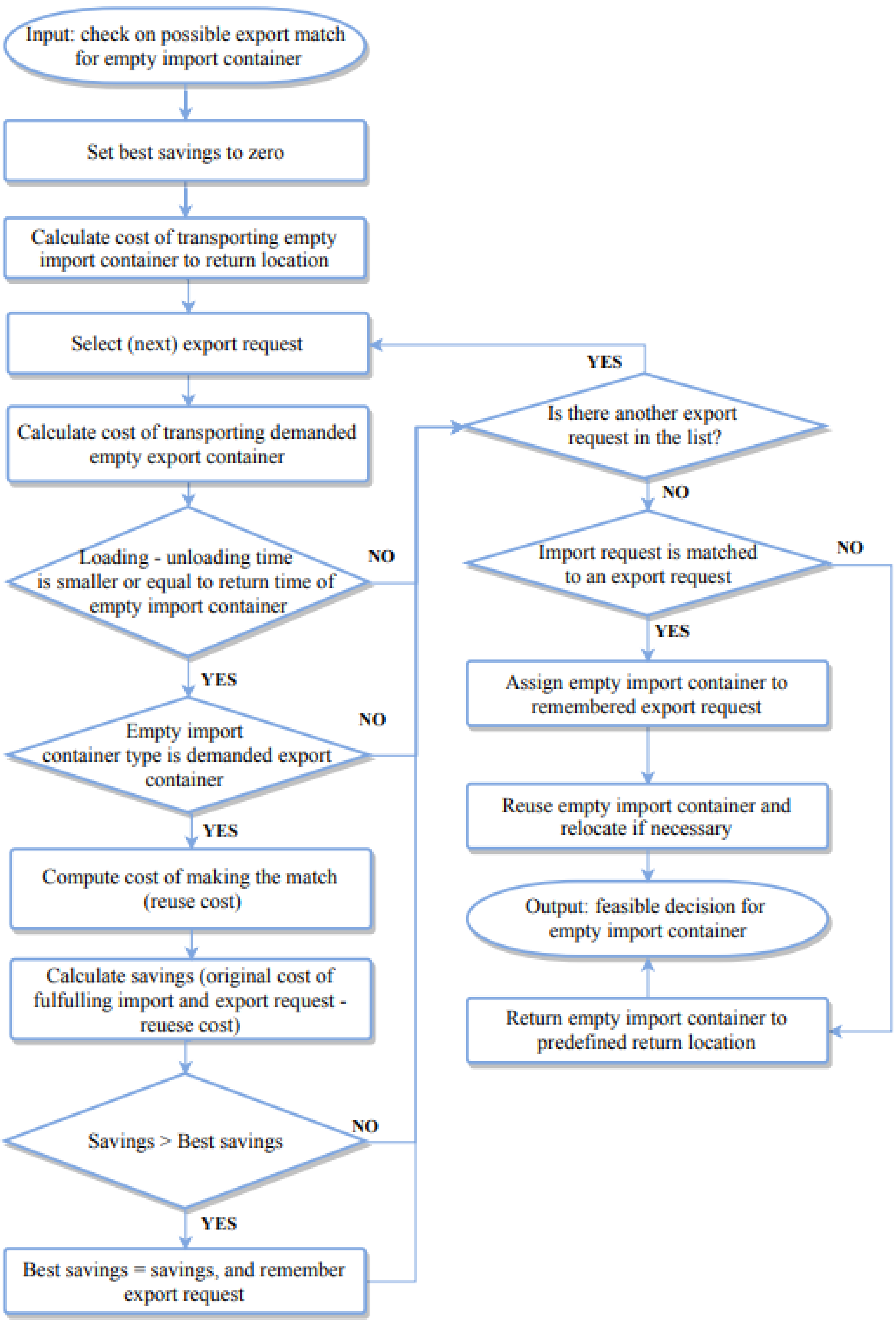

Figure 4.3: Decision making process. Matching each import to possible export request

4.4 Empty container reuse model

The algorithm is programmed using Excel VBA. First the total distance, empty distance and related cost to fulfil all requests without matching is computed. After matching, the total distance, empty distance and reuse distance, as well as the related costs, are computed as well.

The matching is demonstrated in two dimensions: time, and location (Figure 4.4). The time axis is divided into *T* periods, where *T* is the planning horizon. At each period *k*, *k=1,...,T*, the locations of import clients are shown by a circle containing an I. For instance, at period *k=1*, there are 2 import requests, I1 and I2, which can be reused for a future export request. On the other hand, at *k= T-1* only one import request (I3) can be potentially matched to a future export request. Similar to that, at each period *k*, *k=1,...,T*, the locations of export clients are shown by circles containing an E. For instance, at period *k=2* and *k = T*, export clients are in need of empty containers. These empty containers can be "supplied" by import requests when a match has been made, or by the deep-sea terminal when no match has been made.

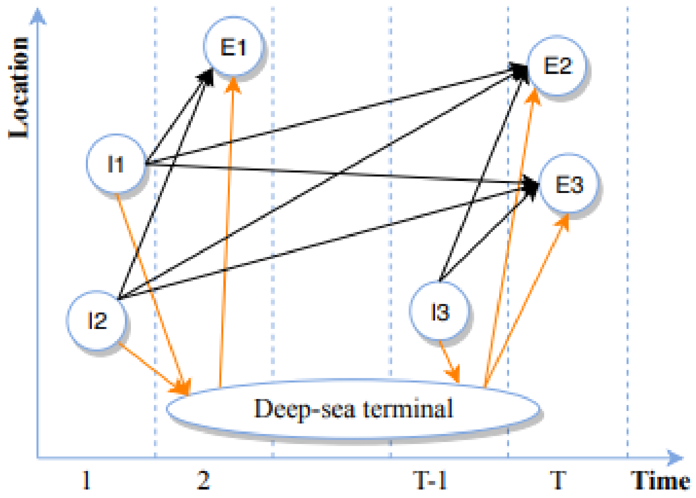

Figure 4.4: Dynamic matching scenario

The initial matching algorithm is based on the First-in/First-out (FiFo) principle. This means that requests that are booked first, are matched first, independent of a possible better match on a later day. The empty import container is reused for an export request resulting in the highest cost savings, and once this export request is matched to the import request, it cannot be "re-matched" to a possible better import request.

Improvements to the algorithm are made using a rolling horizon and continuously finding the best match between import and export requests. This means that when an export request is already matched with an earlier import request, it is checked whether matching that export request to a later import request might result in higher costs savings in terms of transport, relocating, storing and detention costs. If so, the earlier match is removed, and a new match is made. The disconnected empty import container, for which the match is removed, is checked on a possible other export match as well.

4.5 Validation and verification

Input values of the algorithm are based on information provided by the deep-sea carrier and own assumptions, such as truck speed, transport costs and container substitution. Other assumptions, such as reuse premium, storage costs and transport modality, make it hard to compare the algorithm with real situations. Therefore, the algorithm cannot be validated based on real data. However, to verify the performance of the initial algorithm and the improved one related to best match, the outcome, the matches made by the algorithm, are verified by the deep-sea carrier to see if matches are indeed realizable and result in cost savings.

The original dataset is tested with both algorithms. Performance related to total and empty distance and cost of fulfilling all requests without matching are shown in Table 4.2. As can be seen, the percentage of empty movements is around 40%. Cost of reuse is the “premium” that needs to be paid for every match made and should be taken into consideration when calculating possible savings. A reuse time window of zero is used, meaning that import and export requests are only be matched when unloading and loading is on the same day.

When applying the matching algorithm based on the First-in/First-out principle, the number of matches made are 31 and the cost of fulfilling all requests decreases from €227,447.99 to €222,764.04. This is a cost decrease of 2.06%. The percentage of empty distance decreases from 41.02% to 37.45% (Table 4.2).

When applying the matching algorithm with continuously finding the best possible match, the number of matches made are 30 and the cost of fulfilling all requests decreases from €227,447.99 to €222,647.82. This is a cost decrease of 2.11%. The percentage of empty distance decreases from 41.02% to 37.36% (Table 4.2).

Without Matching	Distance (km)	Percentage	Costs
Total	151,126		€ 227,447.99
Empty	61,989	41.02%	

With Matching			
FiFo	**Distance (km)**	**Percentage**	**Costs**
Total	148,027		€ 222,764.04
Empty	55,441	37.45%	
Reuse	3,450	2.33%	€ 2,480.00
Number of matches	31		

Best	**Distance (km)**	**Percentage**	**Costs**
Total	147,530		€ 222,647.82
Empty	55,116	37.36%	
Reuse	3,277	2.22%	€ 2,400.00
Number of matches	30		

Table 4.2: Results of the matching algorithms

Table 4.2 shows that the performance of both algorithms does not differ that much in terms of total costs and percentage empty movements. Interesting is the small decrease in total cost for both algorithms, which might suggest that constraints and assumptions made for the algorithm are limiting the overall performance. To find the most suitable algorithm for further experimentations, outcomes of both algorithms are verified by the deep-sea carrier. Verification showed that both algorithms result in matches which are indeed realisable and possible to make in real life. However, the algorithm which is continuously searching for the best possible match is preferred, because it allows for continuously finding the best import/export match when new requests come in. Therefore, the algorithm based on best match is used for the remainder of this research.

4.6 Advantages and disadvantages

To summarize, this section discusses several advantages and disadvantages of the proposed algorithm. Advantages of the algorithm are related to cost savings and improvement of hinterland container logistics. For the matching, several constraints have been used to ensure the model reflects reality. Advantages of the algorithm are:

1. The algorithm matches import and export requests based on characteristics (such as container type, loading locations and date).
2. The algorithm considers requests in the near future and not only of one day.

3. The algorithm minimizes unnecessarily empty container movements between deep-sea terminals and clients.
4. It improves sustainability of hinterland transportation
5. It can improve capacity utilization by carrying more loaded containers
6. The algorithm decreases the overall cost of hinterland container transportation since every match made results in cost savings.

However, the algorithm also has some disadvantages. For instance, the algorithm:

1. Does not consider the difference in direct transportation between import/export clients, or temporary relocation to depot, and which depot to pick.
2. Cost of transport is an average of operators and is not necessarily the true transport cost.
3. Does not consider "piggy" bagging. Transport for free (or lower cost) on barge which is already going to that destination.
4. Several constraints are might be limiting the performance of the matching algorithm.

4.7 Conclusion

This chapter discusses the third research question, designing a suitable decision support algorithm for matching import and export requests within the hinterland container logistics.

Section 4.1 describes the dataset used for the design of the solution algorithm. Data of a deep-sea carrier with multiple inland clients is used. Invalid data, requests with missing information, as well as requests scheduled for reload trips are removed from the dataset. The resulting dataset contains 733 requests, of which 553 import and 180 export requests, of different clients. The schedule made for the original dataset shows 8 times import and export requests have been matched with reload and 17 times with reuse. However, most requests are fulfilled using roundtrips.

Section 4.2 describes the output and requirements the algorithm should meet. For every import request a decision needs to be made what to do with the resulting empty container: return or reuse. The objective of the algorithm is to minimize the total cost of fulfilling all request. The total costs consist of transport costs, relocating costs, storage costs and detention costs. Minimizing the total costs is achieved by minimizing the total distance of empty containers and matching suitable import and export requests. Additionally, Section 4.2 describes several assumption and constraints, which need to be taken into consideration for the design of the solution method.

Section 4.3 discusses the approach used to come to the required output. A constructive heuristic is used, to find a feasible solution in a limited amount of time. The heuristics tries to find a suitable match for each import request in the provided dataset, where each match made should result in cost savings, related to total cost of transport. Flowcharts (Figure 4.2 and Figure 4.3) are used to describe the process which should be used to design the solution algorithm.

Section 4.4 describes the result, the proposed algorithm for matching import and export flows. Two different algorithms are used. The first one, based on the First-in/First-out principle, matches import and export requests when time is standing still. Meaning that when new requests arrive, matches made are not reconsidered for a possible better match. The second algorithm does consider new requests and is continuously checking the dataset for improved matches.

Section 4.5 discusses the validation and verification of the model. The proposed solution is checked by the company, deep-sea carrier, to check if matches made are indeed possible and realizable, and the algorithm continuously searching for the best possible match is preferred.

Section 4.6 discusses several advantages and disadvantages of the algorithm. The algorithm does result in overall cost decrease of hinterland container transportation since every match made results in cost savings. Additionally, the algorithm minimizes unnecessarily empty container movements in the hinterland. However, the algorithm does not take into consideration the distance to relocate the empty container to a temporally storage location. Additionally, cost of transport is an average of truck transportation and in reality, combinations of different modalities are often used for hinterland transportation, which is not validated with the current algorithm.

CHAPTER 5

IMPROVED PERFORMANCE

This chapter discusses the testing of the solution method and includes several experiments to evaluate the solution algorithm. It answers the fourth research question 'Which settings should be used to optimize performance of the decision support algorithm?'. First, Section 5.1 discusses the experimental set-up. Several experiments, which can be used to test the solution method and the quality of the algorithm are discussed in Section 5.2. The performance indicators which are used to evaluate the quality of the modal are discussed in Section 5.3. Section 5.4 describes how the proposed solution performs related to distance and different configurations for time windows, container matching restrictions, import/export ratios and reuse premium. Finally, the chapter ends with a conclusion in Section 5.5.

5.1 Experiment set-up

This section describes the experimental set-up, the experiments and settings used to test and validate the solution design. For the experiments, a dummy dataset is used, which is based on the original dataset containing historical data of the month February, from the deep-sea carrier as described in Section 4.1.

Several steps are taken to create the dummy dataset. First all requests not originating from the Port of Rotterdam, as well as the requests not returning to the Port of Rotterdam, are deleted from the original dataset. This to ensure that all requests are released and returned from the same deep-sea terminal, Rotterdam, resulting in a total of 653 requests, from which 504 import and 149 export. The dataset provides information about import/export requests, container type, loading date and time, and loading locations.

Next, based on the dataset containing 653 requests, a histogram is made of the requests per day. The histogram shows that most days have 20-40 requests (Figure 5.1). Appendix E contains a detailed description and explanation of the calculations related to the histogram.

For the number of requests per day, a lognormal distribution is hypothesized. To show that the data is indeed lognormal distributed, a chi-square test with $\alpha = 0.05$ and 8 degrees of freedom is conducted. Found value for the lognormal distribution (4.930) is smaller than the chi-square value of 15.507, which means that with 95% significance level the data is lognormal distributed, with a mean of 32.65 and standard deviation of 20.86. Based on the lognormal distribution, random values for requests per day are generated and the total request per week is the sum of the orders from Monday till Friday.

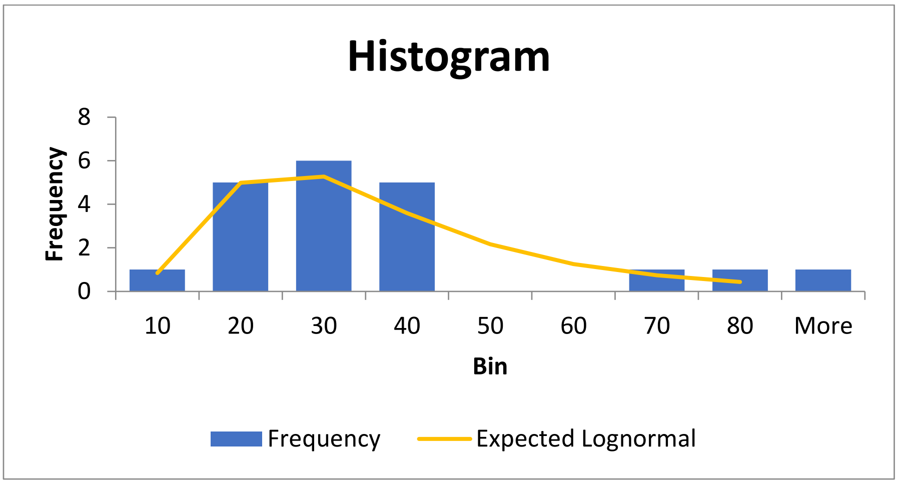

Figure 5.1: Histogram on requests per day

Since transport schedules are generally made per week, the final step is to generate datasets containing requests per week. This is done by randomly selecting requests from the original dataset, copying all related characteristics such as import/export request, container type, loading time and loading locations to a separate sheet. The number of requests incoming per day for one week are generated using the above described lognormal distribution. Table 5.1 shows the generated values for the first 8 weeks. For example, for the first week the number of incoming requests for Monday, Tuesday, Wednesday, Thursday and Friday are 38, 23, 25, 9 and 53 respectively, which results in a total of 148 requests per week. To generate the first dataset, 148 requests are randomly selected from the original dataset and copied with all related characteristics (import/export request, container type, loading time and loading locations). The loading date of the first 38 copied requests are set to 1 (Monday), the loading date of the next 23 copied requests are set to 2 (Tuesday) and so on.

	Week 1	**Week 2**	**Week 3**	**Week 4**
Mon	38	42	37	33
Tue	23	6	18	50
Wed	25	53	69	31
Thur	9	37	71	25
Fri	53	43	56	44
Total requests p.w	148	181	251	183
	Week 5	**Week 6**	**Week 7**	**Week 8**
Mon	9	28	75	35
Tue	48	32	23	44
Wed	67	4	7	50
Thur	20	56	0	44
Fri	13	62	25	42
Total requests p.w	157	182	130	215

Table 5.1: Randomly generated requests based on the lognormal distribution.

5.1.1 Replications

Based on the performance of the generated weeks, a study is conducted to find the number of replications. The number of replications is the number of weeks the algorithm should run, for which the estimated relative error is smaller than the corrected target value. Appendix F contains a detailed description of the calculations. Once the relative error is smaller than the corrected target value, the corresponding number of replications is considered to be satisfactory. As can be seen in Table 5.2, the number of replications needed is 5 and from now on this value is used. Meaning that for each experiment, 5 runs (weeks) are executed and performance of each run is documented.

	Total cost decrease	df	t-table CI-5%	Mean	Variance	Relative error	Corrected target value	Accept
1	2.48%	0						
2	2.62%	1	12.71	0.02548	0.000001	0.3446	0.0476	NO
3	2.68%	2	4.30	0.02592	0.000001	0.0984	0.0476	NO
4	2.72%	3	3.18	0.02624	0.000001	0.0646	0.0476	NO
5	**2.69%**	**4**	**2.78**	**0.02637**	**0.000001**	**0.0455**	**0.0476**	**YES**
6	2.48%	5	2.57	0.02611	0.000001	0.0435	0.0476	YES
7	2.83%	6	2.45	0.02642	0.000002	0.0450	0.0476	YES
8	2.43%	7	2.36	0.02615	0.000002	0.0450	0.0476	YES

Table 5.2: Number of replications

5.1.2 Parameters

For the dummy dataset, several experiments are executed. First of all, it is checked if different distances between the deep-sea terminal and import/export clients influence the performance of the matching algorithm. In the original dataset, only matches are made when import and export requests are on the same day. However, changing this time window from 0-5 might result in different outcomes. Additionally, in the current algorithm, the assumption is made that containers of the type reefer cannot be matched, because of the current environmental and governmental regulations. However, these regulations might change in the future, and once these containers can also be matched, the algorithm might improve with respect to overall performance. Another assumption made in the current model is related to container substitution. The current algorithm does not allow for container substitution, meaning that one container type cannot be replaced by another. This might influence the performance of the algorithm as well.

Furthermore, the ratio between import and export requests in one week might also impact the outcome of the algorithm. Finally, several assumptions are made related to costs, such as the reuse premium, which need to be paid for every match made. This reuse premium might influence the overall performance of the matching algorithm as well. Concluding, experiments in this research are conducted on:

- Distance between deep-sea terminal and import/export clients.
- Different time windows.
- Different container matching restrictions.
- Ratio between import and export requests.
- Reuse premium, which needs to be paid when linking an import and export request.

5.2 Simulating different experiments

This section describes the different experiment scenarios and their outcomes. These outcomes are compared. For the dummy dataset, not all three variables can be checked simultaneously. Experiments are performed on the dummy dataset with different time windows for reuse. Since the number of replications has been defined as 5 weeks, the dataset contains a total number of 920 requests (the total number of requests for the first 5 generated datasets = 148 + 181 + 251 + 183 + 157 = 920). The time window varies between 0-5, 0 meaning the match is made on the same day, and 5 within 5 days. For all other experiments, a time window of zero is used.

With the same dummy dataset, the impact of container substitution and allowing reefer containers to match can be checked. Therefore, three different settings are compared:

1. No container substitution, reefer containers are not allowed to be matched.
2. No container substitution, reefer containers can be matched.
3. Container substitution, reefer containers matching is allowed.

Next, experiments are conducted on different import/export ratios and the effect on the performance of the algorithm. Which requests become import and which requests export, is randomly decided. Three different scenarios are checked:

1. An import/export ratio of 70:30.
2. An import/export ratio of 60:40.
3. An import/export ratio of 50:50.

Finally, experiments are conducted on the reuse premium and how this influences the performance of the algorithm. Three different input values are tested: €0.-, €40.- and €80.-. For each configuration, performance of all 5 generated datasets are documented separately. For comparison of the different configurations the mean performance over 5 weeks is calculated as well.

5.3 Performance indicators

This section describes the performance indicators used to check the performance of the algorithm with different configurations. A sensitivity analyses is conducted to check how different variables influence the performance of the algorithm in terms of key performance indicators. Six key performance indicators have been described in Section 2.4.

1. **Travel costs:** all costs associated to transport a container.
2. **Transit time:** planned travel time from port to port, including loading and unloading procedures.
3. **Frequency:** the number of shipments offered by an operator (transportation company) in a given period of time.
4. **Flexibility:** the number of unexpected shipments that is dealt with, without excessive delay. Measured as the percentage of unplanned shipments that is dealt with in respect to the total ones.
5. **Loss and damage:** the percentage of the commercial value of shipped goods that is lost because of theft, damages or losses.
6. **Reliability:** the number of shipments that are delivered in time, without any delay. Measured as the percentage of timely deliveries.

Frequency and flexibility are not relevant in this research since all shipments are provided by the same deep-sea carrier. Additionally, loss and damage cannot be measured. The same applies for reliability, since the algorithm assumes that time constraints cannot be violated, and all requests are delivered in time. In general, both travel distance and travel time influence the travel cost. However, in this research a cost structure is used where the travel cost depends on the distance to cover. Therefore, this research focusses on:

- **Travel costs**: all costs associated to transport a container.
- **Travel distance (km):** total distance needed to fulfil a request.
- **Empty distance (km)**: to evaluate the percentage decrease in empty movements.
- **Cost savings**: cost decrease due to matching, compared to total cost without matching.

Table 5.3 shows the mean performance of the dummy dataset with and without matching. Settings of the matching algorithm are a time window of zero and the constraints and assumptions as described in Section 4.2. The mean total cost of fulfilling all requests from the dummy dataset as described in Section 5.1 without matching is €50,014.35, and the mean empty movements are 14,630 km (Table 5.3). When applying the matching algorithm, the mean total cost of fulfilling all requests is €48,664.16 and the mean empty movements are 12,496 km (Table 5.3). This is a cost decrease of 2.70% and a decrease in empty movements of 14.59%.

Mean performance	Without matching		With matching	
	Distance (km)	Costs	Distance (km)	Costs
Total	29,261	€ 50,014.35	28,362	€ 48,664.16
Empty	14,630		12,496	
Relocating	0		1,236	

Table 5.3: Performance of fulfilling all requests with and without matching

5.4 Experiments

As described in Section 5.1.2, five different experiments are conducted. These experiments are described in the next sections.

Warm-up and cooling down effect

When the time window increases, the effects of warmup length and cooling down should be taken into consideration. When the time window is zero, matches are only made when import and export requests are on the same day. However, when the time window increases to 3 or more, this means that export requests of one week can be matched with import request of the previous week. Additionally, import requests of the one week can be matched with export requests of the next week. Table 5.4 shows the mean number of import requests matched per day for each time window when the 5 datasets are considered separately (the mean of the 5 datasets).

	Import requests matched					
	Exp 01	Exp 02	Exp 03	Exp 04	Exp 05	Exp 06
Time window	0	1	2	3	4	5
Monday	2	4	8	9	9	9
Tuesday	2	5	5	6	6	6
Wednesday	3	5	6	4	4	4
Thursday	2	5	3	3	3	3
Friday	3	2	2	2	2	2
Total	12	21	24	24	24	24

Table 5.4: Mean number of requests matched on each day with different time windows

Concluding, when the 5 datasets are considered separately, the number of import requests matched early in the week tend to increase and the number of import requests matched later in the week tend to decrease when the time window increases. This makes sense, because one dataset consists of one week and matches cannot be made with requests from the previous or next week. However, in reality requests of multiple weeks are known. Therefore, the 5 different datasets are combined into one dataset consisting of all 5 weeks and performance of each separate week is documented. This ensures that requests of one week can be matched with requests of the previous or next week when the time window increases. However, it should be noted that the problem remains for the first and last week of the dataset, when the time window is 3 or more. Therefore, performance of the middle three weeks is evaluated when comparing performance of different time windows. For all other experiments with a time window of zero, performance of all 5 weeks is evaluated.

5.4.1 Distance

As described in Section 5.2, the first step is to see how the distances between deep-sea terminal and import/export clients influence the performance of the matching algorithm. For experimentation, 5 different dummy datasets are used, where each dataset contains data of one week and consists of different loading locations and thus overall distance to cover. Table 5.5 contains the performance of the 5 different datasets with and without matching, using a time window of zero.

	Without matching				
Dataset	**1**	**2**	**3**	**4**	**5**
Total dist (km)	24,975	31,654	38,176	27,677	23,822
Empty dist (km)	12,487	15,827	19,088	13,839	11,911
Total costs	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54
	With matching				
Total dist (km)	24,279	30,700	36,888	26,725	23,217
Empty dist (km)	11,079	13,621	16,070	11,433	10,275
Reloc dist (km)	713	1,251	1,730	1,453	1,032
Matches	6	9	13	11	7
Total costs	€ 40,547.30	€ 50,479.95	€ 64,497.08	€ 46,923.45	€ 40,873.03
Cost decrease	2.48%	2.62%	2.89%	2.72%	2.69%

Table 5.5: Performance for each independent run

Table 5.5 shows that when the total distance for fulfilling all requests is high, this obviously leads to higher costs. However, when applying the matching algorithm, the percentage cost decrease due to matching is almost the same for all 5 datasets. This suggests that when the total distance for fulfilling all requests increases, matching does not lead to higher cost savings. This can be explained by the fact that matches are generally made between import/export clients that are closely located to each other.

5.4.2 Time windows

This section describes how different time windows influence the outcome of the algorithm.

Appendix G shows the performance related to distance and cost with matching for each week. Table 5.6 shows the mean (weekly average) performance of the middle 3 weeks for different time windows.

	Mean performance					
	Exp 01	Exp 02	Exp 03	Exp 04	Exp 05	Exp 06
Time window	0	1	2	3	4	5
Total dist (km)	31,438	30,224	29,524	29,008	28,680	28,648
Empty dist (km)	13,708	11,408	10,481	9,388	9,048	8,989
Reloc dist (km)	1,478	2,565	2,792	3,369	3,380	3,408
Matches	11	23	27	32	33	34
Total costs	€ 53,966.83	€ 52,042.17	€ 51,194.73	€ 50,597.32	€ 50,199.16	€ 50,151.95

Table 5.6: Mean performance with matching and different time windows

Empty distance is defined as an empty return of an import container or an empty release of the export container. The relocating distance are the movements to relocate empty import containers to the demanded export client.

Table 5.7 shows the mean performance without matching. The mean total and empty distance without matching are 32,503 km and 16,251 km respectively. The mean total cost of fulfilling all requests without matching is €55,497.13. Comparing these values with the mean performance with matching as shown in Table 5.6, the percentage decrease is calculated (Table 5.8). Figure 5.2 shows the graphical representation of the percentage decrease in total and empty distance, and total costs.

Mean performance	Without matching	
	Distance (km)	Costs
Total	32,503	€ 55,497.13
Empty	16,251	

Table 5.7: Mean performance of the middle 3 weeks without matching

	Exp 01	Exp 02	Exp 03	Exp 04	Exp 05	Exp 06
Time window	0	1	2	3	4	5
Total dist (km)	3.28%	7.01%	9.16%	10.75%	11.76%	11.86%
Empty dist (km)	15.65%	29.80%	35.51%	42.23%	44.33%	44.69%
Total costs	2.76%	6.23%	7.75%	8.83%	9.55%	9.63%

Table 5.8: Percentage decrease due to matching with different time windows

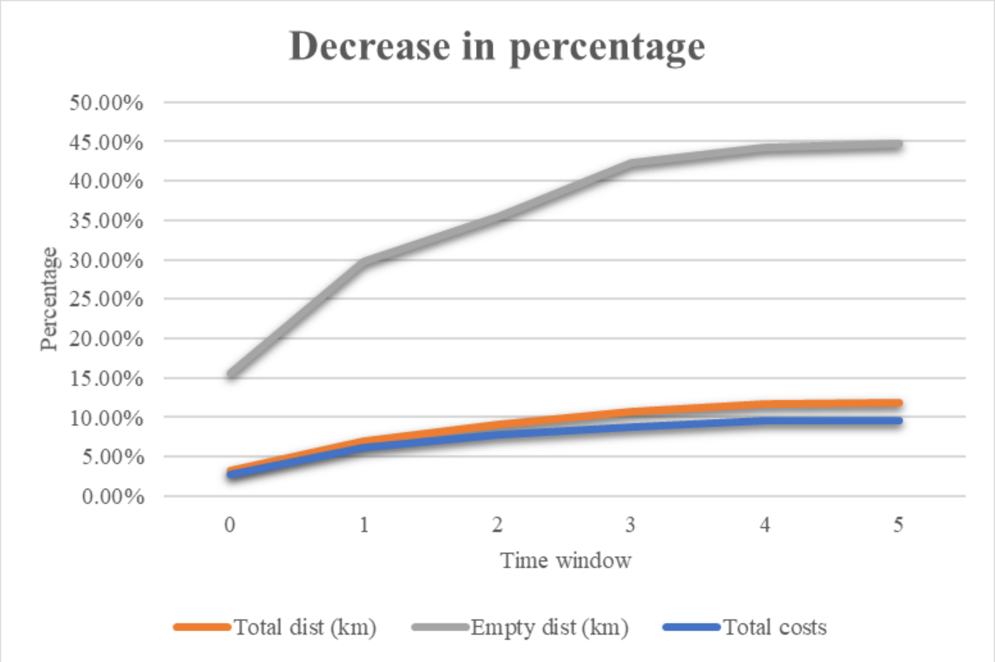

Figure 5.2: Percentage decrease due to matching with different time windows

In conclusion, increasing the reuse time window results in decreased total and empty distance, and decreased total cost. Increasing the reuse time window from 0-3 highly influences the total and empty distance and total costs. However, increasing the reuse time window even more does not highly affect the total and empty distance, nor the total costs. This can be explained, because when a match is made between an import and export request for which the loading dates are more than 3 days apart, detention costs are incurred. These detention costs are incurred per day and are relatively high and therefore a time window of 4 or more does not highly influence the performance compared to a time window of 3. Additionally, Table 5.6 also shows a time window of 4 or more does not lead to more matches made, compared to a time window of 3.

A statistical comparison of the 6 different time window configurations is done using a two-sample z-test for difference between means, with α = 0.05 and z-value of 1.96. The different configurations are compared on total cost to fulfil all request with matching. The z-score is calculated using the following formula:

$$Z = \frac{M_1 - M_2}{SE_D}$$

Appendix H describes the calculations of the two-sample z-test for difference between means for different configurations. Results of the calculations are shown in Table 5.9.

	Exp01 Exp02	Exp01 Exp03	Exp01 Exp04	Exp01 Exp05	Exp01 Exp06
Difference in mean	1924.65	2772.09	3369.50	3767.67	3814.87
Standard error	515.79	506.74	515.57	506.69	512.24
Z score	3.73	5.47	6.54	7.44	7.45
Z-table	1.96	1.96	1.96	1.96	1.96
Significant	Yes	Yes	Yes	Yes	Yes

	Exp02 Exp03	Exp02 Exp04	Exp02 Exp05	Exp02 Exp06	Exp03 Exp04
Difference in mean	847.44	1444.85	1843.01	1890.22	597.41
Standard error	492.02	491.97	491.97	497.69	491.79
Z score	1.72	2.94	3.75	3.80	1.21
Z-table	1.96	1.96	1.96	1.96	1.96
Significant	No	Yes	Yes	Yes	No

	Exp03 Exp05	Exp03 Exp06	Exp04 Exp05	Exp04 Exp06	Exp05 Exp06
Difference in mean	995.57	1042.78	398.16	445.37	47.21
Standard error	482.47	488.30	491.74	497.46	488.25
Z score	2.06	2.14	0.81	0.90	0.10
Z-table	1.96	1.96	1.96	1.96	1.96
Significant	Yes	Yes	No	No	No

Table 5.9: Two-sample t-test for difference in means with different time windows

Table 5.9 shows that there is a significant difference between the mean total cost of fulfilling all requests when the time window increases from 0 to 1, 2, 3, 4 or 5. However, there is no significant difference between the mean total cost of fulfilling all requests for experiments related to a time window of 3, 4, or 5.

Discussion

Concluding from Table 5.9, using a time window of 3 would be the most suitable for the matching algorithm. Results indicate that as the time window increases to 3, there is a higher probability of matching import and export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs. Increasing the time window even more does not have significant impact on the total cost of fulfilling all requests. This indicates, that even though increasing the time window more than 3 should result in a higher probability of matching import and export requests, the additional cost savings are not higher than the detention costs which are incurred after three days, and the number of matches made does not increase.

However, it should be noted that the current dataset does not consider the possible increase in distance when trucks have to make a detour to temporary store an empty container at an inland depot. When this is incorporated, the reuse costs might increase.

5.4.3 Container types

In the initial algorithm the assumption is made that reefer containers cannot be matched, and no container substitution is allowed. Meaning that one container type cannot be replaced by another container type. This limits the performance of the solution algorithm and this section researches the effect of allowing reefer containers to be matched, as well as container substitution. Three different configurations are used:

1. No container substitution, reefer containers are not allowed to be matched.
2. No container substitution, reefer containers can be matched.
3. Container substitution, reefer containers matching is allowed.

The time window used in these configurations is zero, so matches are only made when import and export requests are on the same day.

This section discusses the performance of these different configurations related to different container matching restrictions. Appendix I contains the performance related to distance and costs with matching for each week. Table 5.10 shows the mean (weekly average) performance for each experiment. These results show the mean performance of all 5 runs for different container restrictions.

	Mean performance		
	Exp 01	**Exp 02**	**Exp 03**
Total dist (km)	28,362	28,251	26,329
Empty dist (km)	12,496	12,312	9,196
Reloc dist (km)	1,236	1,308	2,502
Matches	9	11	25
Total costs	€ 48,664.16	€ 48,434.56	€ 46,160.71

Table 5.10: Mean performance with matching and different container restrictions

Concluding from Table 5.10, different container restrictions influence the mean total, empty and relocating distance. Allowing for reefer containers to be matched does not have a large impact on the total, empty or relocating distance. However, allowing container substitution, replacing one container type by another, does have a larger impact on the total, empty and relocating distance. This makes sense since more matches can be made.

Table 5.3 in Section 5.3 shows the mean performance without matching. The mean total cost to fulfil all requests is €50,014.35, and the mean total and empty movements are 29,261 km and 14,630 km respectively (Table 5.3). Comparing these values with the mean performance with matching as shown Table 5.10, the percentage decrease is calculated (Table 5.11). Figure 5.3 shows the graphical representation of the percentage decrease in total and empty distance, and total costs.

	Exp 01	Exp 02	Exp 03
Total dist (km)	3.07%	3.45%	10.02%
Empty dist (km)	14.59%	15.84%	37.14%
Total costs	2.70%	3.16%	7.71%

Table 5.11: Percentage decrease due to matching and different container restrictions

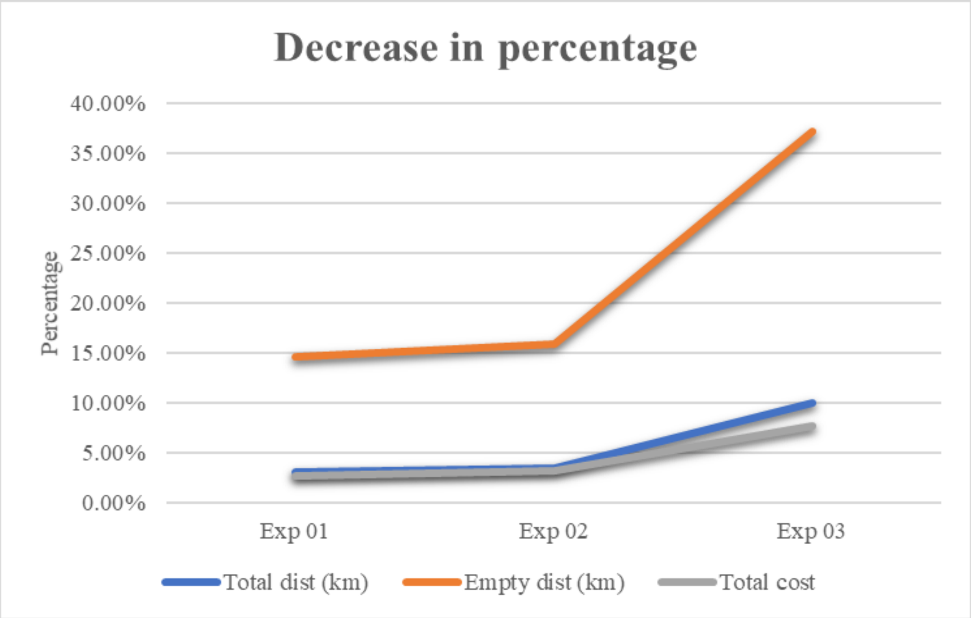

Figure 5.3: Percentage decrease due to matching for different container restrictions

In conclusion, allowing reefer containers to be matched does not highly influence the performance related to total distance, empty distance or total cost decrease. However, allowing container substitutions does largely impact the percentage decrease for these performance indicators. This makes sense since more matches can be made when all container types can be “replaced” by other container types. Table 5.10 shows a small increase in the number of matches made when allowing for reefer containers and no container substitution, and a large increase in the number of matches when allowing container substitution as well.

Again, a statistical comparison of the 3 different container restriction configurations is done using a two-sample z-test for difference between means, with α = 0.05 and z-value of 1.96. The different configurations are compared on total cost to fulfil all request with matching. The z-score is calculated using the following formula:

$$Z = \frac{M_1 - M_2}{SE_D}$$

Appendix H describes the calculations of the two-sample z-test for difference between means for different configurations. Table 5.12 shows the results of the calculations.

	Exp01 Exp02	Exp01 Exp03	Exp02 Exp03
Difference in mean	229.60	2503.45	2273.85
Standard error	456.11	451.70	451.21
Z score	0.50	5.54	5.04
Z-table	1.96	1.96	1.96
Significant	No	Yes	Yes

Table 5.12: Two-sample t-test for difference in means with different container restrictions

Concluding from Table 5.12, there is no significant difference between the mean total cost of fulfilling all requests between experiment 1 and experiment 2, but there is a significant difference between expimeriment 1 and experiment 3, and experiment 2 and experiment 3.

Discussion

Three different configurations are tested: 1) no container substitution, reefer containers are not allowed to be matched, 2) no container substitution, reefer containers can be matched, and 3) container substitution, reefer containers matching is allowed. Allowing reefer containers to be matched, but no container substitution leads to a small increase in overall performance but no significant difference in total cost of fulfilling all requests. On the other hand, allowing container substitution has a high impact in the overall performance of the algorithm and shows a significant difference in total cost of fulfilling all requests. Experiments related to container restrictions demonstrate that as the number of container restrictions decrease, the total cost of fulfilling all requests decreases. This indicates that as the number of container restrictions decreases, there is a higher probability of matching import and export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs.

However, it should be noted that in real life not all container types can be replaced by another container type, since not all operators can transport all container types, and not all cargo can be transported in every container type. In this research, that is not taken into consideration.

5.4.4 Import/export ratios

This section describes experiments related to different import/export ratios. As described in Section 5.2, different import/export ratios might influence the overall performance of the algorithm. To change the ratio, requests are randomly selected and changed from import to export, or the other way around, with the use of an excel macro. Three different configurations are used:

1. An import/export ratio of 70:30.
2. An import/export ratio of 60:40.
3. An import/export ratio of 50:50.

The time window used in these configurations is zero, so matches are only made when import and export requests are on the same day. It should be noted that the "places" where import is changed to export, or the other way around, does impact the solution outcome. This because, it matters for the match on which date/time an import is changed to export, vice versa. For experimentation, the average of 5 different runs for each import/export configuration is taken. Appendix J shows the mean performance for each import/export configuration.

Appendix K contains the mean and individual performance related to distance and cost with matching for each week for each import/export ratio. Table 5.13 shows the mean (weekly average) performance for each experiment. These results show the mean performance of all 5 runs for each import/export ratio.

	Mean performance		
	Exp 01	Exp 02	Exp 03
Import/export ratio	70|30	60|40	50|50
Total dist (km)	27,714	27,468	27,287
Empty dist (km)	11,921	11,550	11,393
Reloc dist (km)	1,163	1,288	1,263
Matches	17	22	24
Total costs	€ 47,456.08	€ 46,968.03	€ 46,638.10

Table 5.13: Mean performance with matching and different import/export ratios

Concluding from Table 5.13, different import/export ratios influence the mean total, empty and relocating distance. The total distance and empty distance tends to increase when the import/export ratios decreases. Additionally, the number of matches made increases when the import/export ratios is smaller. This makes sense since the possibility of a match increases when the number of import requests is closer to the number of export requests.

Table 5.3 in Section 5.3 shows the mean performance without matching. The mean total cost to fulfil all requests is €50,014.35, and the mean total and empty movements are 29,261 km and 14,630 km respectively (Table 5.3). Comparing these values with the mean performance with matching as shown

Table 5.13, the percentage decrease is calculated (Table 5.14). Figure 5.4 shows the graphical representation of the percentage decrease in total and empty distance, and total costs.

	Exp 01	Exp 02	Exp 03
Import/export ratio	**70|30**	**60|40**	**50|50**
Total dist (km)	5.29%	6.13%	6.75%
Empty dist (km)	18.52%	21.05%	22.13%
Total costs	5.12%	6.09%	6.75%

Table 5.14: Percentage decrease due to matching for different import/export ratios

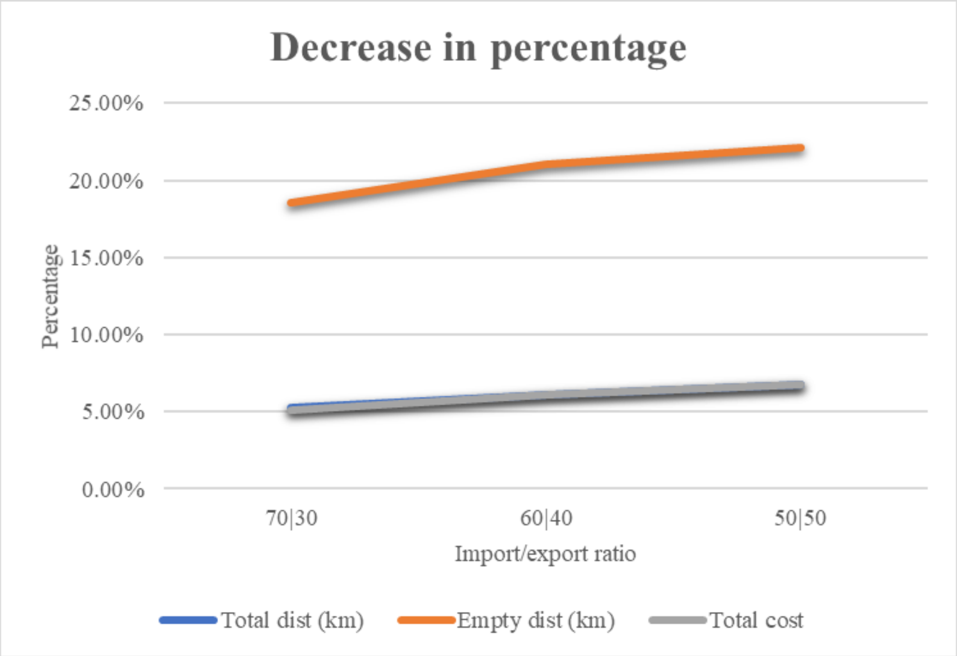

Figure 5.4: Percentage decrease due to matching for different import/export ratios

Discussion

Three different configurations are tested: 1) an import/export ratio of 70:30, 2) an import/export ratio of 60:40, and 3) an import/export ratio of 50:50. Table 5.13 also shows an increase in the number of matches made when the import/export ratios decreases. Different import/export ratios do influence the performance related to total distance decrease or total cost decrease. Especially the impact on the percentage decrease in empty movements is interesting. Reasons for this might be that smaller import/export ratios results in an increase in the number of matches and a decrease in the number of empty trips to/from the deep-sea terminal and an increase in movements between import and export clients. Matches are only made when the cost of reuse is less than empty return. Since the costs are calculated based on distance to cover, the distance between import and export clients is generally smaller than the distance from import to export client and hence more matches result in decreased empty movements.

Concluding, experiments related to different import/export ratios demonstrate that as the ratio decreases, the total cost of fulfilling all requests decreases. In a perfect world each export request can be fulfilled using an empty import container. Therefore, the highest savings are achieved when the import/export ratio is 50:50. This indicates that as the import/export ratio decreases, there is a higher probability of matching import/export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs and reduction in empty movements. However, it should be noted that the matching still depends on container characteristics of both import and export requests.

5.4.5 Reuse premium

This section describes experiments related to different values for reuse premium. As described in Section 5.2, for the initial matching algorithm a reuse premium of €80.- is used. To test the influence of the reuse premium on the matching algorithm, three different configurations are tested.

- A reuse premium of €0.-
- A reuse premium of €40.-
- And a reuse premium of €80.-

Appendix L shows the performance related to distance and cost with matching for each week. Table 5.15 shows the mean (weekly average). These results show the mean performance of all 5 runs with different values for the reuse premium.

	Mean performance		
	Exp 01	Exp 02	Exp 03
Reuse premium	**€ 80.00**	**€ 40.00**	**€ -**
Total dist (km)	28,362	28,331	28,323
Empty dist (km)	12,496	12,434	12,356
Reloc dist (km)	1,236	1,266	1,337
Matches	9	10	10
Total costs	€ 48,664.16	€ 48,611.85	€ 48,556.62

Table 5.15: Mean performance with matching and different reuse premium

Table 5.3 in Section 5.3 shows the mean performance without matching. The mean total cost to fulfil all requests is €50,014.35, and the mean total and empty movements are 29,261 km and 14,630 km respectively (Table 5.3). Comparing these values with the mean performance with matching as shown Table 5.15, the percentage decrease is calculated (Table 5.16). Figure 5.5 shows the graphical representation of the percentage decrease in total and empty distance, and total costs.

	Exp 01	Exp 02	Exp 03
Reuse premium	**€ 80.00**	**€ 40.00**	**€ -**
Total dist (km)	3.07%	3.18%	3.20%
Empty dist (km)	14.59%	15.01%	15.55%
Total costs	2.70%	2.80%	2.91%

Table 5.16: Percentage decrease due to matching with different reuse premium

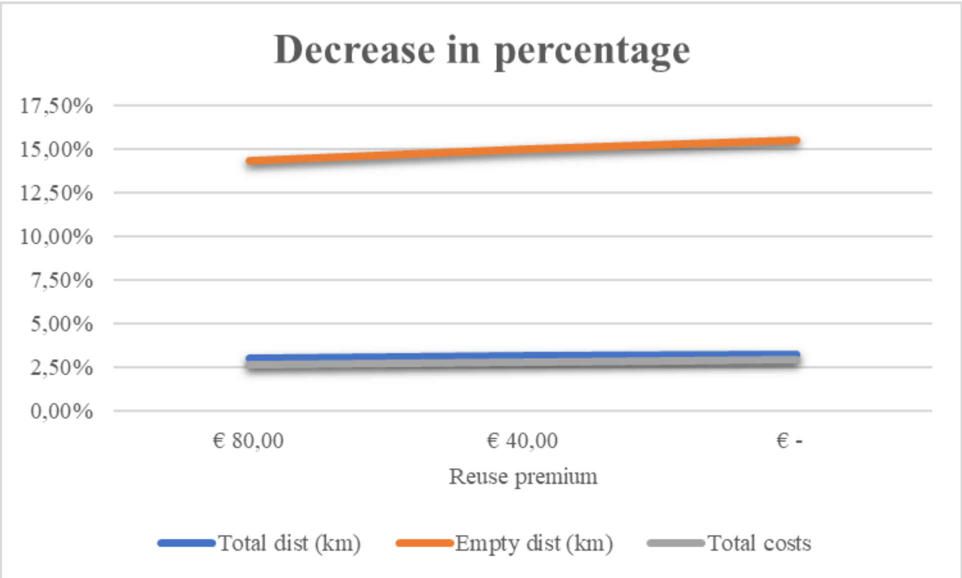

Figure 5.5: Percentage decrease due to matching with different reuse premium

Discussion

Experiments related to the reuse premium demonstrate that as the reuse premium decreases, the total cost of fulfilling all request is not highly affected. Table 5.15 also shows that decreased reuse premium does not lead to more matched made. This indicates that as the reuse premium decreases, the probability of matching import and export requests does not increase, nor the number of matches. Therefore, the number of trips between the deep-sea terminal and inland clients stay the same and hence the total cost of fulfilling all requests and the percentage of empty movements stay the same.

5.5 Conclusion

This chapter answers the fourth research question 'What improved performance can be expected of hinterland transportation?'. Chapter 4 describes the solution model which is tested in this chapter.

Section 5.1 describes the experimental set-up, which is used to test the solution method and its quality. This Section includes the assumptions, experiments and variables influencing the matching algorithm. The used dataset is described, as well as the number of weeks the algorithm should run during experimentation.

Section 5.2 discusses the different experiment scenarios. Five different experiments are described. The first experiment is related to distance. The second experiment is related to different time windows. The time window varies between 0 and 5, where a time window of 0 implies that reuse must occur on the same day, and a time window of 5 implies reuse must occur within 5 days. The third experiment is related to different container matching restrictions. Three different configurations are tested: 1) no container substitution, reefer containers are not allowed to be matched, 2) no container substitution, reefer container can be matched, and 3) container substitution, reefer container matching is allowed. The fourth experiment is related to different import/export ratios. Again, three different configurations are tested: 1) an import/export ratio of 70:30, 2) an import/export ratio of 60:40, and 3) an import/export ratio of 50:50. The final and fifth experiment is related to different values for the reuse premium. Three different input values are tested: €0.-, €40.- and €80.-.

Section 5.3 describes the performance indicators used to check the performance of the algorithm with different configurations. Since not all key performance indicators as discussed in Section 2.4 are possible to validate, performance of the algorithm is measured in terms of travel costs, travel distance (km), empty distance (km) and cost savings due to matching.

Section 5.4 discusses the different experiments related to distance, time windows, container restrictions, import/export ratios and reuse premium.

- Section 5.4.1 discusses whether total distance to fulfill all requests influence the percentage cost decrease due to matching. Results show that when the total distance to cover increases, matching does not lead to higher cost savings. This might be explained by the fact that matches are generally made between import/export clients closely located to each other.
- Section 5.4.2 discusses the influence of different time windows on the performance of the matching algorithm. Results show that as the time window increases to 3, there is a higher probability of matching import and export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs. Increasing the time window even more does not have significant impact on the total cost of fulfilling all requests. This indicates, that even though increasing the time window more than 3 should result in a higher probability of matching import and export requests, the additional cost savings are not higher than the detention costs which are incurred after three days, and the number of matches made does not increase.
- Section 5.4.3 discusses the influence of different container matching restrictions on the performance of the matching algorithm. Results show that as the number of container restrictions decrease, the total cost of fulfilling all requests decreases. This indicates that as the number of container restrictions decreases, there is a higher probability of matching import and export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs.
- Section 5.4.4 discusses the influence of different import/export ratios on the performance of the matching algorithm. Results show that as the import/export ratio decreases, there is a higher probability of matching import/export requests, which results in an increase in the number of matches and a decrease in the number of trips between the deep-sea terminal and inland clients and hence a reduction in total costs and reduction in empty movements. However, it should be noted that the matching still depends on container characteristics of both import and export requests.
- Section 5.4.5 discusses the influence of different values for reuse premium on the performance of the matching algorithm. Results show that that as the reuse premium decreases, the probability of matching import and export requests does not increase, nor the number of matches. Therefore, the number of trips between the deep-sea terminal and inland clients stay the same and hence the total cost of fulfilling all requests and the percentage of empty movements stay the same.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This chapter discusses the results of this research and its relevance compared to the complex reality. Section 6.1 elaborates on the results of the research and how to successfully implement the algorithm within TEUbooker's online platform. The recommendations for TEUbooker and their objectives are discussed in Section 6.2, and Section 6.3 describes the limitations. Finally, the chapter ends with some suggestions for further research in Section 6.4.

6.1 Conclusions

TEUbooker's ambition is to continuously improve the booking of container transportation for all concerned parties. They aim to reduce truck transportation between deep-sea terminals and the European hinterland and stimulate re-use and better planning of equipment by matching import and export flows. The following research question is proposed for this research: *How can we add decision support to TEUbooker for matching import and export flows, improving the performance of hinterland container transportation?*

In order to answer this research question, the current situation of hinterland container transportation is studied to find out where problems arise and how to overcome them. TEUbooker's aims and the process of TEUbooker hinterland is described. After that, a literature study is conducted to learn more about the regional empty container management problem, empty container repositioning and empty container reuse models. Based on the gathered knowledge, a decision support algorithm is developed which matches import and export requests based on their characteristics. Finally, a sensitivity analysis is performed on how different input values influence the performance of the matching algorithm.

This research shows that the total throughput for the Port of Rotterdam has grown in the past years and is still growing. This requires improved performance of hinterland transportation. Additionally, hinterland transportation is becoming increasingly important since it is the most costly part of container transportation, and arising issues related to congestion and pollutions problems caused by excessive truck use.

The literature review shows a lot of research is done in the field of empty container management. The regional empty container management problem on an operational level is in literature often divided into the container allocation problem and the vehicle routing problem to decrease complexity. This research focusses on the container allocation problem. The literature research shows that opportunities for optimizing the empty container management can be found in preventing some empty containers from moving back to the deep-sea terminal immediately.

To support TEUbooker in the matching of import and export flows and the further optimization of the hinterland container transportation, a matching algorithm is proposed in Chapter 4. The output of the algorithm provides TEUbooker with a plan which import and export requests to match to achieve cost savings. A combination of heuristics is used to make sure containers are picked up and delivered in time, while minimizing the number of empty movements. Input values, such as reuse time window, transport costs, storage costs and other costs can easily be changed.

Performance of the algorithm is checked based on travel costs, travel distance (km), empty distance (km), and cost savings, with a time window of zero. The matching algorithm results in an 3.07% and 14.59% decrease in total and empty distance respectively, compared to the total and empty distance without matching. Additionally, the matching algorithm results in a 2.70% decrease in total cost of fulfilling all requests.

A sensitivity analysis on the solution algorithm demonstrate how different input values influence the performance of the matching algorithm. Experiments related to distance show that matches are generally made between import and export clients closely located to each other, and not a lot of distance is covered for relocating an empty import container. Experiments related to time windows demonstrate that the larger the reuse time window, the more savings can be achieved. However, detention costs are incurred after three days and are relatively high. Experiments demonstrate that increasing the time window even more than 3 does not have a significant impact on the total cost of fulfilling all requests. This indicates, that even though increasing the time window more than 3 should result in a higher probability of matching import and export requests, the additional cost savings are not higher than the detention costs which are incurred after three days, and the number of matches made do not increase.

On the other hand, experiments show that the reuse premium, which need to be paid for every match made between an import and an export request, does not influence the performance of the matching algorithm. However, container restrictions, which container types can be matched, do influence the performance of the matching algorithm. Experiments show that in general, less container restrictions lead to more matches made and increased cost savings. Finally, the highest savings are achieved when the import/export ratio decreases, because in a perfect world each export request is fulfilled using an empty import container. However, it should be noted that these values still depend on container characteristics of both import and export requests.

Concluding, the matching algorithm has the potential to become a decision support tool that assist TEUbooker in planning and scheduling of import/export requests at several operators. At this point, it provides insight in which request to match to achieve cost savings and minimizing empty container movements, improving turnaround time, total costs and performance of hinterland container transportation. With further developments, the tool will be a valuable addition to the hinterland container logistics. The process of matching import and export requests and combining trips becomes easier when using the tool since it considers all import and export requests.

6.2 Limitations

Limitations of this research arise due to the complexity of the problem and time availability. Assumptions are made to simplify the problem, which also means that the model does not optimally reflect reality and results should be reviewed with care. This section discusses the assumptions made during this research, the consequences and how to deal with this.

Some limitations are related to available data. This research only uses data of one deep-sea carrier. However, the online platform of TEUbooker deals with multiple operators and deep-sea carriers, which makes the problem more complex.

Additionally, some factors are not considered in the algorithm but should be considered in real life. For example, this research does not consider inland terminals when matching occurs within 1 or more days. In reality a container can be transported to an inland depot for temporally storage and later transported for reuse. Therefore, in real life, this might result in additional distance to cover and different cost calculations.

Furthermore, currently the algorithm does not consider container substitution. However, this might be possible for some operators, depending on the transport modality and characteristics of the containers. Experiments are conducted on allowing container substitution, replacing one container type by another. However, in the real situation this might not be as easy, since not all operators can transport all container types, and not all cargo can be transported in every container type.

The testing of the model is also limited. In this research, experiments are only performed for one deep-sea terminal, fixed locations and different time windows, container matching restrictions, import/export ratios and reuse premium. More experiments related to parameters and different input values make the algorithm more reliable.

Additionally, experimentations are affected by warm-up and cooling down effects since this research is focussed on import/export requests per week. When the time window is zero, matches can only be made when import and export requests are on the same day. However, when the time window increases to for instance 3, this means that export requests on Monday can be matched with import requests from Friday of the previous week. In order to eliminate the warm-up and cooling down period, this research only focusses on the performance of the middle weeks when comparing the results of different time windows In reality, import and export requests of the previous and next week are generally know and the matching algorithm is not affected by a warm-up or cooling down period.

6.2.1 Limitations related to implementation

This section discusses the limitations related to the implementation of the decision support algorithm. The current algorithm is not yet useful for TEUbooker, but several improvements can make it useful. One of the biggest limitations of this research is that the algorithm is only tested using truck transportation. Before implementation in TEUbooker hinterland, the algorithm should be able to deal with all three modalities. To achieve this, data needs to be gathered on transport costs for different barge/train operators to several inland terminals. Additionally, the current algorithm uses an average for the cost of truck transportation, the cost of storing, waiting and detention. However, in reality, each operator has its own cost structure, related to transport costs, storage costs, waiting costs, which makes it more complex. So, before implementation, the algorithm should be able to deal with multiple operators and cost structures.

6.3 Recommendations for implementation

This section gives some recommendations for the implementation of the proposed solution algorithm within TEUbooker hinterland.

When implementing the matching algorithm in TEUbooker hinterland, data needs to be gathered and stored for the matching. Information needed to make a match is: inbound/outbound request, transport reference, container type, container owner, release location, loading location and date, return location. This information is acquired when a shipper places a request for transport.

The current process for matching only considers matching on the same day. Therefore, when implementing the matching algorithm, the first step is to only consider matching when the import and export loading date is on the same day. The matching is based on container characteristics, loading location and date/time. Matches are only made when it results in an overall cost decrease. Once this works properly, matching on the next or later days can be included to achieve higher cost savings. However, when matching on the next or later days is considered, the algorithm should include the possible increase in distance when trucks have to make a detour to temporary store an empty container at an inland depot and later to the export client’s location, storage costs, waiting time, and detention costs.

To maximize performance of the matching algorithm, the matching algorithm should run every once in a while, to be able to deal with changes in data. This ensures that all matches are considered when data of import/export requests is changed or updated.

6.4 Further research

This research provides insight into the complex reality of hinterland container logistics and the possibility of matching import and export flows. Several assumptions are included in the model, and some of these assumptions need further research. As mentioned before, this research only considers street turns, directly transporting the empty import container to the demanded export client and does not consider container substitution.

Results show that as the number of container restrictions decrease, the total cost of fulfilling all requests decreases. Therefore, further research is needed to gain more insight into the possibilities of container substitution, replacing one container type by another type of container, to improve the performance of the algorithm. Even so, when the reuse time window increases, the concept of street turn is often replaced by depot direct. Depot direct is the concept where an empty import container is transported to an inland depot, close to the import or export client, for temporally storage and can later be reused. Further research is needed on the effects and costs of such transport and how it can be incorporated in the current matching algorithm.

Additionally, the current algorithm is tested with data of one deep-sea carrier, who only uses truck transportation. Further research is needed on how the algorithm would perform with multiple deep-sea carriers, operators and modalities. Furthermore, the current algorithm is tested on historical data, but in reality, the algorithm needs to cope with data that changes continuously. It may be decided to make matches one day before the loading date or earlier. Additional research must be conducted to check what planning horizon results in an optimal performance.

Furthermore, additional research should be conducted on collaboration of different operators and deep-sea terminals. Within the TEUbooker platform, there are multiple stakeholders involved, and when matches are made with multiple container owners, some guidelines and rules must be developed on how to deal with this.

This research is interesting for all deep-sea carriers, operators and other transport companies, who need to transport several import and export requests between deep-sea terminals and the European hinterland. The proposed solution algorithm provides insight in which request to match to achieve cost savings and minimizing empty container movements, improving turnaround time, total costs and performance of hinterland container transportation.

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APPENDIX A

BOOKING INFORMATION

This appendix describes the required information needed for scheduling and planning different import and export requests.

Minimum information needed for import and export requests:

- Booking ID
- Container number
- Container type and characteristics
- Pick-up reference
- Pick-up and delivery location
- Pick-up and delivery time
- Modality

Additional information needed for shipments

- Customs forms
- Permissions forms to handle containers
- Closing time
- Detention time
- Demurrage time

APPENDIX B

IMPORT/EXPORT DATA

This appendix shows the first 30 rows of the data provided by the deep-sea carrier.

Transport Reference	Size/Type	Release Sub Location	Release Location	Date	Time	Zip Code	Loading/unloading Location	Return Sub Location	Return Location	Inbound / Outbound
ONA18C020206	40ST	RST	NLRTM	07.02.2018	13:00	1432 DJ	AALSMEER	PR3	NLRTM	I
ONA18C020371	40HC	RST	NLRTM	15.02.2018	13:00	1432 DJ	AALSMEER	PR3	NLRTM	I
ONA18C020480	40HC	RST	NLRTM	21.02.2018	13:00	1432 DJ	AALSMEER	PR3	NLRTM	I
ONA18C020628	40HC	RST	NLRTM	27.02.2018	13:00	1432 DJ	AALSMEER	PR3	NLRTM	I
ONA18C020177	20ST	PR3	NLRTM	06.02.2018	08:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020173	20ST	PR3	NLRTM	06.02.2018	15:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020548	20ST	PR3	NLRTM	22.02.2018	07:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020549	20ST	PR3	NLRTM	22.02.2018	08:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020550	20ST	PR3	NLRTM	22.02.2018	09:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020551	20ST	PR3	NLRTM	23.02.2018	13:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020552	20ST	PR3	NLRTM	23.02.2018	09:00	7602 KJ	ALMELO	RST	NLRTM	O
ONA18C020446	20ST	RST	NLRTM	20.02.2018	10:00	2408 AP	ALPHEN A/D RIJN	PR3	NLRTM	I
ONA18C020330	20ST	UNI	NLRTM	13.02.2018	11:00	1042 AS	AMSTERDAM	PR3	NLRTM	I
ONA18C020448	20ST	UNI	NLRTM	19.02.2018	13:00	1114 AG	AMSTERDAM-	PR3	NLRTM	I
ONA18C020045	45HW	RST	NLRTM	01.02.2018	06:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020049	45HW	RST	NLRTM	01.02.2018	07:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020046	45HW	RST	NLRTM	01.02.2018	08:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020050	45HW	RST	NLRTM	01.02.2018	09:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020047	45HW	RST	NLRTM	01.02.2018	10:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020051	45HW	RST	NLRTM	01.02.2018	11:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020048	45HW	RST	NLRTM	01.02.2018	12:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020052	45HW	RST	NLRTM	01.02.2018	13:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020053	45HW	RST	NLRTM	01.02.2018	14:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020054	45HW	RST	NLRTM	01.02.2018	15:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020057	45HW	RST	NLRTM	02.02.2018	06:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020061	45HW	RST	NLRTM	02.02.2018	07:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020058	45HW	RST	NLRTM	02.02.2018	08:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020062	45HW	RST	NLRTM	02.02.2018	09:00	B-2030	ANTWERPEN	RST	NLRTM	I
ONA18C020059	45HW	RST	NLRTM	02.02.2018	10:00	B-2030	ANTWERPEN	RST	NLRTM	I

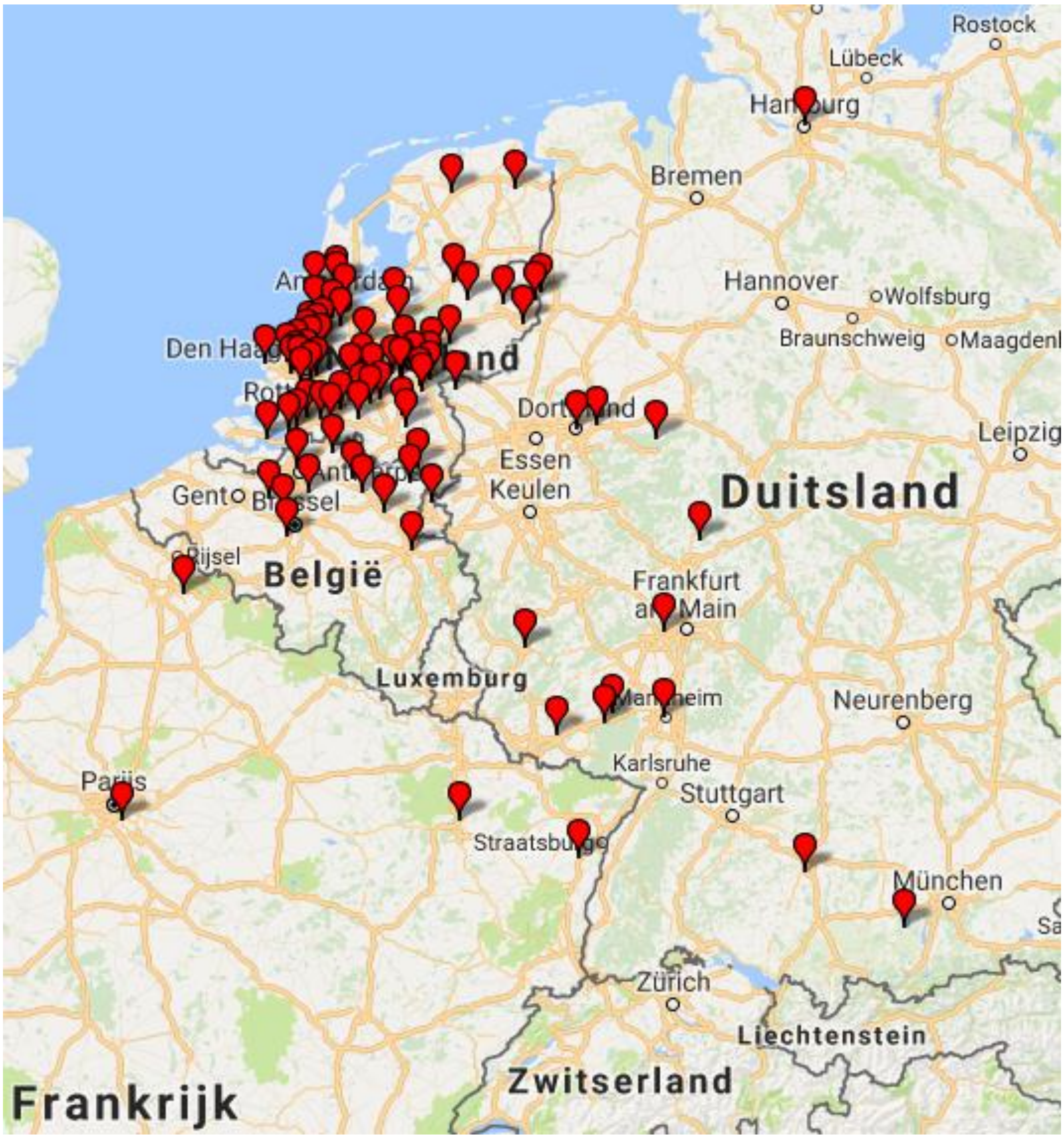
APPENDIX C

LOADING LOCATIONS

This appendix visualizes the loading/unloading locations, and the release and return locations of February from the provided dataset.

The loading/unloading locations of February

Place	Country	Place	Country	Place	Country
Aalsmeer	Nederland	Haaften	Nederland	Raalte	Nederland
Almelo	Nederland	Hamburg	Duitsland	Ridderkerk	Nederland
Alphen A/D Rijn	Nederland	Hasselt	Belgie	Rijkevorsel	Belgie
Amsterdam	Nederland	Hazerswoude-Dorp	Nederland	Rotterdam	Nederland
Antwerpen	Belgie	Heerle	Nederland	Rotterdam Botlek	Nederland
Appels	Belgie	Herstal	Belgie	Sembach	Duitsland
Arnhem	Nederland	Hillegom	Nederland	s Hertogenbosch	Nederland
Barendrecht	Nederland	Hofheim	Duitsland	Sin le Noble	Frankrijk
Beneden-Leeuwen	Nederland	Hoogezand	Nederland	Sittard	Nederland
Bergen op Zoom	Nederland	Ijmuiden	Nederland	St. Katelijne Waver	Belgie
Bexbach	Duitsland	Kaiserslautern	Duitsland	Tessenderlo	Belgie
Bleiswijk	Nederland	Kleve	Duitsland	Tiel	Belgie
Boven-Leeuwen	Nederland	Kruiningen	Nederland	Tilburg	Nederland
Breda	Nederland	KS-Vlaardingen	Nederland	Unna	Duitsland
Bree	Belgie	Leerdam	Nederland	Utrecht	Nederland
Champigneulles	Frankrijk	Lieshout	Nederland	Veenendaal	Nederland
De Lier	Nederland	Lot (Beersel)	Belgie	Veghel	Nederland
Delft	Nederland	Ludwigshafen	Duitsland	Villeneuve St. Georges	Frankrijk
Denekamp	Nederland	Maasvlakte	Nederland	Waalwijk	Nederland
Diessen Am Ammersee	Duitsland	Mijdrecht	Nederland	Waddinxveen	Nederland
Dodewaard	Nederland	Mollem Asse	Belgie	Warstein	Duitsland
Dortmund	Nederland	Nederasselt	Nederland	Weert	Nederland
Drachten	Nederland	Nieuwkuijk	Nederland	Wijchen	Nederland
Ebsdorfergrund	Duitsland	Nijkerk	Nederland	Wittlich	Duitsland
Eerbeek	Nederland	Nijmegen	Nederland	Wormer	Nederland
Elst	Nederland	Nordhorn	Duitsland	Zaandam	Nederland
Enschede	Nederland	Obernai	Duitsland	Zeewolde	Nederland
Etten Leur	Nederland	Oosterhout	Nederland	Zoetermeer	Nederland
Geel	Belgie	Oud Gastel	Nederland	Zoeterwoude	Nederland
Giessen	Nederland	Oud-Beijerland	Nederland	Zwolle	Nederland
Gorinchem	Nederland	Pernis	Nederland		


Rostock
Lübeck
Bremen
Hannover
Wolfsburg
Braunschweig
Leipzig
Essen
Keulen
Duitsland
Gent
België
Frankfurt
Luxemburg
Neurenberg
Karlsruhe
Stuttgart
München
Zürich
Liechtenstein
Zwitserland
Frankrijk

The release and return locations of February

Abbreviation	Place	Country
BEANR	Antwerpen	Belgie
DEAND	Andernach	Duitsland
DEDUI	Duisburg	Duitsland
DEGHM	Gernsheim	Duitsland
DELUD	Ludwigshafen	Duitsland
DEMUC	Munchen	Duitsland
FRSXB	Strasbourg	Frankrijk
NLHGL	Hengelo	Nederland
NLRTM	Rotterdam	Nederland
NLMOE	Moerdijk	Nederland

APPENDIX D

TRUCK TARRIF

This appendix contains the data related to cost of truck transportation. This cost structure is used for the design of the initial solution algorithm.

	From	To	Cost	
Staffel 1	1	20	€	160.56
Staffel 2	21	40	€	181.24
Staffel 3	41	60	€	196.02
Staffel 4	61	80	€	210.79
Staffel 5	81	100	€	226.55
Staffel 6	101	120	€	231.48
Staffel 7	121	140	€	246.25
Staffel 8	141	160	€	261.03
Staffel 9	161	180	€	276.79
Staffel 10	181	200	€	291.56
Staffel 11	201	220	€	301.41
Staffel 12	221	240	€	311.26
Staffel 13	241	260	€	321.11
Staffel 14	261	280	€	331.95
Staffel 15	281	300	€	341.80
Staffel 16	301	320	€	351.65
Staffel 17	321	340	€	361.50
Staffel 18	341	360	€	371.35
Staffel 19	361	380	€	386.12
Staffel 20	> 380	Kilometerprijs	€	1.00
Retourlaadpremie op bovenstaande tarieven (tot 600 km rondrit)			€	80.00

APPENDIX E

ORDERS PER DAY

This appendix shows the calculations for the histogram and expected lognormal distribution for the number of requests per day.

Based on the provided data (historical data) a histogram can be made on the requests per day. This is done by first calculating the number of requests per day and deciding on the bin values. Bin values and descriptive statistics can be found in Tables below.

Descriptive Statistics		Ln(x)
Mean	32.65	3.319475942
Standard Error	4.664126815	
Median	27	
Mode	26	
Standard Deviation	20.85860923	0.589651704
Sample Variance	435.0815789	
Kurtosis	2.048687376	
Skewness	1.588274415	
Range	81	
Minimum	7	
Maximum	88	
Sum	653	
Count	20	
Alpha	13.32562263	
Beta	2.450166938	

Descriptive statistics on requests per day

Bin	*Frequency*		*Expected Lognormal*	*Expected error*
10	1	0.846064588	0.846064588	0.028007449
20	5	5.829764905	4.983700317	5.33097E-05
30	6	11.10228013	5.272515221	0.100376022
40	5	14.68998196	3.587701831	0.555950916
50	0	16.8505995	2.160617548	2.160617548
60	0	18.11191621	1.261316708	1.261316708
70	1	18.84867934	0.736763127	0.094051465
80	1	19.28454147	0.435862131	0.730165601
More	1			
				4.930539017
			Chi-square	***15.50731306***

Bins and expected distribution for requests per day

For the number of requests per day, a lognormal distribution has been hypothesized. Calculate de LN of all x (requests per day) and calculate the mean and standard deviation. These values can be used to plot the data with a lognormal distribution to the histogram. To proof that the data is indeed lognormal distributed, a chi-square test with $\alpha = 0.05$ and 8 degrees of freedom is conducted. Found value for the lognormal distribution (4.930) is smaller than the chi-square value of 15.507, which means that with 95% significance level that the data is lognormal distributed, with a mean of 32.65 and standard deviation of 20.86.

APPENDIX F

REPLICATIONS

This appendix shows the calculation for the used number of replications. To determine the number replications for which the relative error is smaller than the corrected target value for the relative error, a study has been made. The corrected target value for the relative error is the maximum allowed relative error. The following formula can be used to find the corrected target value for the relative error (gamma') with an alpha of 0.05:

$$\gamma' = {}^{\alpha}/_{(\alpha + 1)} = 0.047619$$

The total cost with matching is used because it is one of the performance indicators of the model. The T-value can be found in the T-table using an alpha of 5%. The number of replications can be found based on calculation of the confidence interval half width divided by the mean, the relative error. The relative error can be found using the following formula:

$$n^* = \min \left\{ (i \geq n : / \frac{(t_{i-1,1-\frac{\alpha}{2}}\sqrt{\frac{S_n^2}{i}})}{(|\overline{X_n}|)} < \left(\frac{\gamma}{\gamma + 1}\right) \right\}$$

Once the relative error is smaller than the corrected target value, that number of replications is considered satisfactory. As shown in Table 5.2, Section 5.1.1, the number of replications used in this study is 5. Meaning that the algorithm runs over 5 weeks.

APPENDIX G

RESULTS TIME WINDOWS

This appendix shows the results for all 5 runs for different time windows.

Time window	0						
EXP01	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,279	30,700	36,888	26,725	23,217	28,362	30,994,754
Empty dist	11,079	13,621	16,070	11,433	10,275	12,496	5,528,313
Reloc dist	713	1,251	1,730	1,453	1,032	1,236	151,661
Matches	6	9	13	11	7	9	8
Total cost	€ 40,547.30	€ 50,479.95	€ 64,497.08	€ 46,923.45	€ 40,873.03	€ 48,664.16	€ 95,898,410.82
Cost decrease	2.48%	2.62%	2.89%	2.72%	2.69%	2.68%	0.00%

Time window	1						
EXP02	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,916	29,593	35,254	25,825	22,548	27,427	26,161,225
Empty dist	10,051	11,801	13,113	9,309	8,859	10,627	3,188,252
Reloc dist	1,378	1,965	3,052	2,677	1,778	2,170	464,607
Matches	13	17	31	22	13	19	57.2
Total cost	€ 39,627.73	€ 48,920.82	€ 61,968.25	€ 45,237.45	€ 39,967.50	€ 47,144.35	€ 83,636,719.16
Cost decrease	4.69%	5.62%	6.70%	6.22%	4.85%	5.62%	0.01%

Time window	2						
EXP03	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,599	29,087	34,459	25,026	22,370	26,908	24,212,002
Empty dist	9,658	10,656	11,929	8,859	8,600	9,940	1,877,275
Reloc dist	1,454	2,603	3,443	2,329	1,859	2,337	575,659
Matches	14	22	35	23	14	22	74
Total cost	€ 39,369.48	€ 48,233.30	€ 60,738.79	€ 44,612.11	€ 39,605.23	€ 46,511.78	€ 76,923,268.24
Cost decrease	5.31%	6.95%	8.55%	7.51%	5.71%	6.81%	0.02%

Time window	3						
EXP04	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,128	28,209	34,186	24,629	20,936	26,218	26,857,249
Empty dist	7,187	9,279	11,324	7,561	7,156	8,501	3,247,758
Reloc dist	3,454	3,103	3,774	3,229	1,869	3,086	527,800
Matches	18	27	39	30	14	26	98
Total cost	€ 39,628.70	€ 46,276.16	€ 60,704.29	€ 44,811.52	€ 36,504.49	€ 45,585.03	€ 86,900,518.78
Cost decrease	4.69%	10.73%	8.60%	7.10%	13.09%	8.84%	0.10%

Time window	4						
EXP05	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	22,882	28,041	33,697	24,302	20,912	25,966	25,473,433
Empty dist	6,938	8,828	10,992	7,324	7,213	8,259	2,875,650
Reloc dist	3,456	3,386	3,617	3,139	1,788	3,077	549,033
Matches	20	30	39	31	13	27	103.3
Total cost	€ 39,786.21	€ 46,177.25	€ 59,919.23	€ 44,501.00	€ 36,334.86	€ 45,343.71	€ 81,473,979.23
Cost decrease	4.31%	10.92%	9.78%	7.74%	13.49%	9.25%	0.12%

Time window	5						
EXP06	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	22,882	28,041	33,721	24,182	20,912	25,947	25,669,255
Empty dist	6,938	8,828	10,935	7,205	7,213	8,224	2,856,264
Reloc dist	3,456	3,386	3,698	3,139	1,788	3,093	572,273
Matches	20	30	40	31	13	27	110
Total cost	€ 39,786.21	€ 46,177.25	€ 60,088.87	€ 44,189.74	€ 36,334.86	€ 45,315.39	€ 82,871,838.11
Cost decrease	4.31%	10.92%	9.53%	8.39%	13.49%	9.33%	0.11%

APPENDIX H

TWO-SAMPLE Z-TEST

This appendix shows the calculations for the two-sample z-test for the difference between means.

To test the significance of an obtained difference between two sample means. The first step is to check whether to use a two-tailed test or one-tailed test. In this research it is tested whether the difference in mean is significant with the use a two-tailed test.

The next step is to set up a null hypothesis (H_0) that there is no difference between the means so the different configurations.

$$H_0: difference\ in\ mean = 0$$

A α= 0.05 is used. The standard error of the difference in mean is calculated using the following formula:

$$SE_D = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

Where

$$\sigma_1 = standard\ deviation\ of\ the\ first\ group$$

$$\sigma_2 = standard\ deviation\ of\ the\ second\ group$$

$$n_1 = size\ of\ the\ N\ of\ first\ group$$

$$n_2 = size\ of\ the\ N\ of\ second\ group$$

Next, the z-score is calculated using the following formula:

$$Z = \frac{M_1 - M_2}{SE_D}$$

The critical value for Z (from the z-table) with a 0.05 significance level is 1.96. This means that the value of Z to be significant at 0.05 must be 1.96 or more.

If Z ≤ z, the null hypothesis cannot be rejected and with 95% significance level it can be stated that there is no significant difference between the means of the different experiments.

APPENDIX I

RESULTS CONTAINER RESTRICTIONS

This appendix shows the results for all 5 runs for different container restrictions.

Time window	0						
	1	2	3	4	5	Mean	Variance
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,279	30,700	36,888	26,725	23,217	28,362	30,994,754
Empty dist	11,079	13,621	16,070	11,433	10,275	12,496	5,528,313
Reloc dist	713	1,251	1,730	1,453	1,032	1,236	151,661
Matches	6	9	13	11	7	9	8
Total cost	€ 40,547.30	€ 50,479.95	€ 64,497.08	€ 46,923.45	€ 40,873.03	€ 48,664.16	€ 95,898,410.82
Cost decrease	2.48%	2.62%	2.89%	2.72%	2.69%	2.68%	0.00%

Time window	0						
EXP02	1	2	3	4	5	Mean	Variance
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,163	30,607	36,683	26,725	23,079	28,251	30,609,349
Empty dist	10,795	13,489	15,809	11,433	10,036	12,312	5,466,080
Reloc dist	881	1,291	1,786	1,453	1,132	1,308	115,901
Matches	8	10	15	11	9	11	7.3
Total cost	€ 40,396.04	€ 50,344.23	€ 64,134.04	€ 46,923.45	€ 40,375.05	€ 48,434.56	€ 95,494,367.61
Cost decrease	2.84%	2.88%	3.44%	2.72%	3.87%	3.15%	0.00%

Time window	0						
EXP03	1	2	3	4	5	Mean	Variance
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	22,850	28,626	34,091	25,455	20,624	26,329	27,734,468
Empty dist	8,550	10,693	11,375	8,846	6,519	9,196	3,674,717
Reloc dist	1,813	2,106	3,628	2,771	2,195	2,502	516,318
Matches	21	23	38	21	23	25	52
Total cost	€ 38,390.62	€ 48,055.21	€ 61,403.17	€ 45,157.21	€ 37,797.34	€ 46,160.71	€ 91,812,246.43
Cost decrease	7.67%	7.29%	7.55%	6.38%	10.01%	7.78%	0.02%

APPENDIX J

FINDING IMPORT/EXPORT RATIOS

This appendix shows the performance of each week for each import/export ratio.

		70|30				
	EXP01	1	2	3	4	5
Mean	Total dist	24,975	31,654	38,176	27,677	23,822
	Empty dist	12,487	15,827	19,088	13,839	11,911
	Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54
	Total dist	23,701	30,229	36,083	26,051	22,504
	Empty dist	10,629	13,383	15,133	10,863	9,595
	Reloc dist	585	1,019	1,862	1,349	998
	Matches	11	16	24	21	16
	Total cost	€ 39,808.03	€ 49,466.45	€ 63,017.38	€ 45,484.05	€ 39,504.50
	Cost decrease	4.26%	4.57%	5.12%	5.71%	5.95%

		60|40				
	EXP02	1	2	3	4	5
Mean	Total dist	24,975	31,654	38,176	27,677	23,822
	Empty dist	12,487	15,827	19,088	13,839	11,911
	Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54
	Total dist	23,561	29,963	35,784	25,854	22,180
	Empty dist	10,307	13,024	14,554	10,559	9,305
	Reloc dist	766	1,112	2,142	1,456	964
	Matches	14	20	29	24	20
	Total cost	€ 39,486.41	€ 48,981.84	€ 62,272.69	€ 45,176.23	€ 38,922.98
	Cost decrease	5.03%	5.51%	6.24%	6.34%	7.33%

		50|50				
	EXP03	1	2	3	4	5
Mean	Total dist	24,975	31,654	38,176	27,677	23,822
	Empty dist	12,487	15,827	19,088	13,839	11,911
	Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54
	Total dist	23,394	29,819	35,585	25,799	21,838
	Empty dist	10,065	13,034	14,337	10,505	9,025
	Reloc dist	841	958	2,160	1,455	902
	Matches	16	21	33	26	23
	Total cost	€ 39,196.00	€ 48,812.92	€ 61,815.06	€ 44,930.36	€ 38,436.16
	Cost decrease	5.73%	5.83%	6.93%	6.85%	8.49%

APPENDIX K

RESULTS IMPORT/EXPORT RATIOS

This appendix shows the results for all 5 runs with different import/export ratios.

Import/export ratio	**70|30**						
EXP01	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,701	30,229	36,083	26,051	22,504	27,714	30,596,924
Empty dist	10,629	13,383	15,133	10,863	9,595	11,921	5,164,358
Reloc dist	585	1,019	1,862	1,349	998	1,163	226,388
Matches	11.4	15.8	23.6	20.6	15.8	17	22.448
Total cost	€ 39,808.03	€ 49,466.45	€ 63,017.38	€ 45,484.05	€ 39,504.50	€ 47,456.08	€ 92,951,217.78
Cost decrease	4.26%	4.57%	5.12%	5.71%	5.95%	5.12%	0.01%
Import/export ratio	**60|40**						
EXP02	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,561	29,963	35,784	25,854	22,180	27,468	30,305,147
Empty dist	10,307	13,024	14,554	10,559	9,305	11,550	4,691,255
Reloc dist	766	1,112	2,142	1,456	964	1,288	291,388
Matches	14	20.2	29.4	24	20	22	32.212
Total cost	€ 39,486.41	€ 48,981.84	€ 62,272.69	€ 45,176.23	€ 38,922.98	€ 46,968.03	€ 90,549,022.22
Cost decrease	5.03%	5.51%	6.24%	6.34%	7.33%	6.09%	0.01%
Import/export ratio	**50|50**						
EXP03	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	23,394	29,819	35,585	25,799	21,838	27,287	30,582,122
Empty dist	10,065	13,034	14,337	10,505	9,025	11,393	4,878,954
Reloc dist	841	958	2,160	1,455	902	1,263	310,718
Matches	16.2	21	32.6	26.2	23	24	37.36
Total cost	€ 39,196.00	€ 48,812.92	€ 61,815.06	€ 44,930.36	€ 38,436.16	€ 46,638.10	€ 90,160,729.71
Cost decrease	5.73%	5.83%	6.93%	6.85%	8.49%	6.77%	0.01%

APPENDIX L

RESULTS REUSE PREMIUM

This appendix shows the results for all 5 runs with different values for the reuse premium.

Reuse premium	**€ 80.00**						
EXP01	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,279	30,700	36,888	26,725	23,217	28,362	30,994,754
Empty dist	11,079	13,621	16,070	11,433	10,275	12,496	5,528,313
Reloc dist	713	1,251	1,730	1,453	1,032	1,236	151,661
Matches	6	9	13	11	7	9	8.2
Total cost	€ 40,547.30	€ 50,479.95	€ 64,497.08	€ 46,923.45	€ 40,873.03	€ 48,664.16	€ 95,898,410.82
Cost decrease	2.48%	2.62%	2.89%	2.72%	2.69%	2.68%	0.00%

Reuse premium	**€ 40.00**						
EXP02	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,279	30,700	36,888	26,570	23,217	28,331	31,126,274
Empty dist	11,079	13,621	16,070	11,126	10,275	12,434	5,710,607
Reloc dist	713	1,251	1,730	1,606	1,032	1,266	172,928
Matches	6	9	13	13	7	10	10.8
Total cost	€ 40,547.30	€ 50,479.95	€ 64,497.08	€ 46,661.87	€ 40,873.03	€ 48,611.85	€ 96,139,763.36
Cost decrease	2.48%	2.62%	2.89%	3.27%	2.69%	2.79%	0.00%

Reuse premium	**€ -**						
EXP03	**1**	**2**	**3**	**4**	**5**	**Mean**	**Variance**
Total dist	24,975	31,654	38,176	27,677	23,822	29,261	33,918,982
Empty dist	12,487	15,827	19,088	13,839	11,911	14,630	8,479,746
Total cost	€ 41,577.84	€ 51,836.38	€ 66,418.17	€ 48,236.83	€ 42,002.54	€ 50,014.35	€ 102,732,120.43
Total dist	24,279	30,674	36,875	26,570	23,217	28,323	31,041,108
Empty dist	11,079	13,375	15,926	11,126	10,275	12,356	5,314,940
Reloc dist	713	1,472	1,861	1,606	1,032	1,337	212,007
Matches	6	11	14	13	7	10	12.7
Total cost	€ 40,547.30	€ 50,299.14	€ 64,401.75	€ 46,661.87	€ 40,873.03	€ 48,556.62	€ 95,220,340.10
Cost decrease	2.48%	2.97%	3.04%	3.27%	2.69%	2.89%	0.00%