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Applying hub-and-spoke networks to inland barge transportation
a quantitative and qualitative analysis for a port terminal operator

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Award date:
2010

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Eindhoven, July 10

Applying hub-and-spoke networks to inland barge transportation: A quantitative and qualitative analysis for a port terminal operator

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In partial fulfillment of the requirements for the degree of

Master of Science
In Operations Management & Logistics

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TUE School of Industrial Engineering
Series Master Theses Operations Management and Logistics

Subject Headings: inland navigation, container, network, multimodal transportation

Abstract

This thesis describes a project conducted at ECT terminals in the Port of Rotterdam. The main focus of this thesis is to determine if inland barge transportation can be cost-effectively improved using hub-and-spoke networks. Based on field data and existing literature, a calculation tool is developed using Excel spreadsheets. This tool can be used to calculate the developments of the total supply chain costs when re-designing the hinterland part of the container shipping supply chain in a hub-and-spoke configuration.

Next to the calculation tool and a corresponding analysis on the feasibility of a hub-and-spoke network, this thesis provides insights on which organizational and network conditions need to be met in order to successfully implement such supply-chain improvements.

Combining these two aspects of the thesis, the viability of hub-and-spoke networks for inland barge transportation is quantitatively and qualitatively assessed. Based on the results, it can be concluded that re-designing inland barge transportation according to a hub-and-spoke configuration will be a challenging task. Next to the fact that such a model is not necessarily cost-effective, many organizational and co-operational issues impede this supply chain innovation.

Management Summary

This Master's thesis was executed at ECT, a company that handles containers in the Port of Rotterdam. This thesis first describes the calculation of applying hub-and-spoke networks to inland barge transportation for the container shipping supply chain. Due to increased importance of reliable and low-cost hinterland access, supply chain actors face many challenges in this area for staying competitive. In the second part of the thesis, the feasibility of the hub-and-spoke configuration is discussed based on inter-organizational issues. The lack of a calculation model and insights on which requirements are needed to implement such a supply chain redesign make it difficult for companies to determine how and where to implement this innovation in practice. A case study has been performed for a network of Dutch inland terminals with which ECT is closely cooperating

Research

A literature study on hinterland access in the container shipping supply chain has shown that little research is available on the total supply chain costs of hub-and-spoke networks for barge transportation. Next to that, although much literature is available on cooperation and coordination within the container shipping supply chain, a gap exists in literature on which (inter)-organizational challenges are faced when implementing such supply chain innovations. The container shipping supply chain and its underlying costs have been analyzed. It showed that a hub-and-spoke configuration for barge transport does not necessarily reduce supply chain costs and that many organizational obstacles stand in the way of reaping its full potential. Based on the literature study and the analysis of the container shipping supply chain, the following two main research questions have been defined:

What are the most important factors influencing the cost-effectiveness of the hub-and-spoke model and *how to establish the conditions and relationships for making the implementation of such models within the hinterland part of the container shipping supply chain possible?*

Tool

As no calculation tool was available to determine the supply chain costs of hub-and-spoke networks in barge transportation, it was necessary to develop a new tool. Based on existing literature and data collected during interviews with several supply chain actors, the required input and model equations were derived. The tool calculates the total cost difference between the current way of operating inland transportation and the way of operating it in a hub-and-spoke configuration. Due to the fact that the tool allows for varying the input values and network characteristics, it is possible to assess which decisions and actions will affect the feasibility of such supply chain redesign, from the operational to the strategic level. Next to a tool for general analysis, a tool was developed for the existing network of Dutch inland terminals.

General results

Based on the collected data and the developed tool, the cost-effectiveness of the hub-and-spoke network for inland transportation was calculated. The most important thing to

conclude is that the hub-and-spoke configuration is not necessarily a cost-effective alternative compared to the manner in which container transport is carried out today. Several network characteristics and operational issues significantly influenced the feasibility of this improvement concept. It proves that, concerning the network characteristics, especially the distance between the port and the hub terminal and the existing restrictions on inland waterways significantly influenced the feasibility of the concept. If one is therefore able to choose specific networks for applying this concept to, these characteristics need to be closely considered first, before taking into account operational issues. In the case one is considering an existing network of inland terminals, the network characteristics are unchangeable and operational issues like achieving a modal shift and increasing the re-use of empty containers become very important. Regard the following table for an indication of which and how network characteristics and the mentioned operational issues influence the cost effectiveness of the hub-and-spoke network.

	Distance port-hub (km)	Empty container re-use	Reduction direct truck transport (modal-shift)	Fuel Price (Eur/ltr)	Variable hub handling costs (Eur/handling)
Standard Value (base case value)	200	10%	0%	€ 0,44	€ 13,50
Value at which H&S network becomes cost-effective, waterway port-inland terminal not limited (156 TEU)	440	38% (280% increase)	40%	€ 1,28	€ 5,70
Value at which H&S network becomes cost-effective, waterway port-inland terminal moderately limited (81 TEU)	277	23% (130% increase)	18%	€ 0,78	€ 9,50
Value at which H&S network becomes cost-effective, waterway port-inland terminal very limited (48 TEU)	166	5% (50% decrease)	0%	€ 0,29	€16,10

Table: Indicative values for important network and supply chain characteristics influencing the cost-effectiveness of the hub-and-spoke model, indicating for which values of these factors the hub-and-spoke model brings about equal costs as the base case scenario. However, these values must be interpreted with great care, as many factors and parameters not shown in this table influence the model outcome as well.

Although the table must be interpreted with great care, as many parameters and there values used in the model are not shown in this table, it does provide insights on where time and resources need to be directed to;

- First of all, achieving a modal shift from truck to barge transportation seems to be a critical success factor in reducing supply chain costs. Due to the large difference between trucking and barging costs, even a minimal shift can bring about considerable cost reductions. From many field interviews it became clear that obtaining a very reliable barge connection is the most important factor in realizing such a modal shift. It also became clear that the cooperation between terminal operators and barge operators needs to be significantly improved for obtaining this goal.
- Second of all, the (variable) terminal handling costs at the hub terminal play a prominent role in the cost-effectiveness of the hub-and-spoke model as many additional handlings will be needed due to consolidation and distribution

activities. Decreasing the hub terminal costs but changing the terminals' cost structure or by reducing the amount of handlings will contribute significantly to the attractiveness of the hub-and-spoke configuration

- Third of all, an increase in empty-container re-use logically contributes to cost savings. It is expected that such an increase is very well possible as one is bundling container flows of different inland terminals. However, actually achieving this increase is difficult due to the attitude of shipping lines and changing this will require a great deal of effort and time.

Case study results

The same operational issues play an important role for the Dutch inland terminals, although more conclusive results can be obtained concerning the required conditions for cost-effectively operating a hub-and-spoke network for these terminals. In the following graphs it is shown how several characteristics need to be improved in order to generate cost savings.

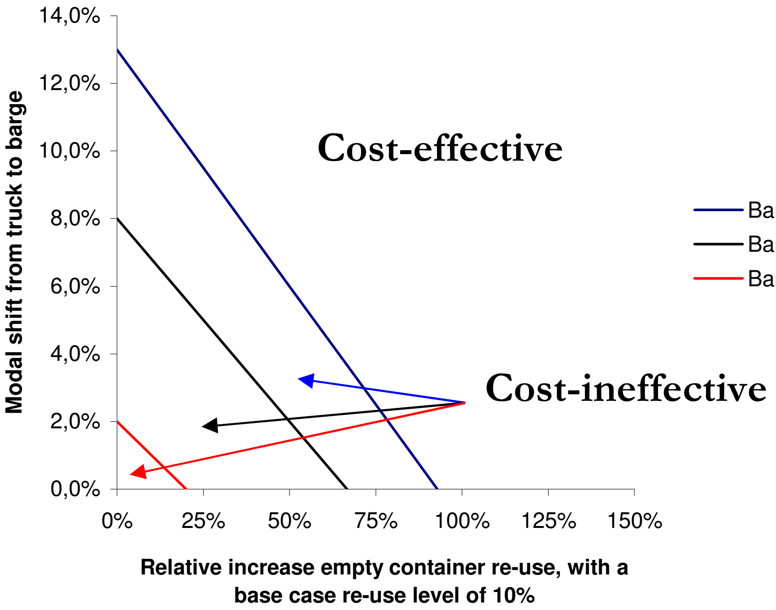

Figure: Cost-effectiveness of the hub-and-spoke model under varying levels of modal shift, increase in empty container re-use and barge capacity between the port and hub.

From this figure it appears that the first step for these inland terminals to take, is to increase the vessel capacity of the ships operating the port-hub connection to 208 TEU, assuming the utilization rate of the vessel can be held approximately equal. After that, only minimal improvements concerning a modal shift from truck to barge or an increase in empty container re-use will be required. As it is expected these improvements can be obtained once a reliable hub-and-spoke network has been set up, I believe the concept is viable for the terminals under consideration and that substantial supply chain cost savings can be achieved.

Requirements for supply chain improvement

The calculation outcomes combined with the insights obtained during in-depth interviews with supply chain actors resulted in an overview of specific requirements for implementing hub-and-spoke networks in practice and reaping its full benefit. Cooperation and coordination between several actors is essential in doing so. Logically, more alignment between the processes of barge operators and port terminals is required to establish a reliable barge connection with the hinterland. In addition to this, following the importance of increasing empty-container re-use in the network for achieving cost savings, shipping lines should also be actively involved in this improvement concept. Also the active involvement of external parties is critical in order to successfully innovate the hinterland supply chain. A change in attitude and possibly also ordering processes at the shippers is required to make the transportation less time-critical and allow for intermodal transportation. Especially in the case containers are intermediately stored at the hub terminal, such a change is required for bringing about a modal shift from truck to barge and prevent the opposite shift from occurring. Next to involvement of shippers, also the government should play a role by the means of regulations and grants as these control mechanisms can bring about change when the incentives for the actors involved are only minor.

In a supply chain characterized by intensive competition, reluctance to change and short term focus, bringing about such changes in cooperation and coordination will require a change in culture. Although such a change does not happen overnight, I do believe many players are willing to take steps towards it as the economical crisis of the former year(s) has revealed many weaknesses of the supply chain. Yet, it will require much time and effort to take these steps, both resources companies are always short of. It is therefore doubtful if supply chain redesign towards hub-and-spoke networks can be achieved if gains are minimal or even non-existent on the short term regardless that they are considerable on the long term. If the involved actors are not willing to make compromises and want to immediately profit from supply chain improvements, bringing about such change will be difficult, if not, impossible.

Preface

This thesis is the result of the graduation project for the MSc program in Operations Management and Logistics. This thesis was conducted at ECT at their facility on the Maasvlakte in the Port of Rotterdam.

I would like to use this opportunity to express my gratitude to my supervisors. First of all, I would like to thank Jan Fransoo for guiding me through this project with a great deal of enthusiasm and well directed feedback. His passion for the subject has been a source of inspiration during the last half year. I enjoyed working with him during this project and I'm very thankful that he provided me the opportunity to conduct my thesis in the container logistics and at ECT in particular. Furthermore, I would like to thank Peter de Langen for his contributions to this graduation project. His feedback on the report and the sharing of his field-experience has lead to a better result. In addition to my supervisors at the TU/e, I would like to express my gratitude to Kristina Sharypova for her critical reflections on my work and her help with developing the eventual model.

I would also like to thank my colleagues at ECT. I am especially grateful to Paul Zoeter for his support and input throughout this project. He always made time for me when I had questions and we conducted many fruitful discussions together. His critical notes on the report and the Excel-tool have really helped me to improve on the final result. Furthermore, I would like to thank Paul Ham, who encouraged and helped me to explore more about the container shipping business than just ECT. This did not only contribute to the project, but also to my personal development. Of course, I would also like to thank my other colleagues of the EGS department for their fun and support throughout my stay with the company.

A special thank you to Brabant Intermodal B.V., Michel van Dijk in particular, for providing the support needed to execute a valuable field-study and enrich the project with a practical application.

Thanks to all my friends who have made these five years of college so enjoyable. I owe many thanks to my parents, sister and brother for their continuing support that allowed me to become who I am.

Ben van Rooy

July 6, 2010

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1. Introduction

1.1. Introduction and motivation

This report presents the results concerning a Master thesis project that was executed at Europe Container Terminals (ECT in short). In this report an analysis is presented concerning the viability of a hub-and-spoke network for inland transport in the container shipping supply chain. The main goal of this analysis was to determine if a hub-and-spoke concept for barge transportation proved cost-effective and if it could contribute in strengthening the market position of ECT in the light of increasing competition. Having reliable barge connections will aid ECT in keeping handling volume once other terminal operators set ground in the Port of Rotterdam with the completion of Maasvlakte 2. In addition to this, effective barge hinterland connections have become an increasingly important topic due to government policy and the increasing road congestion on the A15 near the port of Rotterdam.

Setting up such a reliable service and achieving effective hinterland access is an organizational challenge. Coordination and cooperation between many actors is required but does not come naturally. The conditions that need to be met in order to allow this kind of cooperation and realize supply chain innovations such as the hub-and-spoke configuration will be addressed in this paper. Next to this qualitative assessment concerning the feasibility of a supply chain redesign, also an extensive quantitative analysis was executed by using a self-developed calculation tool. By combining both aspects I hope to provide a complete picture of the obstacles that stand in the way of improving hinterland access by using a hub-and-spoke configuration for barge transportation. These insights will not only be valuable for Dutch hinterland transport but will comprise a framework applicable to inland transport chains across the globe as similar challenges are faced there. They will furthermore contribute to existing literature on barge transportation and will uncover interesting fields for further research

1.2. Research scope

During the last decade, researchers have directed renewed attention towards the hinterland access in container shipping supply chains (Notteboom, 2005, Iannone et al., 2007), while beforehand, research was predominantly aimed at terminal operation and deepsea transportation. This paper continues on the research concerned with hinterland access by addressing the feasibility of hub-and-spoke networks for inland barge transportation. Although existing research (Konings, 2009) examines the application of such a network to barge transportation, the calculations are limited and must be extended to determine the total cost-effectiveness of this redesign. The aim of this study is therefore to expand on this literature and determine which factors are most important in decreasing hinterland access cost of barge transportation by using a hub-and-spoke configuration. Furthermore, it will be discussed what these results imply for existing companies and for network design. For example, the trade-off between economies of scale in barge transportation and the extra transshipment of containers at the hub terminal could make specific networks more suited for the hub-and-spoke model than others. This study thoroughly analyzes such issues with the use of a calculation model concerning total supply chain costs and thereby extends on existing literature and practical insights with an elaborate qualitative assessment.

Next to this qualitative assessment, this study will also provide a discussion concerning which conditions need to be met in order to successfully operate a hub-and-spoke network. Although existing literature addresses organizational issues impeding cooperation and coordination between supply chain actors (De Langen et al., 2006; Van der Horst & De Langen, 2008), most of this literature discusses these problems in general. The specific issues encountered when applying the hub-and-spoke model to barge transportation are not addressed in most of existing literature. Although Konings (2009) does discuss some of the conditions and implications of operating these networks in barge transport, the focus of this discussion mainly was on operational conditions and implications and not on (inter)organizational ones. With the use of information obtained in the field and results obtained from the quantitative analysis, this study expands on existing literature by discussing these specific issues for hub-and-spoke networks.

1.3. The Company

ECT is a company founded in 1966 that finds its home base in the Port of Rotterdam. The company's core business is in container handling, involving ship-, train- and truck transport. Since 1966, ECT has grown out to be the largest and most advanced container handling company in Europe with over 2,300 employees. Since 2001, ECT has become part of the Hutchison Port Holdings (HPH), a company that is headquartered in Hongkong, but is active in 25 countries and 49 ports worldwide.

ECT operates two terminals positioned on the Maasvlakte, the Delta Terminal and the Euromax Terminal, and one terminal positioned further inland, the City Terminal. The company now handles almost 75% of all containers going through the port of Rotterdam, equal to an amount of 6.3 million TEU (Twenty-feet Equivalent Unit).

1.4. The Supply Chain

As it is important to understand the existing dependencies and relationships within the container shipping supply chain, I will present a brief outline on the relationships and power differences as they are today in the market ECT is operating in. In Figure 1.1, the relationships, contracts and container flows in the container shipping supply chain have been presented based on the papers by De Langen et al. (2006) and Henesey et.al. (2003).

Although Figure 1.1 does not show the complete international supply chain, it remains obvious that the supply chain involves many actors and a lot of different relationships. In short, the roles of the most important players are the following (Martin and Thomas, 2001);

- **Shipper or Consignee***:* In the container shipping supply chain, the shipper or consignee is the most important player, since it is the end-shipper. Although the smaller shippers tend to let a freight forwarder handle their shipments, larger shippers exist having contracts with several players of the supply chain.

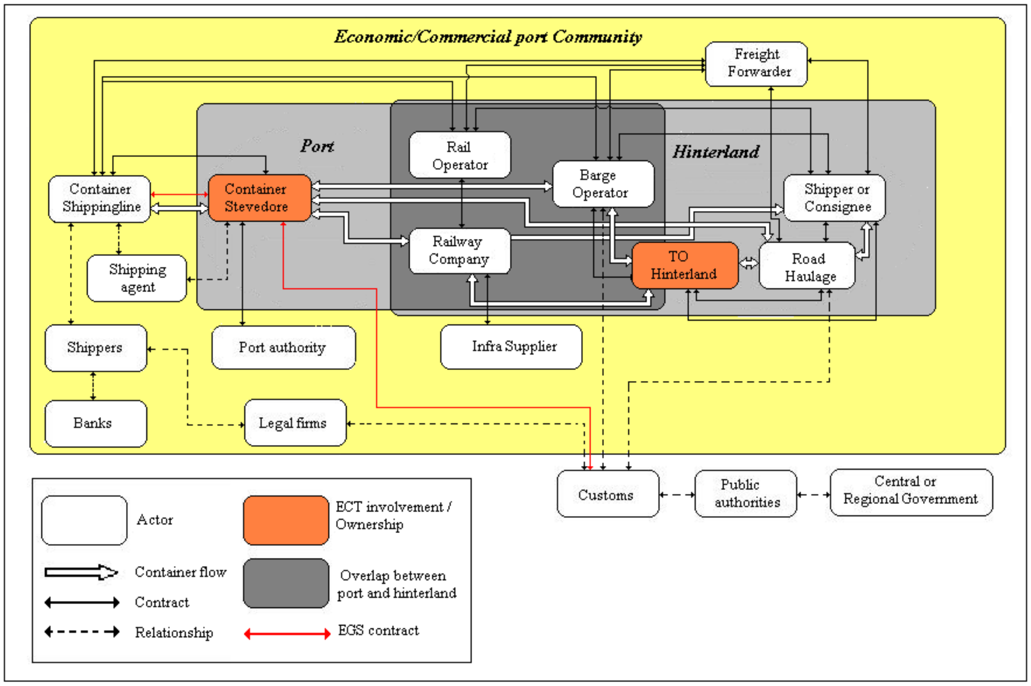

Figure 1.1 Graphical illustration of relationships, container flows and contracts within the container shipping supply chain, *Source:* De Langen et al. (2006), Henesey et al. (2003)

- **The Port Authority***:* The port authority is the organization that is responsible for leasing sites to port-related businesses and for an efficient and safe handling of shipping transport. Next to that, the port authority handles the port infrastructure aspects and takes care of other port facilities (Douma, 2008)
- **The Container Shipping Line***:* The container shipping line is originally responsible for shipping the container for a specific shipper from one port to the other. However, recent developments are that shipping lines now offer the shipper comprehensive door-to-door services and integrated logistic packages.
- **The Terminal Operator (Container Stevedore)**: The terminal operator in the port is in charge of all terminal handling activities. It is in control of the loading/unloading of seagoing vessels, but also for moving containers from the stack to inland transport modes (truck, barge and rail). Next to terminals in the port, also inland terminals exist. These terminals handle the container flow carried by barges via inland waterways and handle trucks for the last part of transportation between the terminal and the shipper/consignee.
- **Freight Forwarder***:* The freight forwarder is an external logistics provider for this supply chain. They offer group services and increasingly provide integrated logistic packages to the shippers. The freight forwarder is responsible for the door-to-door delivery of a container. Generally, the freight forwarder does not own any ships, terminals, trains or trucks, but acts as an agent between the shipper and the supply chain actors.
- **Barge Operator**: The barge operator is responsible for the transport of containers using inland waterways. Barge operators use 'small' vessels to transport containers from the port terminals to inland terminals. These companies do usually not own

barges themselves, but contract barge companies, which do own barges and operate them (Douma, 2008).

- **Road Hauler***:* The road hauler is responsible for transporting the containers by land, using trucks to carry the containers. In many countries, they have become professional service providers with whom the shipping line can outsource part or all of its inland distribution operation. Although the amount of containers transported by barge is increasing, still the majority of transport of containers is executed by truck.

It can be noticed that, although many container flows and many interdependencies exist, the number of contractual relationships is limited. The lack of contractual relations between different actors can and will lead to coordination problems (De Langen et al., 2006). I will elaborate on these problems more thoroughly further on in this report, where it is shown that setting up the desired cooperation is not straightforward and will require a lot of effort of all parties involved.

One of the main organizational challenges of ECT is to establish more reliable barge hinterland connections to improve shipper service and to bring about a modal shift from truck to barge. As currently many problems occur concerning the reliability of this transportation mode, the focus of this research was on means to establish reliable and competitive hinterland access through barge transportation. Next to that it was analyzed if the hub-and-spoke concept currently applied to the extended gates of ECT could be extended to terminal networks and make this transportation mode competitive and cost-effective compared to truck transport. Following this statement, and the fact that the available time for executing this research was limited, it was decided to leave out the container flow between the container stevedore and the container shipping line and flows concerning rail transport. Truck transport was included as it logically plays a significant role in the topic concerning the modal shift[1].

1.5. Project Scope

As mentioned in Section 1.1, ECT is looking into possibilities to improve their market foothold in the container handling industry. Although the main focus of terminal operating companies has always been on providing optimal service for shipping lines, the connections between the port and its hinterland have received much attention from ECT in the last few years. It is increasingly acknowledged that efficient and effective hinterland connections can provide ECT with the competitive edge they are looking for as establishing such connections requires a lot of time, effort and money. Therefore, ECT is currently setting-up a network of inland terminals called 'extended gates'. For a graphical representation of the extended gate concept, regard Figure 1.2.

When an inland terminal is used as an extended gate for the port terminal, it means that the function of these inland terminals changes from just a facility of handling containers to that of a distribution node where containers will be accumulated and kept on storage until it is required by the shipper (Notteboom, 2008). The use of the extended gates provides ECT

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[1] A transfer of transportation volume from truck to barge/rail

with more control in the hinterland transportation as, next to the terminals, also the connections between the port and the terminal are more under their control.

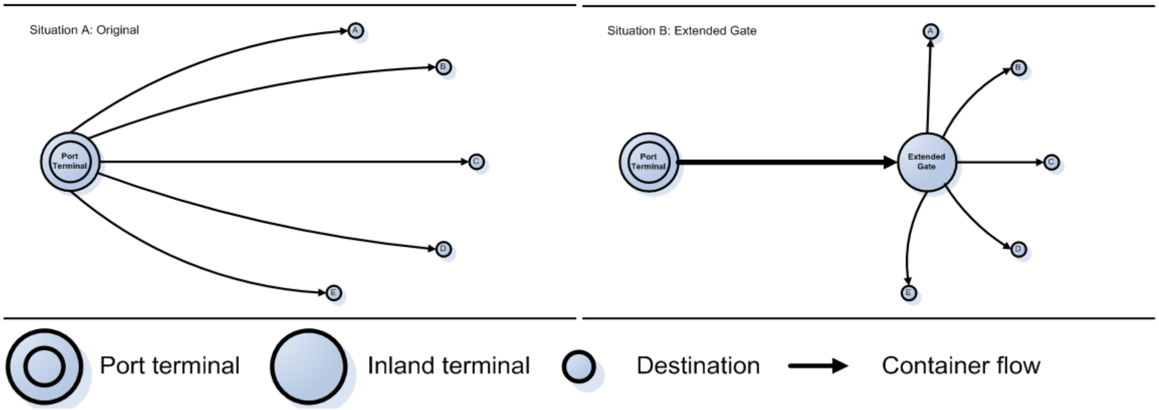

Figure 1.2: Graphical representation of the container flow with and without extended gate

Due to the fact that the hinterland of the Port of Rotterdam is characterized by terminals being located at waterways and no waterway congestion exists, it is believed that barge transportation can provide the efficient hinterland access ECT is looking for. Yet, it is not an option to set up extended gates with all inland terminals in the hinterland of Rotterdam.

Next to the fact that there are just too many, too small terminals, it is not strategically justified to be in control of such a diverse network. Because of this, ECT must look into other possibilities to improve the hinterland access towards these other terminals. One of these possibilities will be addressed thoroughly in this paper and concerns taking the extended gate concept to a more aggregate level to become a hub-and-spoke network of inland terminals. The basic idea of such a hub-and-spoke concept is similar to that of the extended gate. In this network, the hub operates as a consolidation point of freight destined to and coming from other inland terminals. The goal of this thesis was to determine if a hub-and-spoke concept for barge transportation proved cost-effective and if it could contribute to strengthening the market position of ECT in the light of increasing competition by improving the reliability of barge transportation.

1.5.1. Cost-effectiveness of hub-and-spoke network

Konings (2009) already conducted a preliminary analysis concerning the costs of a trunk-feeder service, which is comparable to the hub-and-spoke concept that will be addressed in this research. He found that, on a reasonable distance between port and hub, the transportation costs per TEU for the trunk-feeder barge connection were lower than those of the direct barge connection. Yet, on shorter distances, it proved that the cost savings in barge transportation were outweighed by the additional handling costs on the hub terminal (transshipment). Although this trade-off between savings in transportation costs and additional handling costs was the main issue addressed in this research on the cost-effectiveness of the hub-and-spoke network, other issues needed to be considered as well.

Based on conversations held within the company and with other actors in the supply chain it seemed that a large cost saving potential exists in more efficient re-use of empty containers. This claim is supported by much existing literature (Jula et.al., 2006, Choong et al., 2002) in which the potential cost savings of efficient empty container re-use were quantitatively uncovered. It was expected that the increased repositioning of empty equipment could play a significant role in the hub-and-spoke network. When terminals cooperate with one another in a network configuration such as the hub-and-spoke concept under consideration, the container flows of the inland terminals can probably be combined to increase the empty container re-use. Shortages at one terminal can be filled with overflows at others (De Langen et al., 2006). Due to this network effect and because empty container re-use can bring about substantial cost savings, it was considered in this research project.

1.5.2. Increasing barge handling reliability

According to ECT, and confirmed by Douma (2008), economies of scale can be achieved on the barge connection. Furthermore, the expected effect of the hub-and-spoke configuration is a reduction of the average number of terminal calls in a barge rotation and an increase of the average call sizes at terminals. For ECT, such a reduction in small and many barge calls would make the barge planning less complex, reduce barge waiting times and make barge a more reliable transportation mode towards its hinterland. However, implementing such an improvement concept would require more than just the fact that it is cost effective. The cooperation between the different actors must improve as such a concept can only be successful if the most important actors are actively involved (Van der Horst and De Langen, 2008).

1.6. Research Questions

In order to address the issues mentioned above, several research questions were defined.

1. What are the underlying supply chain costs for applying a hub-and-spoke model to hinterland access and does it provide substantial cost savings compared to the current situation?

    a. What are the most important factors influencing the feasibility of the model?

    b. What are the sensitivities concerning the trade-off between reduced transportation costs and additional handling costs?

2. How to establish the conditions and relationships for making the implementation of such models within the hinterland part of the container shipping supply chain possible?

1.7. Thesis Outline

The outline of this thesis is as follows; the container flows under consideration and the calculation model will be discussed in Chapter 2. In Chapter 3 an analysis can be found concerning data collection and analysis. The results concerning the cost effectiveness of the hub-and-spoke model can be found in Chapter 4. In this section it is discussed which factors had the largest impact on calculation outcomes and therefore need close consideration when implementing such a concept in practice. Next to costs, also other issues need to be considered when introducing improvements for hinterland access. Some of these issues are addressed in Chapter 5. The thesis concludes with an outline on the most important conclusions and recommendations in Chapter 6, after which directions for further research will be presented in Chapter 7.

2. The transportation model

In this chapter, the hub-and-spoke model developed for analyzing the feasibility and profitability of barge transport within the container shipping supply chain will be discussed. In Section 2.1 the container flow within the network will be presented based on the data gathered as mentioned in the former section and based on several assumptions. The cost structure of the logistical chain will be outlined in Section 2.2. The input parameters for the model will be discussed in Section 2.3. Hereafter, Section 2.4 will elaborate on the formulas used for calculating aspects such as costs, reliability, utilization rate etc. and will explain these formulas based on common algebra and field data.

2.1. Container flow

In the container shipping supply chain there are many ways of transporting a container. When a container has arrived at the destination port, getting the container from the port to the hinterland can be achieved using several intermediaries and several modes of transport, as has been shown in Figure 1.1. Because of these characteristics, the routing of a container through a network is not straightforward and the development of a general framework is very difficult if all possibilities would be taken into account. Therefore, it is important to define the scope of this research. As explained in the introduction, in this study the focus has been on the transportation of containers between a port and its hinterland and back by using barge transportation. More specifically, the aim was on the port of Rotterdam in The Netherlands and several inland terminals in its inland network. To get an understanding of the amount of barge transportation in this Dutch port, see Table 3.1 for an indication on the modal shift development during the last three years. As can be seen, barge transport gained in market share last year compared to the years before.

	2007	**2008**	**2009**
Truck	58,5%	57,1%	55,9%
Barge	30,4%	30,2%	33,2%
Train	11,1%	12,7%	10,9%

Table 2.1: Development of the modal shift for container transport during the period 2007-2009, *Source:* Port of Rotterdam

2.1.1. The inland network configuration

Although it was important to limit the research to a certain extent, the eventual model had to have a certain degree of validity, making it very important to define the most important container flows and take these into account during the development stage. Consider Figure 2.1, resembling a current network of inland terminals and a hub-and-spoke network for barge transport.

The current situation represents how the inland transport of containers by barge is currently organized. Inland terminals control direct barge connections with the port terminals.

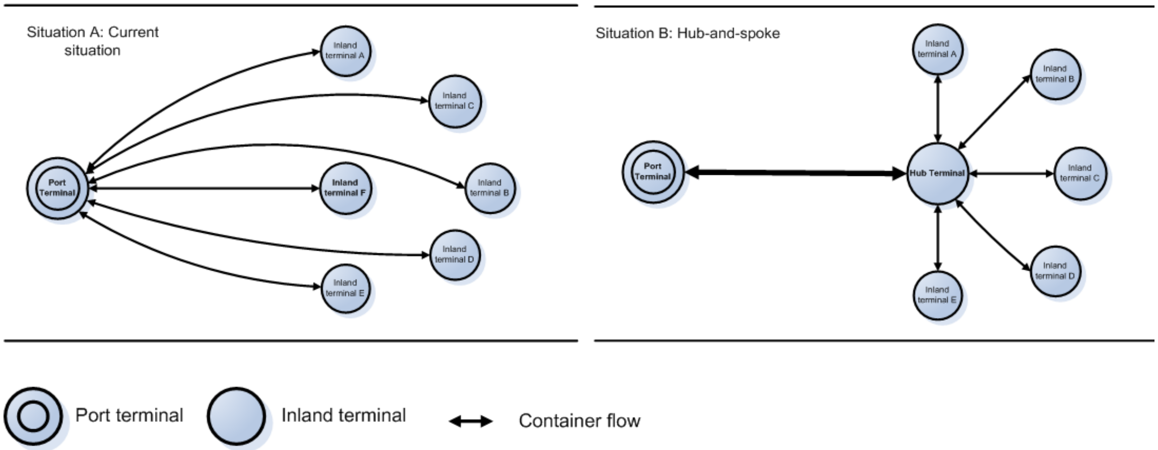

Figure 2.1: Graphical representation of the container flow between the port and inland terminals for the current situation and the situation when a hub-and-spoke model is used

However, in the hub-and-spoke network these inland terminals do not have direct barge connections with the port terminals but only with a 'hub' terminal. This hub operates as a consolidation point of freight destined for the port and as a distribution point for freight destined for the inland terminals. The idea behind this concept is to decrease the amount of barge calls at the port terminals and make economies of scale possible due to bundling activities. However, due to the fact that containers destined for or originating from the inland terminals need to be transshipped at the hub terminal, the hub-and-spoke concept requires more handling per container and possibly also additional trip distance due to necessary detours. Such a concept is therefore only viable if these additional costs are outweighed by the cost savings generated by the bundling of freight.

In the following sections, the left part of Figure 2.1 is referred to as the base case scenario, whereas the right part will be referred to as the hub-and-spoke network. The latter can be compared to the extended gate concept as executed by ECT. If one compares Figure 1.2 with Figure 2.1 the similarities between the two concepts can be observed, with the hub-and-spoke network being an extended gate on a somewhat aggregate level.

2.1.2. Overview container flows

Summarizing the different container flows in the base case scenario and the hub-and-spoke network, Figure 2.2 shows the simplified container flows that were taken into account in the analysis. In this figure, 'Direct truck' represents unimodal transport from the port to the shipper and 'Base case intermodal' represents intermodal transport in the base case situation. 'H&S-Truck' stands for transport to the hub terminal by barge and then by truck to the shipper in the hub-and-spoke network, whereas 'H&S-Barge' represents the transport to the hub by barge, then to the inland terminal by barge and eventually by truck to the shipper. For a more detailed description of the different container flows, we refer to the Appendix B.

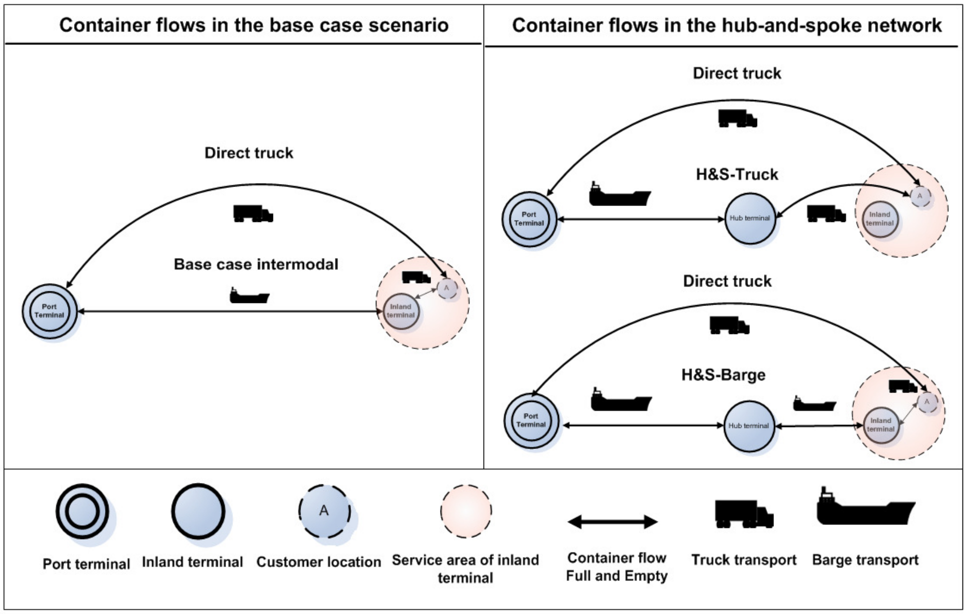

Figure 2.2: Depiction of the simplified container flows that were taken into account during the analysis

2.1.3. Empty container re-use

In general, all containers follow one of the abovementioned flows when being moved between port and shipper. However, for empty containers that are being re-used the flow is somewhat different. For direct truck transport empty container re-use was assumed to take place during the same roundtrip. For intermodal transport, it was assumed that the empty container was always brought back to the inland terminal before it was re-used. An additional possibility for empty container re-use occurred in the hub-and-spoke network. In the hub-and-spoke network, the demand of empty containers for one terminal's service area could also be fulfilled using empty equipment originating from the service areas of other terminals. Figure 2.3 presents the intermodal transport flow, including the flow of empty equipment in the hub-and-spoke network compared to the same flow in the base case scenario. Direct truck transport and the H&S-Truck container flow are not included in Figure 2.3 as this figure denotes the (total) intermodal flows only.

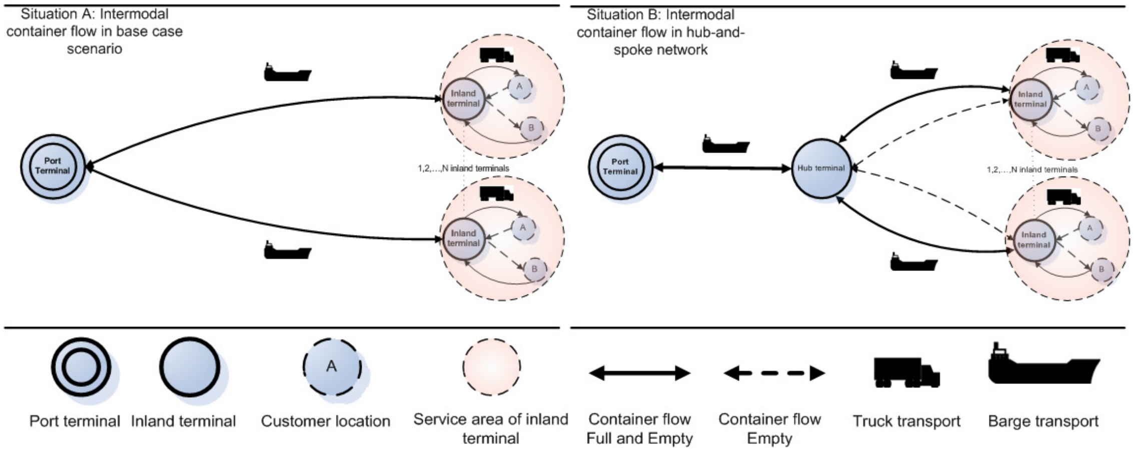

Figure 2.3: Representation of the intermodal container flows in the base case scenario and in the hub-and-spoke network

2.1.4. Assumptions:

1. Once a container is loaded on a truck in the port area, this truck directly drives to the shipper site, without intermediate handling at the hub or inland terminal. As truck transport is usually used when the container needs to be transported quickly this is a reasonable assumption.
2. It is assumed that all empty equipment that can be re-used in the hub-and-spoke network, but which cannot be used for a terminals' own service area, is transported back to the hub before it is re-distributed, i.e. no mutual empty equipment exchange between inland terminals is assumed.
3. It was assumed that all empty containers not being re-used are transported back to either a port terminal or an empty depot in the port area but all full containers destined for export are transported back to a port terminal only.
4. It is assumed that the transportation was executed using standard 20ft and standard 40ft containers only. The impact of this assumption on eventual results is negligible as the share of standard containers in total container volume is very substantial (Appendix E. Furthermore, other sized container only marginally influence costs or are not used for the operation under consideration.
5. Empty and full containers are shipped between two nodes simultaneously, meaning that a barge can carry both empty and full containers at the same time.

2.2. Cost structure

In order to determine whether or not a model like a hub-and-spoke network is viable in practice, the costs of operating such a concept were determined and compared to the base case. However, determining these costs was not straightforward as many players are involved in the logistical chain and all of them incur some costs when executing their services. This made it essential to distinguish between costs and prices, as they are not the same. When determining the viability of the hub-and-spoke network the focus was therefore aimed at the 'basic' costs of such a network. How each player involved in the chain will eventually make profit by using pricing mechanisms will be the next step to implementing the concept in practice and will require additional research. Therefore, the analysis was focused on the actual cost of hinterland transportation and not on the division of benefits and costs among the players involved. For the container shipping supply chain, these actual costs predominantly arise from the two basic activities required for getting a container from the port to the shipper; Transportation and Handling. In the following sections, these costs will be further elaborated on and it will also be explained why the costs of the goods (holding costs) were not taken into account.

2.2.1. Transportation costs

As mentioned, one of the two main activities in the hinterland part of the container shipping supply chain is the transportation itself. The transport of containers can be executed using several transportation modes. As explained earlier, only truck and barge transport will be considered in this research project as possible ways of transporting a container between two locations. For these two modes, fixed and variable costs were both taken into account when calculating the total cost of transportation. In Table 2.2 one can find what the fixed and variable transport costs are composed of. For barges, due to the fact that the largest part of barge owners and personnel work continuous shifts of 24 hours a day, it was assumed that the cost of personnel wages could be considered as fixed instead of variable.

2.2.2. Handling costs

Next to transportation, the other main activity of hinterland transport of containers concerns the movement of containers between transportation modes and stacking areas. This movement of containers is called handling and is the core activity of terminal operators. In order to be able to handle containers and perform the required movements, large investments need to be made in space and equipment, bringing about a fair amount of fixed costs due to depreciation and lease charges. Based on information received concerning terminal operation costs, another cost dimension was added; semi-fixed costs. This category of costs was added to the model as it was in between variable and fixed and could not be completely assigned to either one of the two. Consider for example the personnel costs of planning and administration. If the level of operation increases marginally, the same amount of administrative staff can handle the extra planning activities required. However, if the level of operation increases significantly, additional administrative personnel might be required, which increases personnel costs. To see this relationship, consider Figure 2.4, in which a graphical representation of the relation between scale of operation and the different cost dimensions is shown.

In Table 2.2 one can find what the fixed, semi-fixed and variable handling costs are composed of. In the eventual model the semi-fixed costs were taken into account ranging between totally fixed and totally variable to determine the range in which the total costs of a terminal fell based on the total amount of handlings and how this influenced outcomes.

	Handling costs	**Trucking costs**	**Barging costs**
Fixed	- Depreciation - Lease of ground - Tax - Selling costs - Housing costs - General fixed costs	- Depreciation - Interest - Tax - Insurance - General fixed costs	- Depreciation - Interest - Tax - Insurance - General fixed costs - Wage - Port taxes
Semi fixed	- Wages - Water / electricity - Lease additional equipment		
Variable	- Transportation - Maintenance - Fuel - Other variable costs	- Wage - Fuel - Tires - Lubricant	- Fuel - Lubricant - Maintenance

Table 2.2: Composition of the costs for handling, truck transport and barge transport

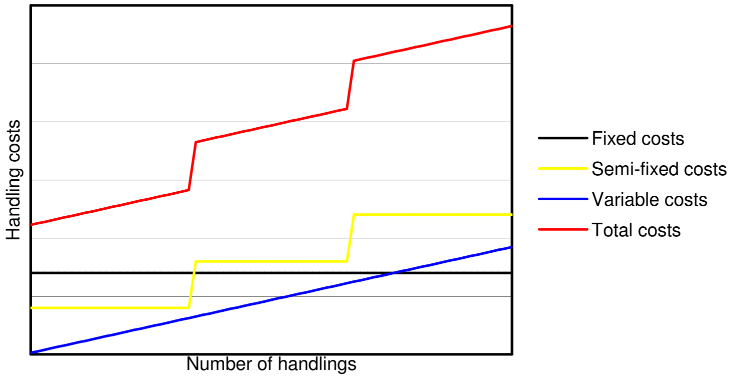

Figure 2.4: Graphical representation of the relationship between the number of handlings and the several cost aspects

2.2.3. Cost of goods

The handling costs and holding costs of the goods within the container were not taken into account in this research project. The cost calculations were based on the premise that the container was a black box with the underlying assumption that the shipper wants to receive his container at the right time. This basically means that delivery should be reasonably fast but most of all reliable, not too early and not too late. This will allow the shipper to control his inventory position and reduce holding costs (pipeline costs) and optimize his warehousing activities as much as possible. Based on this assumption and on the decision to consider the container as being a black box, holding costs of goods were not taken into in the model development and the eventual calculations.

2.2.4. Storage costs

Next to handling costs and holding costs of the goods, the storage costs of the container were not taken into account explicitly in the model either. Although terminal operators need to buy or lease a certain amount of land to temporarily stack containers, the costs of this land was assigned to the basic activity of a terminal; the handling of containers. This was done as a large part of the stacking area is required for efficient handling to be possible and is generally not used as a storage area for containers. Yet, one might argue that more storage capacity would be required at the hub terminal due to an increase in handling volume and the fact that containers destined for inland terminals needed to be intermediately stored there. Although this is a valid claim it was expected that its impact on eventual outcomes would be only marginal. First of all, the intermediate storage time at the hub terminal was expected to be only short as it is in the interest of the inland terminals to align the barge schedule between their terminal and the hub with that between the hub and the port. Second of all, the costs of additional storage capacity were negligible to the costs of handling and transportation (Source; ECT).

2.2.5. Cost of the container

An interesting cost aspect of the container shipping supply chain is the aspect concerning the container itself, especially when a container is empty. Basically, carrier companies earn money when transporting full containers and not when repositioning empty containers between regions with overflows to regions with shortages, for example from Europe to Asia.

Shipping lines therefore incur costs when they are not able to use a container for exporting goods, the so called opportunity costs. Although not taken into account quantitatively, these costs were considered in the qualitative assessment of the hub-and-spoke model.

2.3. Input parameters

For determining the costs of container transportation from port to the hinterland and developing a model for the analysis of the base case and a hub-and-spoke network, several parameters needed to be determined upfront. Throughout this report, the parameters as mentioned in Table 2.3 will be used.

General	
N	Amount of inland terminals in the model
D_i	Total yearly demand of containers for the service area of terminal i, with $i = 1,2,\ldots,N$
D_i^f	Yearly Demand of full containers for the service area of terminal i
α^b	Fraction of empty containers that can be re-used in the total network in the base case
α^h	Fraction of empty containers that can be re-used in the total network in the H&S network
$TEUF_i$[2]	The factor the demand in TEU must be divided with to get the demand in containers for terminal i.
Truck transport	
$u_{P,i}$	Percentage of unimodal transport by truck between the Port and terminal i
$u_{H,i}$	Percentage of unimodal transport by truck between the Hub and terminal i
$d_{P,i}$	Average distance between the Port and shippers in the service area of terminal i
$d_{H,i}$	Average distance between the Hub and shippers in the service area of terminal i
$d_{t,i}$	Average distance between terminal i and shippers in its service area
v_{gem}^T	Average speed of a truck during a roundtrip
w_P^T	Waiting time in hours of a truck per call at a port terminal
w_i^T	Waiting time in hours of a truck per call at terminal i
j_P^T	Time loss of a truck due to traffic jams in the port area (congestion)
vc_d	Variable costs of truck transport per kilometer
vc_h	Variable costs of truck transport per hour
TEU^T	Average amount of TEU transported during a roundtrip
Barge transport	
C_i	Capacity of the barges operating the connection between the Port/Hub and terminal i
SL_i^{req}	Required service level for the barge connection between the point of origin and terminal i

---

[2] The $TEUF_i$ actually depicts which percentage of total containers concerns 40ft containers and which percentage concerns 20ft containers. As a 20ft containers counts as 1 TEU and a 40ft container counts as 2 TEU, The variable is calculated as follows; $TEUF =$ fraction of 40ft containers + 1.

$f_{\min}$	Minimal required frequency of the barge connection between the point of origin and the inland terminals
$t_{P,i}$	Transit time in hours of the barge between the Port and terminal i
$t_{H,i}$	Transit time in hours of the barge between the Hub and terminal i
w_P^B	Waiting time in hours of a barge at a port terminal
w_i^B	Waiting time in hours of a barge at terminal i
$TT_{P,i}$	Average total roundtrip time between the port and terminal i
Gt_c	Fuel consumption of a barge with capacity c in liters per hour transit time
Gw_c	Fuel consumption of a barge with capacity c in liters per hour idle time
P^G	Fuel price per liter of fuel
VC_c^B	Variable costs of a barge with capacity c in euro per week
FC_c^B	Fixed costs of a barge with capacity c in euro
Terminal characteristics	
r_i	Production rate of barge loading and unloading at terminal i in moves/hour
r_P	Production rate of barge loading and unloading at a port terminal in moves/hour
FC_i^H	Amount of yearly fixed costs for terminal i
SC_i^H	Amount of yearly semi-fixed costs for terminal i
VC_i^H	Variable costs per handling for terminal i

Table 2.3: The input parameters as used in the calculation modal

2.4. *Model formulas and calculations*

In this section, the formulas for the cost calculation model will be elaborated on. In Section 2.4.2 the assumptions used in the calculation model will be presented. The calculations are shown for the base case in Section 2.4.2, whereas in Section 2.4.3 they are shown for the hub-and-spoke network. In this section only equations are elaborated on which were additional to or different from those of the base case scenario. The formulas denoted with an * are discussed more thoroughly in Appendix C.

2.4.1. Assumptions

1. The transit time of a barge between the port and an inland terminal is equal for the port terminal and the empty depot. This is a reasonable assumption, as some of these terminals are located in the same port area
2. The transit time of a barge is independent of their starting and arriving periods and independent of the transport direction.
3. When a barge has to make calls at both the port terminal and the empty depot, this does not increases the transit time between the port and the inland terminal.
4. It is assumed the total waiting time of a barge in the port is unrelated to the number of terminal calls it has to make. Further on in this report one can find analytical support for this assumption.

5. The waiting times do not include the time for docking the barge at the quay and the time for sailing from one terminal to the other in the port area.
6. The waiting time of a barge in hours at an inland terminal consists of docking time only as it is assumed quay capacity is always available at inland terminals. This assumption is in line with practice.
7. Barges operate 7 days a week, 24 hours per day, 52 weeks a year. This assumption has been made based on the results from an interview with a barge operator.
8. Terminals operate 7 days a week, 24 hours a day, 52 weeks a year. Although, in practice, this might not always be the case for inland terminals, it does hold for port terminals.

2.4.2. The base case

2.4.2.1. Volume calculation

The following formula was derived for determining the total volume of containers, $\mathbf{V}_i$, that needs to be transported between the port and the service area of a terminal:

$$\mathbf{V}_i = \mathbf{D}_i - \min(\mathbf{D}_i^f * \alpha^b, \mathbf{D}_i - \mathbf{D}_i^f) \qquad (1)$$

The minimum expression in this function is included as one cannot re-use more containers than the total demand of empty containers for the service area.

Total truck volume, $\mathbf{V}_i^T = \mathbf{V}_i * u_{P,i}$ (2)

Total barge volume $\mathbf{V}_i^B = \mathbf{V}_i * (1 - u_{P,i})$ (3)

2.4.2.2. Barge connection calculation

As demand is normally distributed, based on the results presented in Appendix 0, the required capacity, $\mathbf{c}_i^{\min}$, of the barge connection can be calculated as follows:

$\mathbf{c}_i^{\min} = \mu_{v,i} + z(SL_i^{req}) * \sigma_{v,i}$, where $\sigma_{v,i}$ is calculated as (4)

$$\sigma_{v,i} = \mu_{v,i} * cv_v \qquad (5)$$

Using the obtained value for the required capacity, one can calculate the frequency, f_i, of the barge connection. However, one must take into account that the frequency must be high enough to offer a certain service. Therefore, the formula becomes the following;

$$f_i = \max\left(f_{\min}, \frac{\mathbf{c}_i^{\min}}{C_i} \right) \qquad (6)$$

The average total roundtrip time between port and inland terminal was calculated as follows;

$$TT_{P,i} = 2t_{P,i} + w_P^B + w_i^B + \frac{4(U_i * C_i) / TEUF_i}{r_i + r_P} \qquad (7)$$

In which the final part of the formula shows the average handling time during one roundtrip.

In order to determine the required slack time to achieve a certain service level, the following formula was used:

$$w_P^B = \left(\frac{(-Ln(SL_i))^{-\xi} - 1}{\xi} \right) * \sigma + \mu \qquad (8^*)$$

With the obtained total roundtrip time the total barging costs per year, $TC_{P,i}^B$, for maintaining the barge connection between the port and terminal i was calculated;

$$TC_{P,i}^B = (FC_{c,i}^B + VC_{c,i}^B) * n_{P,i} \qquad (9)$$

$$VC_{c,i}^B = P^G * \left(t_{P,i} * Gt_c + (w_P^B + w_i^B) * Gw_c \right) \qquad (10)$$

.

In which $n_{P,i}$ represents the number of barges required per year.

The total yearly cost of barge transport for the base case was then calculated using the following summation;

$$TC^B = \sum_{i=1}^{N} TC_{P,i}^B = \sum_{i=1}^{N} \left((FC_{c,i}^B + VC_{c,i}^B) * n_{P,i} \right) \qquad (11)$$

2.4.2.3. Truck connection calculation

For the yearly costs of direct, unimodal transport between the port and the shippers in the service area of terminal i, $TC_{P,i}^T$, the following equation was used;

$$TC_{P,i}^T = \left(vc_d * 2d_{P,i} + vc_h \left(\frac{2d_{P,i}}{v_{gem}^T} + w_P^T + j_P^T \right) \right) * \left(\frac{\mathbf{V}_i^T}{TEU^T} \right) \qquad (12)^3$$

The costs of truck transport from the inland terminal to its service area, $TC_{t,i}^T$, were calculated similarly;

$$TC_{t,i}^T = \left(vc_d * 2d_{t,i} + vc_h \left(\frac{2d_{t,i}}{v_{gem}^T} + w_i^T \right) \right) * \left(\frac{\mathbf{V}_i^B}{TEU^T} \right) \qquad (13)$$

---

[3] In w_P^T handling time and waiting time at the port terminal was included

By adding these cost with the costs of direct trucking between the port and the hinterland the total costs of truck transport were calculated as follows;

$$TC^{T} = \sum_{i=1}^{N}\left(TC_{P,i}^{T} + TC_{t,i}^{T}\right) \tag{14}$$

2.4.2.4. Handling costs calculation

The yearly amount of truck handlings, h_i^T , and the yearly amount of barge handlings at inland terminal i , h_i^B , were calculated using the following two formulas;

$$h_i^T = \left(\frac{\mathbf{D}_i * (1 - u_{P,i})}{TEUF_i}\right) * 2 \tag{15}$$

$$h_i^B = \left(\frac{\mathbf{V}_i^B}{TEUF_i}\right) * 2 \tag{16}$$

For terminal handlings, the assumption was made that barge handlings are more expensive than truck handlings due to the use of more expensive equipment and more resources when handling barges. It was therefore assumed the variable costs for barge handlings were a factor ε larger than the variable costs of truck handling. The total handling costs for terminal i , TC_i^H , could then be calculated as follows;

$$TC_i^H = FC_i^H + SFC_i^H + VC_i^H * (h_i^T + \varepsilon h_i^B) \tag{17}$$

For calculating handling volumes at the port, where h_P^T and h_P^B represent truck handlings and barge handlings at the port respectively, the following equations were used;

$$h_P^T = \sum_{i=1}^{N} \frac{D_i * u_{P,i}}{TEUF_i} + \beta * \sum_{i=1}^{N} \frac{u_{P,i} * (2V_i - D_i)}{TEUF_i} \tag{18*}$$

$$h_P^B = \sum_{i=1}^{N} \frac{D_i * (1 - u_{P,i})}{TEUF_i} + \beta * \sum_{i=1}^{N} \frac{(1 - u_{P,i}) * (2V_i - D_i)}{TEUF_i} \tag{19*}$$

For empty depot handlings, where h_E^T and h_E^B represent truck handlings and barge handlings at the empty depot respectively, the following equations were used;

$$h_E^T = (1 - \beta) * \sum_{i=1}^{N} \frac{u_{P,i} * (2V_i - D_i)}{TEUF_i} \tag{20*}$$

$$h_E^B = (1 - \beta) * \sum_{i=1}^{N} \frac{(1 - u_{P,i}) * (2V_i - D_i)}{TEUF_i} \tag{21*}$$

In these equations β represents the percentage of empty containers brought back to the port terminal.

The total yearly handling costs for the port terminal and the empty depot can then be calculated by using the following equations;

$$TC_P^H = VC_P^H * (h_P^T + \varepsilon h_P^B) \tag{22}$$

$$TC_E^H = VC_E^H * (h_E^T + \varepsilon h_E^B) \tag{23}$$

2.4.2.5. Total costs

The total yearly costs, TC^{tot} of the base case can be calculated using the following formula;

$$TC^{tot} = TC_P^H + TC_E^H + \sum_{i=1}^{N} \left(TC_i^H + TC_{P,i}^T + TC_{t,i}^T + TC_{P,i}^B \right) \tag{24}$$

2.4.3. The hub-and-spoke model

2.4.3.1. Volume calculation

Because of the fact that the volumes transported between the port and the inland terminals are consolidated in the hub terminal, the volume calculation differs considerably from that of the base case. The yearly volume transported directly between the port and terminal i was calculated using the following formula:

$$\mathbf{V}_{P,i}^T = \mathbf{V}_i * u_{P,i}^H \tag{25}$$

The remaining volume that needs to be transported towards the service area of terminal i, $\mathbf{V}_i^{T,B}$, was calculated as:

$$\mathbf{V}_i^{T,B} = \left(\mathbf{D}_i - \min(\mathbf{D}_i^f * \alpha^h, \mathbf{D}_i - \mathbf{D}_i^f) \right) * (1 - u_{P,i}^h) \tag{26}$$

The yearly volume transported by truck between the hub and the service area of a terminal was then calculated as follows:

$$\mathbf{V}_{H,i}^T = \mathbf{V}_i^{T,B} * u_{H,i} \tag{27}$$

For yearly volume transported by barge between the hub and terminal i, the following equation is used:

$$\mathbf{V}_{H,i}^B = \mathbf{V}_i^{T,B} (1 - u_{H,i}) \tag{28}$$

For the yearly volume transported by barge between the port and the hub terminal, $\mathbf{V}_{P,H}^B$, the calculations are somewhat more difficult. The following equation was used:

$$V_{P,H}^{B} = \sum_{i=1}^{N}\left(D_i^f * (1-u_{P,i}^h)\right) + \max\left(0, \sum_{i=1}^{N}\left((1-u_{P,i}^h) * \left(D_i - (1+\alpha^h)D_i^f\right)\right)\right) \qquad (29^*)$$

2.4.3.2. <u>Barge connection calculation</u>

The frequency of the barge connection between the port and the hub and number of port calls per visit calculated in equation (6) is different in the hub-and-spoke network due tot the fact that the connection needs to be point-to-point in the hub-and-spoke network in order to reduce the uncertainty and risk. The frequency was therefore calculated as follows:

$$f_i^h = \max\left(2f_{\min}, \frac{\mathbf{c}_i^{\min}}{C_i}\right) \qquad (30)$$

Because of the accumulation of demand for inland terminals at the hub, the amount of variation for the connection between the port and the hub decreased. The calculation became the following:

$$C_H^{\min} = \sum_{i=1}^{N}\mu_i^V + z(SL_i^{req}) * \sqrt{\sum_{i=1}^{N}(\sigma_i^V)^2} \qquad (31)$$

2.4.3.3. <u>Truck connection calculation</u>

The calculations for the costs of truck transport are completely similar to the calculations in the base case with the exception that the costs from transporting containers between the hub and terminal i must be added to the cost calculation. For calculating these costs, $TC_{H,i}^T$, the following equation was used;

$$TC_{H,i}^T = \left(vc_d * 2d_{H,i} + vc_h\left(\frac{2d_{H,i}}{v_{gem}^T} + w_H^T\right)\right) * \left(\frac{\mathbf{V}_{H,i}^T}{TEU^T}\right) \qquad (32)$$

Following this extra container flow by truck between the hub and the service areas of inland terminals, the yearly costs of truck transport for the hub-and-spoke network was calculated as follows:

$$TC^T = \sum_{i=1}^{N}\left(TC_{P,i}^T + TC_{t,i}^T + TC_{H,i}^T\right) \qquad (33)$$

2.4.3.4. <u>Handling costs calculation</u>

For calculating the yearly amount of truck and barge handlings at the hub terminal, h_H^T and h_H^B, the following equations were used:

$$h_H^T = \left(\frac{\mathbf{D}_H * (1 - u_{P,H}^H) + \sum_{i=2}^{N} \mathbf{V}_{H,i}^T}{TEUF_i} \right) \tag{34}$$

$$h_H^B = \frac{2 * \left(\mathbf{V}_{P,H}^B + \sum_{i=2}^{N} \mathbf{V}_{H,i}^B \right)}{TEUF_i} \tag{35}$$

For calculating the total amount of truck and barge handlings at the port terminal and the empty depot, $h_P^{H,T}, h_P^{H,B}, h_E^{H,T}$ and $h_E^{H,B}$, the following equations were used:

$$h_P^{H,T} = \left(\frac{\sum_{i=1}^{N} u_{P,i}^H * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \right) * \min(1, \frac{E_{tot}^C * \beta}{E_{tot}^H}) \tag{36*}$$

$$h_P^{H,B} = \left(\frac{2\mathbf{V}_{P,H}^B - \sum_{i=1}^{N} (\mathbf{D}_i * (1 - u_{P,i}^H))}{TEUF_i} \right) * \min(1, \frac{E_{tot}^C * \beta}{E_{tot}^H}) \tag{37*}$$

$$h_E^{H,T} = \left(\frac{\sum_{i=1}^{N} u_{P,i}^H * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \right) - h_E^{H,B} \tag{38*}$$

$$h_E^{H,B} = \left(\frac{2\mathbf{V}_{P,H}^B - \sum_{i=1}^{N} (\mathbf{D}_i * (1 - u_{P,i}^H))}{TEUF_i} \right) - h_P^{H,B} \tag{39*}$$

In which E_{tot}^C and E_{tot}^H represent total amount of available empty containers in the base case and the hub-and-spoke scenario respectively

3. Data Collection and Analysis

In this chapter, the data collection methods and the results of the data analysis will be presented. In Section 3.1, the data collection methods and the difficulties encountered during the data collection stage will be discussed. The results of the analysis of data used as input for the calculation model will be elaborated on in Section 3.2. In Section 3.3, several data will be discussed for which uncertainty exists concerning the data reliability.

3.1. Data Collection

During the execution of this research project several ways of data gathering and analyses were used to provide input for the calculation model and the qualitative analysis. The following sections briefly describe the data gathering methods used during this research project and the problems encountered during the data collection.

3.1.1. Data collection methods

To collect the required data for building the calculation model and determine the conditions and implications necessary to operate a hub-and-spoke network, several sources were used. First of all, existing literature concerning the topics under consideration was used. These articles were predominantly found by using Google Scholar and ABI Inform and accessing the articles using the rights reserved for Eindhoven University of Technology. The findings of this literature review (Van Rooy, 2009) were used to develop an understanding of the supply chain and to comprise indications concerning the costs of transportation and handling. Second of all, internal and external sources were used to collect field data. These indications were compared to data gathered with the literature review. In Figure 3.1, one can find an overview of which sources were used to collect which data.

Source\Data	Trucking costs	Terminal costs (handling)	Barging costs	Demand characteristics	Waiting time barges	Other requirements
Literature	X		X		X	
Terminal operator port (internal)		X	X	X	X	X
Terminal operator inland	X	X	X			X
Barge operator						X
Truck operator	X					X
Shipping line						X

Figure 3.1: Matrix indicating which information was received from or validated by which source

In Appendix A on can find a detailed description of the interview methodology used during this project to collect internal and external data.

3.1.2. Data collection difficulties

As can be seen in Figure 3.1, the most data was gathered at the terminal operator in the port. This is logical, as the terminal operator was the initiator of this project and was therefore committed to it. The willingness to share sensitive information was therefore more present at the terminal operator in the port than at the other actors spoken with during the project. However, it was difficult to assess the impact of a hub-and-spoke operation on port terminal costs as a detailed understanding of terminal costs was not present at the terminal operator. This made it difficult to depict the cost advantages the concept would bring about for the port terminal operator and constrained me in confirming or invalidating the claim that the terminal operator in the port would achieve cost savings when operating hub-and-spoke networks for barge transportation.

In addition to the data gathered internally, also much data was gathered with the help of several inland terminal operators in the Netherlands. Because of the initiative launched by a handful of inland terminal operators to implement the hub and spoke concept for their terminals in the Dutch hinterland and the fact that they want to apply insights from this project for their network, they were willing to share some sensitive information. However, not all terminals provided the data required to perform the eventual analysis and some input data needed to be estimated. Later on in the project, it was confirmed by the spokesperson of the inland terminals that, although some input parameters were estimated, the model outcomes were accurate.

For the obtained trucking costs the data was gathered by first using sources in literature. With the use of research executed by NEA in 2002, it was possible to develop a point of reference for data gathered later on. Additional data came from the inland terminal operator who provided me with a cost calculation model for truck operation. Although the assumptions in this model were based on the situation in the year of 2007 and the NEA research was conducted in 2002, the findings were quite similar. Because of the detail in the truck calculation model, it was used to calculate the costs per km and costs per hour my own calculation model.

Unfortunately, no barge operator provided data needed to derive the barging cost of container transport. However, due to the fact that ECT is responsible of some barge connections with the hinterland and is closely cooperating with some barge operators, some data concerning barging costs was available internally. The data that was not available was gathered using literature (Van Dongen et al., 2006) and validated with inland terminal operators. From later model calculations, it proved that the used input parameters for calculating barging costs were quite accurate. The barging costs per TEU as calculated in the model were approximately equal to the costs as calculated by the inland terminal operators themselves.

Concerning the data collection on costs, it did not occur that different sources significantly provided contradictory data. When multiple sources were used to determine the same input data, it mostly proved to be very similar. This is quite logical, as costs are just costs and are not influenced by opinions and personal beliefs. When collecting data on the conditions required for operating a hub-and-spoke network, different sources did contradict one another. For example, the port terminal operator believed that one should not rely on the government for implementing such network redesigns whereas the truck operator did believe government involvement would be a prerequisite for doing so. These different views are a result from differences in culture and strategic beliefs and such expressed opinions were therefore always handled with extreme care. In case contradictory claims were made by different supply chain actors, it was assessed how many actors shared one belief and how many the other. Based on these assessments and common sense, it was determined which claims were of significant importance and which were not.

3.2. Data Analysis

3.2.1. Weekly demand for barge capacity

Due to the fluctuating world trade volumes and the fact that the container volumes passing through the port each day vary under the influence of many factors, the demand for containers for inland transport is not constant during the year. This variation has an impact on the required transport capacity in order to attain a certain service level. This is caused by the fact that, in order to obtain the service level, the capacity of the barge connection must be higher than the average demand for it. In order for determining the required capacity of the barge connection, I analyzed loading and unloading volumes for barge connections between the Delta terminal in Rotterdam and several inland terminals. The results of this analysis can be found in Appendix K. Because fictitious demand values were used in the general analysis, and therefore the derived means and standard deviations differed from those used in the calculations, the derived coefficient of variation in Appendix K was used to determine the variability of demand in the model.

Although the demand for containers showed certain variation, this does not necessarily have to lead to high amounts of idle barge capacity as this capacity is not fixed but flexible. In the current market of the container shipping supply chain, it is quite easy to lease ships as they are abundantly available due to recent economical developments. As the amount of containers that needs to be shipped in the following days/weeks to come is known some time in advance, the barge capacity of the connection can be adjusted accordingly. This makes fluctuations in demand less detrimental for the achieved service level and makes it possible to control the utilization rate of the barge to a certain degree.

3.2.2. Waiting times of barges in the port area

As has been discussed in Chapter 1, the waiting times of barges in the port are detrimental for realizing reliable barge connections between the port and the hinterland. According to Douma (2008), a relationship exists between the number of terminal calls in a barge rotation and the total average waiting time. As barges are able to visit other terminals during this waiting time, Douma (2008) concluded that the total waiting time in the port depends on the waiting time at the bottleneck terminal. He furthermore discussed the fact that waiting times can be significantly reduced under full cooperation between terminal operators and barge operators. Yet, although some cooperation between barge operators and terminal operators exists in practice, it is not the same as the fully cooperative situation described by Douma (2008) due to strategic behavior at both sides of the relationship. It is therefore expected that the waiting times in practice are larger than calculated by Douma in the full cooperative scenario. In order to determine what the average total waiting time of a barge in the Port of

Rotterdam actually is and how this is related to the rotation length, demand data was analyzed.

In Table 3.1 the results are shown concerning the relationship between rotation length and total delay for all barges visiting the ECT Delta terminal during the first two quarters of the year 2009. In Table 3.2 the cumulative results are shown concerning this relationship for barges originating from 8 Dutch inland terminals visiting the ECT Delta terminal during the first two quarters of the year 2009. Note that these results concern the visits at the ECT terminals only and do not include other terminal visits in the port for the barges under consideration.

#terminal calls	Count	Average waiting time	Standard deviation	Av. Wt. Per call
1	3560	2,53	4,58	2,53
2	1722	3,16	4,82	1,58
3	539	3,81	5,39	1,27
4	190	4,54	5,93	1,13
5	19	3,15	4,75	0,63

Table 3.1: Relationship between number of terminal calls and the total waiting time in the port for all barges in the data sample. *Source:* Internal database terminal operator

#terminal calls	Count	Average waiting time	Standard deviation	Av. Wt. Per call
1	916	2,56	3,90	2,56
2	346	2,60	3,43	1,30
3	34	2,92	3,45	0,97

Table 3.2: Relationship between number of terminal calls and the total waiting time in the port cumulated for barges operating connections between the port and 8 Dutch inland terminals. *Source:* Internal database terminal operator

In these tables, the first column shows the number of terminal calls during one rotation. The second column denotes the number of occurrences of the specified rotation length. The third column denotes the average total waiting time / delay during a rotation, whereas the fourth column shows the amount of variation concerning the total waiting time. The last column denotes the average total waiting time per call.

Some interesting insights can be obtained from these tables. First of all, the results to some extent contradict the claims made by Douma (2008) and Melis et al. (2003) that a barge makes 8 terminal calls on average during each port visit. This difference is possibly caused by the fact that ECT has only recently taken a specific barge/feeder terminal into operation. Second of all, terminal operators in the Dutch hinterland claimed to operate barge connections with very short rotation lengths (point-point connection). This partially explains the results presented in the table that barges originating from the Dutch hinterland on average called at fewer terminals than barges operating the Rhine corridor. Third, an interesting result is the fact that the average total waiting time was not (linearly) related to the number of terminal calls in one rotation. As shown in Appendix L the relationship between number of port calls and total waiting time for barges originating from the Dutch hinterland did not prove to be significant at the 0.05 level ($p = 0.631$) when using linear regression analysis. Yet, for the entire sample, there seemed to be a positive relationship between number of port calls and total waiting time ($p = 0.000$).

The difference between barging in the Dutch hinterland and barging along the Rhine corridor can be explained by looking at the connection characteristics. For most connections with Dutch inland terminals, the waterway capacity is very limited, which only allows for the deployment of small vessels. Because these smaller vessels are used, even if call sizes per terminal are small, it is possible to operate point-point connections with port terminals. As barging along the Rhine corridor is executed with large vessels, small call sizes per terminal lead to many terminal calls in the port (Konings, 2009). This relationship between vessel length and number of terminal calls in the port is graphically depicted in Figure 3.2. In this figure, the relative increase in rotation length compared to the smallest vessels has been depicted for increasing vessel lengths.

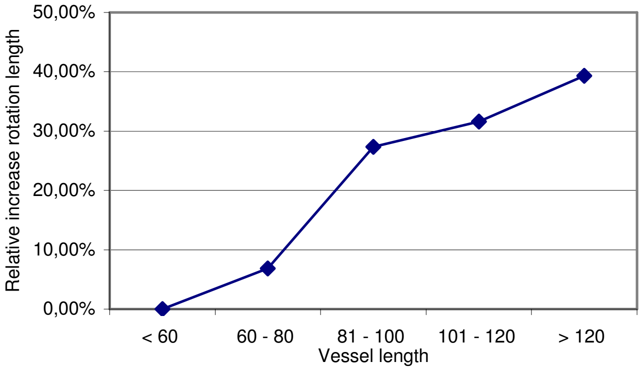

Figure 3.2: Relationship between vessel length and number of terminal calls in the port

The differences between Dutch inland barging and Rhine barging can furthermore be explained by a higher fragmentation of freight along the Rhine corridor. In order to operate a frequent connection and achieve a high barge utilization rate, barges operating the Rhine corridor call at several terminals inland whereas barges operating connections between the port and the Dutch hinterland only call at one inland terminal. Because of these many calls in the hinterland, the freight on these vessels is more diverse regarding at which port terminals this freight was or will be handled (Source; port terminal operator). This also leads to more terminal calls in the port area.

In Appendix L also results can be found concerning the waiting time distributions for several connections with Dutch inland terminals. For the model calculations the (parameters of the) waiting time distribution concerning the total dataset was used in combination with equation (12) to determine the required slack time in the barge schedule for achieving a certain service level. The same distribution was applied to all barge connections between the port and inland terminals. As the barge destined for CTV was handled with priority in order to obtain a reliable and speedy service, this barge connection best represents the 'should-be' barge connection between the port and the hub in the hub-and-spoke network. Therefore, the (parameters of the) waiting time distribution of CTV was used for calculating the required slack time of the barge connection between the port and the hub terminal in the hub-and-spoke network.

A critical note that must be placed at these results is that they were calculated using data of the year 2009. During this year, trade volumes declined and the utilization rates of the port terminals dropped accordingly. The waiting times will probably increase and possibly also the relationship between number of calls and average total waiting time will change once the trade volumes start to grow and the terminals become highly utilized. Unfortunately, no similar data was available for the year of 2007 or 2008, making it not possible to analyze the waiting times under high utilization circumstances.

3.3. Unreliability of data

3.3.1. Barge transport costs

For a large part, the data concerning the costs of barge transport was gathered with the use of existing literature. Most of all, findings by Van Dongen et al. (2006) and the results of the NEA (2004, 2009) were used to derive the barging costs. These sources were used to derive the fixed barging costs and the fuel consumption for different vessel sizes. The personnel costs of barging were derived using the wage tables available on the website of the CBRB (CBRB) and taking employers cost into account based on 17% for insurance premiums (Belastingdienst) and 16% for pension premiums (www.rijnenbinnenvaartpensioen.nl).

As the amount of personnel required on barges of different size and for different operating hours is determined by law, the personnel costs of barging as derived for the model were considered to be very reliable. This could not be said for the fixed costs of barging and the fuel consumption. For example, the derived data for fixed costs was based on new buy prices of barges, whereas the current market is characterized by barges being sold second-hand at low prices due to an existing surplus in supply. One could therefore argue that the derived values for fixed costs were estimated too high. However, following the claims made by an inland terminal operator during an interview held, this did not have to be the case. First of all, second-hand vessels are depreciated along a shorter time period which decreases the impact the smaller required investment had on the difference in fixed costs between the used data and practice. Second of all, second-hand vessels require more maintenance and are usually upgraded with a new engine, increasing the yearly fixed costs. For the fuel consumption, the data for several vessel types was confirmed by the inland terminal operator. However, a fixed value of liters/hour was used as input for the fuel consumption of barges, without considering fill rate, weight and cruising speed. In practice, actual fuel consumption could therefore vary considerably, something that was not taken into account during calculations.

Following the above reasoning it was believed that the fixed barging costs were somewhat lower in practice than estimated during execution of the model calculations. Also a difference was to be expected in barge fuel consumption. Because it was confirmed by an inland terminal operator that the input data was reasonably accurate, these input values were changed along a limited range. The impact of a change in the fixed costs was calculated for a change ranging from -20% till 0%. For the input data concerning fuel consumption, as no indication exists whether the input data for fuel consumption was over- or underestimated, a range was used from -25% till +25%. The outcomes of this analysis will be presented in Section 4.3.1.

3.3.2. Terminal handling costs

For determining the terminal costs, data was gathered on the terminal costs for an inland terminal in the Dutch hinterland. Based on these terminal costs and on the assumption that fixed and variable terminal costs are smaller for smaller terminals, the terminal costs for the terminals in the model were derived. Although some of these values were validated during the interviews held with terminal operators and it proved that the estimated costs were not much different from practice, it was very difficult to derive a general value for these costs as every terminal has its unique cost structure. Especially for the terminal that was used as consolidation and transshipment point of containers, the operation level was expected to change considerably. As will be elaborated on further on in this report, the additional handling costs at this terminal provide the largest bottleneck for the container shipping supply chain for implementing concepts such as a hub-and-spoke network. The reliability of the input data used for this terminal was therefore expected to have a large impact on model outcomes. Because such a transshipment terminal should be large enough to handle the additional handling volume, the input data concerning terminal costs was based on that of a large inland terminal owned by ECT. Although this provided some reliability in the input data, the fact that it still contained uncertainty required further consideration.

Next to uncertainty in the input data concerning terminal cost, there is also uncertainty about how these costs develop when increasing the scale of operation. As will be discussed more thoroughly in the following section, the costs of inland terminals are divided into three different categories; fixed, semi-fixed and variable. For the fixed and variable costs, the development as a consequence of scale increase is not difficult to estimate. However, for the semi-fixed costs it is, making it important to consider the model outcomes under different scenarios of semi-fixed costs development.

In Section 4.3.2 one can find the results concerning the analysis of the impact of unreliable terminal input parameters and semi-fixed cost development on model outcomes.

4. Numerical Analysis and Results

In this chapter calculations for the described model will be presented. In Section 4.1, results of a comparison between the base case scenario and the hub-and-spoke network will be presented. For this comparison the input parameters in the model were changed to analyze the impact of several network characteristics on total cost and on overall performance. In Section 4.2, results will be presented concerning the feasibility of the hub-and-spoke network for several terminals and their network in the Dutch hinterland. In Section 4.3 the results of a sensitivity analysis will be presented concerning unreliable input data.

4.1. Comparison base case scenario vs. hub-and-spoke network

This section is built up in the following way; Section 4.1.1 presents the experimental design. The section is concerned with which input parameters were varied during the analysis in order to determine under which circumstances a hub-and-spoke network performs better than the base case situation. In Section 4.1.2 results concerning the issues discussed in the experimental design will be presented. Section 4.1.3 presents the conclusions of the comparison between the base case scenario and the hub-and-spoke network.

4.1.1. Experimental design

4.1.1.1. Distance between port and hub terminal

In a paper by Beuthe and Kreutzberger (2001) the concept of a hub-and-spoke network is part of their analysis on transshipment in the container shipping supply chain. Due to the fact that the hub-and-spoke concept requires more handlings per container, Beuthe and Kreutzberger (2001) concluded that such a concept is only profitable if the distance over which the freight is carried is large enough to generate sufficient cost savings due to obtained economies of scale. For Europe, they concluded that using such intermodal transport is not competitive over distances shorter than 350 km, or even 500 km, due to existing tariffs, corridor characteristics, and network organization. Because of these findings it was expected that the distance between port and hub would significantly influence the cost-effectiveness and thus viability of the hub-and-spoke concept for container shipping.

4.1.1.2. Capacity of barge connection

The cost savings as mentioned by Beuthe and Kreutzberger (2001) should, for some part, be generated by economies of scale in barge transport. As the fixed costs and fuel usage per freight unit increases as the vessel size decreases, small and medium sized vessels transport freight at higher costs per unit than do larger ships. In Figure 4.1, an indexation on vessel size, fuel consumption, fixed costs and personnel costs is presented for several vessel sizes, setting the index of a small 24 TEU vessel at 100. On the left side of the figure the indices are presented per vessel whereas they are presented per TEU on the right side of the figure. These graphs indicate that the barge cost and fuel consumption increase at a larger pace than the vessel capacity, decreasing the costs and fuel consumption per TEU.

The economies of scale in the hub-and-spoke network are generated by the fact that the connection between the hub terminal and the port is less capacitated than the connections between the port and other inland terminals. This connection can therefore be operated using larger vessels. The smaller vessels originating from the other inland terminals do not have to travel the distance between the port and the hub anymore as they load and unload their containers at the hub terminal. Furthermore, as explained in Appendix G, the barge operating the connection between the port and the hub can be operated with a higher average utilization rate. As this leads to the fact that freight units are transported at lower costs on this port-hub connection, it was expected that significant cost savings could be achieved in barge operation when using the hub-and-spoke configuration.

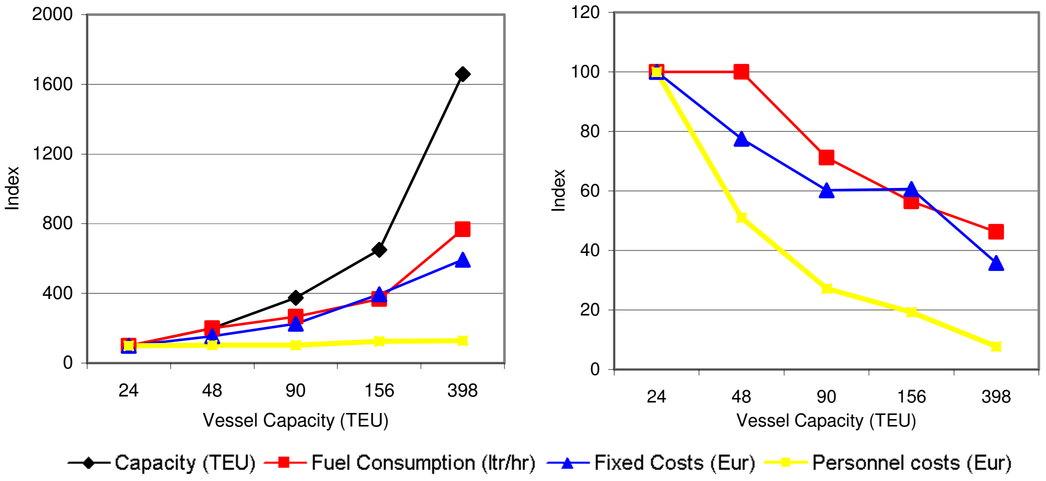

Figure 4.1: Indexation on the capacity, fixed cost, personnel costs (Eur) and fuel consumption (ltr/hr) per barge (left) en per TEU (right), setting the index of a 24 TEU vessel at 100, *Source:* Van Dongen et al. (2006), NEA transportonderzoek (2009).

4.1.1.3. Total volume transported through the network

As mentioned by Konings (2009), the vessel size one is able to use on certain connections depends on several factors. One of the most important factors is the available transport volume. If one is able to increase the load factor of vessels due to an increase in volume, the transportation costs per unit of freight will decrease. Furthermore, as has already been mentioned in the former section, (additional) economies of scale can be achieved if the transportation volume is large enough. It was expected that the transportation volume plays a significant role in the feasibility of a hub-and-spoke network

4.1.1.4. Fraction of containers re-used for export

As mentioned in section 2.4.3 it was expected that the hub-and-spoke network could bring about additional empty container re-use. Because of the fact that inland terminals are connected with one another through the use of a hub terminal in the hub-and-spoke network, it was assumed that in this situation more matches between supply and demand could be made than in the base case scenario. Because of this expected increase in re-use of empty containers, it was expected that fewer containers needed to be transported from the port area to inland destinations, which decreases transportation costs.

Because the potential empty container re-use is largest if the import and export flows within a network are balanced, it was expected that this balance significantly influences the cost savings that could be obtained within a hub-and-spoke network.

4.1.1.5. Percentage of truck transport

Because of the increase larger barge calls and point-point connections in the hub-and-spoke network, it is expected that such a configuration can significantly influence barge reliability. Due to this reliability increase a possible modal shift from truck to barge was expected to take place. A terminal operator in the Dutch hinterland even mentioned that he could shift 50% of his total yearly truck volume towards barge transport if the barge connection could be made more reliable.

4.1.1.6. Reverse modal shift

A concern emphasized by ECT related to the modal shift issue was the fact that a reverse modal shift, a shift from barge to truck, might take place when the inland terminals and their service area's are located nearby the hub terminal. Due to the fact that intermodal transport brings about additional handling costs compared to direct trucking, it was expected that the reduction of transportation costs were outweighed by these additional handling costs on short distances between hub and inland terminal. A more elaborate description on the reverse modal shift can be found in Appendix F.

4.1.1.7. Fuel Price

As shown in Figure 4.1, larger vessels use relatively less fuel than smaller vessels. When operating a hub-and-spoke network, in which relatively more large vessels were used, it was therefore expected that a substantial reduction in fuel consumption could be achieved. The impact of such a reduction on total cost savings would logically be larger when fuel price was at a high level than when it was at a low level. It was therefore expected the fuel price to be positively correlated with the cost-effectiveness of the hub-and-spoke model.

4.1.2. Results

In this section, the results of the analysis for the experimental design will be presented. In Appendix M one can find the parameters and their input values that were fixed during the analysis. The hub-and-spoke network under consideration consisted of one hub terminal and 6 inland terminals. The inland terminals were assumed to have the same terminal characteristics.

In Table 4.1 one can find the input parameters that were varied during the analysis. In the third column of the table, one can find the range along which the input parameter was varied during the analysis. In the fourth column the value of the parameter is presented that was used during the analysis when varying other inputs.

Parameter	Description	Range	Value if fixed
D_i	Total yearly demand of containers for the service area of terminal i (TEU)	Hub = 30,000-140,000 Terminal = 0.5* D_H	Hub = 70,000 Terminal = 35,000
a^h	Fraction of empty containers that can be re-used in the hub-and-spoke network	0.1-0.4	0.1
$ut^h_{P,i}$	Percentage of unimodal transport by truck between the Port and terminal i in the hub-and-spoke network	0%-20%	20%
$ut_{H,i}$	Percentage of unimodal transport by truck between the Hub and terminal i	Dependent on $ut^h_{P,i}$	0%

$d_{P,i}$	Average distance between the Port and shippers in the service area of terminal i (km)	Hub = 100-600 IT = $d_{P,i} + d_{H,i}$	200
$d_{H,i}$	Average distance between the Hub and shippers in the service area of terminal i (km)	25-150	75
C_i	Capacity of the barges on the connection between the Port/Hub and terminal i	Port-Hub = 90-398 Port /Hub- IT = 24-156	Port– Hub = 208 Port – IT =81
$tt_{P,i}$	Transit time in hours of the barge between the Port and terminal i	Dependent on $d_{P,i}$	Port – Hub = 17 Port – IT = 23
$tt_{H,i}$	Transit time in hours of the barge between the Hub and terminal i	Dependent on $d_{H,i}$	8
ρ	Fraction of semi-fixed costs that is considered as variable costs	0.0 – 1.0	0.5

Table 4.1: Input parameters that were varied during the analysis, indicating what range for the input values was used and what the value of the input parameters was when varying others

4.1.2.1. Distance between port and hub terminal

As mentioned before, the distance between the port and the hub terminal is a crucial factor according to Beuthe and Kreutzberger (2001) for the feasibility of the hub-and-spoke network. In Figure 4.2 support for this claim can be found, as the hub and spoke network proved to be more expensive then the base case scenario if the hub was located less then 277 km near the port terminal. This 'break-even' distance was reduced if the amount of empty containers re-used was increased for the hub-and-spoke network. Therefore, from Figure 4.2, it can be concluded that the re-use fraction of empty containers significantly influenced the difference in total cost between the base case scenario and the hub-and-spoke network. When empty containers were re-used in case the hub was located further away from the port, this generated more savings in absolute and relative terms then when it was located nearby the port, explaining the (slightly) increasing mutual space between the graphs in Figure 4.2.

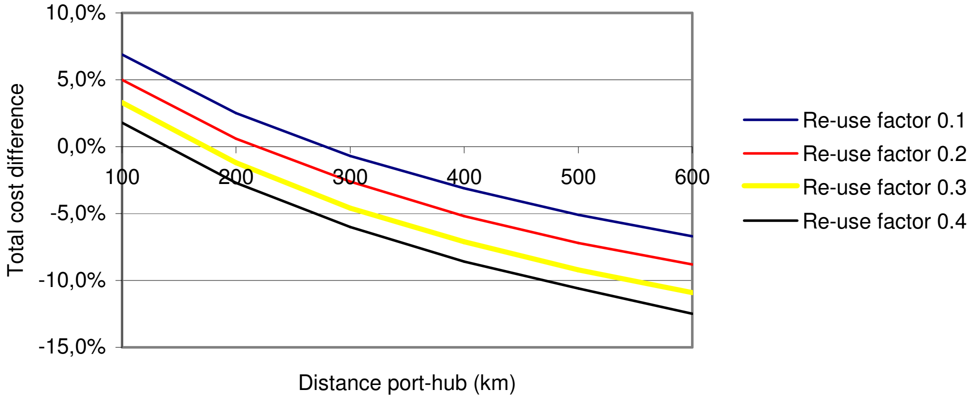

Figure 4.2: Difference in total cost between the base case scenario and the hub-and-spoke network for varying distance between the port and the hub terminal under different levels of empty container re-use

From Figure 4.2 it must concluded that the feasibility of the hub and spoke network was clearly dependable on the distance between the port and the hub terminal. This was a consequence of the economies of scale in barge transport. As freight could be transported at lower prices per kilometer when using larger barges, increasing the distance between the port and the hub terminal increased the savings generated by the fact that this distance did not have to be covered by smaller (more expensive) vessels. As the size of the vessel therefore also played a significant role in these results, the influence of barge capacity on total costs will be discussed more thoroughly in the following section.

4.1.2.2. Capacity of barge connection

As has already been shown above, savings in barge transport can be gained due to economies of scale. In order to determine the impact of these economies of scale on total costs, it was analyzed how the difference in total costs developed when deploying varying sized vessels on the barge connections. During this analysis both the barge capacity on the connection between the port and the hub and the capacity on the connection between port/hub and inland terminal was varied. The results of this analysis can be found in Figure 4.3. In this Figure the different lines represent the cost savings for varying capacities of the waterway between the port (hub) and the inland terminals. In Figure 4.4 results are presented concerning the analysis on how the distance between the port and the hub influences the impact of economies of scale on total cost difference between the base case scenario and the hub-and-spoke network. In this Figure the different graphs represent different capacities of the connection between the port and the hub.

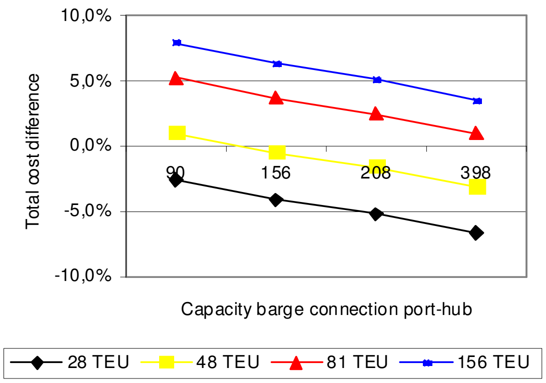

Figure 4.3: Difference in total costs between the base case scenario and the hub-and-spoke network for different capacities of the barge connections between the port, the hub and the terminals

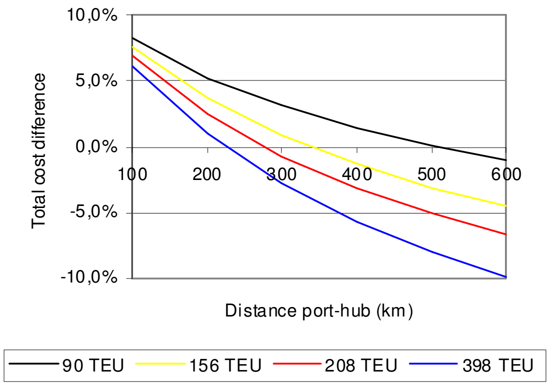

Figure 4.4: Difference in total costs between the base case scenario and the hub-and-spoke network for varying distances and different capacities of the barge connection between the port and the hub,

It can be concluded from both Figure 4.3 and Figure 4.4 that the generated cost savings by the hub-and-spoke network increased when the barge capacity of the connection between the port and the hub was increased. Furthermore, costs savings were larger if only smaller vessels could be used on the connection between the port and inland terminals (between hub and terminals in hub-and-spoke network). This indicated that the hub-and-spoke model generated (more) significant cost savings in situations where the capacity of the waterways between the port and the inland terminals was limited but the waterway between the port and the hub was not. However, such a situation increased the threat of a reverse modal shift, as will be shown further on in this section. As depicted in Figure 4.4 the distance between the port and the hub terminal positively influenced the savings gained due to economies of scale. This finding is logical as economies of scale obtained in barge transportation stem from a lower cost per kilometer traveled per freight unit when deploying larger vessels. As these travel distance was increased, so did the effect of economies of scale on total costs.

4.1.2.3. Transportation volume

The results shown above were obtained when keeping the demand of freight fixed at a certain level. However, the transportation volume was expected to play a significant role in total cost difference between the base case scenario and the hub-and-spoke network as it is a key factor in obtaining economies of scale. In the left part of Figure 4.4 difference in total costs are presented for different demand levels in the total network for different barge capacities between the port and the hub. During this analysis, the demand of freight for inland terminals was half of the demand for the hub terminal and the barge capacity between the port (hub) and the inland terminals was held constant at 81 TEU.

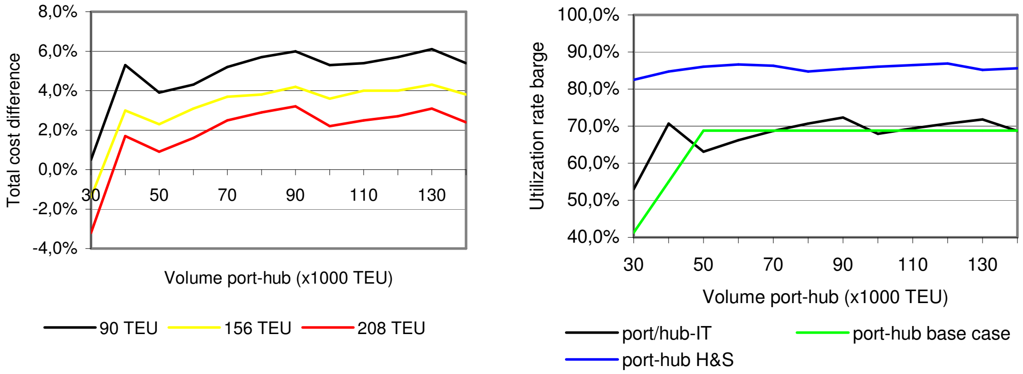

Figure 4.5: Influence of varying demand on difference in total costs between the two scenarios and on the utilization rate of the barge connections

In the right part of Figure 4.4 the utilization rate of the barge connections is shown for varying demand levels, explaining the graphs in the left part of the Figure. During the analysis, the barge utilization of the vessels operating the connections with the inland terminals was equal in both scenarios. The presented results are different from what was expected beforehand. When the volume transported through the network was increased, the relative cost difference between the base case scenario and the hub-and-spoke network increased for smaller demand levels and remained roughly equal for higher levels of demand. Although these findings contradict our expectations, they can be explained when considering the fact that the bundling of freight in the hub-and-spoke network led to higher vessel utilization, as shown in the right part of the Figure, and thus to decreased transportation costs. This finding is in line with the results obtained by Konings (2009) who found the cost advantage of a trunk-feeder connection to be largest in cases transportation volumes are small due to the fact that the barge connection between the port and the hub was more highly utilized.

The low utilization rate for the barge connections (predominantly for the connections in the base case scenario) as shown in the right part of Figure 4.4 can be explained by the existing trade-off between service frequency and utilization rate. In the current analysis, it was assumed a certain minimal required frequency existed for the barge connections towards the inland terminals. In low demand circumstances, this led to significant underutilization of the vessel. Therefore, decreasing the distance this vessel had to travel in the hub-and-spoke network led to significant cost savings. Furthermore, cost savings were achieved due to a higher utilization of the barge operating the port-hub connection[4]. However, it is not to be expected in practice that certain barge connections are operated with this level of underutilization. From this finding it can therefore not straightforwardly be concluded that the hub-and-spoke network will be suited for low demand/volume environments. Another important finding is that the relative cost difference between the base case scenario and the hub-and-spoke network was roughly equal after a certain level of demand was reached due to a more or less constant utilization rate of barges. This led to the very important finding that increasing demand, while keeping all other parameters equal, will not cause a shift from the hub-and-spoke network being cost-ineffective to being cost-effective or vice versa. However, as will be explained in the following section, the threat of a reverse modal shift was influenced by the transportation volume

4.1.2.4. Reverse modal shift

An analysis was executed to examine at which distance between the hub and the shippers of the inland terminal it the threat existed for a reverse modal shift to occur. The results of this analysis can be found in Figure 4.6

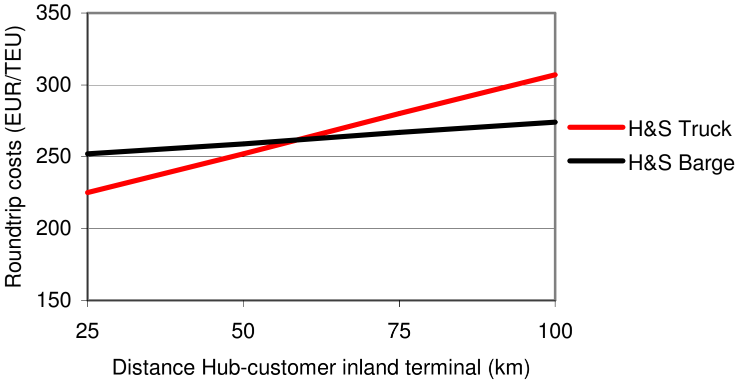

Figure 4.6: Comparison of the roundtrip costs in euro/TEU for the H&S-Truck and H&S-Barge container flow for varying distance between the hub and the shippers in the service area of the inland terminal

What can be concluded from this result is that when the distance between the hub terminal and shippers in the service area of inland terminals was less than 59 km, it was cheaper, on average, to transport containers from the hub to the shipper site by truck than by using intermodal transport from the hub onward. The difference in roundtrip costs between H&S-Truck and H&S-Barge were caused by the difference in transportation costs between barge and truck transportation and by the additional handling costs on the inland terminal. For example, when demand was increased from 35.000 TEU to 70.000 TEU, which decreased fixed terminal handling costs per move, the break even distance as shown in Figure 4.6 decreased from 59 km to 44 km, a decline of almost 25%.

The above analysis of the reverse modal shift was based on the cost perspective only. If we consider the time it takes from the hub terminal onward, the H&S-Truck container flow

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[4] See Appendix G for a more detailed explanation of this fact

takes about 0.15 days to complete, while the H&S-Barge container flow takes about 1.30 days. Therefore, if also the time aspect plays a significant role in a shippers' decision for either truck transport or intermodal transport from the hub onward, H&S-Truck could be preferred above H&S-Barge even if it brings about additional costs. This fact makes it even more important to implement the proper (price) mechanisms to prevent the inland terminals (spokes) from loosing business.

As was found earlier, the cost-effectiveness of the hub-and-spoke network was dependent on the limit of the waterway connection between the port and the inland terminals, as the impact of economies of scale in the hub-and-spoke configuration was larger when these connections were very limited. Although such a situation therefore increased the overall attractiveness of the model, it increased the threat of a reverse modal shift occurring, as the barging costs per TEU between the hub and the inland terminal were higher in this case. In Figure 4.7, this relationship between distances within the network and the limit on waterway capacities is shown. In this figure, the red lines indicate the break even distance between the port and the hub terminal for which the network becomes cost-effective for a 48 TEU and a 81 TEU barge connection. The black lines indicate the break-even distance for the reverse modal shift for the same barge capacities. In the square, several existing connections are shown for which it was calculated if the hub-and-spoke network proved to be cost-effective. If this indeed was the case, the connection is shown in black text, while it is shown in red if it the hub-and-spoke network was not cost-effective for this connection.

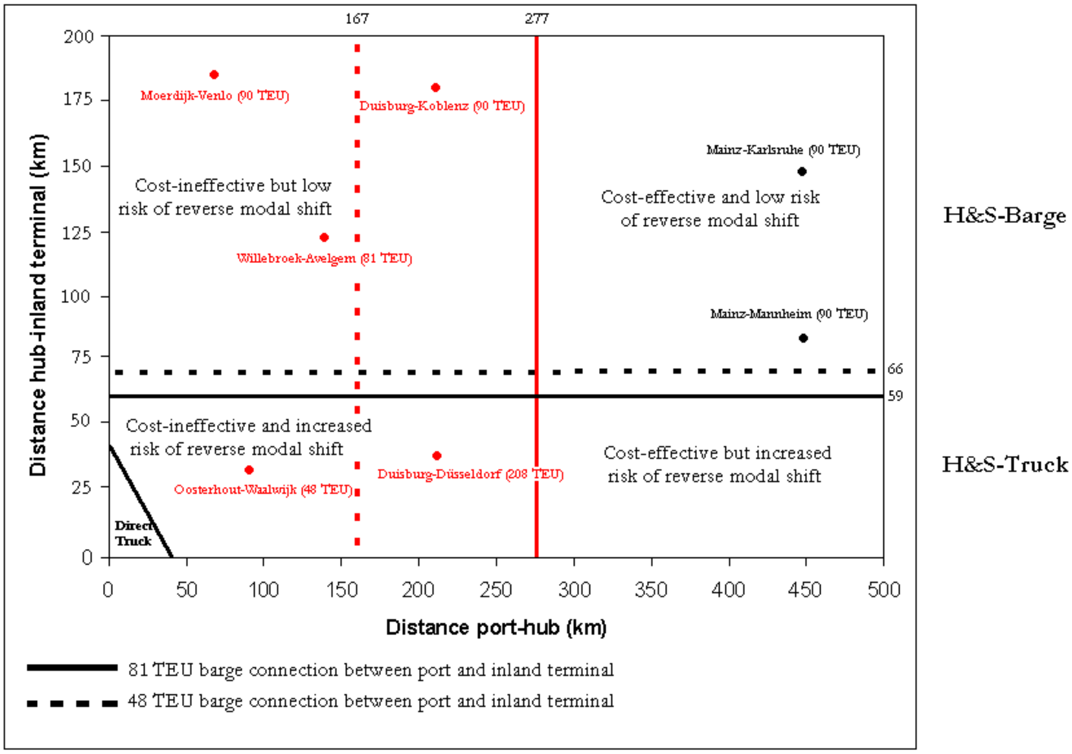

Figure 4.7: Overview of the preferred container flow towards the hinterland in the hub-and-spoke network, depicted for varying distances between the port-hub and port-terminals.

As can be seen in this figure, is that indeed the hub-and-spoke network was more attractive in the case the barge capacity between the port and the inland terminal was limited.

However, this increased the risk for a reverse modal shift occurring. More interestingly, the analysis showed that for many existing connections, the hub-and-spoke did not prove to be cost-effective per se. This was only the case on connections along the middle Rhine, where the hub-and-spoke network realized cost savings compared to the base case scenario.
It needs to be mentioned that the cost-effectiveness of these existing connections was based on the initial input parameters of the model. This cost-effectiveness could therefore change due to operational measures or changes in network characteristics. Therefore, the 'terminal pairs' denoted with red text are not cost-ineffective per se and need to be analyzed more thoroughly when examining the applicability of the hub-and-spoke network for these connections.

4.1.2.5. Empty container re-use

As has already been shown in Figure 4.2 the re-use fraction of empty containers is positively related to the total cost savings that could be achieved in the hub-and-spoke network. These cost savings are caused by the fact that less empty containers need to be transported between the port and the hub and by reduced empty depot costs as its function is taken over by the hub terminal. In Figure 4.8 results are presented concerning the impact of the re-use fraction on total cost difference for several import and export characteristics of inland terminals. Remember that the re-use fraction in the base case scenario was 0.1. The percentages mentioned in the figure, for which different graphs were made, represent the demand of full (import) containers for inland terminals. These containers could be re-used for export purposes once they were empty. During this analysis, it was constantly taken into account that the amount of containers transported to the port terminal must be equal in both the base case scenario and in the hub-and-spoke network as global imbalance/repositioning was assumed to remain equal.

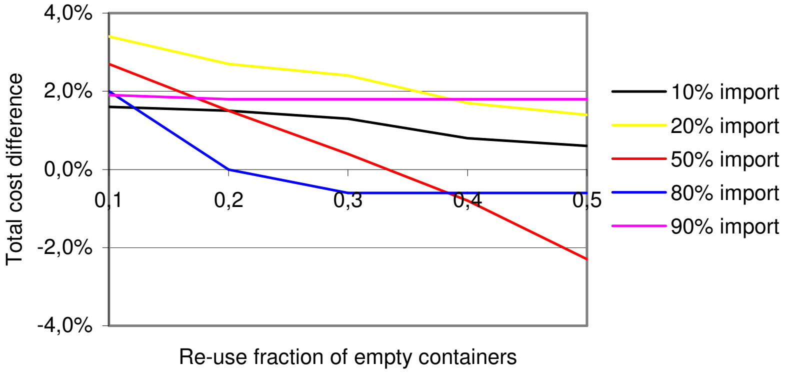

Figure 4.8: Total cost difference between the base case scenario and the hub-and-spoke network for different empty container re-use fractions and different levels of import flows

What can be observed in Figure 4.8 is that an increase in re-use fraction in the hub-and-spoke network always led to an increase in cost savings, regardless the import flow. However, the relationship between re-use fraction and costs savings differs significantly for these different import flows. Take for example the 10% and 20% import scenarios. Because of the fact that only a small amount of containers transported towards the inland terminals was full, only few containers became available for re-use. The impact of the re-use fraction on total cost difference in such situations is small as the absolute amount of containers re-used barely increased as the re-use fraction did. When considering the 80% and 90% import scenarios, in contrary to the 10% and 20% scenarios, the amount of full containers was large and therefore the re-use potential was large as well. However, when demand predominantly consisted of full containers, only few of them needed to be re-used in order to fulfill empty container demand. This reasoning explains why the graphs belonging to the 80% and 90% scenarios are constant after a certain re-use fraction was reached. When the import and export flows were completely balanced, as was the case in the 50% scenario, the amount of containers that was re-used was not limited by availability of empty containers or by empty container demand. As a consequence, the re-use fraction had a higher impact on total cost difference than was the case in the 10% and 20% import scenarios and the effect was not bounded as was the case in the 80% and 90% scenarios. Based on these outcomes it can be concluded that the impact of the re-use fraction on total cost difference between the base case scenario and the hub-and-spoke network is dependent on the balance between import and export. This balance should therefore be considered when setting up a hub-and-spoke network.

4.1.2.6. Fuel price

As expected, the hub-and-spoke configuration led to a substantial reduction in barge fuel consumption compared to the base case scenario. The obtained reduction of approximately 30% contributed significantly to the reduction in barging costs in the hub-and-spoke network and thus in the eventual cost savings. Therefore, the cost effectiveness of the hub-and-spoke network was positively correlated with the fuel price, as graphically depicted in Figure 4.9. In this figure, the relationship between the cost effectiveness of the hub-and-spoke model and the distance between the port and the hub is depicted for varying fuel prices for barge transportation. The fuel price has been varied according to the highest level in July 2008 (€ 0.72/ltr), the current fuel price (€ 0.44/ltr) and the lowest fuel price in February 2009 (€ 0.27/ltr). It can be seen in this figure that the 'break-even' distance between port and hub significantly reduced when the fuel price increased.

Under ceteris paribus conditions, no reduction in fuel usage by trucks was observed due to the fact that the amount and distance of truck transport was equal for both scenarios if the initial parameters were used. However, the fuel usage was decreased in the hub-and-spoke network if the amount of direct truck transport between the port and the shippers could be reduced and executed from the hub onward in stead. A reduction of this direct truck transport with 50% led to a decrease in truck fuel usage of approximately 25%.

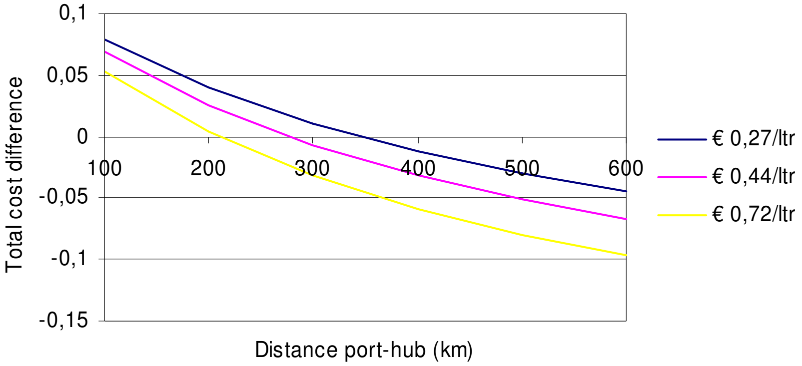

Figure 4.9: Difference in total cost between the base case scenario and the hub-and-spoke network for varying distance between the port and the hub terminal for different fuel prices for barge transportation

This impact of fuel costs on the feasibility of the hub-and-spoke is therefore quite significant. Although it is difficult to predict how this fuel price will develop in the future, it is possible to present some expectations based on the price developments in the past and the existing market forces. Following a research report of the NEA (2009), it is to be expected that the fuel price will rise when the economical growth increases, a logical development considering the fact that demand for fuel will increase along with global trade. Because of the fact that the economy is improving at the moment and is gradually growing compared to former years, I expect the fuel price to increase accordingly. This development makes the hub-and-spoke network a more attractive alternative to the base case scenario.

The substantial reduction in fuel consumption also leads me to conclude that implementing the hub-and-spoke concept can contribute to obtaining a more sustainable supply chain as a reduction in fuel consumption decreases emissions. Yet, what must be mentioned is that the additional required handlings on the hub terminal will bring about additional fuel usage of terminal equipment, something that will negatively influence the supply chain sustainability. Although this additional fuel usage of terminal equipment is expected to be outweighed by the fuel reduction of truck and barge transportation, based on results obtained by Schers (2009), it needs to be taken into account when determining the carbon footprint of the supply chain.

4.1.2.7. Other findings

Next to the outcomes on the issues raised during the experimental design, the analysis of the cost-effectiveness of the hub-and-spoke network resulted in other important findings that will be discussed in the section below.

Increase in required handling capacity on the hub terminal

The amount of handlings at the hub terminal significantly increased in the hub-and-spoke network. In the ceteris paribus condition, the required handling capacity for the hub terminal grew with almost 300%. In practice it could be that such an increase in handlings requires an expansion of the handling capacity or even an expansion of the entire hub terminal. Although the costs of the hub terminal increased as a consequence of this additional handling volume, this increase was solely based on an increase in variable (and for some part semi-fixed) costs. An expansion in terminal handling capacity would bring about additional fixed costs as well. Although these costs were not considered in the calculations, they should be added to the model in order to obtain more reliable and valid results. This will require additional research concerning which investments need to be made to increase the terminal handling capacity to the required level.

Reduced port terminal costs

The hub-and-spoke network also brought advantages and possible cost savings for the port terminal. When using a hub-and-spoke network the number of barge calls in the port reduced with approximately 75%. Due to this substantial reduction, although the same amount of containers needed to be handled in both scenarios, total usage of the quay decreased as less time was spent on mooring barges. Therefore, the portion of effective handling time compared to total handling time increased and more quay capacity became available for other operations. Furthermore, if it is possible to operate a point-point schedule between port terminals and the hub, internal terminal transport could be reduced.

Due to the fact that no data was available concerning the port terminal costs, it was very difficult to discuss the impact of these developments on possible cost savings at the port terminal. However, some cost savings were to be expected. In Figure 4.10 on can find a graph representing the expected port terminal cost savings when implementing the hub-and-spoke network. It was assumed the port terminal was highly utilized. The relationship between reduction in barge quay occupancy and cost savings is shown for several scenarios concerning the point-point sailing schedule between port and hub. Following well known results from queuing theory that congestion increases exponentially with utilization, the first percentages of reduction in quay occupation will have the largest impact on congestion reduction and thus on increased effective handling time (cost savings). The cost savings in Figure 4.10 were therefore depicted to be decreasingly ascending when the quay occupancy reduction was increased. Furthermore, it was expected that cost savings were higher in the case that it was possible to operate full point-point connections than in the case no point-point connections were established.

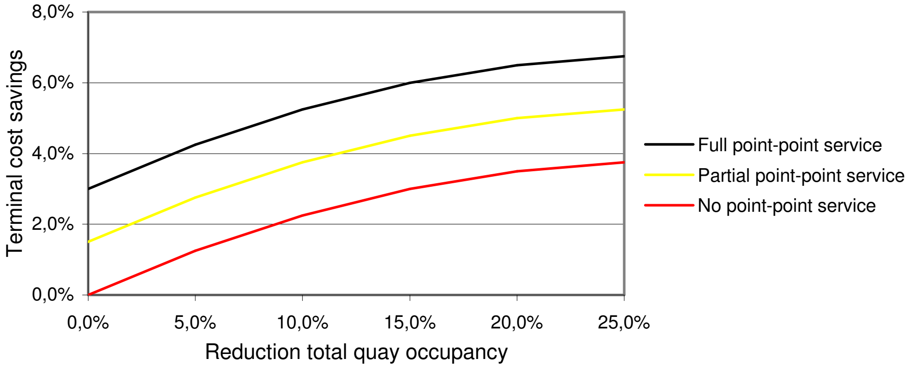

Figure 4.10: Estimation on port terminal savings in the hub-and-spoke network as a consequence of a reduction in quay occupancy and point-point connections between port and hub

It needs to be mentioned that a reduction in barge calls for only 7 inland terminals has only a minimal impact on port operation. Nonetheless, the results presented in Figure 4.10 are interesting. As port terminal costs accounted for approximately 10% of total costs, a decrease of 1.0% in port terminal costs led to a decrease in total costs of 0.1%. Although this decrease seems to be only minimal, considering the small differences found earlier between the base case scenario and the hub-and-spoke network, it could mean the difference between the hub-and-spoke network being cost effective or not. It is therefore highly recommended that more research is executed to analyze how the hub-and-spoke configuration impacts port operation and port terminal costs.

External costs

The abovementioned reduction in fuel usage contributed to a reduction in emissions and therefore to a decrease in external costs of the container shipping supply chain. These external costs depict public costs that cannot be calculated directly, such as costs of congestion and accidents. In Appendix I more detail about these costs and how they were calculated is presented. Next to a reduction in emissions, external costs could be decreased due to other reasons. First of all, freight currently transported directly between the port and the shipper by truck could be transported intermodally due to an increase in transport reliability. As the external costs for truck transport are much higher than those of barge transport, this shift from truck transport to intermodal transport decreased external costs considerably. Second of all, due to the fact that more empty containers could be re-used in the hub-and-spoke network, one can save total transportation distance and decrease the total value of ton*km[5] in the network. Although the impact on external cost reduction of increasing the re-use fraction was less than that of the modal shift from truck to barge, it still was quite substantial. In short, if one is able to obtain a model shift from truck to barge and increase the re-use of empty containers, a substantial reduction in external costs can be achieved, indicating the importance of achieving these supply chain improvements in terms of social benefits.

4.1.3. Conclusions

Based on the abovementioned model outcomes, the most important thing to conclude is that the hub-and-spoke configuration is not necessarily a cost-effective alternative compared to the manner in which container transport is carried out today. As uncovered in the above analysis, several network characteristics and operational issues significantly influenced the feasibility of this improvement concept. Both need to be closely considered when investigating the possibility of setting-up a hub-and-spoke network for hinterland transport.

First of all it was shown that the distance between the port and the hub had a significant impact on the feasibility of the hub-and-spoke network as alternative to the base case scenario. It was furthermore an important factor as it moderated the relationships between other network characteristics and total costs. Economies of scale achieved in barge transportation seemed to be the reason why this distance had a significant impact on model outcomes. Predominantly the savings in barge fuel consumption contributed significantly to total cost savings. The hub-and-spoke concept therefore seems an attractive alternative for the base case scenario in the case a network of terminals is located at a substantial distance from the port and when the fuel price of barge transportation goes up. Next to a reduction in costs, the significant reduction in fuel consumption improved the sustainability of the supply chain and improved its carbon footprint. It was mentioned by several actors within the supply chain that shippers are increasingly aware of their public responsibility and deliberately choose intermodal transport above unimodal transport due the fact that it is more sustainable. The improved sustainability of intermodal transport in the hub-and-spoke network therefore seems to provide additional reasons for shippers to use it.

In addition to the distance from the port, also the limit on waterway capacity was an important factor contributing to the attractiveness of the hub-and-spoke network. It was shown that the hub-and-spoke model can generate significant cost savings in situations where the capacity of the waterways between the port and the inland terminals is limited but the waterway between the port and the hub is not. However, this limit on waterway capacity increased the threat of a reverse modal shift, as it increased the cost of barge transportation between the hub and the inland terminal, making intermodal transport from the hub onward less attractive.

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[5] Measure used for calculating total external costs for certain modalities (see Appendix I

Another interesting finding was the fact that an increase in demand did not increase the obtained economies of scale as expected and thus did not make the hub-and-spoke model relatively more attractive compared to the base case scenario. However, the hub-and-spoke network did provide some cost savings when demand was low, as the bundling of freight at the port-hub connection led to a significant increase of the utilization rate of this vessel, decreasing the costs for unit transported. This finding corresponds with the findings of Konings (2009) concerning the relationship between frequency, available volumes and load factor.

In contrary to a volume increase, the increase in re-use fraction did have a substantial impact on model outcomes. If more empty containers could be re-used in the hub-and-spoke network compared to the base case scenario, this would significantly make the concept more attractive. However, to reap the benefits of this cost saving potential, several important network characteristics must be considered. For example, it proved that it was very important to balance the network, meaning that the network should contain similarly large import and export flows. This denotes the necessity of including the right inland terminals in a hub-and-spoke configuration. If this issue is not properly considered when setting up such a network, one will loose a large cost saving potential.

Another potential benefit of the hub-and-spoke model compared to the base case scenario is the possibility to decrease the amount of direct truck transport in the network due to a highly reliable port-hub connection. Due to the fact that intermodal transport could be executed at considerable lower costs than unimodal transport, even a small reduction in direct truck transport led to a large cost reduction in the hub-and-spoke network. According to a study executed by Kiesmüller et al. (2005), especially in the case of low value products, only a very small part of products needs to be transported by truck as the additional holding costs are outweighed by savings in transportation. To put it in other words, the current fraction of approximately 56% of truck transport in total hinterland access could be significantly reduced based on the results obtained by Kiesmüller et al. (2005). This implies that one of the most important requirements in cost-effectively operating a hub-and-spoke network seems to be quite easily achievable.

An additional benefit of decreased truck transport was a considerable reduction in external costs. These external costs consisted of aspects such as emissions and accidents and provided an indication on the impact of container transportation on its natural and social environments. Therefore, from a societal point of view, reducing unimodal transport, and with it the external costs, is highly desirable.

Finally, although the lack of port terminal data made it not possible to accurately analyze the cost development at the port, an estimation of this change could be made based on the reduced number of barge calls and the reduced barge handling time. As a consequence of this reduction in calls and time, handling capacity at the port could be used more effectively, reducing the handling cost per container. Yet, this effect needs to be examined more thoroughly in order to determine its impact on total cost development.

4.2. Case study

In this section, results will be presented concerning the analysis conducted on the feasibility of the hub-and-spoke model in a real life situation. The case study under consideration concerns a cooperation of 4 inland terminals in the Dutch hinterland. Due to the fact that the terminal and waterway characteristics are given in this situation, the input parameters were more predetermined than in the experimental design. In Appendix N one can find the input parameters for the terminals under consideration.

Section 4.1.1 presents which input parameters were varied during the analysis in order to determine under which circumstances a hub-and-spoke network performs better than the base case situation. In Section 4.1.2 results concerning the issues discussed in the experimental design will be presented. Section 4.1.3 presents the conclusions of the comparison between the base case scenario and the hub-and-spoke network.

4.2.1. Experimental design

As the terminal parameters are fixed for the inland terminals under consideration, there is less room for changing input parameters to determine their impact on total costs and on the feasibility of the hub-and-spoke network. For example, as the location of the hub terminal is given, the case study does not allow for analyzing how the distance between the port and the hub affects total cost difference. This experimental design therefore differs from the one presented in Section 4.1.1.

4.2.1.1. Capacity of barge connection

As mentioned before, in practice waterways available for barge transport are often capacitated due to depth, width, bridges and slots. For the barge connections between the port and the Dutch inland terminals, this is indeed the case. For all inland terminals, excluding the hub terminal, only small to medium sized vessels can be deployed for operating the barge connection between their terminal and the port. It was therefore expected that, due to achieved economies of scale, the hub-and-spoke network would bring about significant cost savings in barge transportation.

4.2.1.2. Fraction of containers re-used for export

From the general analysis it became clear that the re-use fraction of empty containers plays an important role in the attractiveness of the hub-and-spoke network. However, empty container re-use has got the largest potential in a network that is balanced when it comes to export and import flows of the terminals involved. Due to the fact that the Dutch inland terminals predominantly operate import flows, the network is not really balanced and the possibilities for empty container re-use were expected to be limited.

4.2.1.3. Percentage of truck transport

During an interview held with an inland terminal operator something very interesting was discussed. According to the terminal operator, who also owns several trucks, he could shift 50% of the transport currently executed by truck to intermodal transport if the barge connection between the port and the hub becomes more reliable. Instead of picking up the containers at the port, he would have the trucks pick up the containers at the hub-terminal. As was shown in Section 4.1.2 this shift considerably reduced total costs in the hub-and-spoke network. Using this reasoning, it was expected that the hub-and-spoke network allowed for a reduction in direct truck transport and therefore could result in substantial cost savings within the supply chain for the Dutch inland terminals under consideration.

4.2.1.4. Reverse modal shift

Due to the fact that the Dutch inland terminals under consideration are located in one another's vicinity and at a reasonably small distance from the hub terminal, the threat of a reverse modal shift was expected to be present in the case study.

4.2.1.5. Fuel price

Following the reasoning and the results of the former section, it was expected that the fuel price was also positively correlated with the attractiveness of the hub-and-spoke model for the Dutch inland terminals.

4.2.2. Results

In this section, the results of the analysis for the case study will be presented. In Appendix M and N one can find the parameters and their input values that were fixed during the analysis.

In Table 4.2 one can find the input parameters that were varied during the analysis. In the third column of the table, one can find the range along which the input parameter was varied during the analysis. In the fourth column the value of the parameter is presented that was used during the analysis when varying other input values.

Parameter	Description	Range	Value if fixed
a^h	Fraction of empty containers that can be re-used in the hub-and-spoke network	0.1-0.4	0.1
$ut_{P,i}^h$	Percentage of unimodal transport by truck between the Port and terminal i in the hub-and-spoke network	0,0%-20,0%	20,0%
$ut_{H,i}$	Percentage of unimodal transport by truck between the Hub and terminal i	Dependent on $ut_{P,i}^h$	0,0%
C_h	Capacity of the barges operating the connection between the Port and hub terminal i	Base case = 90 H&S = 90-398	Base case = 90 H&S = 156

Table 4.2: Input parameters that were varied during the analysis, indicating what range for the input value was used and what the value of the input parameter was when varying others

4.2.2.1. Capacity of barge connection between port and hub

In Figure 4.11 the relative cost difference between the base case scenario and the hub-and-spoke network is presented for varying barge capacities deployed on the port-hub connection. During this analysis, the barge capacity on the connection in the base case scenario was held constant at 90 TEU. This figure therefore indicates what effect increase in scale has on relative total cost difference.

What can be concluded from this figure is that an increase in vessel size on the port-hub connection led to a decrease in total costs for the hub-and-spoke network. This was caused by the fact that total barging costs were lower when a larger vessel was used due to existing economies of scale. The figure furthermore depicts that additional cost savings as a consequence of an increase in vessel size was limited by the minimal required frequency. As mentioned by Konings (2009), the vessel size is dependent on the volume and the required transport frequency as one wants to achieve a high vessel utilization to decrease the fixed costs per unit. Because the minimal required frequency could be achieved with these 208 TEU vessels without decreasing the vessel utilization, the economies of scale achieved were largest when using these ships.

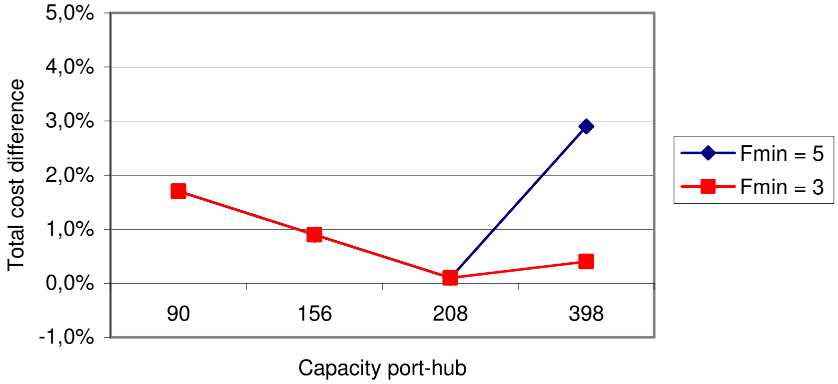

Figure 4.11: Relative cost difference between the base case scenario and the hub-and-spoke network for varying deployed barge capacity and frequency of the port-hub connection

For the case study this implies that the scale of the barge connection between the port and the hub can and should be increased to transport the containers destined for and originating from this part of the Dutch hinterland if this still allows for a certain minimal frequency of the barge connection.

4.2.2.2. Fraction of containers re-used for export

To determine the impact of empty-container re-use on the feasibility of the hub-and-spoke network for the Dutch inland terminals, the total costs and the difference between these costs were calculated for different re-use fractions obtained in the hub-and-spoke network. In Figure 4.12 one can find the results of this analysis. The graphs depicted in this figure represent the changing costs for different import balances of the inland terminals. Different import levels were considered because no data on these figures was available during the analysis and they needed to be estimated.

From this figure, the same can be observed as was the case in Figure 4.8. The better the balance between the import and export flows, the more matches one can make between demand and supply of empty containers and the more cost savings can be generated with empty container re-use. As the container flows for the Dutch inland terminals are predominantly import, the potential cost savings of empty container re-use are limited.

What needs to be mentioned about the impact of the re-use fraction on total cost difference between the two scenarios is that its potential is probably larger in practice than as shown in this analysis. Considering the assumption that all empty containers redistributed across the terminal network must first be transported to the hub terminal, additional cost savings can be achieved if empty container exchange takes place amongst the different inland terminals directly. This would namely save the double handling costs of the empty containers at the hub terminal.

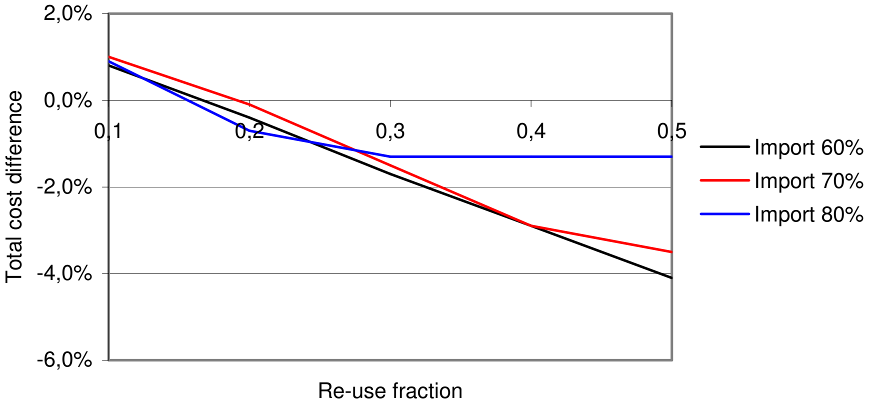

Figure 4.12: Total cost difference between the base case scenario and the hub and spoke network for increasing empty container re-use fraction and varying import/export balance of the inland terminals

4.2.2.3. Percentage of truck transport

As explained before and as was shown in earlier analyzes, the decrease of truck transport between the port and the shippers in the service area of the inland terminals can contribute significantly to total cost savings of the hub-and-spoke network. In Figure 4.13 one can find the results of the analysis for the Dutch inland terminal when this amount of truck transport was reduced and the corresponding containers were transported by barge to the hub and then by truck onward (H&S-Truck container flow). Considering this figure, it must be concluded that if it is possible to reduce the amount of direct truck transport between the port and hub with 50%, as claimed by the inland operator, the hub-and-spoke network would become cost-effective compared to the base case scenario (-3.6% total cost reduction)

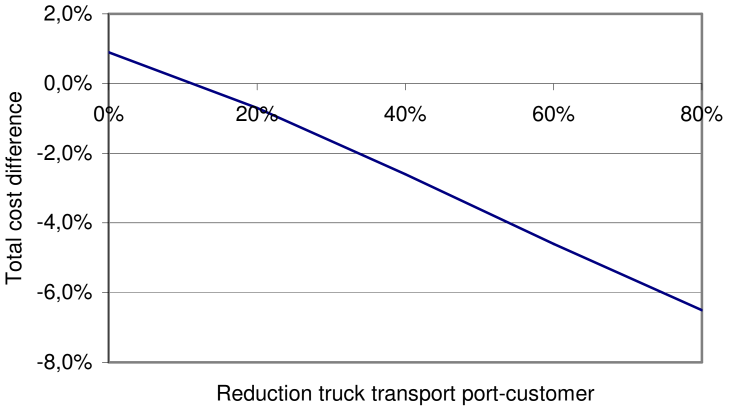

Figure 4.13: Total cost difference between the base case scenario and the hub-and-spoke network for different levels of reduction in truck transport between the port and shippers in the service area of the inland terminals

4.2.2.4. Reverse modal shift

For the Dutch inland terminals, the threat of a reverse modal shift is a very important issue as the inland terminals are located near each other and, more importantly, near the hub terminal. As shown in the left part of Figure 4.14, the roundtrip costs for the H&S-Barge container flow was larger than the H&S-Truck container flows for all inland terminals except for the hub. This indicates that it cost less to transport a container from the hub onward by truck than by barge.

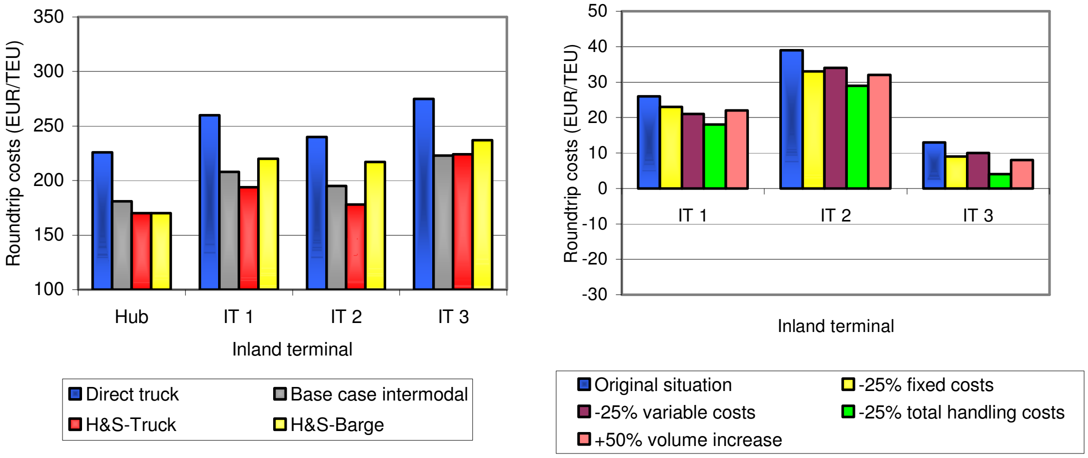

Figure 4.14: Comparison of roundtrip costs in euro per TEU for the inland terminals under consideration for several container flows and the difference between H&S-Truck and H&S-Barge for varying input characteristics

Considering this large threat of a reverse modal shift, it needed to be analyzed how the cost structure or other network characteristics should change to reduce the large differences in roundtrip costs between H&S-Truck and H&S-Barge. The results of this analysis can be seen in the right part of Figure 4.14. The difference in roundtrip costs between the H&S-Truck and H&S-Barge container flows are presented for varying terminal costs and handling volumes. These findings indicate that even significant changes in terminal cost structure or network volume did not take away the threat of the reverse modal shift. Therefore, it is very important for the Dutch inland terminals to take measures to prevent the reverse modal shift from happening. For example, the reduced costs for the connection between the port and the hub terminal must not show itself in tariffs towards shippers. Furthermore, the intermodal connection between the hub and the inland terminals must be very reliable, such that shippers are able to set up their ordering processes around these longer transit times and are not dependent on the faster truck transportation to prevent them from going out of stock. This will require well aligned sailing schedules and reliable terminal operations at the hub terminal. Further on in this report, these issues will be discussed more thoroughly.

Next to an indication on the threat of a reverse model shift, Figure 4.14 shows another interesting development in the hub-and-spoke network that needs closer consideration. As can be seen, roundtrip costs for container flows H&S-Truck and H&S-Barge decreased for the hub terminal compared to the intermodal transport flow in the base case scenario. This was caused by a decrease in barge transport cost, as a consequence of bundling and economies of scale, and by the decrease in handling costs per container, as share of fixed costs per move decreased. For the other terminals, the intermodal transport flow going through their terminal was significantly more expensive in the hub-and-spoke network than it was in the base case scenario. The cost savings in barge transport were not sufficient to cover the additional handling costs at the hub terminal. This finding reveals an important issue that needs to be addressed and analyzed thoroughly by the Dutch inland terminals. All parties must share the advantage of decreased costs of the barge connection between port and hub. This also goes for the decreased handling costs at the hub terminal. Further on it will be explained how the barge handling costs developed when hub-and-spoke network was implemented.

4.2.2.5. Fuel Price

Similarly to the finding obtained in the general analysis, the fuel price proved to be positively correlated with the feasibility of the hub-and-spoke model for the Dutch inland terminals. In Figure 4.15 it is shown how the fuel price impacts the difference in total cost between the base case scenario and the hub-and-spoke model for the Dutch inland terminals.

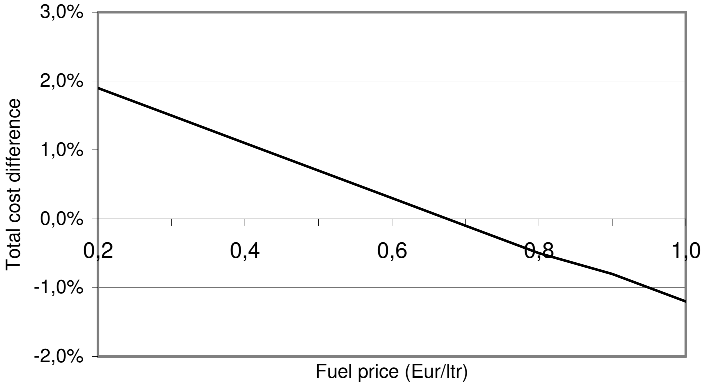

Figure 4.15: Total cost difference between the base case scenario and the hub-and-spoke model, for the Dutch inland terminals, depicted for varying fuel prices (Eur/ltr)

From this Figure it must be concluded that the fuel price significantly influenced the attractiveness of the hub-and-spoke model as it proved to be cost-effective in case the fuel prices was high while it was not in case the fuel price was low. Although the current fuel price is at a level such that the hub-and-spoke model is cost-ineffective, following the reasoning that the fuel price will rise as a consequence of increasing global trade, it is expected that the hub-and-spoke model will become a more feasible alternative in the (near) future.

4.2.2.6. Difference between Case Study and General Analysis

A remarkable result obtained during the case study was the fact that, under ceteris paribus conditions, the total cost difference between the base case scenario and the hub-and-spoke network was only 0.9% although the distance between the port and the hub was just 90 km. To achieve a 0.9% cost difference in the general analysis, the distance between the port and hub had to be changed to 247 km. Although this difference is quite considerable, it can be explained with the help of Figure 4.3, in which the relationship between total cost difference and barge capacity between inland terminal and port was depicted. It was shown that the cost savings of the hub-and-spoke network were highest in case the waterway capacity between the port and the inland terminals was very limited. As the waterway capacities of the Dutch inland terminals was (much) lower than the 81 TEU assumed in the general analysis, the hub-and-spoke network generated relatively more cost savings. Next to the difference in waterway capacity, also the lower hub terminal handling costs partially explains the difference between the case study and the general analysis. As the hub handling costs were considerably less for the Dutch inland terminals, the impact of the required transshipment on total costs was less than found during the general analysis. See Section 4.3.2 for a more detailed analysis on the impact of hub terminal costs on model outcomes.

4.2.2.7. Other findings

Just as in Section 4.1, other important performance indicators concerning the comparison between the base case scenario and the hub-and-spoke network were measured and analyzed. The results were obtained when keeping all input parameters fixed as mentioned in the last column of Table 4.2 or as mentioned in Appendix M

Increase in required handling capacity on the hub terminal

It has been mentioned in Section 4.1.2 that the required handling capacity for the hub terminal grew considerably in the hub-and-spoke configuration. For the Dutch inland terminals, the increase in required handling capacity at the hub was more than doubled from 100.000 moves/year to 225.000 moves/year. It is reasonable to believe that such a substantial increase would require a terminal expansion. However, this has not been taken into account during the costs calculations. This topic therefore needs further research and specific attention when determining the feasibility of the hub-and-spoke network.

Barge handling costs hub

This measure is very important for the Dutch inland terminals as it needs to be determined what costs the hub terminal should charge the other terminals for making use of the hub terminal as transshipment point. Because the (semi-)fixed costs at the hub terminal were divided among more handlings, the costs per handling decreased compared to the base case scenario. If the hub terminal would charge the others according to its current cost price, the other terminals would pay too much and the hub terminal would be the only one to benefit from the decrease in handling cost per unit. Next to this, the hub terminal operator obtained additional benefits due to the fact that freight destined for its own service area was handled and transported at lower prices per unit, due to scale increase of transportation and the mentioned decrease in handling costs. As explained earlier with the help of Figure 4.14, this uncovers an important issue that needs to be addressed by the inland terminals. The profit margin of the freight towards the hub terminal increased while the profit margin decreased for the freight destined for the other inland terminals (assuming constant shipper tariffs). Therefore, if theses differences are not eliminated with the use of mutual costing mechanisms, the hub-and-spoke network is not beneficial for all terminals involved, not even when total costs in the network are lower than in the base case scenario.

4.2.3. Conclusions

Several important conclusions can be made concerning the implementation of a hub-and-spoke network for the Dutch inland terminals under consideration. First of all it proved that implementing the hub-and-spoke concept for these Dutch inland terminals was not cost effective per se, although the difference in total costs was only 0.9% under ceteris paribus conditions. Although one would have expected the difference to be larger as the hub is only located 90 km from the port, the limited waterway capacities in the network and the lower terminal costs of the hub terminal increased the attractiveness of the hub-and-spoke configuration on this short distance. The hub terminal costs were lower for the Dutch inland terminals because this terminal was of smaller scale than the one on which the input data for the general analysis was based. As the cost difference between the hub-and-spoke configuration and the base case was only minor, several operational issues significantly influenced the feasibility of this improvement concept.

Increasing the vessel size on the port-hub connection led to a decrease in total costs for the hub-and-spoke network. For the case study this implies that the scale of the barge connection between the port and the hub can and should be increased to transport the containers destined for and originating from this part of the Dutch hinterland. Yet, the obtained economies of scale proved to be dependent on the minimal required frequency as this determined the vessels' utilization rate. Therefore, the largest vessel size should be used for which the minimal required frequency can be obtained without reducing its utilization rate. For the Dutch inland terminals, this means using a 208 TEU vessel for the port-hub connection

The re-use fraction of empty equipment significantly influenced total costs and it therefore proved an important factor in the feasibility of the hub-and-spoke network for the Dutch inland terminals. It became clear that, because the container flows are predominantly import, the potential cost savings of empty container re-use for the Dutch inland terminals are limited. A note was placed at the obtained outcomes that additional cost savings can be achieved if empty container exchange takes place amongst the different inland terminals directly. However, in order to determine how large the cost savings of empty container re-use would be in this situation, an expansion of the model and a more detailed analysis of the container flows for the terminals under consideration is required.

A reduction in direct truck transport between the port and the shippers of approximately 10% provided total cost savings that made the hub-and-spoke network cost effective. This implies that a minimal modal shift substantially contributes to cost savings in the network. Also, it led to a significant reduction of external costs. When considering this potential reduction in external costs and also the significant reduction in fuel consumption in barge transport, it must be concluded that implementing the hub-and-spoke concept for the Dutch inland terminals can contribute to obtaining a more sustainable container shipping supply chain. Even on a small scale, as is the case for the terminals under consideration, the improvement was very significant. However, as the amount of barge handlings on the hub terminal almost tripled compared to the base case scenario, additional fuel usage of terminal equipment needs closer consideration as it was not taken into account during the analysis. This must be taken into account if one wants to use the existing model to calculate the change in carbon footprint of the logistical chain.

The three abovementioned factors have been combined to draw up Figure 4.16. In this figure the lines represent which combinations between modal shift and increase in empty-container re-use bring about equal costs of the hub-and-spoke network compared to the base case scenario for the Dutch inland terminals. The different lines represent the combinations for varying barge connections between the port and the hub. The areas to the right of the lines, represent the situations in which the hub-and-spoke network brings about cost savings, whereas the areas left to the lines represent situations in which the hub-and-spoke configuration brings about additional costs.

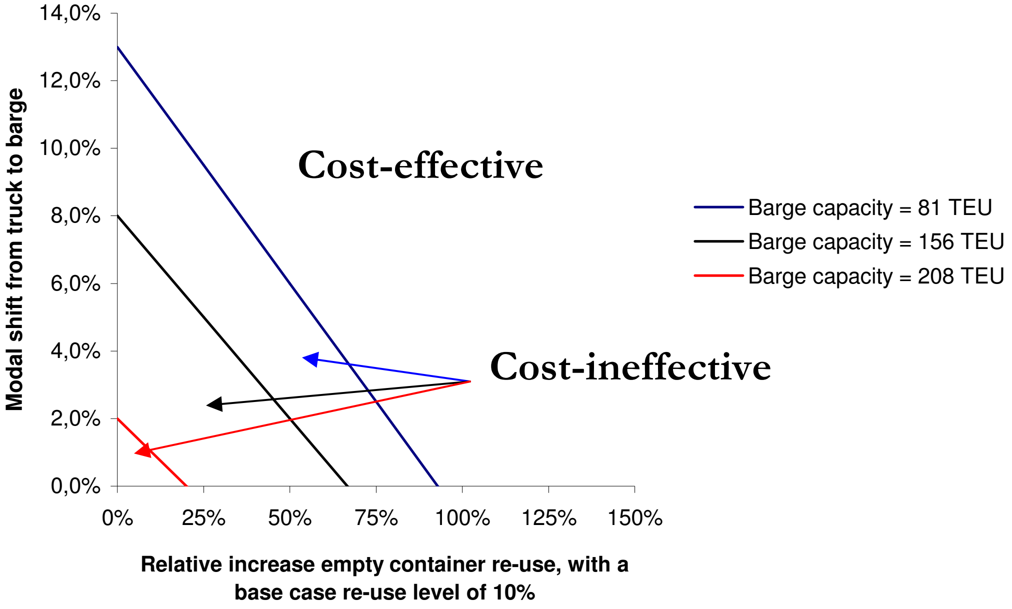

Figure 4.16: Cost-effectiveness of the hub-and-spoke model under varying levels of modal shift, increase in empty container re-use and barge capacity between the port and hub.

The figure needs to be interpreted as follows; when operating the barge connection between the port and the hub with a 156-TEU vessel, an achievement of 50% increase in empty container re-use and a 2% shift of total freight from truck to barge will result in equal costs between the two scenarios. If a modal shift of 10% is obtained in this case, the hub-and-spoke model would become cost-effective.

From Figure 4.16 it can be concluded that only minor improvements are required to cost-effectively operate a hub-and-spoke network for the Dutch inland terminals. A modal shift of 15% would for example already suffice regardless of the increase in empty container re-use or increase in barge capacity between port and hub. This insight provides strong support for redesigning the network to a hub-and-spoke configuration.

For the Dutch inland terminals, the threat of a reverse modal shift proved to be a very important issue as the inland terminals are located near each other and, more importantly, near the hub terminal. It is therefore very important for the Dutch inland terminals to take measures and prevent the reverse modal shift from happening. Due to the fact that the reduction in truck transport was outweighed by the extra barging costs, changing the cost structure of the inland terminals was not sufficient to reduce the lurking threat.

Another interesting finding was that the intermodal roundtrip costs of freight destined for the service area of the hub terminal decreased compared to these costs in the base case scenario. On the other hand, the roundtrip costs of freight destined for the service areas of other terminals increased. Therefore, there seems be an imbalance between at which parts in the chain cost savings are achieved and at which parts additional cost occur. This finding reveals an important issue that needs to be addressed and analyzed thoroughly by the Dutch inland terminals. All parties must share the advantage of decreased costs of the barge connection between port and hub. This also goes for the decreased handling costs at the hub terminal.

4.3. Impact of unreliable data on model outcomes

As discussed in Section 3.3 not all the data gathered for executing the analysis was fully reliable. It was therefore analyzed how a change in this input data affected the outcomes presented in the former sections.

4.3.1. Barging costs and fuel consumption

Although the data on personnel costs of barge transportation was quite reliable, this did not apply for all data used for calculating barging costs. In this section, the impact of unreliability in this input data on model outcomes will be discussed.

4.3.1.1. Depreciation costs

As mentioned in Section 3.3, from an interview held with an inland terminal operator it became apparent that the data used for calculating barge depreciation costs was quite accurate but it could be slightly overestimated. Although the operator explained that the overestimation of depreciation costs could be outweighed by the fact that the maintenance costs were somewhat underestimated (as second-hand vessels require more maintenance), the impact of this possible overestimation needed to be analyzed. The results of this analysis can be seen in Table 4.3.

4.3.1.2. Barge fuel consumption

Because of the fact that the input data concerning the fuel consumption of barges was predominantly based on existing literature, the impact of a change in this input data on model outcomes needed to be analyzed. The results of the analysis concerning the impact of possible lower barge fuel consumption are presented in Table 4.3.

These findings indicate that the outcomes presented earlier in this report were only minimally dependent on the input values used for barge fuel consumption and fixed barging costs. The findings were therefore reasonably insensitive to the unreliability of this input data. The unreliability of the data concerning barging costs therefore does not undermine the validity of the findings presented earlier.

	Performance indicator	
Change input data	Cost difference H&S with base case	Break even distance port-hub
Reduction fixed barging costs (excluding personnel)		
- 0%	2.5%	277 km
- -10%	2.7%	283 km
- -20%	2.9%	290 km
Reduction barge fuel consumption		
- 0%	2.5%	277 km
- -10%	2.8%	290 km
- -20%	3.2%	308 km

Table 4.3: Change in several performance indicators as a consequence of a change in input data used for calculating barging costs

4.3.2. Terminal costs

As expected, especially the handling costs at the hub terminal proved to be an important factor during the analysis phase. It was therefore important to examine how this data uncertainty affected the presented outcomes. The operation at the inland terminals did not significantly change as a consequence of the hub and spoke configuration. Therefore, most results obtained in former sections were not affected by the unreliability in input data for these terminal costs as most differences were calculated in relative terms. Yet, the results concerning the reverse modal shift were affected by a change in inland terminal costs as handling costs at the inland terminal form a substantial share of total roundtrip costs in the H&S-Barge container flow. In Figure 4.17 it is depicted what the impact of changing variable and fixed inland terminal costs was on the distance between the hub and inland terminal at which the H&S-Truck flow brings about higher costs than the H&S-Barge flow.

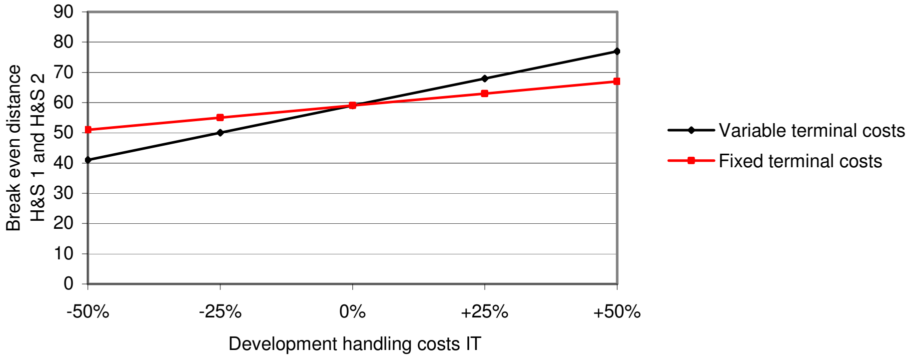

Figure 4.17: Distance at which the costs of the H&S Truck and H&S Barge container flow are equal, depicted for several levels of reduction in fixed and variable terminal handling costs

From this figure it can be concluded that both fixed and variable cost had an impact on the outcome concerning the reverse modal shift and that the uncertainty in input data therefore reduces the reliability of the findings obtained before. Yet, it is logical that when inland terminal costs decrease, the intermodal product of the H&S-Barge container flow becomes less costly. The unreliability of the used input data therefore does not influence the validity of the outcomes presented earlier.

Unreliability in terminal costs for the hub terminal more significantly affected the outcomes as presented earlier in this report. As was shown in the former sections, it was the trade-off between the savings in barge transportation and the additional costs due to barge-barge transshipment at the hub terminal that predominantly determined the feasibility of a hub-and-spoke network. Furthermore, it is shown in Appendix H that the impact of the semi-fixed cost estimation significantly influenced the results of the analysis. In Table 4.4 the change in cost differences between the two scenarios and the change in break-even distance between the port and the hub has been depicted for varying input data used for calculating terminal handling costs at the hub terminal.

	Performance indicator	
Change input data	Cost difference H&S with base case	Break even distance port-hub
Variable hub terminal costs		
- -25% (= € 6)	0.3%	210 km
- 0% (= € 8)	2.5%	277 km
- +25% (= €10)	4.7%	345 km
Amount of semi-fixed costs as variable		
- 0% (fully fixed)	-1.0%	171 km
- 50% (standard value)	2.5%	277 km
- 100% (fully variable)	6.3%	392 km

Table 4.4: Change in several performance indicators as a consequence of a change in input data used for calculating terminal handling costs at the hub terminal

From these outcomes it must be concluded that way in which terminal handling costs were calculated significantly influenced model outcomes. Next to the fact that considerable differences can be observed, the hub-and-spoke network even proved to be cost-effective if semi-fixed costs were considered to be completely fixed, while it was not under ceteris paribus circumstances. This finding leads me to conclude that the validity of the calculation model is highly dependent on accurate input data of the hub terminal costs. It is therefore very important to make detailed estimations about the costs of the hub terminal before considering implementing the hub-and-spoke concept in container transportation. For the Dutch inland terminals considered in the case study presented in Section 4.1.3, determining how the costs on the hub terminal will develop as a consequence of (increased) transshipment volume should be somewhere on top of the priority list.

5. Requirements for supply chain improvement

In the former chapter, the container shipping supply chain and the improvement concept of the hub-and-spoke network was discussed based on its cost performance. It proved that cost savings might be achieved when implementing this concept in practice. However, due to the fact that the supply chain of container shipping is influenced by actions of a great deal of internal and external players, implementing this concept will not be straightforward. In the following sections, existing boundaries and future requirements for bringing about this redevelopment in the network design will be discussed.

5.1. Cooperation between barge operator and terminal operator

One of the most important requirements for improving hinterland access through barge transportation will be a close cooperation between the terminal operator and the barge operator. This close cooperation will be necessary to achieve the required service of barge transportation. During varying interviews, it was emphasized by different players of the supply chain that achieving this is essential in improving the competitive advantage of barge transportation. Yet, in order to obtain this reliability, several issues must be addressed.

5.1.1. Reduction of barge waiting times

First of all, a reduction in barge waiting times is a critical success factor when wanting to improve the reliability of barge transportation. According to inland terminal operators during this research project, the best way to achieve a reduction in waiting times is to use fixed windows for barge handling at the port terminal. A fixed window means that a certain amount of quay capacity is reserved for one specific barge for a specific time period. This specific time period is called the time window. In the case this time window is fixed, it means that the same window is reserved for the same connection on a certain schedule. An interesting discussion whether these fixed time windows indeed reduce average barge waiting time or not is presented by Douma (2008). In his paper on the barge handling problem in the port he mentions that, in a cooperative environment, the waiting time of barges was reduced when using fixed windows. Introducing such windows in the hub-and-spoke network is therefore expected to be a possible measure in reducing the average waiting time of barges, although this would require the cooperation as mentioned by Douma (2008). Next to fixed windows, one could also work with priority rules. Currently, the barge connection between the port and the extended gates of ECT receives handling priority above all other barges calling at the terminal. As shown in the analysis, the average idle time for this barge connection in the port area was considerably less then the average waiting for barge connections that did not receive priority. Although such a mechanism will bring about more flexibility compared to using fixed windows, using priority rules will become very difficult when the concept is applied to many different barge connections.

5.1.2. Point-point barge connection

It was shown in the analysis that establishing point-point barge connections combined with larger call sizes, as a consequence of bundling freight, was expected to increase effective handling time of handling equipment and reduce the need for internal terminal transport. As mentioned above, such activities could therefore bring about the required benefits for the terminal operator. However, establishing point-point connections is not easy to realize as freight destined for the hinterland enters and leaves the port through many different terminals. This makes it difficult to operate point-point connections if the volumes are spread out over these terminals. With the arrival of even more terminal operators in the port of Rotterdam, this problem will become even more prominent. Before establishing a hub-and-spoke network it is therefore very important to analyze if and which container flows between the inland terminals and the port allow for bundling and point-point connections.

5.1.3. Information sharing

In order to achieve the abovementioned benefits of a reduction in barge waiting times (fixed windows, priority rules) and point-point connections (bundling, larger call sizes), the cooperation and coordination between the barge and terminal operator must be greatly improved. Information between these parties needs to be shared more pro-actively in the sense that changes in barging schedules and quay occupancy need to be interchanged if anything changes in the predetermined schedules, either from the side of the barge operator or from the side of the terminal operator. As explained by Douma (2008), although this will contribute to decreasing the sojourn time of barges in the port, both operators are reluctant in sharing this kind of information to prevent deterioration of their competitive position. Furthermore, the incentives for doing so are lacking (Van der Horst and De Langen, 2008). As the hub-and-spoke network is expected to bring about advantages and the possibility to increase the competitive position for both parties, it is expected that improving the coordination and cooperation, next to the fact that it is a simple necessity, is something both parties are willing to do.

Although increasing the coordination and cooperation in the supply chain between these two actors is very important, it should be increased chain-wide. For example, if one wants to implement a hub-and-spoke network, this would also require intensive cooperation between the inland terminal operators involved. As their freight is bundled on the port-hub connection, continuous alignment of container flows is required. This is also the case for empty-container availability and demand. The potential benefits obtained by reconfiguring the current way of operating transport to that of a hub-and-spoke network therefore stands or falls with the sharing of information and a very close cooperation between the inland terminals.

The abovementioned examples present just a small part of the issues concerning the sharing of information between the parties involved that should be in place for successfully implementing a hub-and-spoke network. From a workshop initiated by the Dutch inland terminals it proved that all actors within the supply chain should be involved to establish the required cooperation and it was emphasized that this topic will need extensive consideration when implementing improvement concepts as the hub-and-spoke network.

5.2. Empty container re-use

It was shown during the analysis that the re-use of empty containers could bring about substantial cost savings. However, the re-use of empty containers is not as easy in practice as it seems to be in theory. In the former section it was already discussed that this requires close cooperation between inland terminals. Furthermore, other practical issues provide obstacles for increased empty container re-use and need to be considered.

5.2.1. Aligning import and export flows

In the container shipping supply chain, there are several ways of organizing transport. In case the organization of transport is executed by the shipping line, one speaks of carrier haulage, while it is called merchant haulage if it is executed by the freight forwarder. When a container is transported using carrier haulage, the shipping line has got the required information in order to make matches between import and export flows. However, in case a container is transported using merchant haulage, this information is lacking (Source: Shipping line). Because the shipping line has furthermore no control concerning this merchant haulage container flow, he often demands that the empty container is brought back to the port as soon as possible. Empty container re-use in case of merchant haulage therefore only occurs when merchant pro-actively make their own matches between import and export and receive permission from the shipping line. However, next to the fact that pricing mechanism used by shipping lines make empty container re-use less attractive, the match making possibilities of merchants are limited.

For the latter problem the possible missing link seems to be the inland terminal operators, as these operators posses information on all shippers using the inland terminal facilities. Because both shipping lines and freight forwarders make use of these facilities, terminal operators could make the matches between empty container flows of these different actors. Furthermore, as these inland terminals will cooperate in the hub-and-spoke configuration, more possibilities arise for re-using empty containers due to the fact that shortages at one terminal can be filled with surpluses at the other (De Langen et al., 2006).

5.2.2. Change in (empty) container costing mechanisms

Next to difficulties in aligning the import and export flows, more obstacles impede empty-container re-use. In practice, several costing mechanisms are in place that significantly influences how and when empty-containers are transported. These costing mechanisms are strategic tools used by shipping lines to have control over their container fleet, the merchant container flow and the container stock at empty depots. Furthermore, it produces a whole lot of revenue. First of all, shipping lines charge the so called demurrage and detention fees towards freight forwarders and shippers. Demurrage fees are charged for having a container on storage in the port area. For most forwarders and shippers a period of 5 days is free of charge. The detention fees are somewhat similar to the demurrage fees, only they are charged after containers leave the port area. What it basically comes down to is that the demurrage and detention fees are charged to reduce the dwell times of containers in the port and to reduce the throughput time of the container transport so that the container becomes available for the shipping line as soon as possible. As mentioned by a freight forwarder during the interviews, predominantly the detention fees make intermodal transportation less attractive. Due to the fact that barge transportation takes longer to execute than truck transportation, the risk of incurring detention costs increases when using intermodal transport. As the throughput time of intermodal transport is even larger in the hub-and-spoke network this would make this issue even more prominent when applying this concept in practice. As the detention charges are quite substantial compared to total transportation costs (see Appendix O) it considerably influences the decision between unimodal and intermodal transportation based on costs. Therefore, something should be done about these charges if one wants to make intermodal transportation more attractive in total. These detention charges are even more detrimental for empty container re-use as it often takes a while before a match between import and export can be made. Currently, the risk of not finding a match in time and having to pay high detention charges is carried by the inland terminal or by the freight forwarder. Due to this fact, a lot of empty container re-use potential is lost.

Second of all, when freight forwarders want to re-use empty equipment or want to hand-in or retrieve empty equipment at empty depots in the hinterland, they often have to pay drop-off and pick-up fees to the shipping line. It is quite commonly the case that these fees are higher than the costs of transporting the container back to the port, making it not attractive to drop-off or pick-up containers at the inland empty depot (Source: Freight forwarder). Next to that, the terminal handling charges freight forwarders have to pay the shipping lines include the handling costs at the empty depot, regardless whether or not the container is actually delivered there. In a sense, the re-use of empty containers therefore brings about double revenue for the shipping line. They receive the pick-up and drop-off fees and do not have to pay the empty depot as these containers will not be handled there. Furthermore, by using inland terminals as empty depots for handling empty equipment, the shipping lines could save the transportation costs of empty equipment towards the hinterland for their own customers. Although one might argue that keeping stacks of empty containers in the hinterland brings about risk and opportunity costs for the shipping line, considering the low costs of leasing containers and the fact that these are available on on-the-spot markets, this claim is not entirely true (See Appendix J). Following the above reasoning it must be concluded that predominantly the shipping line benefits from empty container re-use, bringing about an unequal distribution of the cost savings generated by it.

If no solid agreements concerning the abovementioned charges can be made with shipping lines, they will always stand in the way of reaping the maximum benefits of re-using empty equipment.

5.3. Sharing of costs and benefits

From the above issue concerning the unequal distribution of gains from empty-container re-use, it becomes clear that it is not straightforward that cost savings in the network realized by a supply chain innovation will lead to cost savings for all players involved. As mentioned by De Langen et al. (2006) all players will need sufficient incentives before they will cooperate in supply chain improvements, especially when the benefits are collective rather than individual. During the analysis it was uncovered that implementing the hub-and-spoke concept for a network of inland terminals indeed brought about an unequal distribution of costs and benefits. For example, under ceteris paribus conditions, the consolidation of freight towards the hub terminal led to decreased transportation and handling costs per TEU for the hub terminal. At the same time, the costs per TEU of freight destined for the inland terminals increased due to transshipment costs at the hub. If one wants to successfully implement the hub-and-spoke network, one should share the cost savings for the hub in such a way that incentives are created for all inland terminals to cooperate.

A possible solution for the issue concerning the division of cost and benefits in a hub and spoke configuration was addressed by an inland and barge operator along the Rhine corridor. The construction they are trying to apply for realizing their hub is based on participation of the different actors in an independent organization. The actors will all be owner of the hub through shares and possibly also through board representation of their companies. By applying this concept, all players have an incentive to cooperate with one another to make the concept successful and the players involved reap the benefits according to the risk and costs they are willing to bear. Something similar is observed at the Dutch inland terminals under consideration in the case study. They have founded an independent organization supporting their cooperation. For the sharing of costs and benefits, they are currently looking into internal costing mechanisms that bring about the most equal distribution of costs and benefits. As these inland terminals are responsible for arranging the lion's share of hinterland transport for their customers, the issue of sharing costs and benefits with other players is less prominent.

Although the abovementioned solutions are applied in practice and many others have been addressed by De Langen et al. (2006) in their paper on cooperation and coordination in container barging, the solutions will always be different for different circumstances. Yet, the solution should always bring about the proper incentives for the players involved of whose input is essential for the success of the improvement.

5.4. Change in shippers' attitude

According to many actors spoken with during this research project, a very large obstacle standing in the way of achieving a modal shift from truck to barge transportation is the attitude of shippers. Still, the shipper eventually determines how the hinterland transport of his containers is executed (Source: Shipping line). Although the deep-sea vessel is underway for a very long period of time, shippers often want their containers within a very short time period once it has arrived in the port (Source: Freight forwarder). This makes the transportation process time critical in such a way that it is not possible or not attractive to use intermodal transportation for a large part of container flows.

It is therefore expressed by the supply chain actors that a change in this attitude will be required if one wants to obtain a significant modal shift. Improvement concepts such as the hub-and-spoke network will not bring about the opted modal shift without shippers accepting the longer transit time of intermodal transport and without them taking this transit time into account in their ordering processes. They should therefore always be involved during improvement projects. An intermodal operator[6] claimed the following; "*It is important to change the current attitude of shippers in order for preventing the longer transit time of intermodal transport undermining improvement concepts.*"

The above reasoning leads me to conclude that, although improvement concepts might make intermodal transportation faster and more reliable, still a large part of hinterland transport will be executed using direct truck transportation if the ordering process and organizational attitude at the shippers' side of the supply chain is not changed. This depicts the need for involving the end-shipper in supply chain improvements.

5.5. Government involvement

Next to a change in shipper attitude, according to some of the actors spoken with, government involvement will be very important when wanting to implement improvement

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[6] An actor involved in terminal operation, barge transport and truck transportation

concepts. Yet, not all actors agree with this point of view and claim that it is up to the supply chain actors to bring about change and that one should not depend on the government for doing so. Although I agree with the latter claim that radical supply chain improvements cannot be realized by the government alone, I do recognize the fact that the role of the government can be substantial nonetheless.

When considering government involvement in realizing change in the container shipping supply chain, it can present itself in two different ways. The first one is by the means of rules and laws that the actors should uphold to. For example, the Dutch government is planning to introduce rules that truck transportation towards the Maasvlakte must be executed with environmentally friendly trucks only after 2013. As many truck operators cannot make the required investments, truck transportation to the Maasvlakte is expected to become a scarce asset (Source: Truck operator). This will increase the attractiveness and need for intermodal transportation from the port towards its hinterland. However, as this will lead to oversupply of truck transport in the hinterland, the threat of a reverse modal shift occurring in the hub-and-spoke network will increase due to lower tariffs in truck inland transportation. Another example of how the government can influence the modal shift from truck to barge with the use of regulation is by the means of road pricing. In the concept of road pricing, road taxes are not fixed per year, but are dependent on the number of kilometers traveled and the amount of kilometers traveled during rush hours. It is expected that this new way of calculating road taxes will make truck transportation more expensive and a less attractive transportation mode.

The second way in which the government can influence the direction of supply chain improvements is by the means of financial support. Especially when cost-effectiveness is small, as was the case for the hub-and-spoke network, subsidies can contribute to bringing about change as these will cover for the extra costs incurred. However, the improvement concepts must realize some social benefit before the government will put monetary means in such a project. In the case of the hub-and-spoke network, it was shown that the impact on social resources decreased due to a reduction in (barge) fuel consumption and external costs. Next to that, due to an increased reliability of barge transportation, the concept could contribute to bringing about the modal shift the government wants to achieve in 2033 (Port of Rotterdam).

This leads me to conclude that the, although supply chain actors must take the lead when improving the supply chain, involving the government in these concepts can provide additional incentives for these actors to do so. Especially during the startup phase of supply chain innovations when risks are high, government involvement could make the difference between failure and success. It is believed that, for the hub-and-spoke concept, the developed calculation tool can assist in convincing the government of the social contributions of the concept. This could realize the required government involvement.

6. Conclusions and Recommendations

In this thesis the cost effectiveness of applying a hub-and-spoke network for organizing hinterland access by barge transportation was analyzed extensively. The first part of this chapter will discuss the research questions and other conclusions based on the analysis and discussions in former chapters. In the second part, recommendations are given for ECT and for the Dutch inland terminals involved during this research project.

6.1. Conclusions

The first part of the research question focused on the factors that are most important for cost-effectively operating a hub and spoke network. With the use of the calculation tool, this part of the research question was answered. From the obtained result the most important finding is that the hub-and-spoke network does not necessarily bring about overall cost savings, although the cost difference with the base case scenario was small in both the general analysis and the case study. The feasibility of the concept is determined by the specific characteristics of the network and the terminals under consideration. For the fictive network, especially the distance between the port and the hub terminal proved to be an important determinant for the cost-effectiveness of the hub-and-spoke configuration, with the hub-and-spoke model being more attractive on long distances. Furthermore, the waterway capacities, the balance between import and export flows and the cost structure of the hub terminal proved to be important network characteristics that influenced overall cost saving potential. The focus of ECT should therefore be on determining which existing networks of inland terminals would allow for a cost-effective hub-and-spoke configuration. To give an indication on which factors determine the cost effectiveness of the hub-and-spoke model and how important improvement measures are affected by network characteristics, Table 6.1 has been drawn up. This table is a summary of the analyses presented earlier and provides an indication concerning the values for which the hub-and-spoke model brings about equal costs as the base case scenario.

	Distance port-hub (km)	Empty container re-use	Reduction direct truck transport (modal-shift)	Fuel Price (Eur/ltr)	Variable hub handling costs (Eur/handling)
Standard Value (base case value)	200	10%	0%	€ 0,44	€ 13,50
Value at which H&S network becomes cost-effective, waterway port-inland terminal not limited (156 TEU)	440	38% (280% increase)	40%	€ 1,28	€ 5,70
Value at which H&S network becomes cost-effective, waterway port-inland terminal moderately limited (81 TEU)	277	23% (130% increase)	18%	€ 0,78	€ 9,50
Value at which H&S network becomes cost-effective, waterway port-inland terminal very limited (48 TEU)	166	5% (50% decrease)	0%	€ 0,29	€16,10

Table 6.1: Indicative values for important network and supply chain characteristics influencing the cost-effectiveness of the hub-and-spoke model, indicating for which values of these factors the hub-and-spoke model brings about equal costs as the base case scenario. However, these values must be interpreted with great care, as many factors and parameters not shown in this table influence the model outcome as well.

However, the table must be interpreted with great care. As can be seen, the cost-effectiveness of the hub-and-spoke model is highly dependent on the network characteristics. For example, if the waterway connection between the port and the inland terminals is not limited, the distance between port and hub must be much larger to generate cost savings than in the case the waterway is very limited. Furthermore, the table only denotes the values of the factors in the case all other factors have their standard value as mentioned in the first row. As one can imagine, all kind of combinations of improvements or network characteristics are possible. Following this reasoning, it must be concluded that it is very difficult to draw up general conditions under which a hub-and-spoke model would be cost-effective, as it is simply dependent on many different parameters.

However, for the network of the Dutch inland terminals under consideration, the above findings concerning distance and waterway capacities are less relevant because the network characteristics for these terminals are given. For this network, especially the modal shift from truck to barge transportation proved to bring about significant overall cost savings. Also, the increase of empty container re-use led to large cost savings in the hub-and-spoke network compared to the current way of operating. In Table 6.2 it is presented for which values of these improvements the hub-and-spoke network brings about equal costs as in the base case scenario. Both the possibility for a modal shift and the empty container re-use are dependent on the existing flow of containers between the port and the terminals. It is therefore very important for the Dutch inland terminals to identify the container flows that allow for a modal shift and to uncover which existing empty container flows of the different terminals allow for increased match-making between import and export.

	Increase empty container re-use	Reduction direct truck transport (modal-shift)
Capacity port-hub 90 TEU	110%	13%
Capacity port-hub 156 TEU	65%	8%
Capacity port-hub 208 TEU	20%	2%

Table 6.2: Important improvements influencing the cost-effectiveness of the hub-and-spoke model for the Dutch inland terminals, indicating for which values of these factors the hub-and-spoke model brings about equal costs as the base case scenario.

The second part of the research question focused on other requirements needed for establishing improved hinterland access by barge transportation. From the discussion in the former chapter, it became clear that for the Dutch inland terminals this implies realizing a change in attitude at the shipper. Furthermore, a close cooperation between the terminals and with other supply chain actors will be required. Especially better agreements with shipping lines need to be established to realize substantial cost savings through empty container re-use. What can furthermore be concluded from the discussion on other requirements needed for successfully implementing improvement concepts is that if one wants to obtain the required cooperation between the parties involved, each actor must have an incentive to do so. This denotes the importance of sharing the obtained benefits amongst the players involved. However, although this issue is very important for bringing about change in the container shipping supply chain, it remained under exposed and should be of considerable interest in new projects. This sharing of costs and benefits should for example be addressed thoroughly to take away the threat of a reverse modal shift. It proved that on short distances between the inland terminals and the hub, truck transportation from the hub onward outperformed intermodal transport for the inland terminals while the opposite was true for the hub terminal. In order to keep the tariffs towards customers unchanged and reduce the threat of a reverse modal shift, this difference should be balanced out by internal costing mechanisms in order to prevent unequal gains and losses from occurring.

It is believed that the involvement of the government in this improvement concept might provide the support and the incentives the different actors need for taking the first steps, especially because differences in total costs between the two scenarios were only minimal. As the hub-and-spoke network proved to realize significant reduction in the impact of hinterland transportation on social resources, it is expected that the government would provide support for such an improvement project. For the project of the Dutch inland terminals but also for other similar initiatives by ECT, the government should always be approached.

Based on the above reasoning, it can be stated that this study confirms the findings in existing literature (Konings, 2009) that indeed, the logistical concept of hub-and-spoke networks can be applied to barge transportation to generate cost savings. However, it has extended the discussion considerably because we now know which factors are most important and will require additional attention in the future. It was especially interesting to see that empty container re-use, a topic that received considerable attention from researchers in the past, plays a significant role in the feasibility of such networks. Furthermore, as the hub-and-spoke network would allow for more reliable barge connections as a consequence of cooperation between port terminal operator and barge operator, earlier research on achieving a modal shift from truck to barge, executed by Kiesmüller et al. (2005), becomes more applicable to practice as much uncertainty in intermodal transportation is taken out of the equation.

If we only look at the cost aspect of hub-and-spoke networks for barge transportation, the findings were in line with what one would expect based on existing theory. Yet, from the discussion on supply chain requirements, it proved that achieving the results in practice is not straightforward. It is strange that only little literature is available concerning these requirements although it might be just as important as the existing quantitative assessments on transportation costs. Although I do believe the developed model can and should be extended for additional analysis, researcher s in the field should shift their attention from quantitative analyses only to more total assessments of the supply chain with special attention directed towards cooperation and coordination between the different actors. In Chapter 7, a more elaborate discussion on further research directions can be found.

6.2. Recommendations

Based on the conclusions mentioned above and the insights obtained during the in-depth interviews and analysis, several recommendations for ECT and for the Dutch inland terminals were developed.

Recommendations for ECT;

1. Explore possibilities for applying the hub-and-spoke concept for networks of inland terminals that are located a substantial distance from the port, as is the case for terminals along the Middle and Upper Rhine.

2. Analyze options for decreasing the (variable) handling costs at the hub terminal, like using push-barges in order to allow direct barge-barge transshipment or by setting-up a new, or expanding an existing terminal, with highly automated handling facilities.
3. Actively involve shipping lines in the development of hub-and-spoke networks and examine the import and export balance of container flows in order to identify how (much) cost savings can be achieved with empty container re-use
4. Define which conditions need to be met, with regard to cooperation and coordination with barge operators, for handling barges according to fixed windows or priority rules in order to establish a reliable barge connection between the port and the hinterland
5. When setting-up a hub-and-spoke network in the hinterland, approach the Dutch government with the results concerning the improved supply chain sustainability to receive grants or influence legislation
6. Investigate how the hub-and-spoke configuration of barge transport and the accompanying increase in call size and point-point connections affect terminal cost in the port to determine the cost saving potential for the company

Recommendations for the Dutch inland terminals;

7. Actively involve shippers in the development of the hub-and-spoke network to change their attitude towards intermodal transportation and make the process less time critical
8. Thoroughly investigate how each terminal involved in the network benefits from the cooperation and determine how additional costs and cost savings must be divided amongst them to create proper incentives for all.
9. Take measures for preventing a reverse modal shift from happening. This entails using certain contracts that prevent the hub terminal from ‘stealing’ customers from the other terminals.

For the Dutch inland terminals, recommendations 2 till 5 also apply.

7. Further Research

7.1. General research topics

The conclusions in the former chapter provide several insights on which topics are interesting for further research. First of all, the issue concerning how costs and benefits should be divided within the container shipping supply chain was not addressed thoroughly during this research although it was of great interest to ECT at the start of this project. Now that it can be analyzed with the cost calculation tool where additional costs are incurred and where costs savings can be realized, the next step is to investigate the issue of sharing them using insights of Game Theory. This would require taking the total supply chain into account, as was already mentioned in the former chapter to be very important in all further research on container shipping. Second of all, it was mentioned during the analysis that it was not possible to quantitatively analyze the impact of implementing the hub-and-spoke network on port operations. Although a qualitative reasoning led to a preliminary estimation, the possible advantages for the port terminal should be investigated more thoroughly and provide a very interesting topic for further research. Next to the fact that it would enrich the research on the feasibility of the hub-and-spoke network, it would provide ECT and theory with more insights on port operations and its sensitivity to environmental and internal factors. Third of all, an interesting topic for further research seems to be the attitude of shippers and how to change these so that the modal shift can take place. Concerning this subject, one could expand on the research executed by Kiesmüller et al. (2005) who found that, based on the trade-off between holding costs and transportation costs, the fraction of direct truck transportation as it is today can be significantly reduced.

7.2. Model expansions

It was mentioned a few times during the analysis that the current calculation tool should be expanded for calculating the effect of several practical solutions for reducing total costs in the hub-and-spoke model. First of all, the possibility of direct mutual empty-container exchange between different inland terminals should be included in the model. As this would reduce the handlings required at the hub terminal, this would reduce total costs of the hub-and-spoke network. Second of all, as on could reduce the transshipment costs at the hub terminal by introducing board-board handling (Konings, 2009), on should extend the model with the costs and benefits incurred by this barge-barge transshipment. For example, the model could be expanded with the possibility of using push-barges, which makes board-board handling possible. As additional costs would be incurred due to the necessity of idle push units, an interesting trade-off arises that requires closer analysis. Third of all, a possible way of reducing the extra costs incurred at the hub terminal could be to build a low cost terminal as proposed by Konings (2009). According to him, the investments of such a terminal are 50% of that of a conventional terminal. It would therefore be very interesting if the possibility exists in the model to choose between using an existing terminal or to built an entirely new, low cost terminal as the one mentioned by Konings (2009) and to examine how this decision influences the feasibility of the hub-and-spoke concept. Finally, I would recommend investigating alternatives to the hub-and-spoke network in which the same advantages of cooperation between inland terminals and bundling of freight occur, but in which transshipment at an inland terminal is not required. For example, one could explore the possibility of a barging roundtrip, a concept similar to a bus line. In such a barging roundtrip freight for all terminals in the roundtrip is bundled on the same vessel. This vessel visits each inland terminal in its roundtrip, where freight is (un)loaded, before it goes back to the port. It would be interesting to analyze under which conditions such a concept would be a good alternative to the hub-and-spoke network (and the base case scenario).

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Zandmaatschappij Twenthe B.V. Gasolietarieven 2010

8.2. Interviews

Barge operator: Danser Container Lines, B Maelissa

Consultancy: Quintell, L. Smulders

Consultancy: Schoonen Advies & Management, N. Schoonen

Freight forwarder: DHL, D. Maaten

Inland terminal operator: Brabant Intermodal, M. van Dijk

Intermodal operator: Contargo, C. Vinke

Port authority Amsterdam: H. Journeé

Shipping line: COSCO, M. van Kruijl

Truck operator: Groenenboom Transport, F. van de Boom

8.3. Internet

Belastingdienst Nederland: www.belastingdienst.nl

Binnenvaart België: www.binnenvaart.be

Caru Schouten Containers: www.carucontainers.com

Centraal bureau voor de Rijn en Binnenvaart (CBRB): www.cbrb.nl

Hoftsra University: http://www.people.hofstra.edu/geotrans/

Port of Rotterdam: www.portofrotterdam.com

Stichting Bedrijfspensioenfonds Rijn- en Binnenvaart: www.rijnenbinnenvaartpensioen.nl

Glossary

ATA	Actual Time of Arrival
ATD	Actual Time of Departure
CBRB	Centraal Bureau voor de Rijn- en Binnenvaart
ECT	Europe Container Terminals
ETA	Expected Time of Arrival
HPH	Hutchison Port Holdings
H&S-Barge	Hub-and-spoke container flow in which the container is transported by barge to the hub terminal and then by barge to the inland terminal. From this inland terminal, the container is transported to the eventual customer.
H&S-Truck	Hub-and-spoke container flow in which the container is transported by barge to the hub terminal and then by truck to the eventual customer
PTA	Planned Time of Arrival
PTD	Planned Time of Departure
TEU	Twenty-feet Equivalent Unit
TU/e	Eindhoven University of Technology

Appendices

A Interview methodology

The interviewing method used during the project was close to that of the long interview as mentioned by Mullins (2007) in his paper concerning the discovery of unknown unknowns. Although this paper the application of the long interview technique is discussed for marketing purposes, it can also be applied to other circumstances. The long interview technique can draw out answers to key questions. It differs sharply from more traditional guided interviews, which typically have lengthy checklists of clearly focused questions and seek direct answers to questions that the interviewer knows to ask. In a long interview, the idea is to ask only a few open-ended questions that let the respondent go where he or she may but control the direction of the conversation by using prompts. This technique was applied in this project due to several reasons. First of all, each interviewee is an expert in his field of operation. Letting them freely elaborate on their business made it possible to draw a complete picture of how their business looked like. With the use of prompts, I was able to learn more about the topics of particular interest for the project at hand. Second of all, when using this technique it was prevented that my own ideas about possible solutions led the conversation. As mentioned by Mullins (2007) doing so can inhibit learning about alternative solutions to the existent problem.

In preparation of each interview, I drew up several questions in order to guide the interview. In accordance with the long interview technique, the questions were open-ended and the first question during the interview was always an 'interview-driver' (Mullins, 2007). An interview driver is a broad open-ended question that encourages an interviewee to tell things from their own perspective. When interviewing players of the supply chain, these questions were concerned with how their business looked like and how the interviewee could contribute to set-up more reliable hinterland connections.

During the interviews a voice-recorder device was used, if the interviewee granted permission for it. Using this device made it possible to focus on the conversation at hand as it was not needed to make notes directly. Because of this, I was able to ask prompting questions when needed and truly lead the conversation.

B Extensive description of the container flows under consideration

In the following section, one can find a more elaborate description of the container flows that were taken into account during the analysis. They are specified for the base case scenario and the hub-and-spoke network as they differ due to changes in network design.

Base case scenario

In the base case scenario, transport between the port and the hinterland can be done using three different transport modes; truck, rail and barge. As mentioned, rail transport was not taken into account when developing the model. What needs to be mentioned about truck transport is that it will always be the last transport mode of a container towards the shipper even if the site of the shipper is in the vicinity of a port or an inland terminal. Considering this, three different ways of transporting a container from a port to its hinterland can be distinguished for the base case network:

- **Unimodal transport**: This is direct transport of a container between the port and the shipper using one truck transport. A full container is loaded at a port terminal or an empty container is loaded at an empty depot in the port en transported directly to the shipper. At the shippers' location, the container is unloaded / loaded and transported back to a port terminal (for full containers) or empty depot (for empty containers).
- **Intermodal transport**: This is indirect transport between the port and the shipper using multiple transportation modes, in this case truck and barge. With indirect is meant that an extra node is added to the connection between port and shipper in the form of an inland terminal. A full container is loaded at a port terminal or an empty container is loaded at an empty depot in the port en transported to the inland terminal by barge. At the terminal, the container is unloaded from the barge and put in the container stack at the terminal. After a period of time, the container is moved onto a truck and transported to the shipper. At his location, the container is unloaded/loaded and transported back to the inland terminal. After a period of time, the container is loaded onto a barge and transported back to a port terminal (for full containers) or empty depot (for empty containers).
- **Synchromodal transport**: Next to transporting a container using either unimodal or intermodal transport, the real challenge exists in offering the market synchromodal transportation. Synchromodal transport means executing unimodal and intermodal transport in parallel and letting the specific circumstances and shipper demand determine how the container will flow through the network. Although this requires complex goods flow control, it will provide the shipper with tailor made service.

In the base case, both unimodal and intermodal transport occur. One part of container transport for certain regions is done using unimodal transport and the other part is done using intermodal transport. In practice, synchromodal transport does exist, although it must be mentioned that it is hardly ever planned this way. Yet, freight forwarders and carriers take specific circumstances more and more into account when determining the transportation mode in order to fit shipper needs.

Hub-and-spoke network

In the hub-and-spoke network containers can flow through the network in even more ways than is the case in the base case. This is caused by the fact that a hub is added to the network through which many containers will flow that are destined for other inland terminals. For the model, it is assumed that an already existing inland terminal is used as hub terminal as this will save large investments in terms of time and money and will provide the connection between the port and the hub with already existing volume. Considering these characteristics the following container flows will be taken into account for the model:

- **Unimodal transport to and from the port:** This is the same direct transport of containers from the port to shippers in the hinterland and back as depicted for the base case.
- **Barge transport to and from hub, truck transport to and from hinterland:** This is indirect transport of containers through the hub using barge for the transport to and from the hub and truck transport from the hub to the shipper and back. As the hub terminal will have its own service area, there will always be a fair amount of containers following this flow. Yet, it is also possible that containers are transported from the hub to regions of other inland terminals whenever a shipper decides he wants his container early and barge transport will not be fast enough.
- **Barge transport to and from hub, barge transport to and from inland terminal, truck transport to shipper and back**: This third possible container flow is also indirect transport of containers from the port to shipper. In this flow, a container is shipped to the hub using barge transport, temporarily stored at the hub site, transported to the inland terminal by barge and eventually transported to the shippers' site by truck.

C Derivation of model formulas

Equation (8)

In order to determine the required slack time, w_P^B, in hours per barge visit in the port that needs to be implemented in the sailing schedule to achieve a certain service level, the following formula was used.

$$F(x;\mu;\sigma;\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \tag{8a}$$

This formula was based on the Generalized Extreme Value distribution which was used for denoting the waiting time distribution based on the analysis of barge waiting times, of which the results are presented in Appendix L.

If $x = tw_P^B$ is the required slack time that needs to be included in the sailing schedule it follows that

$$w_P^B = \left(\frac{(-Ln(SL_i))^{-\xi}-1}{\xi}\right)*\sigma+\mu \tag{8b}$$

Equations (18)-(21)

For the port terminal and the empty depot, calculations were slightly different than those for inland terminals. First of all, it needed to be considered that the volumes handled at the port terminal consisted of both full and empty containers while only empty containers were handled at the depot. Second of all, the fixed and variable costs of operation on port terminals could not be distinguished during this research. Therefore, only variable costs per handling were used with the assumption that these costs were slightly higher for barge handling than for truck handling. Again it was assumed the variable costs for barge handling were factor ε larger than the variable costs of truck handling.

For the yearly truck and barge volumes handled at the port, h_P^T and h_P^B respectively, it needed to be calculated how many full and how many empty containers were handled at the port and at the empty depot. As the amount of full containers did not change as a consequence of empty container re-use, calculating the full volumes was fairly straightforward. The calculations for the volumes of empty containers handled at the port and empty depot were somewhat more difficult. For calculating the yearly handling volumes, the following equations were used;

$$\text{Full containers truck} = \sum_{i=1}^{N}\frac{\mathbf{D}_i^f * u_{P,i} + (\mathbf{D}_i - \mathbf{D}_i^f)*u_{P,i}}{TEUF_i} = \sum_{i=1}^{N}\frac{\mathbf{D}_i * u_{P,i}}{TEUF_i}$$

$$\text{Full containers barge} = \sum_{i=1}^{N}\frac{\mathbf{D}_i^f *(1-u_{P,i}) + (\mathbf{D}_i - \mathbf{D}_i^f)*(1-u_{P,i})}{TEUF_i} = \sum_{i=1}^{N}\frac{\mathbf{D}_i *(1-u_{P,i})}{TEUF_i}$$

Empty containers truck =

$$= \sum_{i=1}^{N} \frac{u_{P,i} * (\mathbf{D}_i^f - \min(\mathbf{D}_i^f * \alpha^b, \mathbf{D}_i - \mathbf{D}_i^f) + u_{P,i} * (\mathbf{D}_i - \mathbf{D}_i^f - \min(\mathbf{D}_i^f * \alpha^b, \mathbf{D}_i - \mathbf{D}_i^f)}{TEUF_i}$$

$$= \sum_{i=1}^{N} \frac{u_{P,i} * (\mathbf{D}_i - 2 * \min(\mathbf{D}_i^f * \alpha^b, \mathbf{D}_i - \mathbf{D}_i^f)}{TEUF_i}$$

$$= \sum_{i=1}^{N} \frac{u_{P,i} * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i}$$

Empty containers barge $= \sum_{i=1}^{N} \frac{(1 - u_{P,i}) * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i}$

Using these formulas and the understanding that full containers were handled at the port terminal only and empty containers were handled at both the port terminal and the empty depot, where β represents the percentage of empty containers brought back to the port terminal, we got the following calculations for yearly port handlings and empty depot handlings.

For calculating handling volumes at the port, where h_P^T and h_P^B represent truck handlings and barge handlings at the port respectively, the following equations were used;

$$h_P^T = \sum_{i=1}^{N} \frac{\mathbf{D}_i * u_{P,i}}{TEUF_i} + \beta * \sum_{i=1}^{N} \frac{u_{P,i} * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \tag{18}$$

$$h_P^B = \sum_{i=1}^{N} \frac{\mathbf{D}_i * (1 - u_{P,i})}{TEUF_i} + \beta * \sum_{i=1}^{N} \frac{(1 - u_{P,i}) * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \tag{19}$$

For empty depot handlings, where h_E^T and h_E^B represent truck handlings and barge handlings at the empty depot respectively, the following equations were used;

$$h_E^T = (1 - \beta) * \sum_{i=1}^{N} \frac{u_{P,i} * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \tag{20}$$

$$h_E^B = (1 - \beta) * \sum_{i=1}^{N} \frac{(1 - u_{P,i}) * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \tag{21}$$

Equation (29)

The hub terminal was used as a consolidation point for total volume going through the network. The total volume going through the hub was calculated using the re-use fractions and the total volume characteristics. As the demand for full containers did not change when the re-use fraction changed, the sum of demand for full containers of all terminals went through the hub, off course without the full containers transported by truck between the port and the service area of terminal i. This gives us the first part of equation (29):

$$\sum_{i=1}^{N} D_i^f (1-u_{P,i}^h) \tag{29a}$$

The amount of empty containers going through the hub terminal was the sum of demand of empty containers that could not be fulfilled by re-using the empty containers in the network. The total yearly demand of empty containers per barge was calculated as follows:

$$\sum_{i=1}^{N} (D_i - D_i^f) * (1-u_{P.i}^h) \tag{29b}$$

The total yearly amount of containers available for re-use by barge was;

$$\sum_{i=1}^{N} D_i^f * \alpha^h * (1-u_{P,i}^h) \tag{29c}$$

This amount needed to be subtracted from the total yearly (barge) demand for empty containers in the network to obtain the volume of empty containers that needed to be transported between the port and the hub terminal. Yet, the volume must not become negative as it was not possible to re-use more containers than needed. This then came down to the following equation:

$$\max\left(0, \sum_{i=1}^{N} \left((D_i - D_i^f) - D_i^f * \alpha^h\right) * (1-u_{P,i}^h)\right) \tag{29bc}$$

In total, the formula became the following:

$$V_{P,H}^B = \sum_{i=1}^{N} \left(D_i^f * (1-u_{P,i}^h)\right) + \max\left(0, \sum_{i=1}^{N} \left((1-u_{P,i}^h) * \left(D_i - (1+\alpha^h) D_i^f\right)\right)\right) \tag{29}$$

Equations (36)-(39)

For the yearly truck and barge volumes handled at the port in the hub-and-spoke model, $h_P^{T,H}$ and $h_P^{B,H}$ respectively, it needed to be calculated how many full and how many empty containers are handled at the port and at the empty depot. As the imbalance of empty containers between Asia and Europe remained equal in both scenarios, it was assumed that the amount of empty containers shipped back to the port terminal in the hub-and-spoke network had to be equal to the amount calculated for the base case. This changed the equations (18) till (21).

In order to be able to determine the yearly amount of empty containers handled at the port terminal in the hub-and spoke network, the total yearly amount of empty containers handled in the port region in total (terminal and empty depot) in the base case, E_{tot}^{C} needed to be determined. This was done using the following equation:

$$E_{tot}^{C} = \sum_{i=1}^{N} \left(\frac{2\mathbf{V}_i - \mathbf{D}_i}{TEUF_i} \right)$$

For calculating the total yearly amount of empty containers handled in the port in the hub-and spoke network, the formula became the following:

$$E_{tot}^{H} = \sum_{i=1}^{N} \left(\frac{u_{P,i}^{H} * (2\mathbf{V}_i - \mathbf{D}_i)}{TEUF_i} \right) + \left(\frac{2\mathbf{V}_{P,H}^{B} - \sum_{i=1}^{N} (\mathbf{D}_i * (1 - u_{P,i}^{H}))}{TEUF_i} \right)$$

$$= \frac{2\mathbf{V}_{P,H}^{B} + \sum_{i=1}^{N} \left(2\mathbf{V}_i * u_{P,i}^{H} - \mathbf{D}_i \right)}{TEUF_i}$$

From these equations, the formulas (36) till (39) were derived:

D Barge planning process in the port

Consider Figure D-1 in which the process for barge planning as it occurs in the Port of Rotterdam is shown.

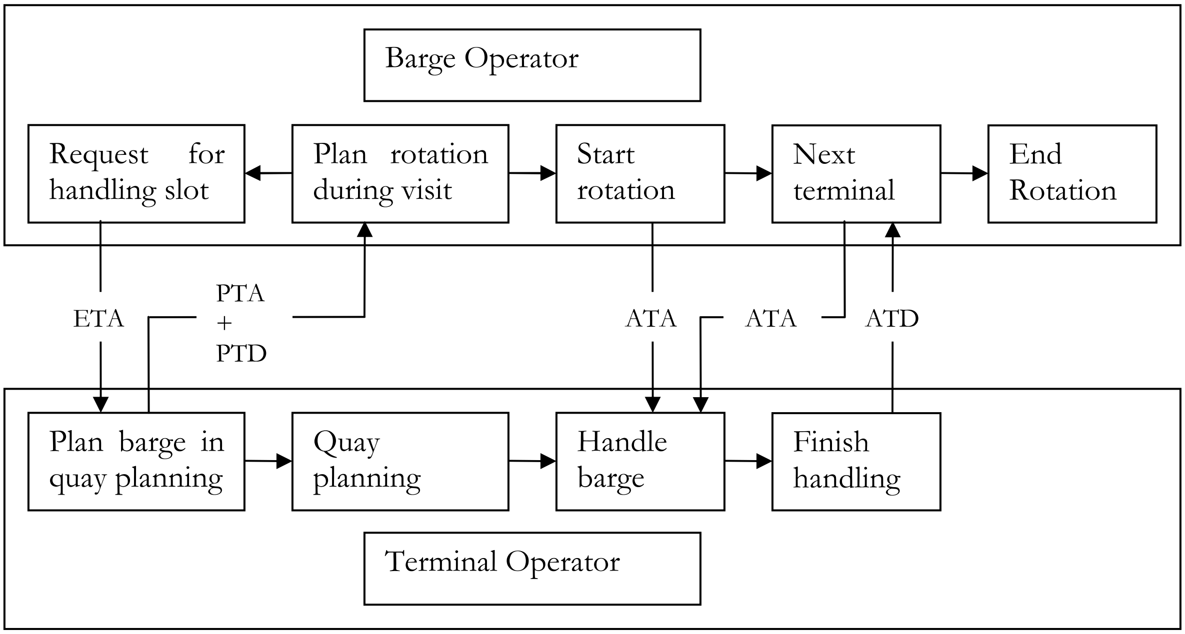

Figure D-1: Representation of the communication process between barge operator and terminal operator for barge handling, *Source:* Made by author

Based on which terminals a barge has to visit in the port and the desired sequence of the rotation, the barge operator issues a request for a handling slot to the terminal operator and announces his ETA (Expected Time of Arrival). Based on this request, the terminal operator checks the availability of the terminal and responds to the barge operator about when the barge will be handled, the PTA (Planned Time of Arrival), and when it will be finished, the PTD (Planned Time of Departure). If the barge operator accepts the PTA, the process is repeated for other terminals. If the barge operator does not accept the PTA, he can send another request to the same terminal operator and the process is repeated. After both terminal operator and the barge operator have made a schedule, the barge operator can start the rotation at the first terminal. The ATA (Actual Time of Arrival) denotes the time the barge and terminal are both available and the handling is started. The ATD (Actual Time of Departure) denotes the time the handling of a barge is finished. After the handling at a terminal is finished, the barge operator repeats the process for the other terminals until all terminals in the rotation have been visited.

Based on the PTA's and PTD's received from the terminal operators, a barge operator can make a certain schedule that reduces his expected idle time as much as possible. In a sense, this process is comparable to the fully cooperative situation described by Douma (2008) in which terminal operators provide waiting profiles to barge operators. However, the problem in practice is that terminal operators sometimes do not keep the appointments made with barge operators. Because quay capacity is scarce, terminal operators will not wait very long for a barge if it has missed his appointment and will start serving the next barge in the planning, if this barge is available for handling, or start handling barges FCFS. Next to that, terminal operators sometimes return PTA's to barge operators that are somewhat earlier than the time the quay actually becomes available to make sure a barge is present on time and to prevent idle handling capacity. On the other hand, the barge operators also show behavior that undermines a good cooperation. For one, it occurs that barge operators sent in requests for handling times and report ETA's they will never be able to achieve. They do so as they are anticipating on delays they expect to encounter at the port terminals. Consider the following example; a barge is expected to arrive at the port terminal at 10.00 hour. However, the barge operator expects a delay at the terminal of 2 hours, meaning that the barge will not be handled until 12.00 hour if the barge operator sends in a request for 10.00 hour. To avoid this waiting time, a barge operator sends in a request for 08.00 hour although the barge will not yet be in the port area at that time. If the delay is indeed 2 hours, the barge can be handled at 10.00 hour and does not have to wait. However, if the delay proves to be just 1 hour, the barge will be too late for his handling slot. As a result there will be either idle handling capacity or the barge planning will have to be adjusted in order to avoid this idle handling capacity.

This type of strategic behavior from both parties is not only counterproductive for them but also for the rest of the supply chain as it undermines the reliability of the quay planning and barge handling and eventually the reliability and performance of intermodal transportation.

Calculation of barge waiting times

Based on the planning process in Figure D-1 the total waiting time of a barge was calculated by subtracting the PTD from the ATD at the last terminal in its rotation. By doing so, the total cumulative delay of the barge during its rotation was determined. However, what must be mentioned about the used data is that it did not provide the reasons causing the delays. Therefore, it was not possible to analyze if the delay was caused by weather conditions, breakdowns etc. and if the delay was caused by either the terminal operator or the barge operator. Furthermore, by using the measure of PTD, the time a barge has to wait because the fact that the first PTA is later than his ETA / ATA in the port was not taken into account. This led to an underestimation of the total waiting time. Yet, the available data concerning the ETA is not reliable due to the strategic games played by barge operators as mentioned earlier and was therefore not used.

E World container fleet

The large majority of the production of containers is geared towards the standard sizes of 20 and 40 foot dry freight containers (89%). Special dry container sizes, such as 45, 48 and 53 footers represent a small but growing market segment (2%) as well as the production of refrigerated containers (reefers; 5%). Regional containers are mainly domestic 53 footers intermodal containers used in the North American market (http://www.people.hofstra.edu/geotrans/)

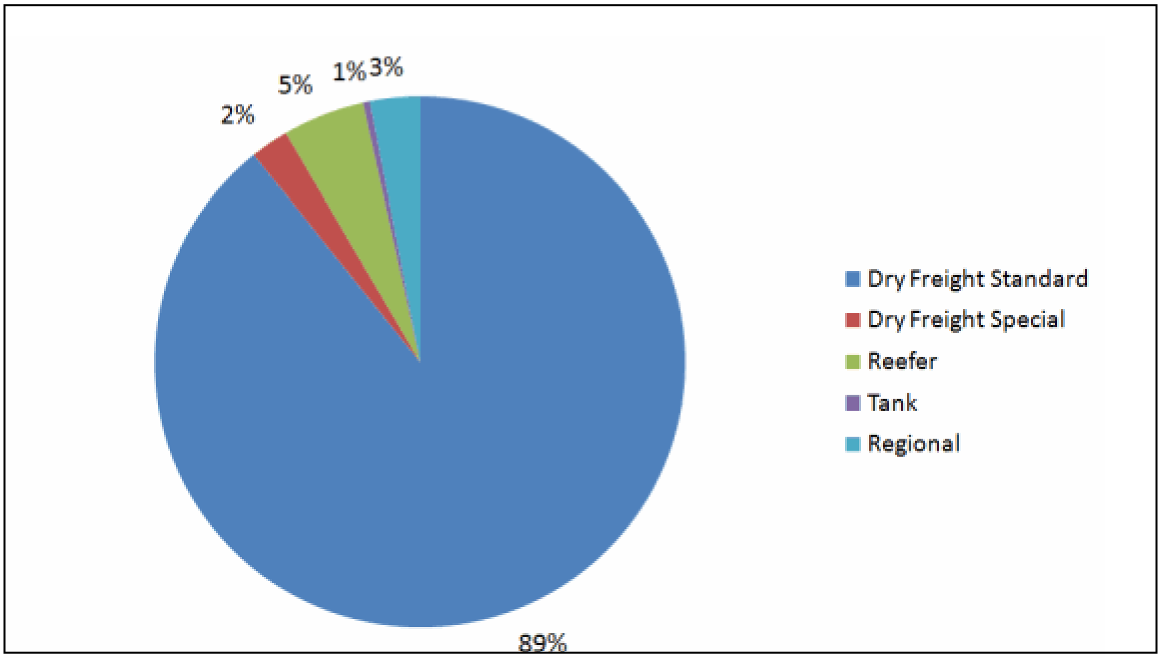

Figure E-1: Composition of the world container fleet in the year of 2007, *Source:,* http://www.people.hofstra.edu/geotrans/

F The reverse modal shift

This reverse shift could take place when transportation by truck from the hub to the shipper site is cheaper and/or faster than transporting the container by barge from the hub to the inland terminal and then by truck to the shipper site. See Figure F-1 for a graphical example of such a situation with the numbers representing costs. As can be seen in this figure, transporting the container from the hub to the shipper by truck is € 20 cheaper than transporting the container using barge transport, inland terminal handling and then truck transport.

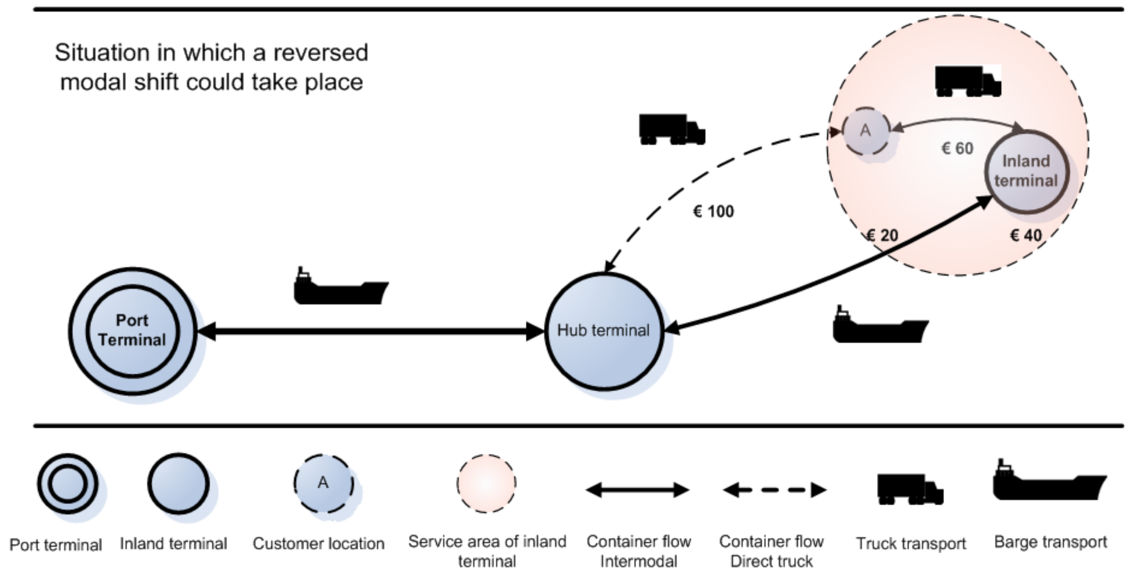

Figure F-1: A situation in which the location of the hub compared to the inland terminal could bring about a modal shift

Although this is just an example, a similar situation could be present in practice. The risk of such a situation is that shippers avoid intermodal transport using the inland terminal and transport their freight directly from the hub to their location using truck transportation. It therefore brings about the risk that inland terminals in the hub-and-spoke network lose shippers and thus revenue if no proper measures are taken to prevent the shift from happening.

G Relationship between required service level, frequency and barge utilization

As was shown in the results of the former sections, the utilization rate of barges influenced barge transportation costs. It follows from the formulas in Section 2.4 that this utilization rate was dependent on the (minimal) frequency of the barge connection. Because this frequency was either preset or determined by the required service level, the utilization rate of a barge was influenced by uncertainty in demand. When demand uncertainty or the required service level was decreased, the utilization rate of the vessels increased. This caused the barge transportation costs per load unit to decrease due to the fact that the fixed cost share per load unit was reduced. The utilization rate of the vessel therefore influences the attractiveness of intermodal transport compared to direct truck transport

The fact that demand uncertainty influenced barge utilization and therefore barging costs, provided additional advantages of consolidation of freight in the hub-and-spoke network. Following simple algebra, it can be shown that adding the demand distributions of the freight destined for the inland terminals decreased the relative variation for barging capacity on the port-hub connection. As this relative variation decreased, the utilization rate of this vessel increased. This led to a decrease in transportation cost per TEU on the port-hub connection and contributed significantly to the gained cost savings in the hub-and-spoke network compared to the base case scenario.

H Calculation of semi-fixed terminal costs

As mentioned in Section 2.2 the semi-fixed costs of a terminal are costs that cannot be considered as completely variable but cannot be considered as completely fixed either. During the analysis, the semi-fixed costs of the terminals were assumed to be 50% fixed and 50% variable. However, as it is not known how these costs develop in practice once the operation on the hub terminal is increased, the proper balance between which amount if fixed and which variable can also be 20%:80% or vice versa. It was therefore analyzed how this measure influenced the results obtained in the former sections.

When the semi-fixed costs were considered to be completely fixed, the handling costs on the hub terminal were significantly lower than in the 50% scenario. When the semi-fixed costs were considered to be completely variable, the story is the other way around. This result is graphically presented in Figure H-1. This figure presents the total cost difference between the base case scenario and the hub-and-spoke network for varying distance between the port and the hub. The graphs represent which percentage of semi-fixed costs was calculated as being variable.

As can be concluded from this figure, the way of measuring the semi-fixed costs significantly influenced the results obtained in the former sections. The graphs in Figure H-1 are further apart from one another on shorter distances between the port and the hub. This is caused by the fact that the relative impact of hub handling costs on total costs is larger on these shorter distances. Consider for example the situation in which the hub was placed 200 km from the port and the semi-fixed costs were assumed to be completely variable. Total roundtrip costs for the H&S-Barge container flow were € 281 per TEU of which € 47 was hub handling costs (17%).

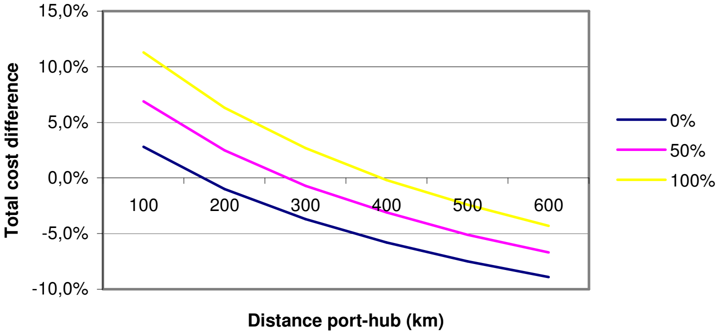

Figure H-1: Difference in total cost between the base case scenario and the hub-and-spoke network for varying distance between the port and the hub terminal for different level of calculating the semi-fixed terminal costs (% as variable)

In case the semi-fixed costs were calculated as being completely fixed, hub handling costs decreased with € 13 which was approximately 5% of total roundtrip costs. In case the hub was placed 600 km from the port, the same € 13 decrease in hub handling cost was equal to approximately 3% of total roundtrip costs indicating that the relative impact of this change decreased as the distance between port and hub increased.

The most important finding from this figure is that the hub-and-spoke network is a more attractive alternative to the base case scenario in the case the costs of the hub terminal are predominantly fixed instead of variable. If the increase in required handlings on the hub terminal indeed only leads to a small increase in the semi-fixed costs (i.e. personnel costs) the additional terminal costs are less detrimental on the feasibility of the hub-and-spoke network.

I External costs calculation

Some of the costs of container transportation are external costs that cannot be directly measured. These costs arise as transportation has a certain impact on its environment in which one mode of transportation has a higher impact than the other.

These external costs are composed of (http://www.binnenvaart.be):

- Accidents
- Noise
- Emissions
- Congestion
- Infrastructure
- Pressure on public space
- Soil- and water-pollution

The sources used, for calculating the total external costs, measure the costs per 1000 ton*km, indicating that it costs a certain amount of money if 1000 ton of freight is transported 1 km using a certain modality. Although the total distance traveled by barge and by truck can easily be calculated by simply multiplying the trip distance with the number of trips (for both barging and trucking) the weight of the freight inside the containers was not discussed before. Therefore, in this section, formulas and assumptions are presented that were used for calculating the total external cost in both the base case scenario and the hub-and-spoke network.

For determining the average weight of the containers transported in the network, the weight of full and empty containers needs to be distinguished. Furthermore, it should be taken into account that the maximum weight that can be loaded into 20ft containers and 40ft containers is approximately equal (Caru containers), which implies that the $TEUF$ plays a role in these calculations as well. The average wait of one full TEU, $\overline{m}_{full}$, can be determined by the following formula;

$$\overline{m}_{full} = \overline{m}_{full}^{20ft} * (2 - TEUF) + \frac{\overline{m}_{full}^{40ft}(TEUF - 1)}{2} \qquad \text{(G1)}$$

In which $\overline{m}_{full}^{20ft}$ and $\overline{m}_{full}^{40ft}$ stand for the average wait of a full 20ft and 40ft container respectively. These values can be calculated using the following formulas;

$$\overline{m}_{full}^{20ft} = \chi * m_{\max}^{20ft} \qquad \text{(G2)}$$

$$\overline{m}_{full}^{40ft} = \chi * m_{\max}^{40ft} \qquad \text{(G3)}$$

In these formulas, χ stands for the average load factor of a container and $m_{\max}$ stands for the maximum weight of a container.

The calculations for determining the average wait of one empty TEU, $\overline{m}_{empty}$, is the following;

$$\overline{m}_{empty} = \overline{m}_{empty}^{20ft} * (2 - TEUF) + \frac{\overline{m}_{empty}^{40ft}(TEUF - 1)}{2} \tag{G4}$$

During the calculations, the values of the input parameters as mentioned in Table I-1 were used

Variable	**Description**	**Value**	**Source**
$m_{\max}^{20ft}$	Maximum weight of a 20ft container (kg)	30,000	Caru container
$m_{\max}^{40ft}$	Maximum weight of a 40ft container (kg)	30,000	Caru container
$\overline{m}_{empty}^{20ft}$	Average weight of an empty 20ft container (kg)	2,300	Caru container
$\overline{m}_{empty}^{40ft}$	Average weight of an empty 40ft container (kg)	3,700	Caru container
χ	Average load factor of a container	85%	Assumption

Table I-1: Input parameters used for the external cost calculation

For the costs per ton*km we used the values in Table I-2 which has been constructed by averaging the costs mentioned by three different sources (http://www.binnenvaart.be).

	Modality		
Externality	Truck	Barge	Train
Accidents	€ 22,00	€ 0,12	€ 1,80
Noise	€ 4,63	€ 0,03	€ 6,33
Emissions	€ 15,63	€ 4,20	€ 4,27
Congestion	€ 4,03	€ 0,00	€ 0,07
Infrastructure	€ 1,47	€ 0,57	€ 1,03
Pressure on public space	€ 0,43	€ 0,00	€ 0,13
Soil- and waterpollution	€ 2,87	€ 0,00	€ 0,00

Table I-2: External costs per ton*km for different modalities, *Source:* http://www.binnenvaart.be

J Characteristics of Container Leasing Arrangements

Leasing a container is more costly than ownership from an operational standpoint, about 60% to 70%. Still, there is a large leasing market with about 40% of the global fleet of containers is owned by leasing companies. This confers flexibility and some leasing arrangements enable the lessee to leave the container back to the leasing company at its destination. If there is a surge in the demand, a carrier can lease containers instead of buying them, particularly if the surge is expected to be temporary. Leasing arrangements come into three major categories (http://www.people.hofstra.edu/geotrans/).

- **Master leases.** They are also called full service leases or container pool management plans and involve a complex and comprehensive leasing arrangement where the leasing company assumes full management. This entails a set of conditions regarding the availability of containers and an accounting system including debits and credits between contracting parties depending on the condition of equipment at the time of interchange. The leasing company is responsible for the full management of the container fleet (maintenance and repair) and for repositioning following off hire and contract termination. In many ways the leasing company acts as a logistics service provider since it must allocate the distribution of its container assets in view of the transportation strategies of the lessee. Thus, it must insure that an adequate supply of empty containers is made available for their customers as pick up locations.
- **Long term lease:** Also called dry leases and are commonly associated with the extended use of the leased container by an ocean carrier. This lease normally follows the purchase of new containers by the leasing company and they do not involve any management service by the lessor. The goal the leasing company is to amortize its investment over the lease period which covers about half of the useful life of a container.
- **Short term lease:** Also called spot market leases since the lease price is strongly influenced by current market conditions pertaining to the volatility of supply and demand. Such arrangements commonly take place when there is a temporary surge in the demand, either cyclical or unforeseen. Because of its volatility leasing companies try to avoid having a large share of their equipment on the spot market because of the risk of having idle containers, but realize that such a condition is unavoidable. Still, with careful planning, containers can be positioned to take advantage of local or regional surges in demand.

Leasing a container costs between $0.60 and $0.80 per TEU per day, depending on local conditions of supply and demand (http://www.people.hofstra.edu/geotrans/).

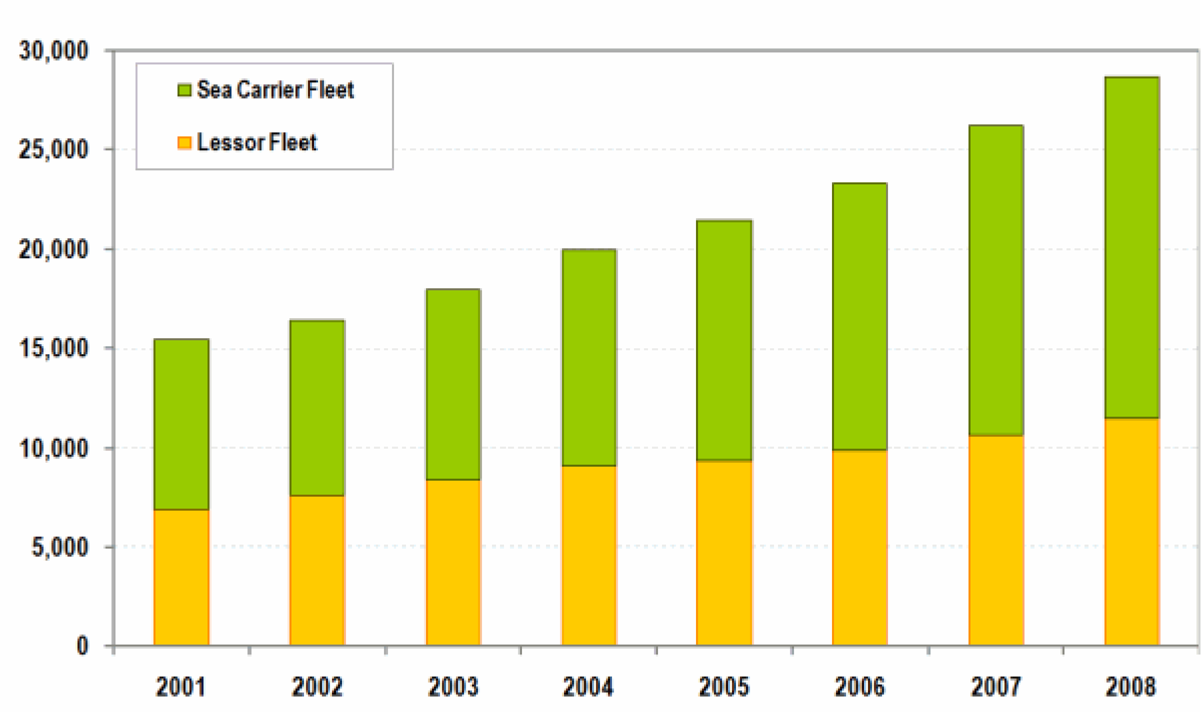

Figure J-1: Development of the world container fleet and its composition in the period 2001-2008, *Source:* http://www.people.hofstra.edu/geotrans/

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