

# **Developing a Small Barge Convoy System to reactivate the use of the small inland waterway network**

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# **Developing a Small Barge Convoy System to reactivate the use of the small inland waterway network**

(Ontwikkeling van een klein bakken concept om het gebruik van de kleine waterwegen te reactiveren)

door

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Scheepsbouwkundig ingenieur  
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# Preface

Being born and raised in the city of 's-Hertogenbosch I have always been surrounded by different waterways (small ones like the Zuid Willemsvaart and large one like the river Maas) and several shipyards (the old Verolme shipyard in the city of Heusden for example). It was during a visit to this yard when I was still at elementary school that my interest for shipbuilding and shipdesign was formed.

During my study of maritime technology at the Delft University of Technology I also developed an interest in the economics behind the ships we were used to design. Therefore the choice to specialize in the field of shipping management was easily made. Prof. Van de Voorde and Prof. Meersman offered me the opportunity to develop a master thesis, in cooperation with the University of Antwerp, which would give a new technical solution to reactivate the use of the small inland waterways which was also economically viable. This master thesis has been the start for the development of this PhD-thesis. This PhD thesis will now connect my interest in the design of new ships and their economic viability, and apply them to a situation which is all too familiar to me.

The thesis will combine the design/technical knowledge with the logistics/transport economics aspects. The economic theories applied in this thesis will not be extensively discussed because it is only my aim to apply these theories to determine the competitiveness of the small barge convoy system.

Although writing a thesis is an individual task, many more people were involved. So this is the moment to express my gratitude to them. First of all, I would like to thank my promoter professor dr. Eddy van de Voorde. He was always there to provide me with advice and feedback on my work. His incredible speed of reading text and commenting is always very much appreciated by me.

I would also want to thank Prof. dr. Meersman, Prof. dr. Verhetsel and Prof. ir. Hopman for commenting on earlier drafts of parts of this thesis. Their suggestion and comments were also very much appreciated. Also the comments and suggestions, on earlier drafts of the thesis, of Prof. dr. Rothengatter, Prof. dr. Savy and dr. Vanelander were very much appreciated.

I would also like to thank dr. ir. Martin van Hees for making the Quaestor software available to me.

I am also very much in debt with my sister Laura van Hassel for making the first effort of improving the English in this thesis. The second person who I want to express my gratitude is Prof. Braecke for his time and effort that he has put into the thesis to improve the English even further to a "PhD level".



Of course, many more colleagues should be credited as they have contributed to a pleasant and inspiring working atmosphere.

Last but not least, I would like to thank my parents, who have always encouraged me and given all possible support to me to study.

Edwin van Hassel

's-Hertogenbosch / Antwerp  
September, 2011

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# **1. Introduction**

## **1.1 Background of the thesis**

Inland shipping in North Western Europe is well known transportation mode which can make use of a large and dense inland waterway network. However in the last 45 years no new small inland ships have been built. As a result the small inland fleet is diminishing, and only in Flanders 4,000,000 tonnes of cargo (WenZ, de Scheepvaart, 2009) transported to and from companies located at the small inland waterways, by small inland ships, risk being shifted to road transportation. Those tonnages are then added to the already heavily congested road network. These extra tonnages and the potential further increase in cargo flows will lead to more investments in expanding the existing road capacity while the available infrastructure of the small waterways will not be used at all. This small waterway capacity is very much needed to deal with a part of the total tonnages that have to be transported from the seaports of Rotterdam and Antwerp to their respective hinterlands.

Another consequence of the diminishing small inland fleet is that the diversity in the total inland fleet will disappear. The new ships that are being built are increasing in size and therefore the available sailing area of these ships is reduced because those large ships can only sail on a limited number of inland waterways. Therefore there is a large risk that there will be only large inland ships left in the future, while more than 50% of the inland waterway network can only be used with smaller (<600 tonne) ships.

Due to a lack of new building of small inland ships, the increasing age of the small inland fleet and no new starters on small ships, without intervention, in the near future the small inland waterways risk not being used at all. This will possibly cause companies, which are located at small inland waterways to use road transport instead of inland navigation or to relocate their activities.

However, due to growing road congestion and an increasing awareness of environmental care, the small inland waterway network can play a vital role in providing solutions to these problems. North-West Europe (the Netherlands, Belgium, Germany and northern part of France), consists of a dense network of (small) inland waterways which connects many regions to important hubs like the ports of Rotterdam and Antwerp, enabling transport of a part of their hinterland cargo over these small inland waterways.

## **1.2 Objectives of the thesis**

The objective of this thesis is to gain insight into the existing problems concerning the diminishing small inland fleet and, as a result of that, a reduction of the use of the small inland waterways. The second objective is to develop a new inland navigation concept that could be used to reactivate the use of the small inland waterway network. The third objective is to determine the optimal design for the concept developed (network and ship design). The fourth objective is to research the possibility of implementing,

in an economically viable way, the small barge convoy system via suitable business cases.

The four main objectives are now reformulated into five main research questions:

- 1) What are the existing and expected problems concerning the use of small inland waterways with the present small inland fleet?
- 2) What type of solution could be developed to reactivate the use of the small inland waterway network?
- 3) How does the proposed solution work? What is the optimal design of the proposed solution?
- 4) Is it possible to construct a suitable business case for the developed solution?
- 5) How could the developed solution be implemented and how will the other modes react to the introduction of the proposed solution?

### **1.3 Methodology**

The main research will be divided into five main research areas each with their own research goals:

#### **A) Problem definition**

This part of the research deals with the existing and expected problems concerning the present small inland fleet on small inland waterways. The existing problems are researched along with the reason behind the lack of new small inland ships via a literature study. Also the effect of losing the small inland waterways on the external costs will be taken into account.

#### **B) Providing a potential solution**

Based on the results of the research of the problem definition an innovative inland navigation concept based on a barge convoy will be proposed to provide a solution for the problems mentioned.

#### **C) Modelling of the proposed solution**

Within this part of the research the small barge convoy system will be researched. This research area can be divided into several smaller sub-areas which all need to be researched.

##### **1) Network design**

In this part of the research the several network design options, limited to the developed small barge system, are analysed, e.g.: what is the number of barges to be pushed, to which waterways and at which speed?

## 2) Tug and barge design

The barges and tug that are used do not exist yet. Therefore new designs should be made. The designs will be based on the main design parameters, such as: required speed, cargo carrying capacity, number of barges pushed by the tug, type of propulsion system (diesel direct, diesel electric). The barges and tug will be designed to comply within the rules of the shipping inspection ("scheepvaartinspectie") and the rules of the Germanische Lloyds.

## 3) Generalized cost calculation of the small barge system

Based on the chosen network and the designs made for the developed concept, the transportation and total logistics costs will be determined.

## 4) Price setting / Competition research

Besides the (generalized) costs of the small barge convoy system, also the (generalized) costs of the competitive modes must be taken into account. Based on the generalized costs of the developed concept and the competitors it can be determined if the small barge convoy system can offer a competitive price.

## D) Applications of the small barge convoy system

When the design of the network, tug & barge convoy, transportation costs and prices of the new concept are known, a concrete business case will be made to see if it is possible to invest in the small barge convoy system. In order to determine if the small barge convoy system can be implemented, a minimum value of the internal rate of the return (IRR) must be achieved.

## E) Implementation research

In this part of the thesis, the start-up phase of the small barge convoy system will be researched. What are the start-up costs, how many barges should one start with? Also an overview of the strength and weaknesses of the small barge system will be researched via a SWOT analysis. Based on this analysis several strategies will be developed in order to deal with the weaknesses and threats of the system.

Research areas A to E show that the total research will consist of: a technical / nautical part and a network / economic part which will be combined into a single research project.

Part A of the research (problem definition) is researched ships via a literature study. Part B will partly be based on a literature study and partly on my own insights and creativity.

For research area C (Researching the proposed solution) a computer model will be made which will be programmed in the program Quaestor<sup>1</sup>. The model will be developed to gain insight in the dynamics of the developed

---

<sup>1</sup> Quaestor is a knowledge management system software tool developed by Qnowledge. It is a development platform, working environment and management tool for engineers, enabling integration of design configuration, calculations and the generation of drawings and graphs. <http://www.qknowledge.nl>

concept and it will give the design of the barges and tug which are used within the concept. Also, the competitiveness of the developed system will be determined in this model. For the graphical output of the tug and barge designs the program Rhinoceros<sup>2</sup> will be used. The Rhinoceros model will be integrated into the total Quaestor model. From the model it must be clear what the influence will be on the generalized transportation costs and therefore on the competitiveness of the small barge convoy system if the design of the barge is changed or if a different network is chosen. Also influences of the size of convoy, the sailed speed, the chosen sailing regime on the competitiveness must become clear.

For the application research (D) the developed model will be applied on the Flemish small waterway network. The implementation research (E) will also be based on the developed model.

## **1.4 Results of the thesis**

The total research must give, at first, an insight into why the small inland ships are disappearing and why it is important to revitalize the small inland waterway network. The research must give insight into whether it is possible to implement the small barge convoy system in a real case. The result of the research must be a potential business case that could be used by an investment company / inland shipping company wanting to invest in the new concept. Besides potential business case(s) also the preliminary designs of the developed barges and tug will be available.

The aim is that the small barge convoy system should not only be a competitive and a profitable business but it must also provide emission and congestion reduction for cargo transportation compared to road haulage.

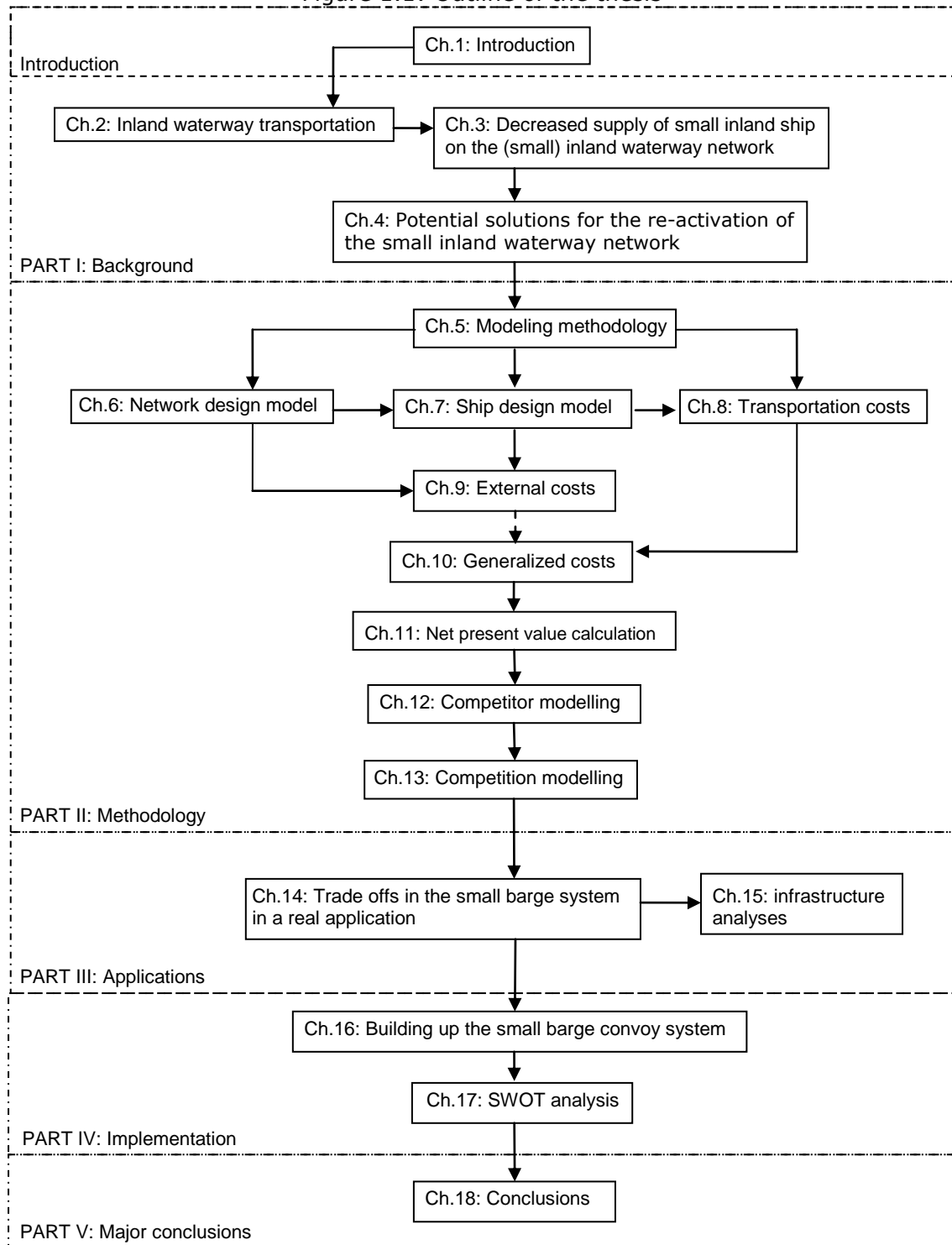
## **1.5 Outline of the thesis**

This thesis is divided into five different parts. In figure 1.1 a schematic overview of the outline of thesis is given. The first part, background, will be dealt with in chapter 2, with a description of the inland navigation structure and the current and potential market on the small inland waterway network in Flanders. Chapter 3 will deal with the problems in the small inland shipping segment. In chapter 4, the new inland navigation concept will be presented which could deal with the problems mentioned in chapter 3.

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<sup>2</sup> Rhinoceros is a 3D cad package that is used to draw the 3D designs of the barges and tug  
[http:// www.rhino3D.com](http://www.rhino3D.com)

Figure 1.1: Outline of the thesis



The second part, the model, will consist of chapters 5 to 13. In chapter 5 an overview of the developed model will be given. In this model the small barge convoy system will be modelled which will consist out of several sub-models. In chapter 6 the first sub-model is given which will deal with the different network design options.

In chapter 7 the designs of the barges and tug are given along with a description of the used design algorithms. In chapter 8 the cost calculations, for the small barge convoy system, are given. In chapters 9 the external costs and in chapter 10 the generalized costs are determined.

In chapter 11 the net present value calculation of the small barge system is given. Chapter 12 of this thesis will deal with the modelling of the competitors of the small barge system. Chapter 13 will deal with the competition modelling of the small barge system in a competitive environment.

In the third part of the thesis, Applications, the model is demonstrated with a complete case study of the Flemish small waterway network including a future scenario analysis (chapters 14). In chapter 14 designs are made for the needed tug and barges and suitable business case(s) will be developed. In chapter 15 an infrastructure variation analysis will be performed to research the influence of network characteristics on the small barge convoy system and its competitiveness towards the other modes.

In the fourth part, called implementation research, it will be determined in which way the small barge convoy system could be implemented and built up. Also the needed crew and personnel that are needed for the tug and barge system will be determined (chapter 16). In chapter 17 a SWOT analysis of the small barge system will be made. This chapter will give an overview of the strong and weak points of the developed concept.

In the last part of the thesis the main conclusions, the main conclusions are presented and recommendations will be given on if and how the small barge convoy system can be implemented (chapter 18).

# **PART I: BACKGROUND**





## 2. Inland waterway transportation

### 2.1 Introduction

This chapter will start with a general introduction of the inland waterway system in North West Europe. The second part will deal with the used definitions for small waterways and small ships. Finally the chapter will deal with the market and transported tonnages via the small inland waterways in Flanders.

### 2.2 Inland waterway system

The inland ships that are sailing on the inland waterways provide a sustainable and reliable transportation mode. In the Netherlands 40% (and in Flanders 11.5%) of the total transported cargo is transported with inland ships (Meersman *et.al.* 2008). These inland waterways have a spare capacity, contrary to the already heavily congested roads. Therefore, these inland waterways can play a vital role to deal with the growing demand for transportation in the Netherlands and Flanders. In figure 2.1 an overview of the inland waterways in the Netherlands and Belgium is given.

Figure 2.1: Inland waterways in the Northwest of Europe



Source: Bureau Voorlichting Binnenvaart, 2009

Figure 2.1 shows that the inland waterways form a dense network that connects the two main ports in the Hamburg- Le Havre range (port of Rotterdam and the port of Antwerp) with its hinterland. That hinterland

consists of the Netherlands, Belgium, Germany, the northern part of France and even Switzerland (via the Rhine). There are large differences between the waterways in Northwest Europe. There are large rivers (Rhine, Waal, Scheldt and Maas), there are small rivers, where only small inland ships can sail on, and there are man-made waterways (either large or small). Every waterway has its own characteristics and own maximum type of inland ship capable of sailing on that waterway. All these waterways are categorized into different E.C.M.T. (= Conférence Européenne des Ministres de Transport) classes which are given in table 2.1. The classes are based on the maximum dimensions of the ships that are capable of sailing on that waterway.

Table 2.1: Overview of the different waterway classes with their ship dimension criteria

Class	Length (m)	Width (m)	Draft (m)	Air draft (m)	Payload (tonne)
I	38,50	5,05	1,8-2,2	4,0	250-400
II	50-55	6,6	2,5	4 to 5	400-650
III	67-80	8,2	2,5	5 to 5	650-1000
IV	80-85	9,5	2,5	5,25-7	1000-1500
Va	95-110	11,4	2,5-4,5	5,25-7	1500-3000
Vb	172-185	11,4	2,5-4,5	9,1	3200 (barge convoy 1x 2 barges in length)
VIa	95-110	22,8	2,5-4,5	7-9,1	3200-6000 (barge convoy 1x 2 barges a breast)
VIb	185-195	22,8	2,5-4,5	7-9,1	6400-12000 (Barge convoy 2x 2 barges)
VIc	193-200	34,2	2,5-4,5	9,1	9600-18000 (Barge convoy 2x 3 barges)
VIIb	195/285	34,2	2,5-4,5	9,1	14500-27000 (Barge convoy 3x3 barges)

Source: New classification of inland waterways 1992 CEMT

The main dimensions of the ships are limited by either dimensions of the smallest locks located on that waterway (length and width) or by the depth of the waterway (draft). The air draft is limited by the height of the bridges crossing the waterway.

## 2.3 Definition of small inland waterways

In BCI (2008) small waterways are defined as waterways of class IV and smaller. On those waterways, ships can sail up to 1.500 tonnes payload. In this research, small waterways are considered to be of class II and smaller. Waterways of class III and IV are classified as medium sized waterways rather than small waterways. The waterways of class V and larger are considered large waterways. Figure 2.1 shows that small waterways (green ones) cover a large region in the Flemish hinterland of the port of Antwerp and in the Netherlands of the ports of Rotterdam and Amsterdam.

## 2.4 History of the small inland waterways

In 18<sup>th</sup> and 19<sup>th</sup> century, the use of inland ships, especially in the Netherlands and Belgium, was the only economically viable way to

transport cargo over long distances. As a result of that, a dense waterway system was built to connect many important economic regions. The characteristics of the waterways were based on the ship dimensions of those days.

The man-made small inland waterways in the Netherlands and Belgium were built in the 19<sup>th</sup> century to connect the major industrialized regions of those days. The Zuid-Willemsvaart (in Belgium), for instance, was built in 1806 for Napoleon who ruled Europe in those days. In 1822, King Willem I of the Netherlands updated the canal and increased its length. Willem I connected the city 's-Hertogenbosch to the cities Maastricht and Liege. The original plans to build a man-made waterway date from 1645 (Bruggeman 2001). The basic characteristics of the waterway (lock size, width, etc have not changed up to now. In figure 2.2 the trajectory of the Zuid Willemsvaart is given.

Figure 2.2: Trajectory of the Zuid Willemsvaart



In Flanders, the small inland waterways were built to connect the port of Antwerp with the main industrialized areas such as Liege and Leuven. The canal Leuven-Dijle, which was built in 1750, was also built to connect Leuven with the river Scheldt to enable sea going vessels to enter the city port and therefore boost the local economy.

## 2.5 Definition of small ships

In the inland shipping sector only a small number of different ship types are used. These ships are categorized according to their payload and dimensions. The names of the ships are taken from the regions where these ships can sail. In table 2.2 the different ship types are given.

Table 2.2: Overview of the current inland ships (with small ships indicated in bold)

Ship type	Tonnage [tonne]	Length [m]	Width [m]	Depth [m]	Waterway class [-]
<b>Spits</b>	<b>250-400</b>	<b>39</b>	<b>5.05</b>	<b>2.2</b>	<b>II</b>
<b>Kempenaar</b>	<b>400-650</b>	<b>55</b>	<b>6.60</b>	<b>2.5</b>	<b>II</b>
New type of Kempenaar	400-600	63	7.20	2.5	II
Canal du Nord schip	800	60	5.75	3.2	III
Dortmund-Ems-Kanaal	968	67-81	8.20	2.5	III
Rijn-Herne-Kanaal	1378	80-85	9.50	2.5	IV
Large Rijnschip	2160	95-111	11.4	2.7-3.5	V
Large container ship	470 TEU	135	17.0	3.0	VI

Source: Promotie Binnenvaart Vlaanderen

According to BCI (2008), small ships are ships with a length smaller than 86 meters and a payload of less than 1.500 tonnes. These are the ships that can sail on the class IV waterways. This definition is adopted in Europe, while the ministry of transportation in the Netherlands defines a ship with a payload less than 1.000 tonnes small (class III). A reason for this distinction can be a political one. The problems concerning the decreased supply on the small waterways are widely accepted so that governmental interference is expected. Therefore the sector wants to define the class of small ships as widely as possible so that as many ships as possible can be served by governmental aid. In this research, however, small ships are defined on the basis of their dimensions, where the criteria for small ships are:

- Length less than 55 meters
- Draft less than 2.5 meters
- Width less than 6.8 meters

These ships have the opportunity to sail with only a captain on small waterways with criteria in the Netherlands (= Alleenvaartregeling) (Jaarbericht Inspectie Verkeer en Waterstaat, 2004). According to these criteria, in table 2.2 only the Spits and the Kempenaar are considered to be small ships. The ships up to 1.500 tonnes are in this research defined as medium sized ships. Ships larger than 85 meters are defined as large ships. The reason for this definition of small ships is based on these criteria that small ships can sail on every class II waterway. Ships with a length of 63 meters (new type of Kempenaar) cannot sail on every class II waterway due to length restrictions of the locks located on those waterways.

## 2.6 Realized demand on the Flemish total waterway network

Via the waterways in Flanders 35,000,000 tonnes of cargo are transported each year. This is shown in table 2.3 where the total transported tonnages via the Flemish waterways are given.

Table 2.3: Total transported tonnage via the Flemish waterways

	2007 [tonne]	2008 [tonne]	2009 [tonne]
Loaded	30,750,129	31,254,942	28,085,189
Unloaded	9,164,633	8,778,580	7,849,199
Total	39,914,762	40,033,522	35,934,388

Source: PBV, 2009a

Twenty million tonnes of the total transported tonnages (50%) are loaded or unloaded on the Albert canal. Of total transported tonnages in 2009, 450,000 TEU were transported to the inland terminals in Flanders. In figure 2.3, an overview is given of the inland terminals.

Figure 2.3: Overview of inland container terminals in Flanders

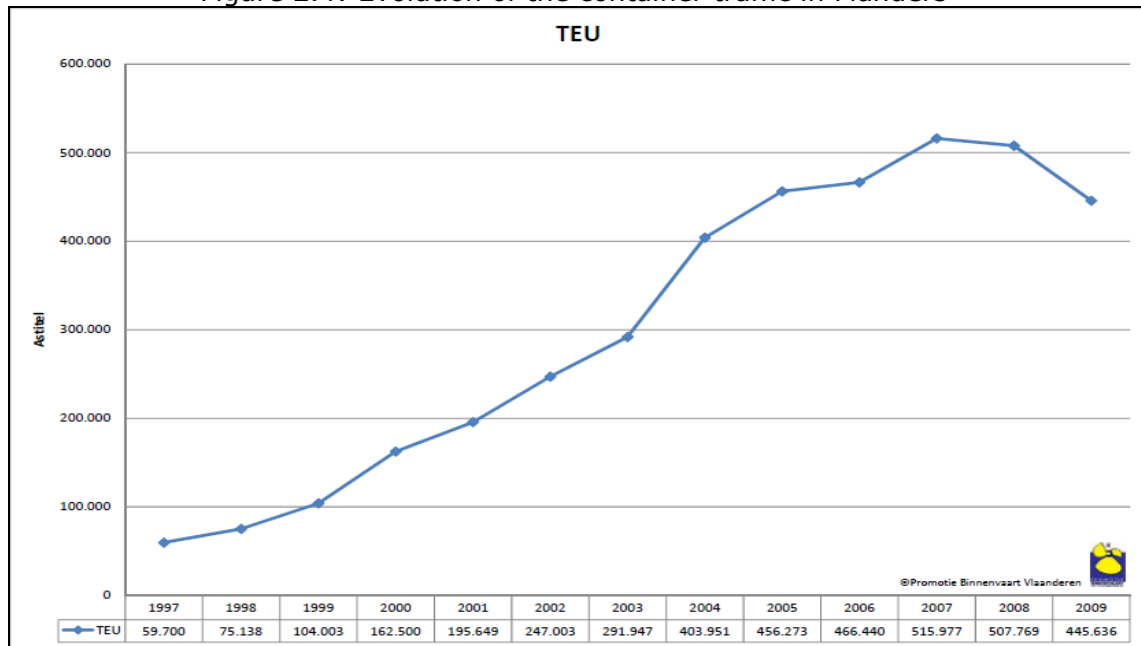


Source: PBV, 2010

Note: numbers indicate the location of the container inland terminals

From figure 2.3 it can be concluded that almost all the inland container terminals are located at large waterways (class IV and larger). There is only one container terminal located at a small waterway (Leuven-Dijle) where this terminal is completely dedicated to Cargill. This company transports its containers from the inland terminal to the port of Antwerp (4,000 / 5,000 TEU per year). In figure 2.4, the evolution of the total container traffic to these inland terminals on the Flemish waterways are given.

Figure 2.4: Evolution of the container traffic in Flanders



Source: PBV; 2009b

There has been a strong increase in container traffic from 1997 to 2007 (from 60,000 to 515,000). In 2008 the amount of transported containers declined a little bit from 515,000 TEU to 500,000 TEU while in 2009 the transported TEUs decreased to 2005 levels due to the economic crisis of 2008.

## 2.7 Demand on the small waterways

### 2.7.1 Current demand

In figure 2.5 the small inland waterways in Flanders are shown. Where in table 2.4 the total transported tonnages to and from those waterways in 2007, 2008 and 2009 are given.

Table 2.4 shows that more than 4,000,000 tonnes of cargo per year are loaded and unloaded on the small waterways in 2008 and 2009. The largest part of the transported tonnages is loaded tonnages that have an origin at one of the small waterways. The majority of the loaded tonnages are of NTS/R category 6 (building materials = sand) and a large part is of NTS/R category 2 (oil products). All these tonnages account for 160,000 truck movements per year in Flanders (based on 25 tonnes per truck). All these truck movements will be added to the already congested road when they are not transported via the small inland waterways.

If the market of the small inland waterways is compared to the total potential demand on the small inland waterways given in table 2.4, it can be concluded that the small waterways are responsible for 10% of the total market. This is an indication that the small waterways are not used as much as the large ones.



Figure 2.5: Overview of the small inland waterways in Flanders



Source: original figure from PBV

Table 2.4: Overview of the transported tonnages per year on the small waterways

	Waterways	Waterway administrator	2007	2008	2009
(1)	Dessel-Turnhout-Schoten	NV de scheepvaart	764,173	811,295	882,228
(2)	Bocholt-Herentals	NV de scheepvaart	2,165,730	1,940,455	1,525,855
(3)	Zuid Willemvaart	NV de scheepvaart	525,919	632,633	661,054
(4)	Dender	WenZ	493,458	474,752	521,822
(5)	Leuven-Dijle	WenZ	217,313	195,539	412,203
		total	4,166,593	4,054,674	4,003,162

Sources: NV de Scheepvaart and WenZ year reports 2007, 2008, 2009

There are not a lot of containers transported via the small waterways. Only on the Leuven-Dijle canal there is a container flow to the port of Antwerp. The reason for the limited amount of containers transported is that there are no container terminals at the small waterways. Another problem with respect to the small ships is that they have to deal with long waiting times in the port. The reason for that is that the number of containers which has to be unloaded (or loaded) per call are small (<16 TEU maximum), and the terminal operator has to deploy a complete crew. Therefore, the deep sea terminals prefer to handle bigger deep sea vessels instead of the (small) inland ships. This increase in waiting time will decrease the reliability and increase the costs (for crew); therefore road transport is a suitable alternative, especially on short distances (see also section 3.4).

### 2.7.2 Potential demand

The total available market for the on the small inland fleet in Flanders consists of cargo flows either having an origin or destination in the port of Antwerp and an origin or destination at the small waterways in the

Flanders. In figure 2.6, the different waterways are shown while in table 2.5 the total potential cargo flows are shown.

Figure 2.6: Overview of the different small waterways in Flanders



Source: original figure from PBV

Table 2.6: Total potential cargo flows from the seaport Antwerp to the different waterways

	ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4
Small Waterway	Dender	Leuven-Dijle	Deseel-Turnhout-Schoten	Bocholt-Herentals
Cargo flow containers (in) [TEU]	2,250	7,500	8,140	-
Cargo flow containers (out) [TEU]	2,720	12,600	9,950	-
Cargo flow bulk (in) [tonne]	233,500	128,000	10,000	231,461
Cargo flow bulk (out) [tonne]	-	-	84,000	463,248

Source: Waterslag (2008), FISN data (2008), cargo flows WenZ and NV de scheepvaart (2009)

Note: all containers are loaded, no empty containers in the cargo flows

The available market consists of existing inland navigation cargo flows taken from cargo flow data of NV de Scheepvaart and WenZ and cargo flows that currently are transported by road (BCI, 2006, WenZ, 2008 and Scheepvaart, 2008). These cargo flows come from companies located at small inland waterways and having an origin or destination at the port of Antwerp. In table 2.6, the total potential cargo flows can be found.

Besides the available and potential market for cargo which have an origin or destination at companies located directly at the small waterway there is also a potential market which includes cargo flows which have an origin or destination in the proximity of the small inland (see also section 4.4 available markets for the developed concept). It has to be researched how many additional road kilometres can be added to the developed system and



which types of goods are suitable for this. In section 13.4 this analysis will be done.

Besides the traditional bulk and container markets also the so-called third wave of palletized cargo could be part of the potential demand. However, to get these cargo flows on the (small) inland waterways three items are important (Verbeke, Macharis, Cornillie, 2007):

- A critical mass is needed (for the inbound and outbound)
- There is maximum allowable road distance that can be added
- The transportation price of the combined inland waterway transport and pre and on carriage must be lower than the price for direct road transport.

Because no studies are available indicating that there are enough palletized cargo flows and because similar projects of palletized cargo transported via the inland waterways have failed (Distrivaart concept<sup>3</sup>) due to the large complexity of organizing palletized cargo via the inland waterways (multi modal) and the absence of large transport volumes (Jansen, Verver, 2008), these cargo flows of the palletized goods are left outside this research.

## 2.8 Supply on the small waterways

Two main modes of transportation are available to companies located at the small inland waterways. First there is road transportation. All the companies, located at the small inland waterways are connected to the road network so that trucks can also reach their premises. The other mode is inland navigation on the small inland waterways. Inland ship types that can sail on the small inland waterways are the Spits<sup>4</sup> and Kempenaar<sup>5</sup>. It is expected that the number of these small inland ships will decrease even more in the near future. The reasons for this decrease can be found in chapter three, where the problems in small inland fleet will be discussed. Moreover, two different types of solutions have already been developed to deal with the reduction of supply on the small inland waterways. The first one is the Neo-Kemp concept and the second solution was the Waterslag project.

### *Neo-Kemp (small inland container ship)*

The Neo-Kemp vessel is a small inland container ship (63 m length, 7 m wide, maximum 32 TEU loading capacity) introduced in 2000 by the Dutch company Neo Logistics Services. The wheelhouse is located at the bow of the vessel so that a good visibility is obtained without the need to lift the wheelhouse. Nine of these ships were built. These ship, where deployed on waterways where the larger vessel could not sail. The investments are relatively high and these ships can only be used by crew members who are employed by a shipping company instead of a small independent entrepreneur (BCI 2008, Konings 2004).

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<sup>3</sup> Distrivaart is a concept in which a ship was used to transport palletized cargo via the inland waterway network.

<sup>4</sup> Inland ship type with an average loading capacity upto 450 tonnes

<sup>5</sup> Inland ship type with an average loading capacity upto 650 tonnes

Due to the dimensions of this vessel it cannot serve the small inland waterways of CEMT class II and smaller. The length and the width are too large. The NEO-kemp ships were sold in 2003 to the Mercurius shipping company, where these are now operated as "normal" inland ships.

*Waterslag project (push barge coupled with a small ship)*

The second project that has been developed for the reactivation of the small inland waterways is the Waterslag project. In this project a small push barge- which can independently pass a lock is coupled to a "classic" small inland ship. The loading capacity of the ship is doubled; as a result a more competitive price can be offered. This could lead to a positive contribution towards mobility, economy and environment. The pushed barge will be specially designed for the use on the small waterways in Flanders and the south of the Netherlands (Waterslag, 2006-2008).

The project was successfully introduced in 2008 but the concept is now taken out of use due to the crisis (2010). The downside of using this concept is that still a small inland ship needs to be used. The main problems concerning the reduction of the captains and the changed social conditions of not willing to live on board of the vessel are not tackled with this concept (see chapter 3). Also the small inland ship has to push the barge on large waterways, which will reduce the total speed of the convoy and therefore it will increase the crew costs by the increase in travel time or the total convoy will sail at its "normal" speed, but then more power is needed and the fuel costs are increased.

If the supply on the small inland waterways is decreased, then the small inland waterways cannot be served so that the companies located at those waterways will have to opt for another transportation mode. This other mode will be road transportation because the companies are not connected to the train network.

## **2.9 Summary**

In this chapter, an overview is given of the existing inland waterway infrastructure and the actual demand on that infrastructure. Also the definition of the small inland waterways and small inland ships has been presented, along with the historical background of the small inland waterways. Besides the demand of the companies located at the small inland waterways also the current supply is described.

Now that an overview is given of the inland navigation sector, the existing and expected problems concerning the use of the small inland waterways will be dealt with in chapter 3.

### **3. Decreased supply of small inland ships on the (small) inland waterway network**

#### **3.1 Introduction**

A lack of new building of small inland ships, the increasing age of the existing small inland navigation fleet and no new starters for small ships are the major reasons that, without intervention, in the near future the small inland waterways risk not being used anymore. Due to a shortage of supply on the small waterways, companies, which are located at small inland waterways, will use road transport instead of inland navigation or they will relocate their activities.

However, due to growing road congestion and an increasing awareness of environmental care, the small inland waterways can play a vital role in providing solutions to these problems. These waterways, especially the small ones in the Netherlands and Belgium, connect many regions to important hubs like the ports of Rotterdam and Antwerp, enabling transport of a major part of their hinterland cargo over these inland waterways. Therefore, it can be worthwhile to re-commercialize the small inland waterways.

In the first part of this chapter, an analysis will be made to determine why there are no new small inland ships. The second part will determine why the current small inland fleet is reduced and what the threats are for the remainder of the small inland fleet. The third part will deal with a specific problem concerning the use of (small) inland ships in a deep-sea port. The fourth part addresses the impact of losing the small inland ships. The fifth part will discuss the existing small inland waterway infrastructure, while the sixth part will treat of the impact of losing the small inland waterways. Finally, the conclusions of this chapter are formulated.

#### **3.2 Lack of new small inland ships**

This section of chapter 3 will deal with the analysis behind the lack of new small inland ships. In figure 3.1, a schematic overview is given of the mechanism that will lead to the lack of new small inland ships. This lack is explained by the lack of cash available in the sector because the small inland shipping sector is not viable anymore. The major underlying reasons for the lack of cash and therefore no new-building of small inland ships are:

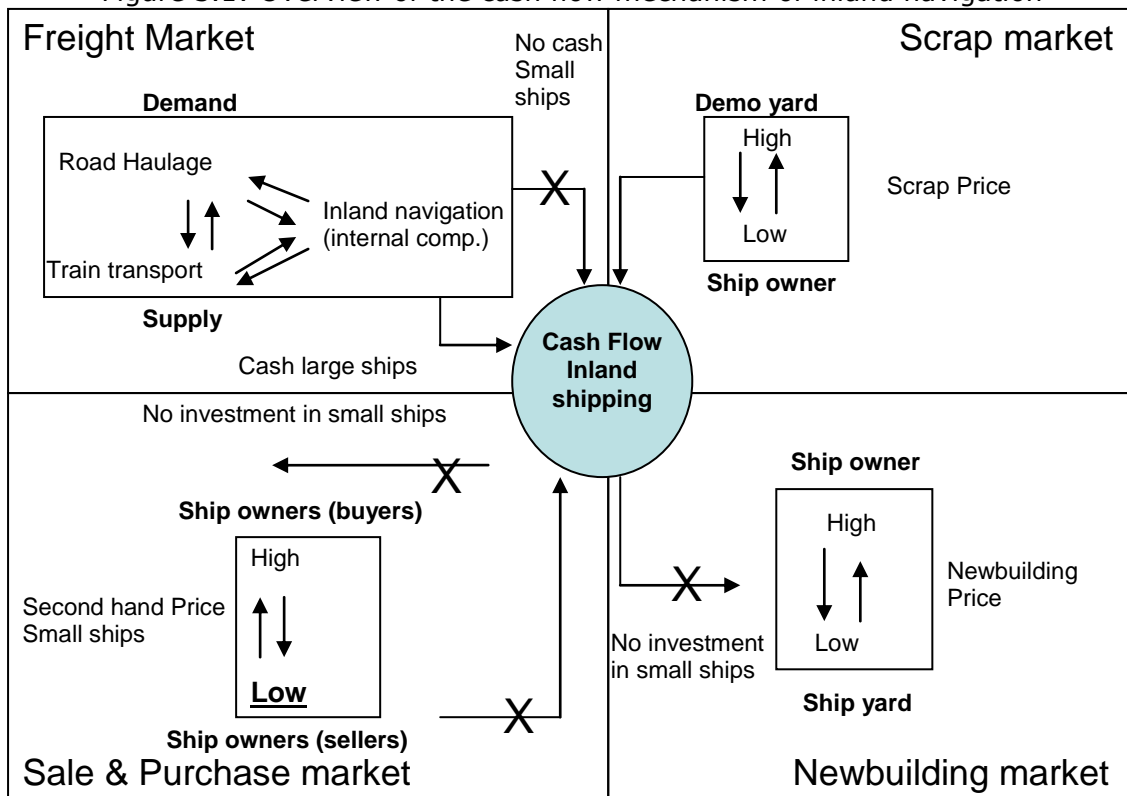
- Competition of other modes of transportation and other inland ships
- Economies of scale of the inland fleet
- Banks / investing companies not willing to invest in small ships
- New ship-owners not willing to operate a small ship
- Entry and exist barriers

These major reasons are further explained in the upcoming sections of this chapter.

In figure 3.1 the four different shipping markets are given (Freight, Sale & purchase, newbuilding and scrap market) (Stopford, 1997). The first market that is described in this figure is the freight market in which the small inland ships have to operate. In this market, the ships have to compete with its main competitors:

- Road
- Train
- Other inland ships
  - o Large inland ships
  - o Small inland ships
- intermodal transport (combination of inland ships, trains and road)

Figure 3.1: Overview of the cash flow mechanism of inland navigation



Source: own composition based on Stopford, 1997

Due to this severe competition of road transportation and larger inland ships small ships do not generate enough money while large ships can.

Due to the lack of cash (own equity and debt financing) not enough money is available to buy second hand ships and as a result the price of those ships will be reduced. As a result, the second hand market, i.e. the sale & purchase market, will hardly generate money and no cash will be moved into the small inland shipping (SIS) cash flow. If the second-hand prices drop and the market conditions are bad, no new ships will be ordered. Therefore there will be no new-building market for the small inland ships.

The only cash that will flow into the SIS cash flow will come from the scrap market or the rebuilding market. In the latter, the ships will be transformed into a living ship for example. As a result, the number of small inland ships will reduce.

### 3.2.1 Competition of road transport, large and small inland ships

There are three different types of competition for the small inland ships. First, there is the competition of road transportation. Companies which are located at small waterways are also accessible for road transport, which can provide a complete door-to-door service, so that these trucks will be the main competitors for the small inland ships on the small waterways.

The second type of competition is the competition of the large ships (of 1,350 tonnes and larger) on the large waterways. Due to the economies of scale of the larger ships they can transport cargo for less cost per load unit than the smaller ones. Therefore, the small ships cannot compete with the larger ships on the large waterways. Small (and medium-sized) inland ships can be used to transport cargo to companies located at large waterways if only small call sizes are required. However, the small inland ships will mostly sail to destinations or origins at small waterways and therefore their biggest competitors, as mentioned before, are the trucks. An exception can occur when the water levels on the large waterways are low and the large ships cannot be completely loaded so that small ships can compete with the larger ship.

The third type of competition is the competition between the small inland ships. All the small ships operate on a standalone basis and have little to no market power. From table 3.1 it can be concluded that 87% of all the vessels registered in the Netherlands and 93% of the vessel in Belgium are one-vessel companies.

Table 3.1: Overview of inland shipping companies in the Netherlands and Belgium in 2002

	Enterprises Netherlands		Belgium	
	Actual	Percentage	Actual	Percentage
1 vessel	2930	87%	1058	93%
2 vessels	230	7%	51	5%
3 vessels	73	2%	11	1%
4-5 vessels	56	2%	7	1%
6-10 vessels	39	1%	5	0%
10-20 vessels	28	1%	1	0%
20+ vessels	9	0%	0	0%
Total	3365	100%	1133	100%

Source: BVB, 2009 (Netherlands), FOD economie 2008 (Belgium)

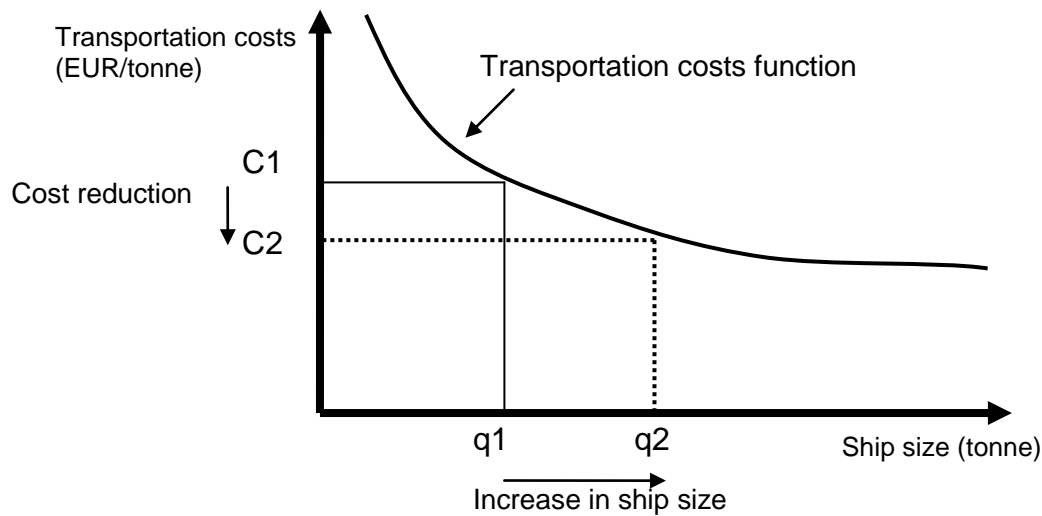
This internal competition is so severe that it is very difficult to start up a business with old second-hand small ships. If a new starting captain wants to operate a small ship, his costs calculation will need to take into account completely the loan, repair and maintenance, fuel and his salary. Owners who have had a ship for years have already paid off the loan. They may be expecting to stop the business in the near future (within 2 to 5 years) and therefore will only sail occasionally when offered some cargo, only charging the operating costs of the vessel (fuel and crew costs). Therefore, the new captain of a second hand vessel cannot compete with these old small-inland ships.

The last type of competition is with intermodal transport. Larger ships can be used for sailing on the large waterways towards an inland terminal (with economies of scale leading to reduction in transportation costs), from where a short distance can be driven with a truck to a company located at a small waterway.

### 3.2.2 Economies of scale

As a result of the competition between road transport and large inland ships and the small inland ships only bigger new ships are being built. These bigger ships can transport cargo at lower costs (and therefore also lower price) than smaller ships (= economies of scale). The economies of scale are illustrated in figure 3.2.

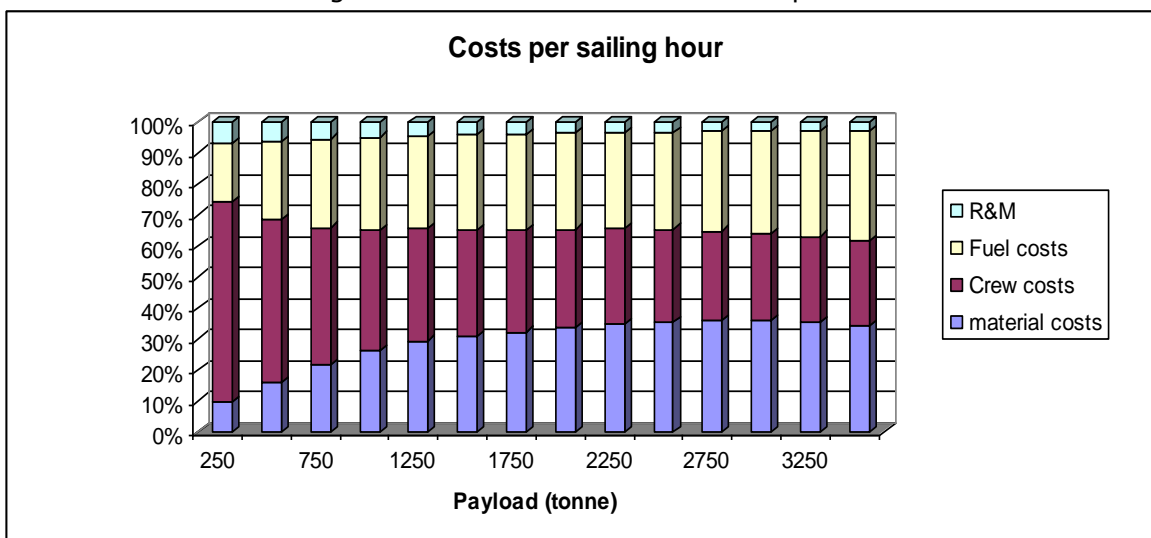
Figure 3.2: Concept of economies of scale



As a result, no new-medium sized ships (<1,500 tonne) and especially no small ships (<600 tonne) have been built for the last 40 years (BCI, 2008).

Figure 3.3 represents the costs structure of the inland ships. If one looks at the cost structure of the small inland ships it can be concluded that the majority of the costs (more than 50%) are made up of crew costs. If the fuel costs are added, more than 70% of the total costs of the small ships are determined by those variable costs. These variable costs are much higher than the fixed costs. When the ship is increasing in size, the ratio between the variable and the fixed costs is changed. The variable costs are substituted for fixed costs. This substitution can be explained by the fact that fewer crew members are needed per tonne transported cargo on larger ships than on smaller ones, while larger ships will have a higher purchase price.

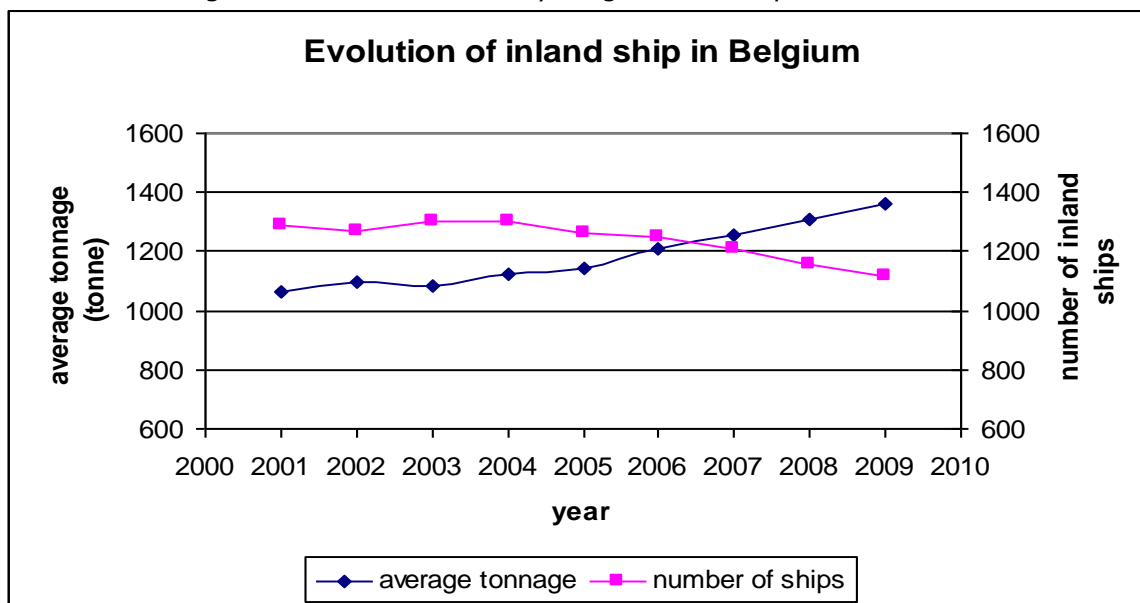
Figure 3.3: Cost structure inland ships



Source: NEA, 2003

The effect of an increase in scale in the inland fleet can be found in figure 3.4. It shows that there is an increase in the average tonnages of the inland ships while the number of ships sailing on the inland waterways is reduced. This means an increase in scale for the inland fleet and a reduction of the number of small ships.

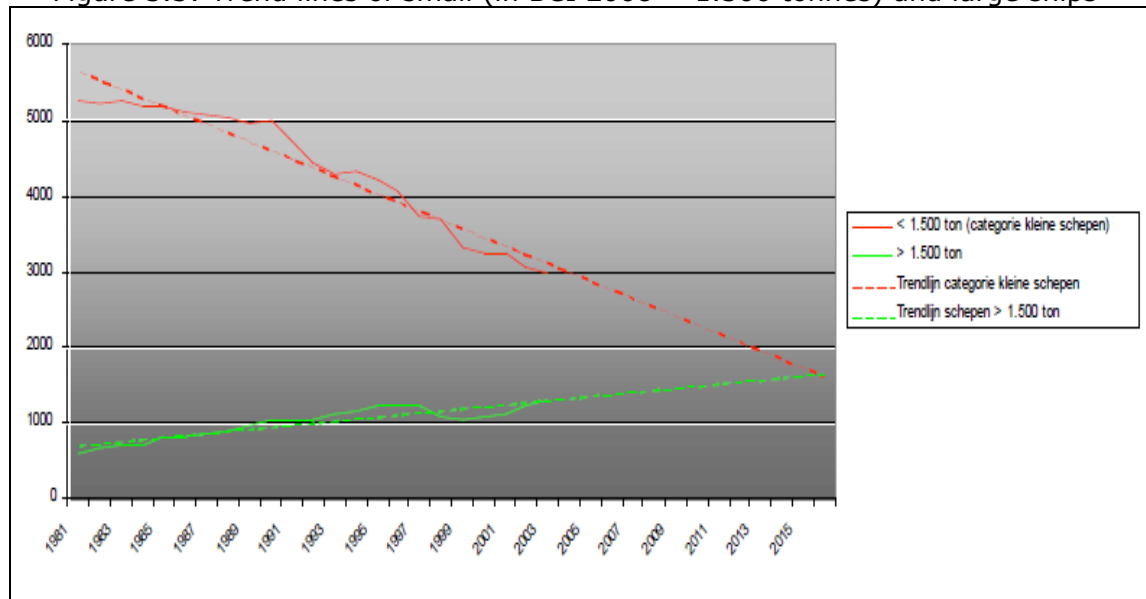
Figure 3.4: Evolution of dry cargo inland ship in Flanders



Source: ITB, 2010

In BCI (2008) the same trend can be found for the Dutch inland fleet. In figure 3.5 the evolution is given of the number of small and large ships. In this figure, the trend up 2003 is extrapolated to the year 2015 (linear extrapolation).

Figure 3.5: Trend lines of small (in BCI 2008 < 1.500 tonnes) and large ships



Source: BCI, 2008

### 3.2.3 Banks

The banks will not invest easily in new small inland ships as these ships cannot be exploited economically with the risk being too high. The risk can be divided into three different types (Stopford, 1997):

- Economic risk
- Operating risk
- Shipping market risk

The first risk relates to the global economy and how that will influence the demand for transportation. The second risk relates to the management capacities of the ship owners and how well the barges are maintained. The third risk is where ship owners are exposed to the competition of other ship owners (large and small) and road and train transportation.

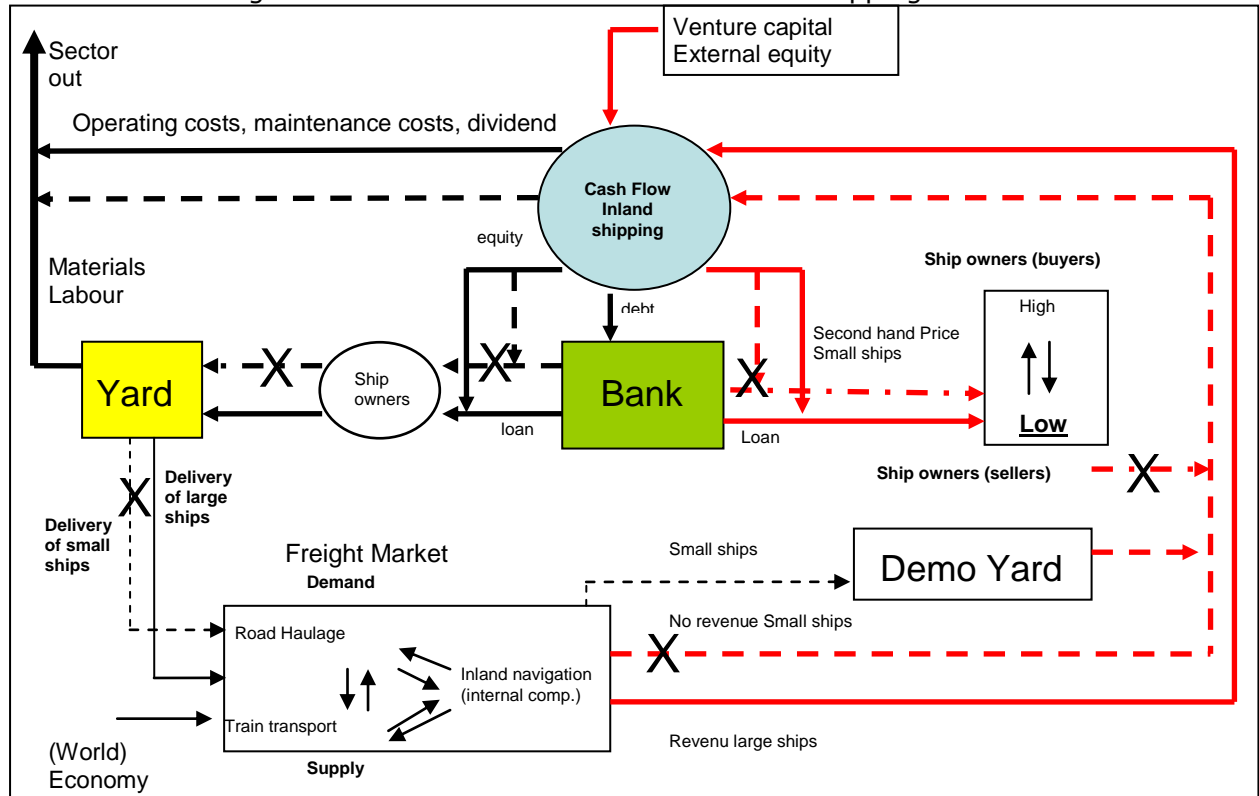
A bank wants to minimize its risk when it is investing in (small) inland ships. The first two risks are risks that all ship owners have to deal with and are relatively unrelated to the size of the ship. Only for the third risk is there a distinction according to the size of the ship. Due to the severe competition between the large ships on large waterways and truck transportation on the short distances (and small waterways) (see also section 3.2.1), the prices in the market are not high enough compared to the costs of operating a small ship on a sound economic basis. The ship owners will not make any profit, and therefore they will not have enough money to invest in new ships as a replacement for the old ones or to repay a loan in order to buy the ship. Therefore a bank will not invest easily into new small inland ships. Also, as the image of the small inland ships is often not so good, banks and investment companies are not too eager to invest in (new) small ships.

In figure 3.6 the schematic overview is presented of the cash flow in the inland navigation market, including the position of the bank. The thick lines



in the figure represent the cash flows in and out of the total inland shipping system. The thin lines represent the delivery of ships from a shipyard to the shipping market or from the shipping market to the scrap market. The red lines represent the cash flow in the inland shipping sector, while the black lines are cash flows out of the shipping market. The dashed lines represent the small inland shipping cycle, while the normal lines are for the larger inland ships.

Figure 3.6: Overview of cash flow in inland shipping



Source: own composition based on Stopford 1997 P.221

Figure 3.6 shows that the bank has a central place. In the shipping market, small ships are competing with the large ships and other small ships and even with other modes (predominantly road). As mentioned before, the lack of money and/or cash flow generated by the small ships is a major reason for banks not to grant loans to build new ships. Due to the bad market conditions of the small ships the banks also do not invest in loans for second-hand vessels. Therefore, the price of the small ships will drop because there are not a lot people willing to buy a vessel purely on their own equity. The result is that the current owners cannot sell their vessels and will keep on sailing until they are going to retire (see also figures 3.12 and 3.13). If then still no new owner is found, the vessel will be scrapped or rebuilt to become a living ship.

The bank plays a vital “pumping” role in the newbuilding of small vessels and if that pumping role comes to a stop, the total cash flow will dry out and the newbuilding of small inland ships comes to a hold.

### **3.2.4 Ship Owners**

As a result of the economies of scale of inland ships, the ship owner, potentially, can make more money with a large ship than with a smaller one if there is enough demand and if the larger ship can sail on the considered waterway. Till now, young starters bought an old small ship and sailed with that ship. After a few years, the ship was sold to a new starter and the bargeman would buy a larger newer ship. This "slowly growing" mechanism has come almost to a stop because it is easier to make a suitable business case with a large ship than with a smaller one. The new ship owner will therefore opt, also supported by the banks, for a large new-building ship instead of a (new or old) small one, especially in good markets (see also figure 3.11 and 3.12).

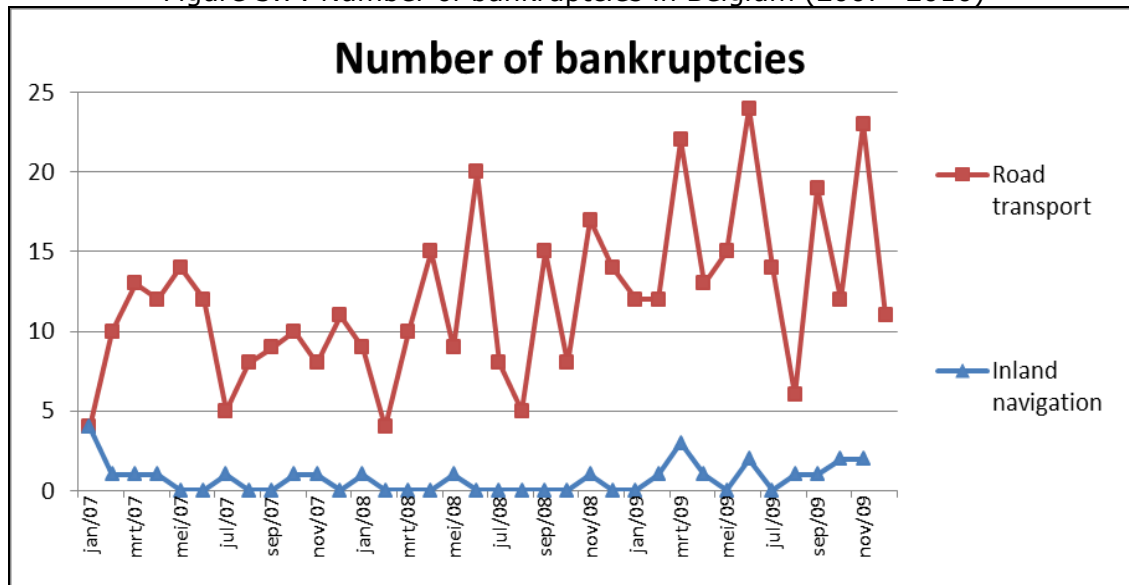
There are not a lot of people willing to live on a small inland ship due to the small living areas. The larger ships, on the other hand, have a much larger living area combined with the increase in comfort of that living area on newer ships. Therefore new captains (with their family) will opt for a newer larger ship instead of a small one (BCI, 2008).

Another, social, aspect is that not many families are willing to live together on a small inland ship these days. Therefore, the new captain of a small inland ship must take a mate on board and pay him the wages agreed in the common labour agreement. This will lead to an increase in costs, compared with the situation of small ship owner's partner living on the ship (mostly the wife of the captain) and counting as the mate of the captain.

### **3.2.5 Entry and exit barriers**

The competition between road haulage and inland navigation has already been considered to be one of the reasons behind the diminishing small inland fleet. Another aspect of the competition between road transport and (small) inland ships is that, when the market is bad, trucking companies can adjust their supply easier than small inland ships. A truck can be sold and the truck driver can start in another job. The owner of a small inland ship also lives at his ship so that he will not abandon his ship/house until the moment that he is really bankrupt. The exit barrier of inland (small) ships is therefore much larger than the exit barrier for trucking companies. This is illustrated in figure 3.7 where the number of bankruptcies in the inland navigation and road sector are given.

Figure 3.7: Number of bankruptcies in Belgium (2007 -2010)



Source: Meersman, et.al., 2010

Besides the exist barrier also the entry barrier for inland ships is much larger than that of trucking companies. In order to sail with a ship the captain must have all its certificates and he must have at least a minimum amount of sailing experience (FOMV 2010a). Also if a captain of a small inland ship has gone bankrupt he will not enter the market again because he will not take that risk again. But it is also very difficult for new captains to enter the market; if one captain abandons his ship, it will be very difficult to find a replacement.

Therefore, the adjustment of supply on the small inland waterways is much more difficult than it is for road transport. In economic downturns, there always will be an overcapacity of small inland ships so that the market prices will be low for a longer time.

### 3.3 Reduction of the small inland fleet

In the previous part, it was explained why no new small inland ships are being built. In this part, the question will be addressed why the existing small inland fleet is diminishing. First the reasons are given for a reduction of the number of small ships. The second part will deal with potential threats to the remaining part of the fleet.

#### 3.3.1 Reduction of the small inland fleet

*Ships are being sold to low wage countries*

There are a number of ships sold from western European countries to eastern European countries because these inland ships cannot be exploited economically in Western Europe. In table 3.2 an overview is given of recently sold inland ships.

Table 3.2: Overview of sold inland ships per tonnage class

	tonnage ships		
	<650 [tonne]	< 1,350 [tonne]	> 1,350 [tonne]
Destinations:			
East EUR	0%	53%	11%
West EUR	100%	47%	89%
total ships	13%	68%	18%

Source: GTS schepen, 2010

Table 3.2 indicates that if small inland ships are sold, they do not go to eastern European countries. These ships will stay in the Netherlands or Belgium. The percentage of small inland ships sold is low (13%), compared to the group of medium and large ships. This is an indication that the trade in small inland ships is very low (see also figure 3.6) and that small inland ships are demolished (see figure 3.7). Table 3.2 also indicates that for the medium-sized inland ships more than half of all the ships sold go to Eastern European countries. The largest ships will also stay within Western Europe and only a limited amount of those ships will be sold to Eastern European countries.

A limited amount of small ships that are traded will stay within the Netherlands and Belgium. This does not mean that the ships will be operated on these waterways because most of them will be rebuilt to become a living ship.

#### *Regulation/policy*

Changes in the inland shipping policy have had a large impact on the small inland fleet. Due to the market liberalization (abandonment of the "tour-de-role-system") and demolition rules (old for new regulations<sup>6</sup> 1989 and the demolishing rules 1989) a lot of small inland ships have been redrawn from the inland fleet (BCI 2008, Dullaert *et.al.* 1998).

The tour-de-role system can be described as follows. A country is divided into several districts with their own shipping exchanged. Charterers within the districts are required to request capacity (for domestic transport) from the exchange, where a register is kept of all available barges which meet certain requirements. The available freight is offered to the bargemen who are registered in the system. The bargeman who is the longest on the list is offered the first choice of freight. The charterer has to accept the barge which is assigned to his cargo on the condition that it meets certain criteria. If the vessel does not fulfil the requirements or if the bargeman rejects the cargo, then the cargo is offered for the second time. If after the second time still no carrier is found, the cargo can be chartered freely outside the tour-de-role-system. If a bargeman does not call on a load, his position will be retained in the system.

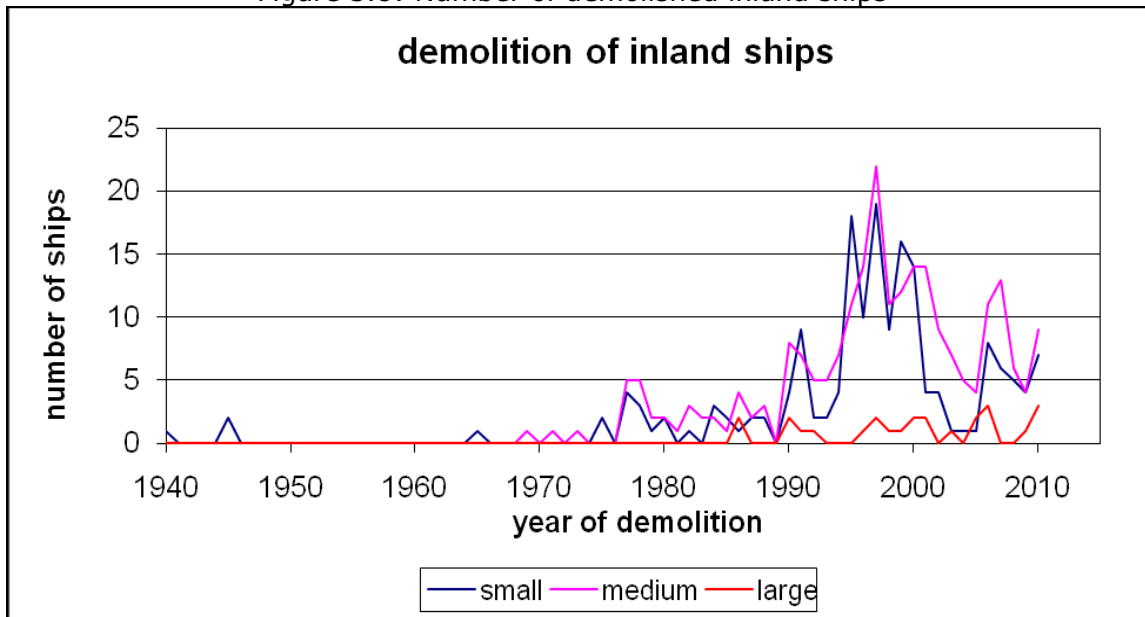
If an agreement is met under the tour-de-role system, the carrier and charterer are bound by the legal conditions of the carriage. If those

<sup>6</sup> Policy to reduce the overcapacity in the inland fleet. In order to build a new ship the same tonnage of the new ship has to be demolished first

conditions are not met, the authorities are entitled to refuse stamping the deal. There are, for example, standard freight tariffs that have to be respected (Dullaert *et.al.* 1998).

The abandonment of the tour-de-role system led to more competition and therefore stimulated the increase of the size of the ship. Due to the demolition rules, where ships have been demolished for a fixed price per tonne in order to reduce the overcapacity in the inland fleet, a lot of small old ships have been demolished. In order to build a new larger ship, the same tonnage of cargo carrying capacity has to be demolished first. As a result, a lot of small ships disappeared and new bigger ships returned in the inland fleet. The reduction of the inland fleet is illustrated in figure 3.8 where the demolition figures are given.

Figure 3.8: Number of demolished inland ships



Source: own figure based on debinnenvaart.nl, 2010

Note: the figures presented in this graph consist out of ships that have been demolished. Rebuildings are not in this figure.

Figure 3.8 shows that there is a large increase in demolished ships from 1990 to 2000. This increase is due to the previously mentioned old-for-new rules and the demolition rules. The old-for-new regulation ended on 29-4-2003. This can also be seen in figure 3.8. From that same figure it can also be concluded that after 2003 the number of demolished ships increased again. This increase is now not “fuelled” by rules and regulation but by market conditions (see previous section).

Besides the demolition and old-for-new regulations, the small ships must also comply with the new regulation for inland ships concerning the structure of the ship and emissions produced<sup>7</sup>. The investments to update the existing small ship to these new standards are higher than the market price of the small ships, so that an investment is not economically viable. As a result, these new rules could force the remaining small ships to stop their work if no exceptions are made for these small ships.

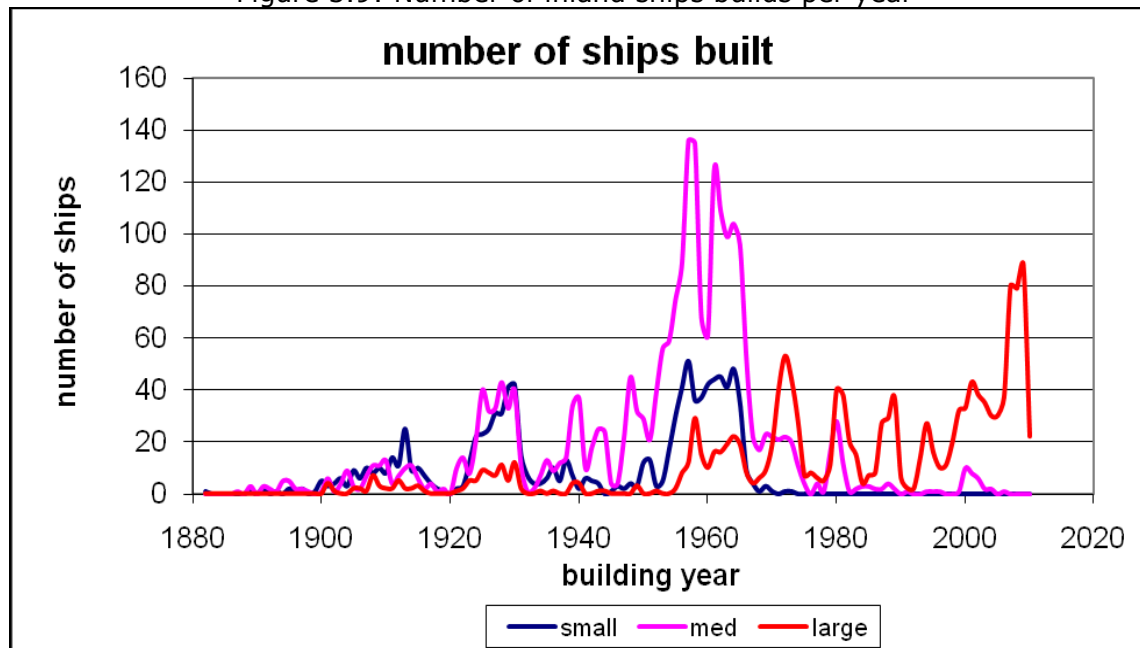
<sup>7</sup> double hull requirements and EURO V rules concerning emissions

### 3.3.2 Threats to the remaining small inland fleet

#### *Increase in fleet age*

The first threat is that the age of the fleet is increasing. The “newest” small ship that has been built dates from the 1960s. The average age of the (hull) small inland fleet is above 70 years. In figure 3.9, an overview is given of the number of inland ships built per year. The total database used to construct this graph consists of 5000 dry cargo ships and dry cargo push barges which represent more than 6,400,000 tonnes of cargo carrying capacity (6,000,000 tonnes if demolitions are included) (debinnenvaart.nl, 2010). This database is very large and therefore figure 3.9 will give a good overview of the current status of the inland fleet in Western Europe.

Figure 3.9: Number of inland ships builds per year

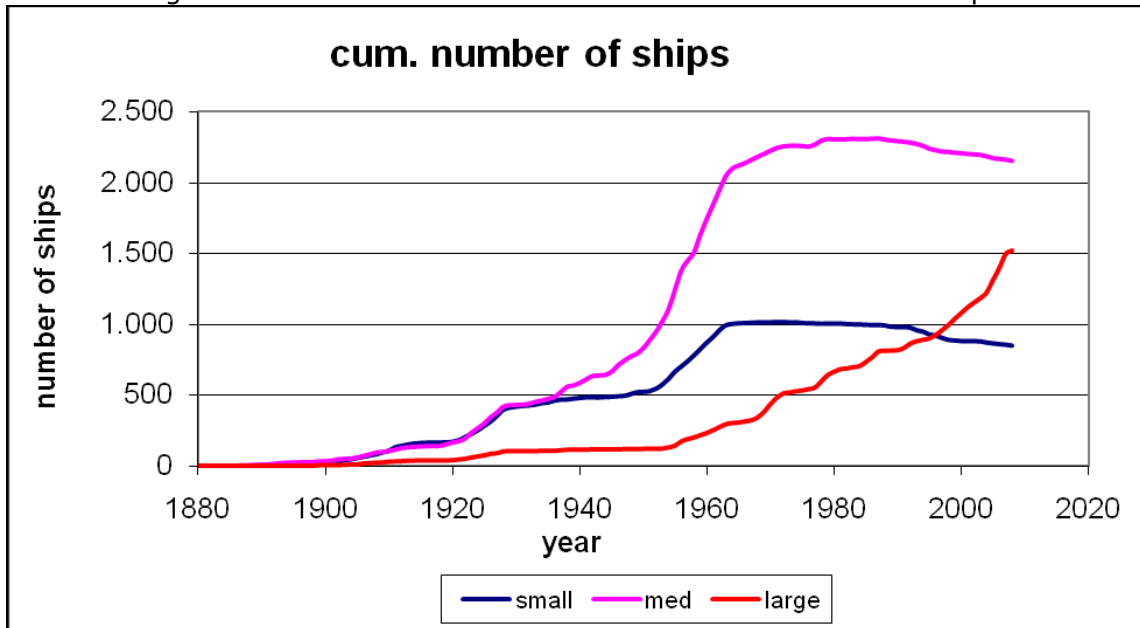


Source: own figure based on debinnenvaart.nl, 2010

Figure 3.9 shows that from 1965 the number of newbuildings of large ships has increased while the number of small and medium-sized ships has decreased. The number of small ships that have been built is even reduced to zero! It can also be seen that the number of small and medium-sized ships built has a peak in period from the 1920s, the post First World War era, after a lot of ships were demolished in the war and had to be replaced with new ones. A new peak occurred from the 1950s to the 1960s. This increase could have been the effect of the end of the Second World War, followed by an important economic growth. In that period the last small inland ships were built. In that period the new buildings consist of a mix of large, medium-sized and small ships. The second big increase in the number (and cargo capacity, see also figure 3.10) of inland ships is from 2000 to 2010. This increase is only caused by the addition of large inland ships. There is no more diversification in the newbuildings in the inland fleet.

If the data from figures 3.8 and 3.9 are combined, then the total number of existing ships per ship category can be determined. The result of the calculation is given in figure 3.10.

Figure 3.10: Overview of the cumulative number of inland ships

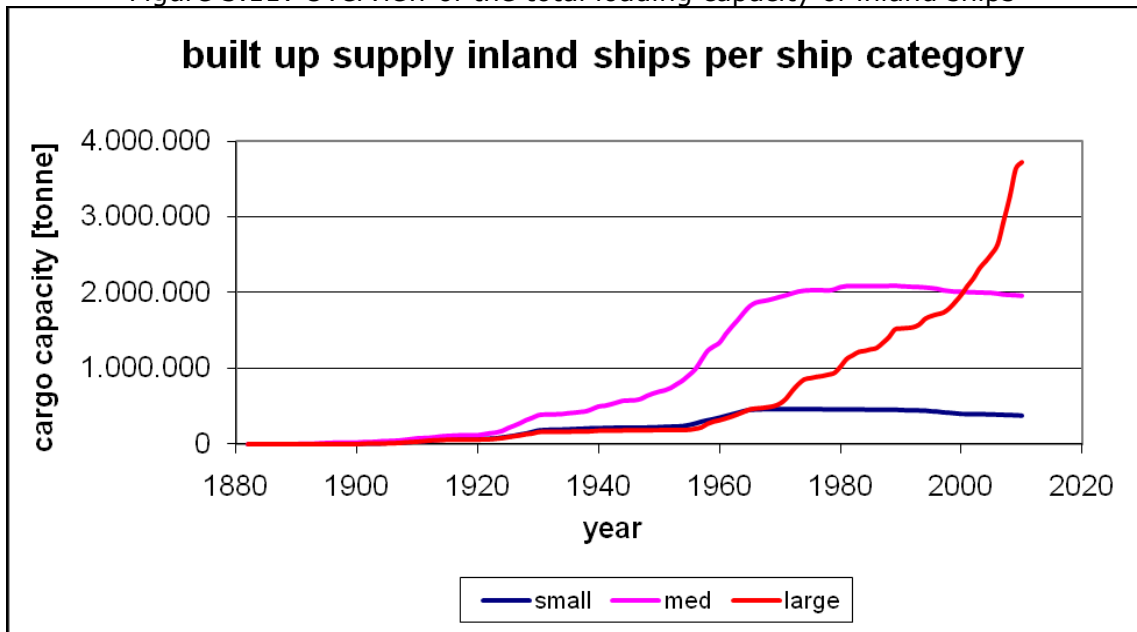


Source: own figure based on debinnenvaart.nl, 2010

From figure 3.10 it can be concluded that the number of small inland ships increased until 1965. From 1965 onwards to the mid-1990s the number of small ships is more or less constant. From 1995 up to 2010 the number of small inland ships is reduced due to the demolition of those small ships (see previous section). The same can be concluded for the medium sized ships. The number of large ships has increased from 1960 onwards.

In figure 3.10 an overview was given of the number of ships in the three different ship categories. In figure 3.11 the actual loading capacity for the three different categories is shown. This figure shows that in terms of loading capacity the large ships represent more than 60% of the total Western European dry cargo ship capacity.

Figure 3.11: Overview of the total loading capacity of inland ships



Source: own figure based on debinnenvaart.nl, 2010

From figure 3.11 it can also be concluded that in terms of loading capacity the small inland ships represent only 6% of the total loading capacity.

In table 3.3 an overview is given of the average age, number of ships and the total cargo capacity per ship category along with the demolition figures.

Table 3.3: Overview of main results of the ship database

	existing ships			demolished ships			Percentage Demolished [%]
	number [-]	tonnage [tonne]	average age [year]	number [-]	tonnage [tonne]	average age [year]	
Small	850	371.888	<b>70,30</b>	184	92.785	<b>64,12</b>	20%
Medium	2.156	1.962.532	<b>59,23</b>	255	222.213	<b>56,34</b>	10%
Large	1.525	3.719.589	<b>26,40</b>	29	48.145	<b>59,36</b>	1%
Total	4.531	6.054.009	-	468	363.143	-	-

Source: own representation based on: debinnenvaart.nl, 2010

Table 3.3 shows that only 6.1 % of the current day cargo carrying capacity of the total inland fleet is determined by small ships. Besides the modest contribution to the total cargo carrying capacity of the inland fleet, also the average age of small inland fleet is much larger than the average age of the large inland fleet (70 to 27 years). In addition, the table shows that on average the small inland fleet is 6 years older than the average demolition age! It is therefore expected that the lifetime of the existing small inland ships is reaching its end.

These small ships are now not only at the end of their economic life but also at the end of their technical life. If the hull is maintained properly, it can last for more than 100 years. This is what is also shown in figure 3.9. There are ships registered where the hull was built at the end of nineteenth century! The problem is that the engines, propellers, bearings have to be replaced every 20 to 30 years (bearings are replaced in smaller time intervals). When the small ships are too old and have too low a value, the investment in new engines and new navigation equipment can become too



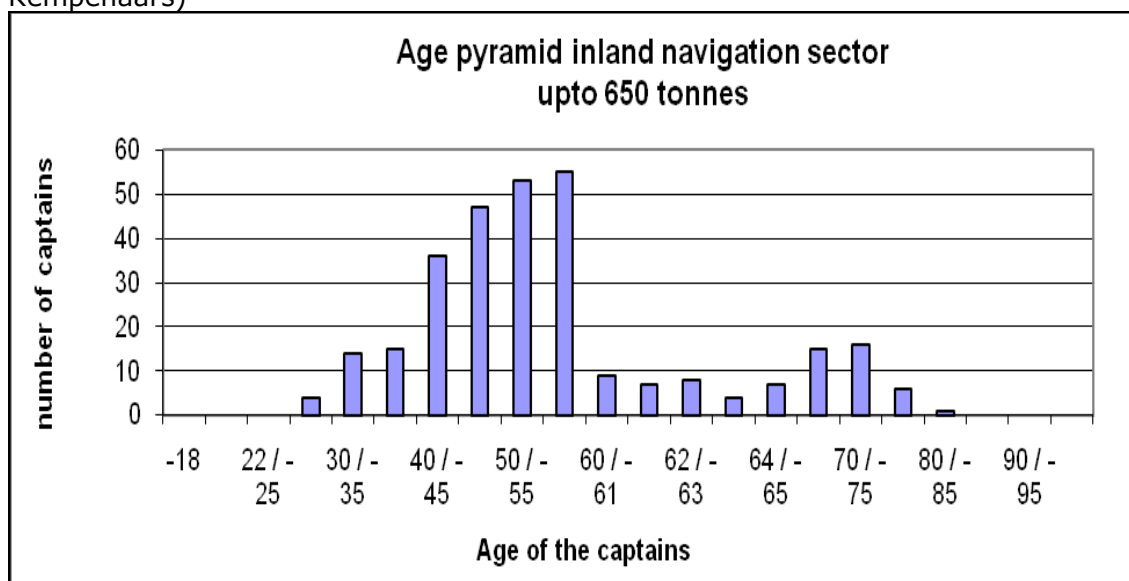
large, so that it is not feasible to keep on using these ships. In that case, those old small ships will be demolished or they will be rebuilt to become a living ship. The demolition of the small inland ships was already shown in figure 3.8.

Due to the increase in number of large ships (and also their respective capacity) an overcapacity in the large inland shipping segment is most likely to occur. Combined with a reduced sailing area, heavy competition between those ships is expected. As a result, small tonnages (cargo flows) with an origin or destination at a large waterway will then be transported with larger ships instead of smaller ones. However, bigger ships cannot transport small sizes of cargo as economically as smaller ships. As a result, the transportation price has to increase and the competitiveness towards road transport will be reduced.

### *Increasing captains' age*

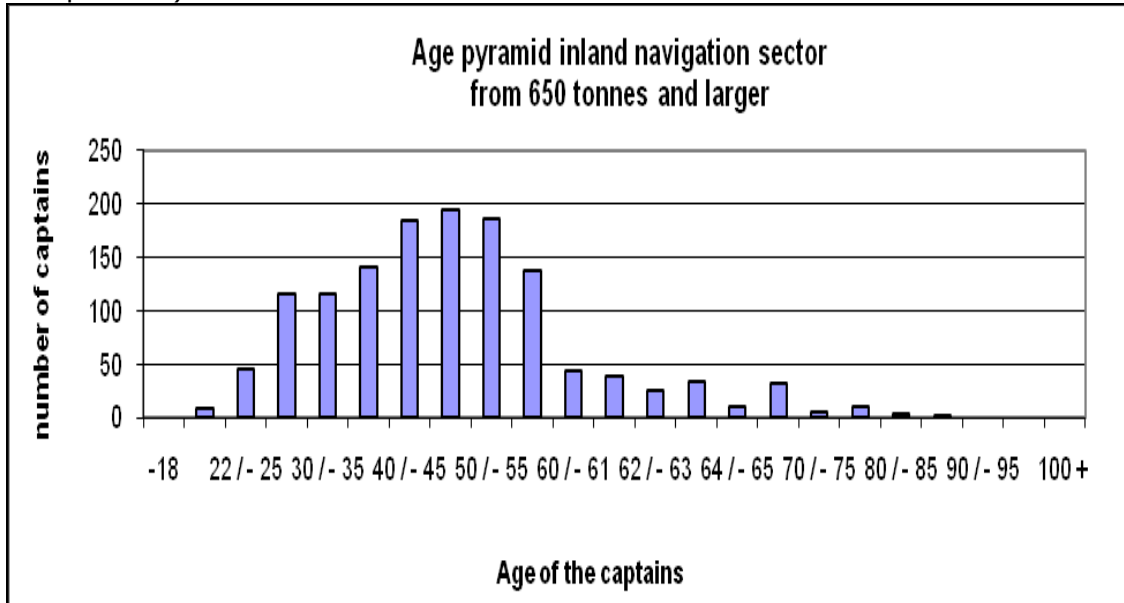
There are hardly any new captains starting up a business with a small ship, so that the average age of the captains of the small ships is increasing. In figure 3.12 the age pyramid of the captains of the small inland fleet in Belgium is shown while in figure 3.13 the age pyramid is given for the captains of the ships larger than 650 tonnes.

Figure 3.12: Age pyramid of the captains of the small inland fleet (excl. Kempenaars)



Source: FMOV, 2010b

Figure 3.13: Age pyramid of the captains of the medium and large inland fleet (incl. Kempenaars)



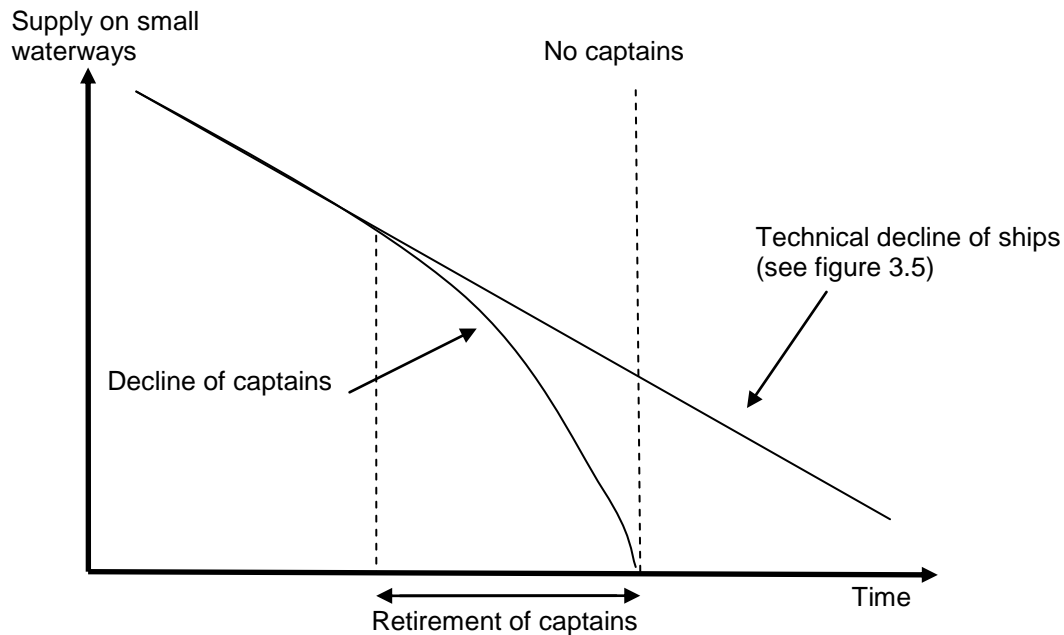
Source: FOMV, 2010b

From figures 3.12 and 3.13 it can be concluded that there is a very small group of young captains on small inland ships. As mentioned before, that is due to the decrease in inflow of starting captains in the small inland fleet. Figure 3.13 shows that for the larger ships there is a group of young starting captains. 8% of all captains below 40 years of age have a small ship. The graphs also show that there is a small group of very old captains (65/70+) that are still registered. A possible explanation could be that these captains are still living at their ships because they have no house on shore. If a ship is still registered as a "cargo-ship", it can be moored at more available places than if registered as a "living-ship". However, as these captains will not sail frequently, their participation in the normal shipping routine is very small.

Figure 3.12 also indicates that most of the existing captains on the small inland ships are reaching the end of their professional working life (average age of 53.04 years against 46.04 years for the larger ships) within 5 years. As a result, the old small ships available will not be used due to a lack of captains. Due to a reduction in the number of captains it could be expected that the remaining part of the captains with a small inland ship will have enough market potential to survive. On the other hand, companies want to have a reliable transportation mode that will operate for years to come. If the remaining captains cannot provide that service for a longer period because they are retiring in the near future, then the companies located at the small waterways will have to shift their cargo to road haulage which can provide continuity.

Because the problems concerning the small inland ships are not only related to the ships, but also to the lack of new captains for the small inland ships, the decreased supply on the small inland waterways will not be linear as in figure 3.5 but it will decrease faster due to a lack of available captains. In figure 3.14, this is shown graphically.

Figure 3.14: Schematic overview of diminishing supply of small inland ships



Source: own composition

The decline of available captains on the small inland ships will therefore be the most dominating factor in the decline of supply on the small inland waterways.

#### *Risk of under-maintained small inland waterways*

The last threat to the small inland shipping fleet will be insufficient maintenance of the small inland waterways. If the depth of the waterways are not maintained by dredging, the depth will be reduced so that the draft of the vessels is reduced limiting their cargo carrying capacity. This reduction can be as much as 100 tonnes if the draft is reduced with 30-50 cm (Kempenaar draft 2.5m → 2.0m). Due to the decreased cargo-carrying capability the transportation costs per unit will increase because the transportation costs remain (almost) constant (a decreased draft will also result in a decrease in resistance and therefore also in fuel costs but this decrease is very small). As a result the competitiveness of the small inland ships will decrease even further.

The waterway administrators have a limited budget available to maintain their infrastructure (€14,900,000 in 2005). The cost of maintaining their infrastructure, such as dredging, is increased. The cost of dredging a cubic metre of sand increased from €1.5/m<sup>3</sup> (1980) to €60/m<sup>3</sup> (2006), while the budget did not increase proportionally (Infrastructuur masterplan, 2010). As a result, the waterway administrators are forced to make choices and they will maintain (and invest) in inland waterway infrastructure which is used the most, although in 2008 there was a one-time investment of €3,500,000 for maintaining the canal Dessel-Turnhout-Schoten (class II waterway) (Infrastructuur masterplan, 2010). There may be a risk of a vicious circle: due to issues mentioned previously, the small inland waterway infrastructure is used less, so that the waterway administrators will invest less in the small waterway infrastructure, which will result in even less use of the small inland waterways, due to their limited depth.

### 3.4 (Small) Inland ships in deep-sea ports

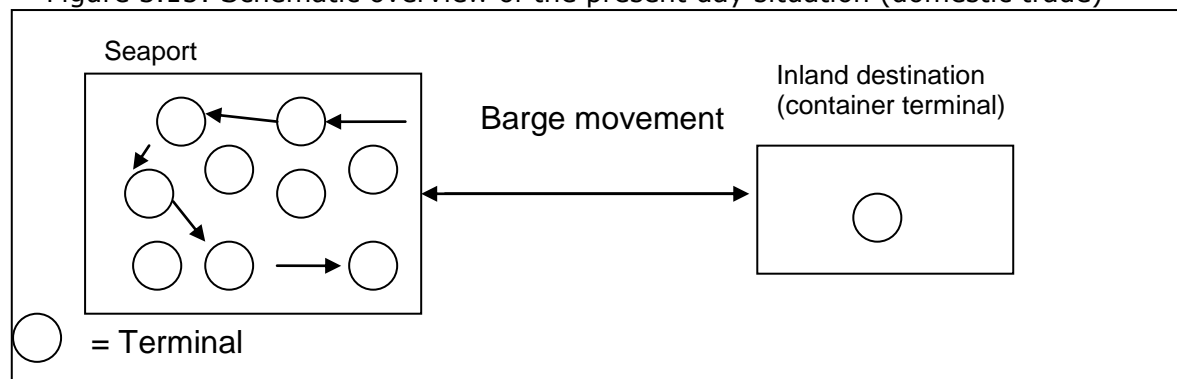
Inland ships are perfectly suitable to deal with the hinterland transportation of cargo loaded or unloaded at deep-sea ports. In the port of Rotterdam, 33 % of all the containers transported to its hinterland are transported with inland ships in 2009 (Port of Rotterdam, 2009). For the port of Antwerp this is 34.8% (Port of Antwerp, 2009). In this section the situation for container transport with inland ships to and from deep-sea ports will be described. Also the situation for bulk transportation is explained. The last part of this section deals with the consequences of (small) inland ships at deep-sea ports.

#### 3.4.1 Container transportation

The present-day situation of container transport for inland ships at the ports of Antwerp and Rotterdam can best be divided into to a threefold typologies<sup>8</sup>.

The first type is the market of the domestic trade of the containers. In this trade one (inland) terminal in the hinterland is visited and numerous terminals in the seaport are visited. The containers that are loaded in the hinterland will have different (overseas) destinations so that several deep sea liners will transport those containers and that the inland ship will have to call at different terminals in the seaport. The call size per terminal is in 50% of the calls less than 6 TEU (Konings, 2007). Consequently, the inland ship will spend a lot of time in the seaport, especially if the waiting time at the terminals and the movement from terminal 1 to terminal 2 are taken into account. On average a 150 TEU inland ship will spend only 1/3 of her total port time at a terminal loading and unloading. The rest of the time the ship has to wait at the terminal or the ship is sailing between terminals. A schematic overview of this situation is given in figure 3.15.

Figure 3.15: Schematic overview of the present day situation (domestic trade)



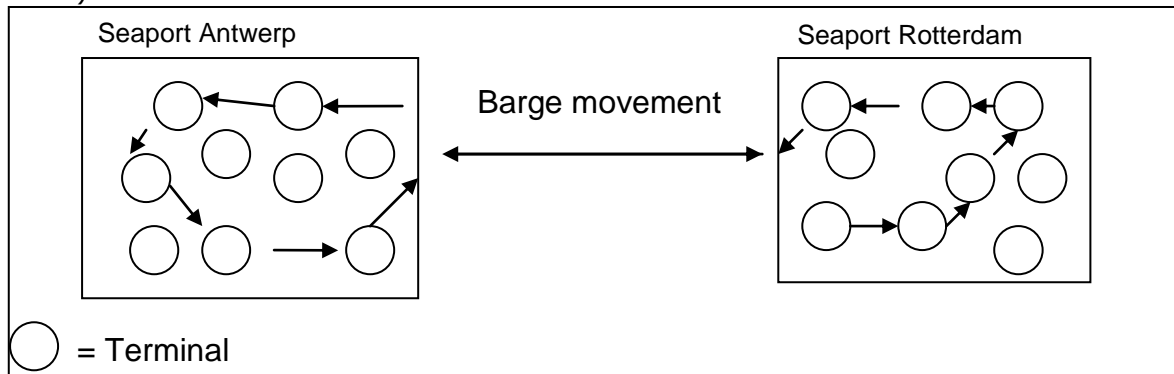
Note: based on Konings, 2007

The second type that can be distinguished is the container trade between Antwerp and Rotterdam. In this trade, large ships are used to transport containers between the two ports. Also these ships will have to call at different terminals because these ships will also transport containers with different overseas destinations. This trade is characterized by the relocation

<sup>8</sup> This distinction is adapted from R. Konings (2007)

Chapter 3: Decreased supply of small inland ships on the (small) inland waterway network (shuffling) of the containers between the two ports so that different terminals need to be visited. In figure 3.16 the schematic overview of this trade is given.

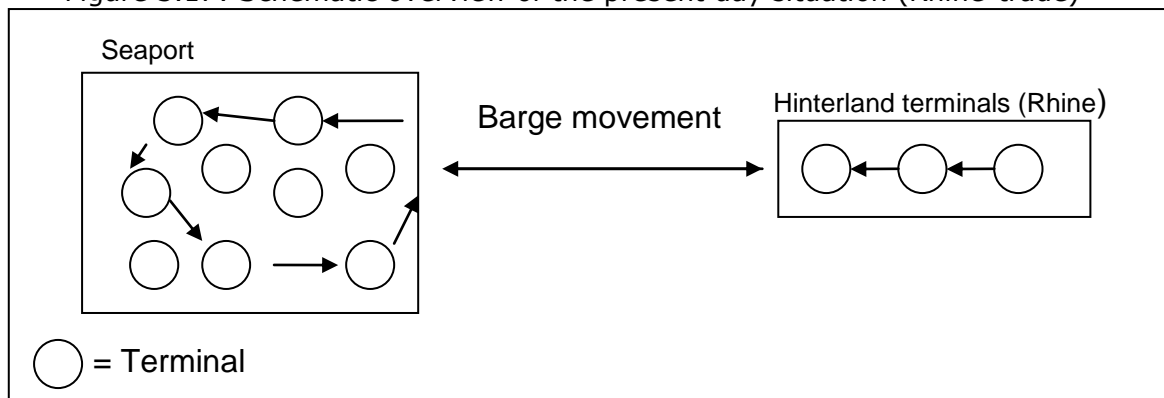
Figure 3.16: Schematic overview of the present day situation (Rotterdam-Antwerp trade)



Note: based on Konings, 2007

The third type is the trade of containers from the deep seaports of Antwerp and Rotterdam that have a destination in the Rhine regions (Germany and Switzerland). In this trade the containers are transported with large inland ships (>150 TEU) that will call at several (+/- 10) terminals in the seaport and (on average) 3 to 5 terminals in the hinterland. This is also due to the different overseas origins or destinations of those containers so that more deep sea liners are used to transport the containers that are transported by the same inland ship. In figure 3.17 a schematic representation of this type is given.

Figure 3.17: Schematic overview of the present day situation (Rhine-trade)



Note: based on Konings, 2007

The different types of container trades shows that inland ships dealing with container transport will have to call at a large number of terminals in the seaport with a limited number of containers per call (50% of the time less than 6 TEU). Also the time spent in port is very important due to the time needed to sail to and from the different terminals and to the waiting time at the different terminals. As a result, the costs per TEU will increase because the number of departures per week is reduced (= reduction of the economies of density).

The container terminals will also experience hindrance from inland ships which will deliver only 6 TEU per call. The number of dockworkers that are

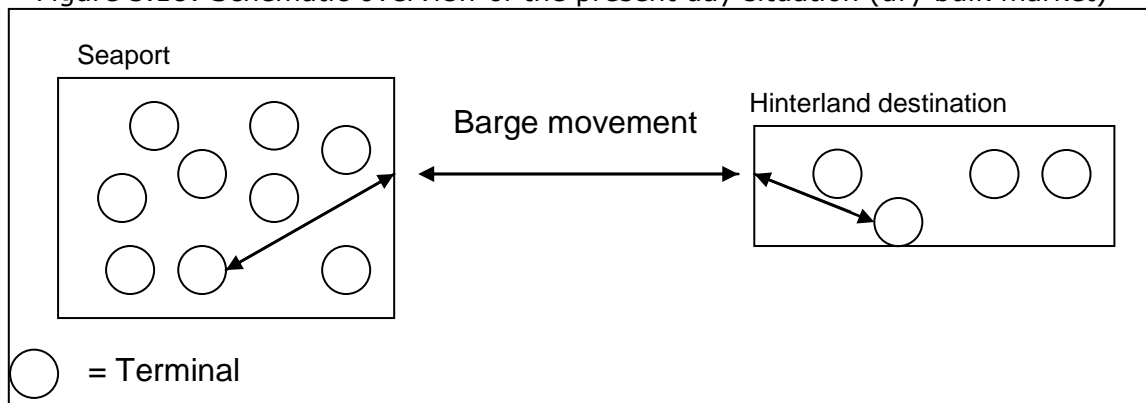
needed to handle a ship at a terminal is not determined by the call size of the ship. Therefore the costs per handled TEU could be reduced if more containers are unloaded at one call. In addition, the terminal handling costs will influence the total costs very much when the sailed distance is short (<100 km). If the distance is large (such a Rhine-trade), then the biggest part of the costs are made up by the transportation costs of the inland ship, while for short distances (Rotterdam-Antwerp trade and domestic trade) the transportation costs play only a small role in the total out of pocket costs. On those trades the biggest advantage can be obtained in the seaport.

### 3.4.2 Dry bulk transportation

The dry bulk market could best be described as a point-to-point connection between either a seaport terminal and an inland destination or an inland origin and an inland destination. In the figure 3.18 the schematic representation of the dry bulk trade from the seaport to an inland destination is given.

The destinations in the hinterland are also the end-users of the transported cargo. The cargo is directly transported to the companies located at an inland waterway. Examples of these trades are the large cargo flows of bulk material (iron ore, steel, sand, etc) from the port of Rotterdam to the German Ruhr area. A part of this trade is done with large push barge convoys operated by ThyssenKrupp Veerhaven BV. These push barge will be loaded at different terminals in the same seaport where these loaded barges are coupled in the seaport and are transported to the final destination in the hinterland (Burgers, 2005).

Figure 3.18: Schematic overview of the present day situation (dry bulk market)



Note: own figure

An example of the other type of dry bulk trade (inland origin and destination) is the transportation of sand from an inland gravel pit to a cement factory which is also located at a waterway. Also other types of dry bulk cargo are transported between different inland origins and destinations.

### 3.4.3 Consequences of (small) inland ships at deep-sea ports

If the two different transported commodity types are compared, it can be concluded that in the container transport the inland ships will lose a lot of time in the seaport. As a result, the total transportation costs are increased

due to the reduction in the economies of density. In order to compensate for this increase in costs, the size of the ship has become larger (increase in economies of scale). The sailing costs per TEU are reduced so that the increase in port residence costs can be compensated for. Therefore, small inland ships cannot be used for the transportation of containers from a deep-sea port to origins or destination at small inland waterways unless there is direct call at one terminal in the seaport (Cargill, see chapter 2). The deep-sea terminals will act as a barrier for the use of small inland ships for container transportation.

For bulk transportation, there is a direct call at one deep-sea terminal and one direct call in the hinterland so that for this type of transportation the deep-sea port will not act as a barrier for using smaller inland ships.

### **3.5 Impact of losing the small inland ships**

Another consequence of the diminishing small inland fleet is that the diversity in the total inland fleet will disappear. The new ships that are being built are increasing in size (see figure 3.10) and therefore the available sailing area of these ships is reduced because the large ships can only sail on a limited number of inland waterways. This explains a large risk that there will be only large inland ships left while more than 50% of the inland waterway network can only be reached with smaller (<650 tonne) ships. Because still a lot of large inland ships have been added to the market, in combination with their reduced sailing area, a heavy competition between those large ships is expected. Normally, when there is a heavy competition a lot of shipping companies will go bankrupt.

However, the shipping companies with large inland ships have the same exit barriers as small inland ships (see section 3.2.5). Moreover there is an additional exit barrier for the largest ships. This extra exit barrier is the bank which has financed the large inland ship. The banks will not let the shipping company go bankrupt. The reason why they do not let the shipping companies go bankrupt is that the ship itself will not disappear from the market if a shipping company has gone bankrupt. So the competition will still exist even when the shipping company is bankrupt. Normally the value of the ship will go down (because there is downturn in the market) so if a new ship owner has bought the ship he could earn money with the ship because its fixed costs are reduced (due to the lower ship value). But if this happens, the bank will have to reclaim the loss of the value of the ship on the initial owner. Because he is bankrupt he cannot repay the total loan so that the bank has to write off a large sum of money. It is therefore not in the interest of the bank to let the shipping company go bankrupt. Therefore these large ships will stay in the market (the ship owners can stop, for a limited period, with repaying its loan) with the help of the banks.

As a result small tonnages (cargo flows) will be transported with large ships instead of smaller ships to destinations on large waterways. Consequently the remaining small inland ships will be pushed out of the large waterways by these bigger ships (their potential market is decreased) (see also figure 3.1).

### 3.6 Infrastructure capacity

In order to deal with the current demand and, potential, additional demand in the future for road transportation an increase extra infrastructure capacity is needed. The available road and railway network do not have a lot of spare capacity so that additional infrastructure needs to be built. Because those networks are not exclusively used for cargo transportation (an exception is for example the Betuwe railway line in the Netherlands), those networks also have to deal with passenger transportation. The inland waterways do not have a capacity problem and person transport does not use the waterways for day-to-day transportation (an exceptions is, for example, the fast ferry from Dordrecht to Rotterdam), so that the available infrastructure can be used to deal with a large part of the transported cargo flows. But due to the reduction of the number of small inland ships, a large part of the available inland waterway network will be used less while that capacity is very much needed.

Besides the spare capacity of the waterways and the consequent absence of need for new investments, the maintenance costs of the waterways are less if they are compared with the other modes. These costs per kilometre of infrastructure can be found in table 3.4.

Table 3.4: Overview of the maintenance costs per km for the different modes

Road	Rail	Inland
[EUR/km/Year]	[EUR/km/Year]	[EUR/km/Year]
36,000	29,500	27,000

Source: Pausenberger L.; 2009

The general maintenance costs of an inland waterway are considered in CE Delft (2004) not to depend on the number of ships sailing on the waterway. If the number of ships is increased, the costs of maintaining the waterway do not increase. The reduction of water depth is dependent on time and not on the number of ships passing through that waterway. The water depth can even be considered to be maintained if a lot of ships are sailing through a shallow waterway. The banks of the waterways could be damaged more if more ships are passing. However, a lot of canals have concrete water banks so that the deterioration of those banks is hardly influenced by the passing of ships. When looking at user-dependent maintenance costs of inland waterways, these depend on management costs such as lock guards, waterway police, etc. But those management costs can also be considered to be not directly dependent on the number of passing ships on the specific waterway. If a lock has to be operated for 24 hours a day, then these costs do not increase if there is an increase in ships passing through that lock. Only if the number of passing ships is reduced very much, should the locks possibly not be operated 24 hours a day and then the costs can be reduced. Also the locks themselves do not need more maintenance if the number of passing ships is increased. Only the moving parts of the locks are affected and not the lock door itself for instance.



### 3.7 Impact of losing the small inland waterways

In order to determine the impact of 'losing' the small inland waterways, a calculation will be made where all the cargo that is now transported via the small inland waterways in Flanders will be transported by road. Train transportation is left outside of consideration, because the companies located at the small inland waterways are not (or not directly) connected to the train network. This means that the number of vehicle kilometres will increase due to the fact that road trucks cannot transport as much cargo as inland ships per shipment. This increase in vehicle kilometres will have an impact on the external costs (emissions and congestion). In figure 3.19 the considered small inland waterways were shown, whereas in table 3.5 the amount of cargo transported per year with an origin or destination at the considered waterways is given.

Because the destination or the origin of the considered cargo flows are not known, the average performed distance of 66.89 km per trip of inland navigation on the Belgian infrastructure (FOD Economie, 2009) is used to determine the amount of preformed tonne\*km.

Figure 3.19: Overview of the different small waterways in Flanders



Source: original figure from PBV

Table 3.5: Cargo flows on small inland waterways

	Waterways	2009
		[tonne]
(1)	Dessel-Turnhout-Schoten	882.228
(2)	Bocholt-Herentals	1.525.855
(3)	Zuid Willemsvaart	661.054
(4)	Dender	521.822
(5)	Leuven-Dijle	412.203
		4.003.162

Source: WenZ and Scheepvaart NV cargo flow data, 2009

The external costs of the two considered modes are given in table 3.6. The external costs are composed of air quality (emissions), climate costs (CO<sub>2</sub>), accident, noise, congestion<sup>9</sup> and infrastructure costs.

Table 3.6: External costs per tonne and vehicle kilometre

	Air quality	Climate	accidents	noise	Congestion*	Infrastructure*
	[EUR/tonne *km]	[EUR/vehicle *km]	[EUR/tonne *km]	[EUR/tonne *km]	[EUR/vehicle* km]	[EUR/vehicle *km]
Inland ships	0.0004	0.0060	0.0001	-	-	-
Road Haulage	0.0015	0.0023	0.0032	0.0006	0.4233	0.0015

Sources: Standaardmethodiek MKBA (MOW, 2006), p. 152, values 2020 projection,  
\*Acradis et.al 2009, p.119 (2020 projection)

The result of the calculation is given in table 3.7, where it shows that the number of vehicle movements increases significantly so as the number of vehicle kilometres. As a result, the external costs increase from €240,000 to €6,400,000 (2020 projection).

Table 3.7: Results of external costs calculations per year

	number of vehicle movements	tonne*km	Vehicle*km	ext. Costs
inland shipping	6,758	271,217,144	452,029	<b>€239,575</b>
Road haulage	168,945	271,217,144	11,300,714	<b>€6,407,505</b>

Source: own calculation

Besides the fact of this increase in external costs, the large network of small inland waterways will not be used while this infrastructure could play a vital role in providing an alternative to the already heavily congested road network.

### 3.8 Preliminary conclusions

The supply on the small inland waterway network is diminishing mainly due to too server competition from road transportation. This has resulted in five main observations:

- No new small inland ships are being built
- Technical decline and withdrawal of the existing small inland fleet
- Limited to no inflow of new young captains for the small inland fleet
- Reduction of the available captains
- Insufficient maintenance of the small inland waterway infrastructure

A consequence of the diminishing small inland fleet is the inevitable disappearance of diversity in the total inland fleet. The new ships that are being built are increasing in size and therefore the available sailing area of these ships is reduced because the large ships can only sail on a limited number of inland waterways. There is consequently a serious risk of being left with only large inland ships, while more than 50% of the inland waterway network can only be reached with smaller (<600 tonne) ships. Due to an increasing number of large ships (and also their respective capacity), an overcapacity in the large inland shipping segment will occur.

<sup>9</sup> In chapter 12 will deal in more detail about the reasons why the congestion costs are taken into account

Because of this, in combination with a reduced sailing area, heavy competition between those ships is expected.

With respect to the small inland waterway infrastructure, the diminishing small inland fleet in Flanders will lead to a shift of 4,000,000 tonnes of cargo, from the waterways to the road. Those tonnages are added to the already heavily congested roads. These extra tonnages and the further increase in cargo flows will lead to more investments in expanding the road capacity, while the available infrastructure of the small waterways will not be used at all. This capacity is very much needed to deal with a large part of the total tonnages to be transported. As the waterways are cheaper to maintain than roads and as they are already present, therefore no new infrastructure investments are needed to deal with a large part of the total transported tonnages. The maintenance costs of the existing waterways will hardly be influenced due to a potential increase of ships sailing on those waterways so that no large increase in maintenance costs of the small waterways is expected.

The reason why almost no small inland ships are used to transport containers from a deep-sea port to destinations in its hinterland (except dedicated transport from a container terminal a hinterland destination) is due to the small call sizes at the deep-sea terminals. Therefore these ship will not get priority at the deep sea terminals so that those ships will experience a large waiting time in the port. These large port residence costs will decrease the number of trips that can be made per year and the costs per TEU are increased (decrease in the economy of density). The deep-sea terminals will act as a barrier to using small inland ships for container transportation.

Due to a growing awareness of environmental care and carbon footprint, the EU member states want to stimulate the use of the modes producing the lowest amount of emissions per preformed tonne\*km. These emissions in transport could be diminished by the reactivation of the small inland waterway network providing transport of part of the cargo flows.

## 4. Potential solutions for the re-activation of the small inland waterway network

### 4.1 Introduction

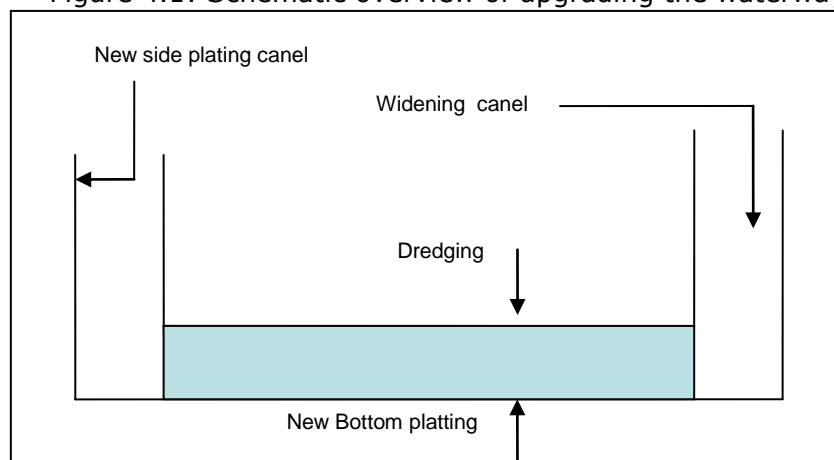
In order to revitalize the small inland waterway network a solution to deal with the diminishing small inland fleet will be developed. First the alternative of enlarging and upgrading the small inland waterways will be discussed. Besides upgrading the small inland waterways also a new inland navigation system will be developed. In this new system, the infrastructure is taken to be constant and the ships are adjusted to the existing infrastructure while in the first solution the infrastructure is adjusted to the existing, (increasing in size) inland fleet. This so called small barge convoy system, which could be used to re-activate the small inland waterway network, will be explained. Also a short overview of the small barge convoy system is given. In part II of the thesis this small barge convoy system will be researched more in depth.

The first part of this chapter will describe the enlargement of the small inland waterway network. The second part will describe the concept for the situation where only one small waterway will be served. The third part is used to describe the concept when more than one waterway needs to be served. The fourth part is used to describe the tug and barge concept if the tug is also used to push the -non self-propelled- barges on the small waterways. The last part of the chapter is to give an overview of the available markets that could be served with the small barge convoy system.

### 4.2 Adjustment of the inland waterway infrastructure

The first solution to deal with the reduced sailing area of the existing inland fleet is to enlarge the small inland waterway network. The suggested solution is to upgrade the existing small inland waterway network from CEMT II to CEMT IV. Figure 4.1 presents a schematic overview of the different necessary adjustments to upgrade an existing waterway.

Figure 4.1: Schematic overview of upgrading the waterway



The locks on the waterways have to be enlarged and the canal width and depth have to be increased. Besides the previously mentioned adjustments also a new bottom and side plating have to be installed. This approach is applied in the Netherlands where two small inland waterways in the southern part of the country are upgraded from class II to class IV waterways (Wilhelmina canal and the Zuid Willemsvaart) (MIRT, 2011). This *Dutch approach* of dealing with the reduced sailing area of the current inland fleet will be applied to the Flemish small inland waterway network. It will be calculated how much money is needed to perform the required investments. The unit costs of performing the required works mentioned in table 4.1 are taken from Technum NV (2008).

The required depth of a class IV waterway is 4.5 meters while the required width is equal to 14 meters. When the existing dimensions of the waterways are known, the costs can be calculated to upgrade those waterways from a class II to a class IV. In figure 3.19 an overview of the small inland waterways in Flanders was given. For these inland waterways the calculations are made. The result of that cost calculation can be seen in table 4.1.

Table 4.1: Overview of the investment costs

Route [-]	Replacing locks [EUR]	dredging [EUR]	investment bottom plating [EUR]	investment widening [EUR]	investment canal sides [EUR ]
1	€ 270,000,000	€ 38,340,000	€ 82,700,100	€ 13,608,000	€ 104,206,500
2	€ 90,000,000	€ 35,784,000	€ 88,213,440	€ 14,515,200	€ 111,153,600
3	€ 30,000,000	€ 25,560,000	€ 73,511,200	€ 12,096,000	€ 92,628,000
4	€ 90,000,000	€ 32,802,000	€ 64,322,300	€ 10,584,000	€ 81,049,500
5	€ 150,000,000	€ 14,910,000	€ 64,322,300	€ 10,584,000	€ 81,049,500
					<b>€ 1,681,939,640</b>

Note: 2009 values

Table 4.1 shows that the total costs of upgrading the small waterways in Flanders will cost approximately 1.7 billion EUR. This is quite a large amount of money which will exceed the current budget of upgrading and maintaining the total inland waterways in Flanders by 755 to 1! The total budget for investments in the inland waterway network in Flanders up to 2015 is limited to 2,248 million EUR (Infrastructuur masterplan, 2010). Besides the very large costs also the time needed to complete all the necessary work is very long. It will take years even decades to complete all the works. It is therefore decided not to focus on the enlargement of the small inland waterway infrastructure but to develop a new inland navigation system that will be adjusted to the existing small inland waterway network.

### 4.3 Adjustment of the inland navigation concept

In this section of chapter 4 the new inland navigation system will be developed and explained. First the concept will be developed and explained. Beside the development of the concept also the combination of different small inland waterways into one network will be explained. Also the potential markets are discussed along with the potential ownership of the different barges.

### 4.3.1 Inland navigation concept development

If a new inland shipping concept has to be developed, at first all the existing solutions must be abandoned. Reflexion should be at one higher level of abstraction and a set of criteria should be defined with which the new system must comply. The criteria for the new concept should also take into account the problems of the current small ships (chapter 3). The main criteria for the developed concept are:

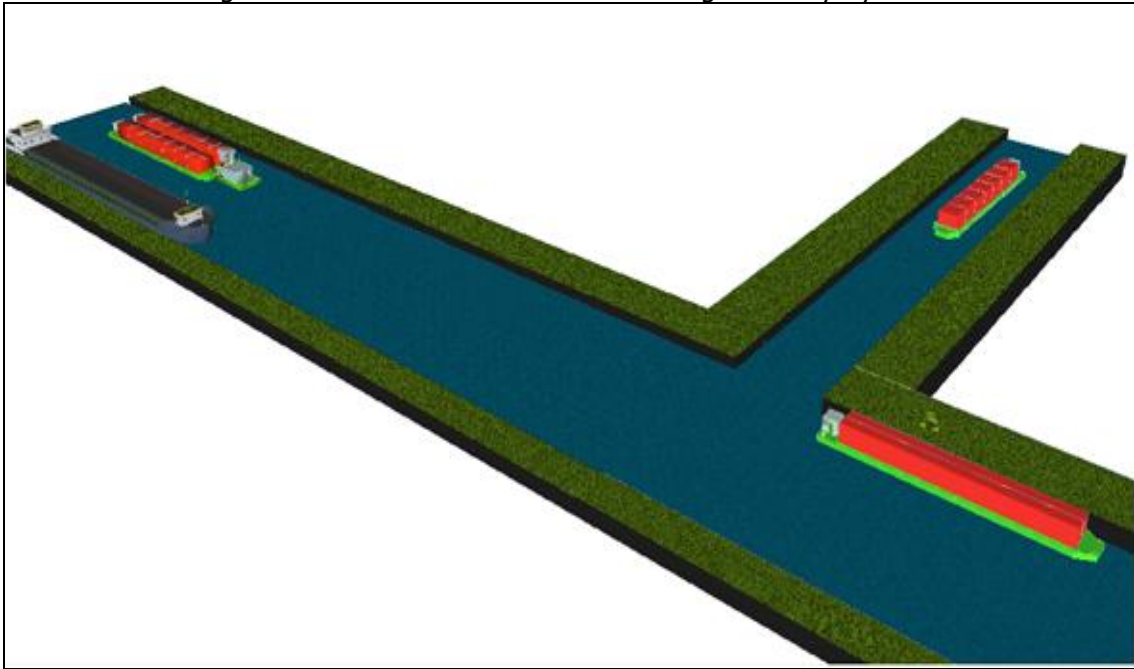
- The concept must be suitable for the small waterways ( $L_{\text{barge}} < 55 \text{ m}$ ,  $B_{\text{barge}} < 6.8 \text{ m}$ )
- The concept must deal with a limited depth of several small inland waterways ( $h = 2.3$  meters instead of 2.5 meters)
- The concept must be able to transport bulk cargo as well as containers so that additional cargo flows can be attracted to the new concept (modal shift of containers from the road to the inland waterways)
- The new system should be a system where the crew who are operating the barges should not live at those barges so that the total available length of the barge can be used to transport cargo
- The new concept should also be capable of providing a solution for the problem of the small call sizes of inland ships at the deep-sea terminals
- The new concept should be able to compete predominantly with road transportation
- The new concept should be a profitable business
- The concept should provide a sustainable transportation solution to deal with the increasing emission problems

In order to fulfil these criteria a concept has been developed that can be described as a two-stage tug and barge concept. In the first stage, the tug and barge concept sails in its usual configuration with several barges pushed by a single tug and travelling through large inland waterways from seaports to the entrance of the small inland waterway. In the second stage, at the entrance of a small inland waterway, the convoy is uncoupled and several small barges will sail separately to their different destinations on this waterway.

Push-barge convoys have already been used for a long time on the large waterways in Europe (Rhine trade, Veerhaven) and the United States (Mississippi trade). In those push barge convoys the barges are left behind at the starting point and end point of the trip. These barges can therefore be handled without the presence of a push ship so that the most expensive part of the ship (the main engine(s) and crewmembers) can be better deployed. At the places where the barges are left behind, a port tug is used to relocate the barges from a clustering point to the terminal. These push barges convoys consist of large push barges.

In the small barge convoy system the barge size will be decreased in order to make such a system applicable for the small inland waterways. The main focus of the concept is to combine economies of scale on large waterways (i.e. tugs and barges together) while the individual barges are small and economically feasible enough to sail on small waterways. In this way the total convoy could compete with road transportation. Figure 4.2 gives an overview of the small barge convoy system.

Figure 4.2: Overview of the small barge convoy system



Source: own composition

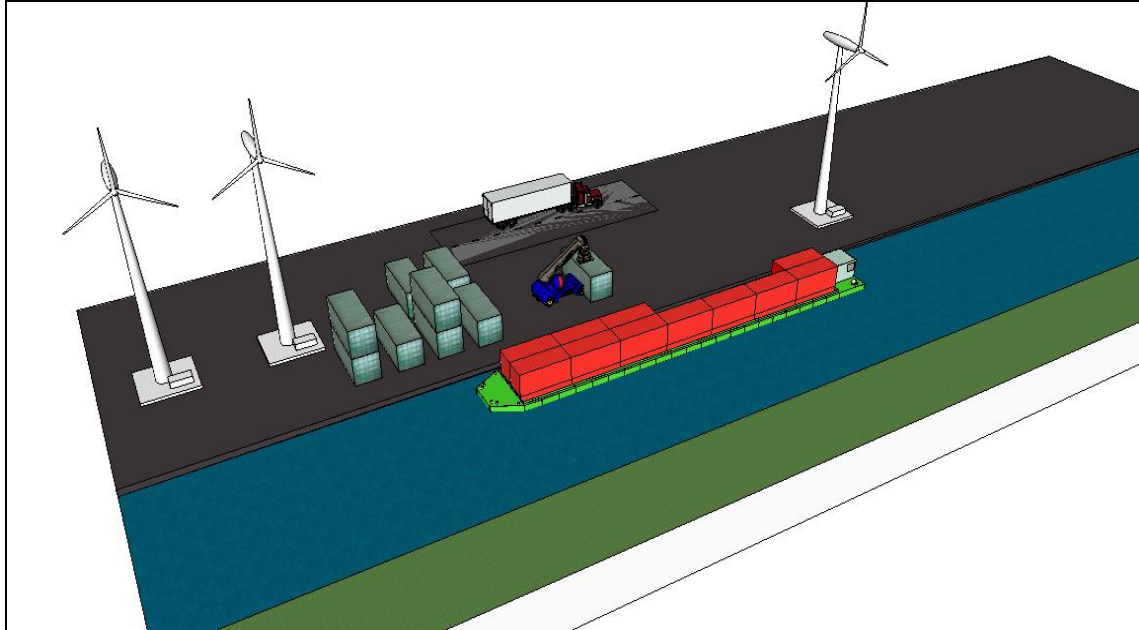
The concept will have different crews who will operate the tug and the barges. One crew will be operating the tug when the barges are pushed to and from the entrance of the small inland waterways and the seaport. This crew will also deal with the coupling and uncoupling of the barges. This crew will work in a week on/ week off regime on the tug so that the crew will not live on board. The next crew will be located in the seaport where they will move the barges from the barge collection point to the terminals in the port. The last crew is a flexible one who will sail the barges, if necessary, on the small inland waterways. This new captain gets on board and sails the barge to the final destination. When the barge is moored, the captains will be brought back to the starting point. These captains will go home when the work is done. It is also possible that people can rotate for instance from seaport-duty to small- river duty or from small-river duty to push-ship duty. This will make the work more diverse.

The barges are "exchanged" at the seaport and at the entrance of the small waterway. The small barge captain does not need to start his sailing activity right at the moment that the tug and barge convoy reaches the entrance of the small waterway. The barges will be left behind at the exchange point and the next day the barge captain can start his work. The barges that have to be sailed back to the seaport only need to be present when the tug and barge convoy reaches the exchange point. Because in the small barge convoy system the barges can sail independently, it is not necessary to have a port tug for the relocation of the barges in the seaport.

For propulsion, the barges use electric engines powered either by a generator set located in the aft of the barge or by batteries located in the double bottom of the barge. Also a combination of the two systems is possible. Several systems could be used to charge the batteries. A power connection to the shore can be used while loading and unloading, preferably using electricity from a grid based on "green" energy such as wind or solar power. In figure 4.3 a schematic overview of a small "green" inland

terminal is given. The figure shows that windmills are used to generate power which can be used to re-charge the barge.

Figure 4.3: Overview of the “green” inland terminal



Source: own composition

If recharging through the grid is not possible due to too high costs or insufficient equipment at the quays at the small waterways, the batteries will be recharged by the main engines of the tug while sailing in the tug and barge configuration.

An additional advantage is that the loading and unloading of the barges is separated from the sailing part. One of the problems for inland ships is that they experience a very long waiting time in the ports, on average 10 to 16 hours. The circulation time is increased which will lead to an increase in transportation costs for inland ships and transit time due to these waiting times (see section 3.4). In our proposed concept, the most expensive part of the inland ship, the main engines and the crew, will be sailing as much as possible because the push ship does not have to wait in the port to load and unload the barges. It only has to spend time in the port to couple and uncouple the barges. Another potential advantage is that the deep-sea terminals can handle the barges at off-peak hours. The handling costs of a container in the seaport (unloading and loading) make up the majority of the total costs, so that a reduction in the handling costs will have a large impact on the total costs. In figure 4.4 an artist impression of the developed small barge system in a seaport is given.



Figure 4.4: Barges being unloaded at a deep sea terminal



Source: own composition

The barges that need to be handled in the seaport are stored at a collection point in the port. That collection point can be one point in the port from where the barges are sailed to the appropriate terminals or more points near large terminals could be formed. From those collection points, the barges are sailed to the sea terminals by a captain who will work only in the seaport (see section 6.3).

The reason why the new concept, initially, will be developed for the small inland waterway network is that on the large inland waterways the large inland ships will be “pushing” the small inland ships from that specific market (section 3.5). On the small inland waterway network the large inland ships cannot compete.

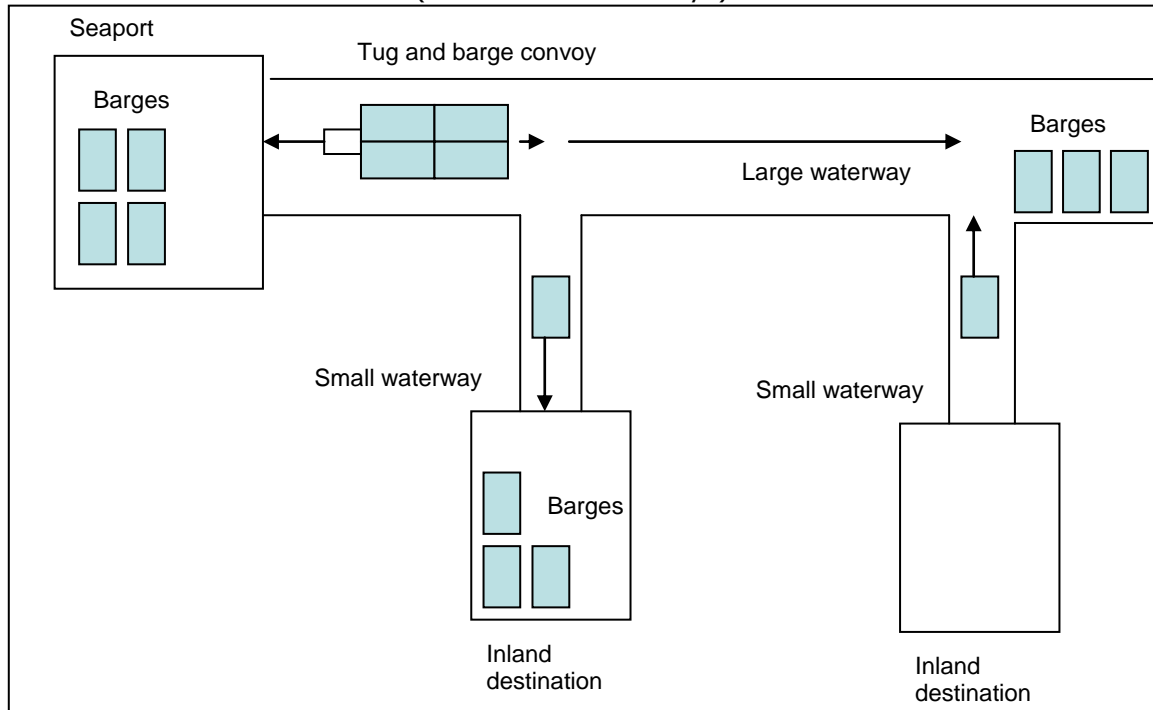
#### **4.3.2 Supply on one waterway**

When the tug and barge convoy are sailing to one waterway, at the minimum three times as many barges are needed as the number of them sailing in the tug and barge stage at one moment. One set will stay at the seaport, one set will be in the tug and barge configuration and the last set is in several places on the small waterway. The barges are “swapped” at the beginning of the small waterway. The barges can travel to and from the exchange point until the convoy arrives.

#### **4.3.3 Supply on two or more waterways**

With this concept it is also possible to use one tug which pushes sets of barges to two or more different waterways. This is shown in figure 4.5.

Figure 4.5: Schematic overview of the concept with a 4 barges configuration (2 different waterways)



Source: Own composition

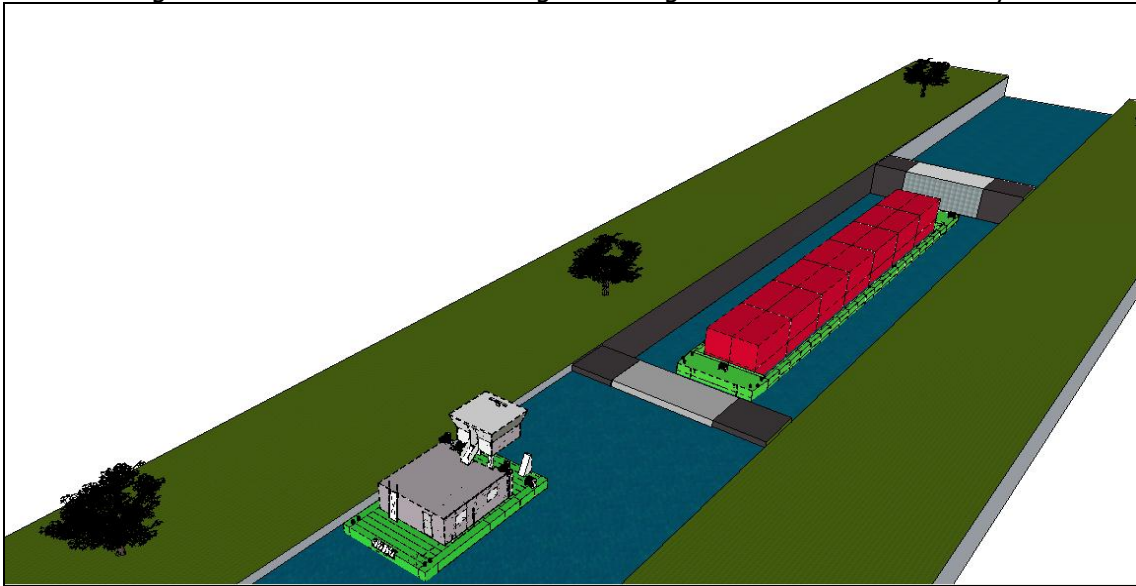
It is also possible to opt for a situation where for example four barges are pushed to the first small waterway and two barges to the second small waterway.

If the tug has to push barges to several small waterways, the barges will spend more time in the seaport and small waterways, and more time will be available to unload and load the barges. As mentioned before, a large waiting time in the seaport does not have an impact on the variable costs (crew and fuel) due to the fact that the actual transport is uncoupled from the loading and unloading part. However, if the numbers of small waterways that one tug has to serve increase, more barges are needed and the total investment as well as the fixed costs will be higher. This aspect will be dealt in more detail in chapters 10 and 14.

#### 4.3.4 Tug sailing on the small waterway

It is also possible to opt for an option where the tug will also sail on the small waterway. This is only possible for a tug and barge configuration of one barge. If the convoy is larger, then it is not possible to sail on the small waterway due to the dimensional limitations on the waterway. In this option, the barge is uncoupled from the tug, is sailed in and out of the lock independently, and is re-coupled after each lock. In this option the barge is only equipped with a number of thrusters and batteries capable of sailing in and out of a lock. Figure 4.6 shows an overview of a small barge plus a tug on the small waterway when they have to pass a lock.

Figure 4.6: Overview of the tug and barge on the small waterway



Source: own composition

In this option the time needed in order to pass the locks is increased because the small barge has to wait for the tug to be pushed further on the small inland waterway.

#### **4.3.5 Available markets for the developed concept**

The small barge convoy system can serve the markets which are located at the small inland waterways. These markets can be divided into:

- Bulk market
- Container market

The bulk and the container market can serve two different types of destinations at the small waterways. These two options are:

- Companies located at the small waterway
- (Small) inland terminals located at the small or large waterways

Besides destinations (or origins) at the small waterways the concept can also be used on large waterways. The small barges could be used for dedicated transport between an inland and a deep-sea terminal without the need of calling, with a single barge, at several different terminals to fill with containers. In that case the cargo flows on the large waterways could be combined with the cargo flows on the small waterways. The barge train could be sailing to an inland terminal with container barges for that terminal, but also carrying barges with bulk material for the small inland waterways.

Another advantage of the barge convoy system is that multiple destinations and origins can be bundled into one barge convoy. So it becomes possible to combine the cargo flows of several smaller companies that on their own could not provide the critical mass needed to transport their cargo by inland ships.

In chapter 2 it was mentioned that palletized cargo flows are not taken into account because a large critical mass is needed to reduce the sailing costs, so that the inland navigation option can compete with road transportation (Verbeke, Macharis, Cornillie, 2007). In the developed concept it is possible to make one barge completely dedicated to palletized goods, while other barges are loaded with containers and / or bulk material. The needed critical mass to transport palletized goods can be taken from other commodity types.

If the small barge system is implemented (based on traditional inland navigation cargo flows), the system could be expanded with additional "pallet barges".

#### **4.3.6 Ownership of the barges**

The small barge convoy system is built up of several small barges which will be operated by a single inland shipping company. But in the small barge convoy system it is also possible to lease or sell barges to large potential clients. In that case the barges are completely dedicated to the companies which have bought (or leased) the barges. The shipping company itself will provide the crew and deal with the transportation on the large waterways, while the clients will have to operate barges on the small waterways. This is similar to a time charter or a bare boat charter in deep-sea shipping. By doing this the potential clients are bound to the new concept and long-term relations could be established. In that case the client is responsible for loading and unloading the barges. For smaller clients the shipping company itself will operate the barges on the small waterways.

#### **4.4 Preliminary conclusion**

In order to deal with the, in chapter 3, mentioned problems of increasing congestion on the road network and growing awareness of environmental care, and the diminished supply on the small inland waterways the adjustment of the inland waterway infrastructure is too costly and will take too long to materialize. Therefore the adjustment of the inland navigation system is a better solution.

This new inland navigation system is the small barge convoy system could be used in dealing with the previously mentioned problems of increasing congestion on the road network and growing awareness of environmental care, and the diminished supply on the small inland waterways. Due to the modular character of the concept potential clients could be bound to the concept by leasing out some of the barges.

As the small barge convoy system is new and no reference material is present, the concept must first be further developed and researched. This will be done in part II of this thesis. In order to research the concept, a model will be made of the small barge convoy system. In the next chapter, the modelling methodology will be developed in which the network design, the design of the barges and tug and the transport economics of the developed small barge system are incorporated.

# **PART II: METHODOLOGY**



## 5. Modelling methodology

### 5.1 Introduction

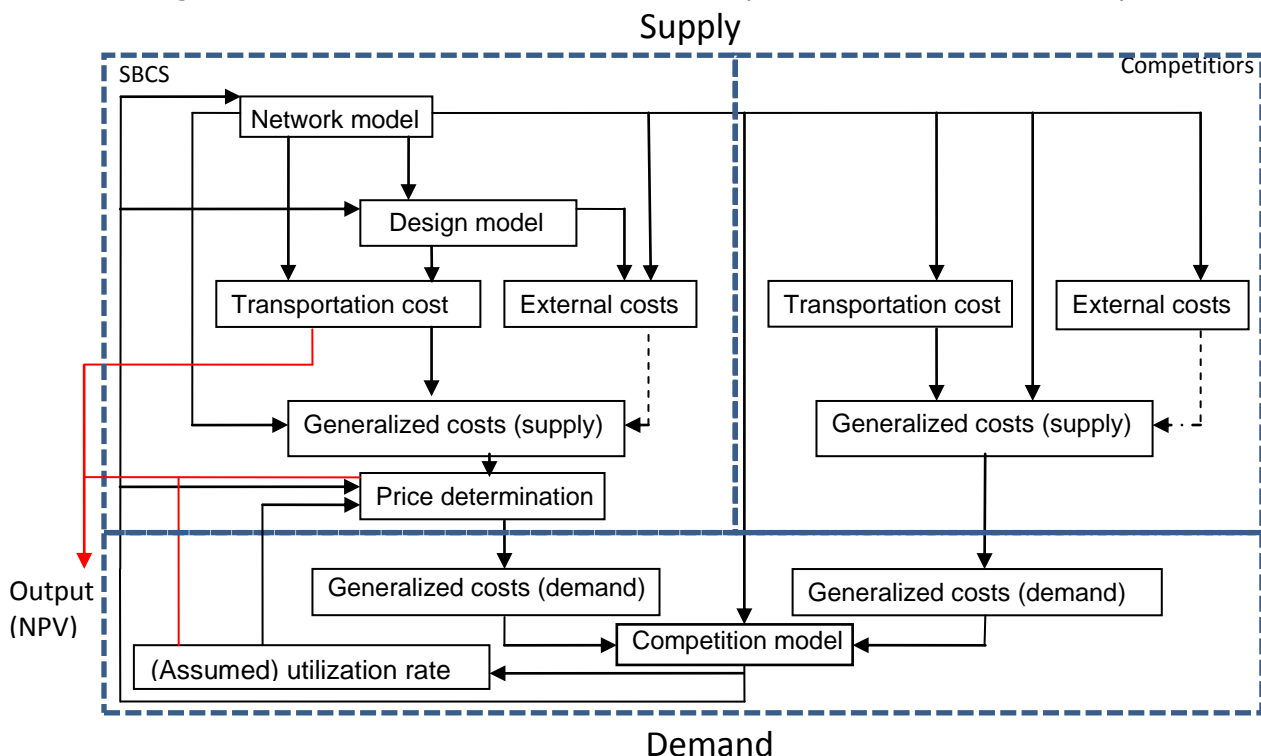
The combination of network design, the design of the barges and tug, costs calculation, competition of other modes and the determination of the external costs strongly characterize the modelling methodology of the small barge convoy system.

The model will be developed to gain insight into the dynamics of the small barge convoy system and it will offer the design of the barges and tug which are used within the small barge system. It is the aim to determine the total system optimum. Therefore, in the model, all the design parameters (network, barge and tug) are variable and will be optimized.

### 5.2 Modelling approach

The aim of the model is to investigate the influence of different network and/or barge/tug design options on the transportation costs and hence on the competitiveness of the small barge convoy system<sup>10</sup>. The total model will be built up of three major model components. In figure 5.1 a schematic overview of the model is given.

Figure 5.1: Overview of the different model parts of the modelled concept



Source: own composition

<sup>10</sup> The transportation price will be based on these transportation cost (see chapters 11 and 13).

The upper part of the model, the supply side, is divided into two parts. The first part (SBCS) is the model concerning the developed small barge system.

First a network configuration in the network model (chapter 6) must be selected. Based on this network the design model (chapter 7) will design the tug and barges. Based on the network and the design of the tug and barges the cost model (chapter 8) will be used to calculate the transportation costs and the external costs (chapter 9). The transportation costs, the external and other non-monetary costs components such as time and reliability will determine the generalized costs (chapter 10).

The final output of the model will be a Net Present Value (NPV) of the investment in the small barge system. The NPV will be based on the total income and costs during the total life time of the small barge system. Based on this figure the different design options are ranked and investment decisions will be made (chapter 11).

The second part of the top side of figure 5.1, i.e. competitors, represents the modelling of supply of the competitors for the small barge system. From the network work model the alternative routes of the competitors are determined and the transportation and external costs are calculated. Also the generalized costs of the competitors are determined (see chapter 12).

The bottom part of figure 5.1 represents the demand side. Here the competition between the small barge system and its competitors is determined. In this part of the model the generalized costs of the cargo owners are determined. This demand part of the model will take into account the generalized costs and the transportation price of the small barge system (see chapters 12 and 13).

Figure 5.1 shows that the network model will influence the design of the barges and tug (number of barges pushed, maximum dimensions of the barges, etc.) but also the transportation costs (travelled distance, number of locks that have to be passed, etc.). The transportation costs are also influenced by the design (speed of the tug, hull shape, propulsion system, etc.). The transportation price of the small barge system will be determined on the basis of its generalized costs and by the competition from the other modes.

In order to determine the transportation price, the utilization rate of the barges must be known. Because the utilization rate cannot be determined a priori an iterative approach is applied. This means that an initial utilization rate of the barges (and thus market share) will be assumed. In the competition model the market share, of the small barge system, will be calculated based on the competition of the other modes. This calculated market share will be compared to the initial assumed market share. If the calculated market share is larger than the initial assumed market share then the initial assumed utilization rate (market share) can be accepted. If not, the assumed initial utilization will be altered.

From the competition model there is also another feedback relation, to the part of the model in which the small barge system is modelled. The



competition of the other modes will have a direct influence on the maximum level of the transportation price and the utilization rate of the barges (first iterative relation). The transportation costs of the small barge system are influenced by changes in the barge network and/or design changes of the barges and tugs (second iterative relation). Therefore the profitability of the small barge system will be determined by balancing these two iterative relations.

The model has been programmed in the knowledge-based system Quaestor<sup>11</sup>. Quaestor is capable of solving iterative relations which are needed to be solved for the design of the barges and tug. Another advantage of the Quaestor system is that it can be extended with other software programs. In this model it combines Excel (final output) and Rhinoceros<sup>12</sup> (3D output of the design model).

In the model a number of parameters can be varied. As such the influence of changing those parameters can be . These variations have been made possible because it is not known a priori what the best design option is and what the influence is of those parameters on the transportation costs. In the network model the following main network options can be selected (see chapter 4):

- independently sailing barges on the small waterways
- tug will push the barge on the small waterways
- "normal" tug and barge option

For each of the chosen logistic options the next parameters can be varied:

Table 5.1: Overview of the different network parameters in the developed model

Parameter	Options to choose
Number of pushed barges in one convoy	1,2,4 and 6 can also be varied per waterway
Number of selected waterways	1 to 5 possibility to sail to an inland terminal on a large waterway
The begin (or end) location in the seaport	can select 1 to 7 terminal groups in a port can also be varied per selected waterway
Sailing regime of the tug	full or semi continuous

The design parameters of the network model can be altered, even when the system is implemented. If there are changes in the demand and/or supply the network can be changed. The only parameters that are fixed are the number of barges<sup>13</sup> and the choice for a specific sailing regime is fixed. If a choice has been made, then the tug will be designed according to the specific requirements. So if a tug has been design for semi continuous

<sup>11</sup> Quaestor is a knowledge management system software tool developed by Qnowledge. It is a development platform, working environment and management tool for engineers, enabling integration of design configuration, calculations and the generation of drawings and graphs. <http://www.qknowledge.nl>

<sup>12</sup> Rhinoceros is a 3D cad package that is used to draw the 3D designs of the barges and the tug <http://www.Rhino3d.com>

<sup>13</sup> Although, technically, they can be sold or scrapped but within the system they are fixed (they can either be used or laid up).

sailing then it is not possible to change the sailing regime to full continuous sailing. However the opposite is possible. A tug that has been designed for full continuous sailing can be re-deployed to semi continuous sailing.

In the design model the following design parameters can be varied:

Table 5.2: Overview of the different design parameters in the developed model

Parameter	Options to choose
Hull form barge	shape of bow and aft ship main dimensions of the barge (L,B)
Propulsions system of the barge	batteries, generator set(s) or hybrid drive number of installed thrusters propelled or non-propelled
Speed of the barge	all speeds are possible
Hull form tug	shape of bow and aft ship Main dimensions of the tug (L,B,T)
Propulsions system of the tug	diesel direct, diesel electric
Number of propellers	1 to 4
Number of engines	1 to 4
Speed of the tug and barge convoy	all speeds are possible
number of trips of the convoy on one fuel tank	all numbers are possible

The design model aims at providing a preliminary design of the barges and the tug in which the influence of the main design choices on the transportation costs is determined. These drawings could be used by a shipyard to start the actual engineering work. It is thus not the aim to provide a complete design from which the barges and tug can be built directly.

The design parameters of the tug and barge design are fixed choices. Once the barges and tug have been built, these design parameters cannot be changed.

The cost model will have the following parameters that can be varied:

Table 5.3: Overview of the different costs parameters in the developed model

Parameter	Options to choose
Percentage equity/debt	0 to 100 %
Interest rate of the loan	all values are possible
Fuel price per tonne	all values are possible
One person sailing per barge on small waterway	yes or no option
Inflation rate	all values are possible

The parameters that can be varied in the cost model are also parameters that will not vary in time. The financing is fixed for 20 years and cannot be altered very easily. The fuel cost and inflation rates are also parameters that cannot be influenced. However these costs cannot be influenced they can vary quite considerable over time. To take this aspect into account several future scenarios will be developed (chapter 14) to determine the

influence of these parameters on the competitiveness (profitability) of the small barge system.

### 5.3 Monetary values in the model

The total model will be built up based on a lot of different model components (see figure 5.1). In all these sub-models a lot of cost data will be inserted. In the design model also the newbuilding costs of the developed barges and tug will be determined. In the transportation cost model the other cost components such as fuel costs and crew costs will be determined. Later in this thesis the (generalized) cost of the small barge system will be compared with the (generalized) cost of its competitors. It is important that all the costs data are from the same base year, in order to allow comparison.

It was not possible to collect all the different cost components in the total model from the same year. Therefore all the costs will be scaled to the same base year. The base year will be (December) 2009. All the cost data from before 2009 will be scaled with sector specific index figures. If those specific index figures are not available, EU-16 inflation figures will be used. These figures are given in table 5.4. In this table the index will start at the year 2002 (index = 100)<sup>14</sup>.

Table 5.4: Inflation figures EU-16 (2002-2009)

YEAR	inflation rate [%]	index (2002 base) [-]
2002	1.90%	100.0
2003	1.90%	101.9
2004	2.50%	104.4
2005	2.00%	106.5
2006	2.50%	109.2
2007	1.90%	111.3
2008	3.70%	115.4
2009	0.00%	115.4

Source: ECB, 2010

### 5.4 Summary

In the chapter the total model used to research the small barge system has been presented, including the links between the different sub-models. The parameters which can be varied in order to determine their influence on the competitiveness of the small barge system are presented. It is the aim of the model to determine the total system optimum (network and ship design) but it can also be used to determine a new optimal network if the tug and barges are already designed (fixed design parameters). In that case the feedback relation to the design model is lost. This option can be useful if there is a change in demand or supply while the system is already operating.

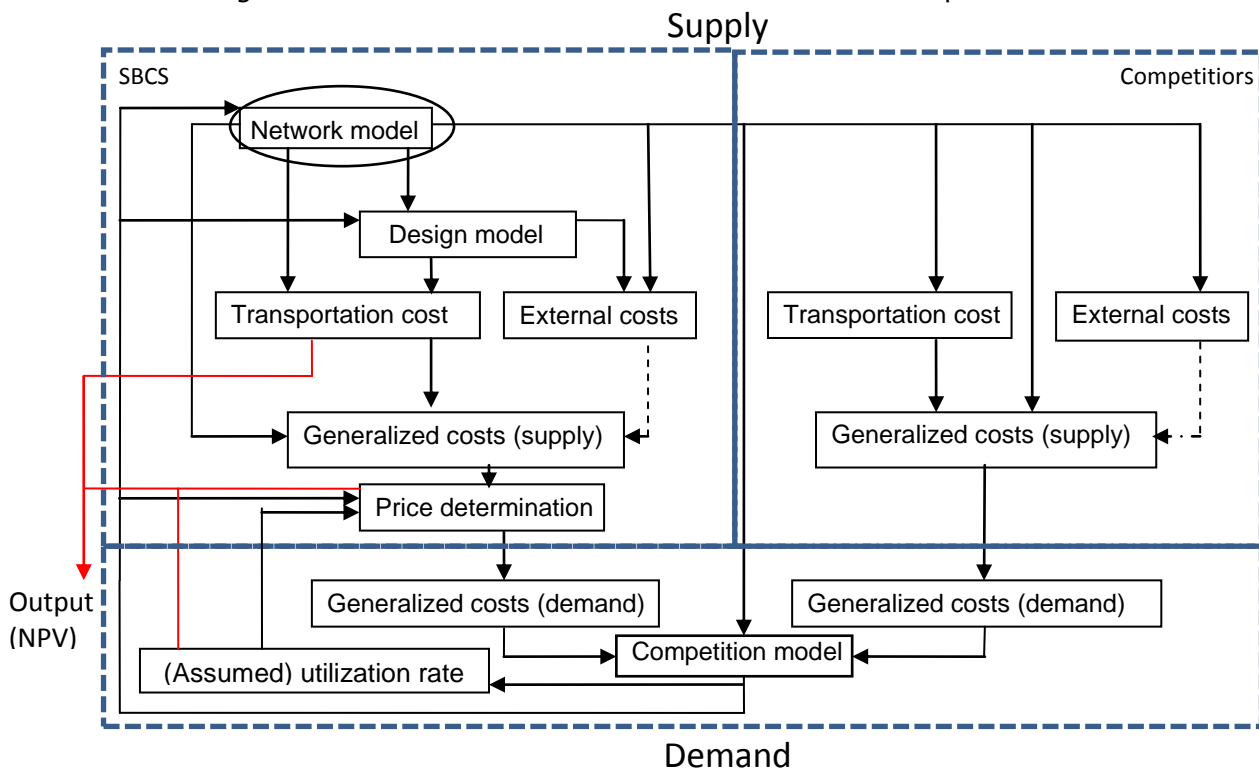
<sup>14</sup> For example, a cost item dates from 2004, will have index equal to 115.4/104.4.

## 6. Network design model

### 6.1 Introduction

The network design model is the first sub-model of the total developed model that will be dealt with. The network model is split up into two parts. The first part will deal with the network design on the inland waterways, while the second part will deal with the port network for the small barge system. In order to determine the transportation costs of a design for the sailing part of the concept, network information such as sailed distance and the number of locks needs to be known. Some of that network information is used only in the ship design part of the model such as the maximum allowable dimensions of the barge, maximum speed on the small waterway, etc., while a part of the information is also used to determine the transportation costs and the design as well as the selected sailing regime. The sailing regime will influence the number of crew members on the ship, and therefore also the crew costs, but it will also influence the minimum required space of the superstructure on the push ship. This will also influence the design and also the new-building costs of the push ship. Figure 6.1 shows the schematic overview of the model and the position of the network model.

Figure 6.1: Position of the network model in the concept model



The network model will also determine the alternative routes of the small barge competitors. The transportation costs of the competitors are thus equally influenced by the network model. If all the different routes are chosen in the network model, then also the potential market is known so that the network model will also influence the competition model (see chapter 12).

## 6.2 Network options

With respect to the network model, three different logistics options can be chosen when operating the barges on the small inland waterway network.

- Option 1a) is an option where the barges are uncoupled at the entrance of the small waterway and from where they will in a self-sustained way to the final destination (see section 4.4)
- Option 1b) is an option where the barges are pushed to destinations at small waterways and to inland container terminals located at large waterways (see section 4.4)
- Option 2) is the option where the tug will join the barge on the small waterway (see section 4.5)
- Option 3) is the option where one can choose a normal push barge convoy

Why is there a distinction between the option where the barges are sailing in a self-sustained manner and the option where the tug will also push the barge on the small waterway? In fact, it is not clear which option will be the most competitive one. Therefore both options are taken into account in the model. The third option has been added so that also "classic" push barge convoys can be designed and analysed. It is then also possible to see if an increase in speed of the tug will lead to more round trips and therefore to higher revenue or if the extra fuel costs lead to higher costs and thus to lower profit.

### 6.2.1 Independent sailing of the barges

The first logistics option is the option where the barges can sail in a self-sustained manner on the small waterways. In that option the barges are equipped with electrical propulsion equipment powered either by a batteries and/or a generator set. The design of the barges will be discussed in chapter 7, while in this chapter the boundary conditions of that design will be given. These boundary conditions are the maximum allowable dimensions of the barge, the water depth of the waterway and the required distance that the barge has to sail. The main dimensions of the barge are determined by the smallest size of the locks that the barge has to pass on the selected waterway. The water depth and the required distance are taken from the water maps.

This logistics option will lead to a situation where there is another crew needed to sail the barges on the small waterway (small waterway crew). The crew on the tug will push the barges from the seaport to the entrance of the small waterway where they will leave the barges.

The small waterway crew will drive, with their own car for example, to the location where the barges are left behind on the large waterway and from there they will sail the barges to the final destination of the small inland waterway. When that has been done the crew members of the different barges are moved back to their starting position. From there the crew will get in their cars and can get back home. The rules in the Netherlands and

Belgium prescribe that the crew on an inland ship must be at least a captain and a mate. However for small inland ships (< 55 metres and equipped with a bow thruster) an exception has been made so that those ships can be sailed by a single captain (Schuttevaer, 2010). The manning rules in Belgium are determined by the federal government. However, the application of the rules is determined for the waterways by the regions (Flanders, Walloon region, Brussels) and by the port authorities for the ports of Antwerp, Ghent and Brussels. The new manning rules are not consistently applied everywhere. For instance it is not allowed to sail alone on large waterways in the Walloon region while it is possible in Flanders (Schuttevaer, 2007). In the model it is possible to opt for both options. Or the barges will be sailed by only a captain or it will be manned by a captain and his mate. This will have an impact on the transportation costs of the concept (see chapter 8: transportation cost).

There is also a third crew needed in this option and that is the crew who will work in the seaport. This crew will sail the barges to and from the clustering point in the port and the terminal.

It is possible for the different crews to rotate from tug duty to small waterway duty so that the work is more diverse. In figure 6.2 the different crews are shown when the barges can sail independently. The dotted line in figure 6.2 indicates that the crew of the small barges need to be transported back to the entrance of the small waterway.

Figure 6.2: Different crews for the independent sailing option



Note: original figure adapted from PBV

### 6.2.2 Barges on small and large waterways combined

The second logistics option that can be chosen is the option in which the tug will push barges with a destination at the small inland waterways, and barges that have a destination at a large waterway. The barges that have a destination at a large waterway will be pushed to an inland terminal located at that large waterway. At the inland terminal the convoy will be broken up,

the “large waterway” barges will stay behind at the terminal, and the other barges will be sailed from the inland terminal to the final destination on the small waterway. In this option, the cargo flows on the large and small inland waterways can be combined and the potential market grows for the concept.

### **6.2.3 Tug and barge on the small waterway**

The last logistics option is the option where the tug will also sail on the small waterway. In that option the barge is not fully equipped with a propulsion package such as a wheelhouse and a lot of batteries, but the barge is equipped with only a small propulsion package of two thrusters to sail in and out a lock on its own. After the barge has passed a lock, the tug will also pass the lock and the two are connected again. As the locks are not large enough to accommodate the tug and barge at the same time, the barge has to wait for the tug after she has passed the lock. It is set that the maximum convoy size for this option is only one barge. In fact, it is not possible to sail with more than one barge on a small waterway because of the dimensional restrictions of the waterway. The advantage of this option is that the need of a small waterway crew is eliminated.

For this situation it is possible to design a specific tug. The tug can be equipped with a diesel electrical propulsion lay-out which can be designed for two different conditions, i.e. the small-river condition and the large-river condition.

### **6.2.4 Classic tug and barge convoy**

An additional logistics option is when the barges are designed as normal barges without propulsion equipment such as batteries, thrusters and a wheelhouse. Also the aft ship of the barges changes into the aft ship of a normal push barge. The crew on the tug will push the barges to and from the seaport to a destination on an inland waterway. The model also allows for the design and calculation of barge train configurations that will only sail on the large waterways. This option will not be used in the main research concerning the small inland waterways, but it also enables the model to investigate the normal tug and barge convoys.

### **6.2.5 Time components in the network model**

In the network model several time components are defined in order to determine the total transportation time to move the barges from the seaport to their final destination. These times are needed to calculate the total transportation time and the total transportation costs.

In figure 6.3 the different times that are used in the model are shown on the map of Flanders.

Figure 6.3: Different times used in the model



Note: original figure adapted from PBV

The first time component is the port time ( $T_{Port}$ ). This port time is the time which a captain will spend on a barge when the barge is being moved from the clustering area in the seaport to the terminal. This time is estimated at 1.5 hours per barge.

Another time component that is used is the time that the tug and barge convoy will spend in the port ( $T_{PORT\_CONVOY}$ ). This time is determined by the distance that needs to be sailed in the port and the speed of the convoy.

The time that the crew of the tug needs to couple and uncouple the barges from the tug ( $T_{coupling}$ ) is also taken into account. This time is set at 30 minutes per barge in the convoy. This procedure has to be done twice, once in the seaport and once at the entrance of the small waterway (first option) or at the final destination (third option). In the second option, where the tug will also sail on the small waterway, then at every lock the barge has to be uncoupled and re-coupled at every lock.

The fourth time component is the time that the total convoy will spend on the large waterway ( $T_{LW}$ ). That time is determined by the sailed distance and the given speed of the convoy. The relation to calculate that time is given in the formula 6.1:

$$T_{LW} = \frac{Dist_{LW}}{V_{convoy}} \quad (6.1)$$

$T_{LW}$  = time large waterway [h]  
 $Dist_{LW}$  = distance large waterway [km]  
 $V_{convoy}$  = speed barge convoy [km/h]



In the model it is also possible to break up the total sailed distance on the large waterway into two parts ( $T_{LW\_A}$  and  $T_{LW\_B}$ ). This has been done so that it is possible to design a tug to sail at two different water depths. This can be useful if the convoy will sail a part of the trip on a water depth of 6 meters and a part at 3 meters. If the convoy has to sail with the same speed at the 3- meter water depth as it will at the 6-meter water depth, the required power will increase tremendously (shallow water resistance). So, if the speed is reduced, then also the sailed time on that part of the waterway will increase.

The time spent by the barge on the small waterway ( $T_{SW}$ ) will be determined next. The sailing time can be calculated with:

$$T_{SW} = \frac{\text{Dist}_{SW}}{V_{SW}} \quad (6.2)$$

$T_{SW}$  = sailing time on the small waterway [h]  
 $\text{Dist}_{SW}$  = distance of the small waterway [km]  
 $V_{SW}$  = speed of the barge (or convoy) on the small waterway [km/h]

In the second logistics option, this time will be set at zero hours. The speed on the small waterway will be given as a default setting by the model and the value is set as the maximum allowable speed on the selected waterway (+/- 7 km/h). The distance of the small waterway is set at the maximum distance of the selected small waterway. The reason is that the locations of the different inland destinations are not known.

Another time component that is incorporated is the time that the barges (or the convoy) have to spend for passing a lock on the waterway ( $=T_{Lock}$ ). This time is set at 30 minutes per lock<sup>15</sup> for the locks at the small and large waterways.

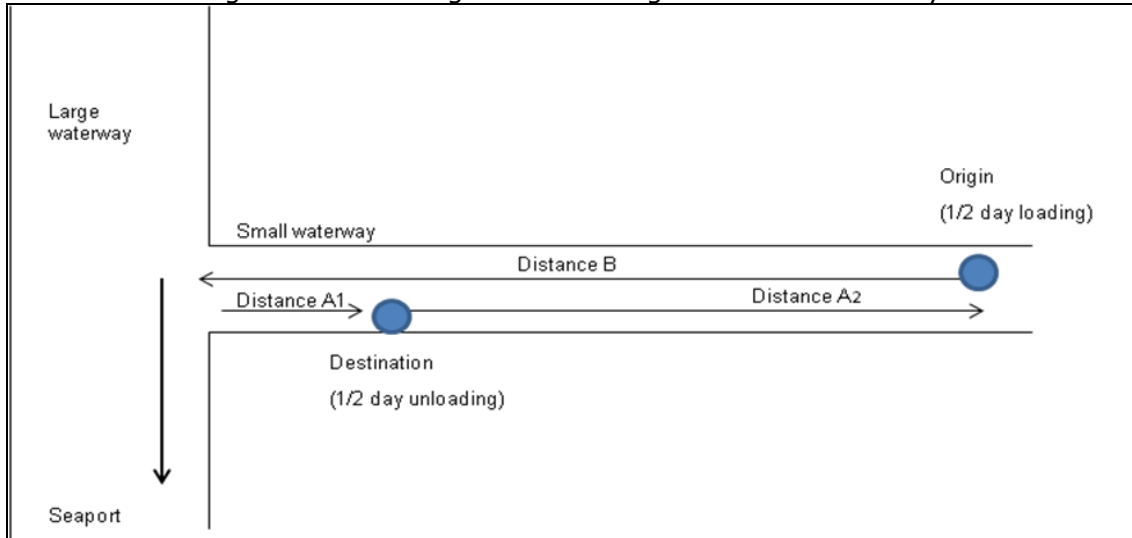
Also the time that is used if the barges are moored on the small inland waterways is taken into account. This time is the time that the crew of the barge on the small waterway needs to moor or to move the barge at the entrance of the waterway or at the destination at the small inland waterway ( $T_{Moor}$ ). This time is estimated at 2 hours.

The next time that will be incorporated is the time that is needed to unload and load the barges at the small inland waterway. The total time that the barge will not be able to use is determined as one day. This time is taken into account in the costs calculation because this will determine the time when the barges have to be returned to the large waterway and therefore also the number of round trips that can be made per year. This time will not influence the crew costs because the barges are left behind by the captain. The total time that a barge will spend on the small inland waterway is determined by the time needed to sail from the beginning of the waterway to the end and back plus one day to handle the barges. By applying this approach (total distance of the small waterway) it is possible to combine the incoming and outgoing cargo flows. If one barge will unload its cargo at the beginning of the small waterway (destination) and load cargo at the end

<sup>15</sup> Scheepvaart in Zeeland 2005, Rijkswaterstaat Dienst Zeeland (2006)

of the waterway (origin) then the total distance of the waterway ( $A_1 + A_2 = B$ ) is taken into account. This is sketched schematically in figure 6.4.

Figure 6.4: Loading and unloading at a small waterway



Source: Own composition

If a destination and origin (incoming and outgoing cargo flows) are not located at the end of the waterway, the transportation costs will be overestimated.

The last time component that has been taken into account is the time that is needed to transport the crew of the small waterway from the inland destination to the entrance of the small waterway ( $T_{Crew\_SW}$ ).

### 6.2.6 Different routes in the network model

In the model, predefined routes, with the network information needs to be selected in order to give the design model the required design criteria and, at a later stage, to calculate the transportation costs per TEU or tonne cargo. The distances on the small and large waterway, the water depths on the small and large waterways, the number of locks on the route and the locations of the inland terminals are given in those predefined routes. In figure 6.4, the different routes are shown where the dots on the map are the locations where the convoy can be broken up into independent sailing barges. If an inland terminal is added to the network, at those locations the barge convoy will be broken up. Then the inland terminal is also used to store the barges.

All the routes start from Antwerp and the routes 1 to 4 have a destination at a small waterway. In the model, it is also possible to choose an option where more routes are sailed with one tug. So one can opt for a logistics option where the tug is pushing a set of barges to one selected waterway or for a situation where the tug is pushing barges to more destinations. In the model it is possible to combine up to five different routes. The main advantage of sailing at more than one destination is that the tug (and her barges) is increasing her potential market. If the distance between a seaport and an inland destination is relatively short (<50 to 100 km), then

the tug is able to do a lot of round trips per year. If more routes are added, then the tug can push more (occupied) barges to and from the seaport.

Because the developed model is generic it is possible to change the network data. It is therefore possible to run the model for any country / seaport hinterland region other than the Flemish one, shown in figure 6.5.

Figure 6.5: Predefined routes in the model



Note: original figure adapted from PBV

If different routes are combined, the barges will be designed in such a way that they can be deployed at all the different waterways, so that the barges will be uniform. Therefore, the main dimensions will be determined by the smallest combinations of lock dimensions. Also the longest required sailable distance is used to determine the range of the barge and the highest allowable speed is used as a design condition for the barges.

### 6.3 Port organization

This part of chapter 6 will deal with the organization of the barges in the seaport (see also section 3.4). The first part will describe three different potential options to handle the barges in the seaport while the second part will deal with the geographical port data implemented in the network model.

#### 6.3.1 Different port organization options for the small barge convoy

As mentioned in the previews part the small barge convoy system can be used to:

- reduce the costs of the inland ship / barge system in the port
- reduce the handling costs per TEU due to larger call size per terminal

There are three different logistical options developed that could be used to deal with the port network of the small barge convoy system.

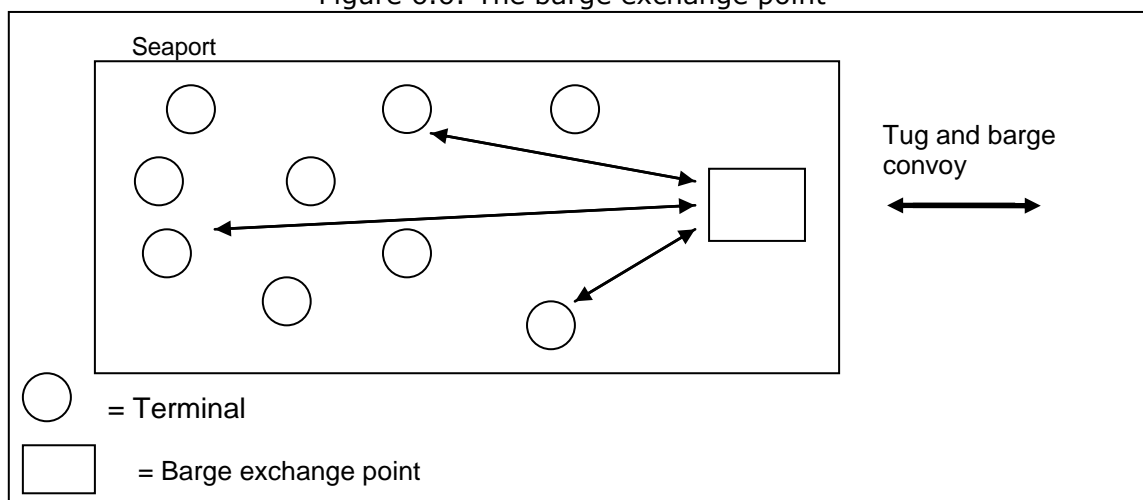
- The barge exchange point
- The barge exchange point with port tug
- Multiple barge exchange points

#### *Barge exchange point*

The first option is the option where the tug will push the barges to a “barge exchange point” in the seaport. From this point the barges are uncoupled and the loaded barges are re-coupled to the tug. Therefore the tug can be used as much as possible. The barges that are collected in the “barge exchange point” will be sailed to the seaport terminals by a captain that will be present at that point (seaport crew). This option can only be applied if the barges can sail independently. The barges will be available for the terminals and the terminals will handle the barges when they have time for them.

A possible disadvantage of this option could arise if the distance between the terminals and the barge exchange point is too large. Another problem occurs if the barges have to sail on large waterways between large deep sea ships. If a barge has to be moved between terminals where the deep sea ships cannot sail without the use tugs then that problem can be smaller. In figure 6.6 a schematic overview of this concept is given.

Figure 6.6: The barge exchange point



Source: Own composition

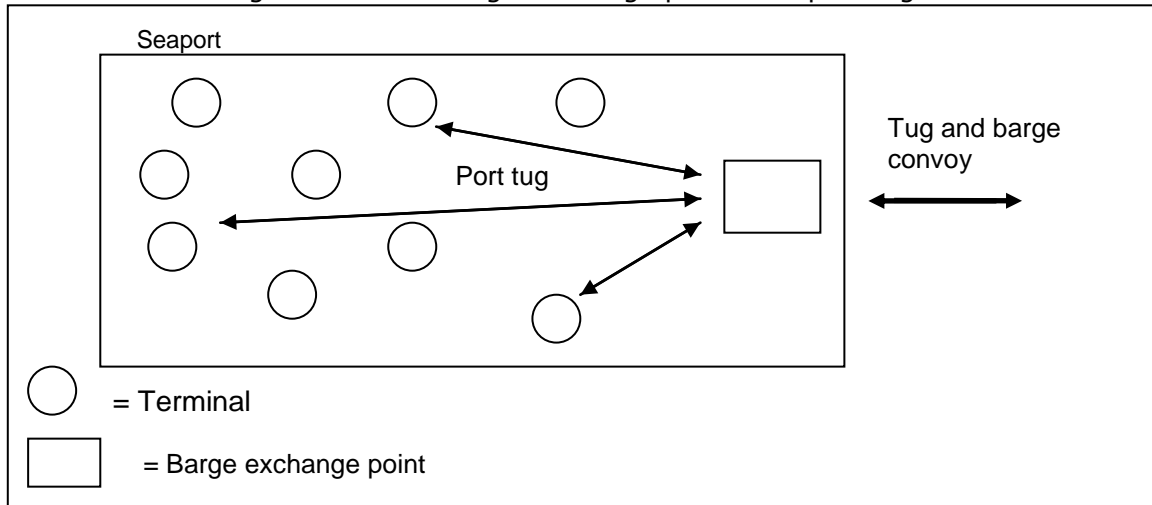
#### *Barge exchange point with port tug*

The second option is an option where the barges are collected at one barge exchange point (BEP) but where the barges are moved from the BEP to a group of clustered terminals with a port tug. In figure 6.7 the schematic overview of this concept is given.

The port tug will have enough power to sail the barges between the deep sea ships. The biggest disadvantage of this option is that this system requires two tugs (one for the hinterland transport and one in the port), which will have a big impact on the total amount of money that needs to be

invested (and on the transportation costs see chapter 8). This option can be the best option if there are enough barges to be moved to a terminal from the BEP. The hinterland tug can be used as much as possible to move the barges to their hinterland destinations.

Figure 6.7: The barge exchange point with port tug

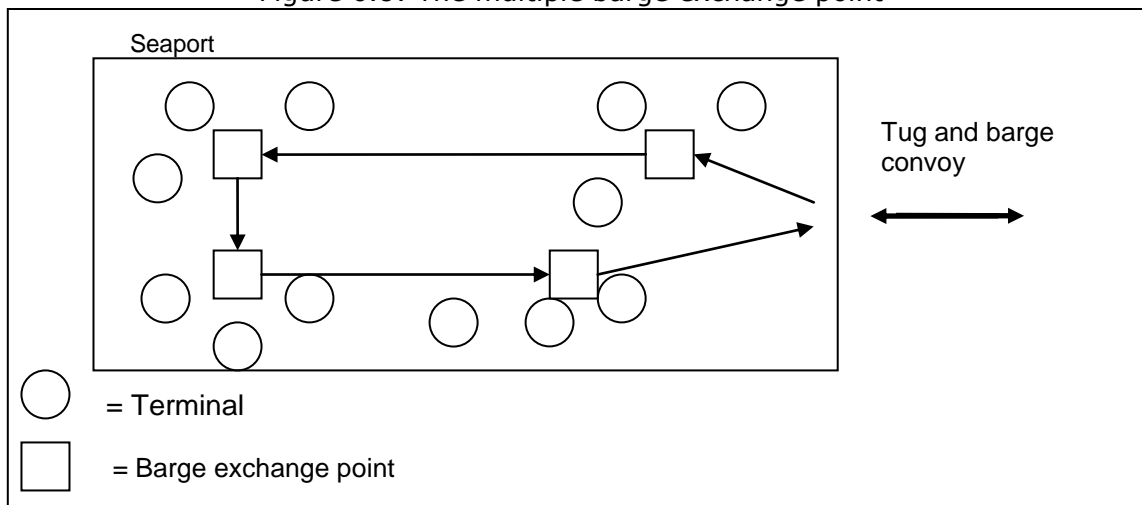


Source: Own composition

### *Multiple barge exchange points*

The third option is an option in which the previous two options are combined. If the distance between the clustered groups of terminals is large, a tug is needed. This tug can also be the tug used for the hinterland transport. That tug will sail to a BEP per clustered group of terminals, where the tug will leave the barges and from where the barges can sail to the terminals independently. In this option the tug will also be used in the seaport, so that the tug is not used optimally. But in the starting-up phase this option can be the best option because the needed investment is minimal. Figure 6.8 offers the schematic overview of this concept.

Figure 6.8: The multiple barge exchange point



Source: Own composition

### 6.3.2 Geographical port data

Choosing a port network option is determined by the situation of the port. The port of Rotterdam, for example, is very long. The different terminal groups are located at large distance. For example, the distance of the Waalhaven to the new to-be-built Maasvlakte II can be up to 40 km. Also in the Port of Antwerp the distances between the different terminal groups are larger. In order to implement the small barge convoy system in the ports of Antwerp and Rotterdam, option one (BEP) cannot be applied. The sailed distance from the BEP to the terminals is too large. The second option will be too expensive due to the use of an extra tug (large increase in fixed costs see chapter 8). Therefore the third option of the MBEP is implemented in the developed model. The port model can offer a choice for several origins / destinations in the selected port. Another option is to use the tug to push the barges on one trip to a selected terminal group, and then on the second trip to another terminal group. Further, an option can be chosen where the tug has to push barges to different port areas in the same trip.

In the total model, both the ports of Antwerp and Rotterdam are implemented. The distances of the different port areas to a starting point in the seaport are used in the model to determine the sailed distance of the tug in the port. Also the number of locks that need to be passed is determined in the model. The terminal groups that have to be called at need to be selected in the model. This choice has to be based on the transported cargo (bulk or containers) and on the overseas destinations of that cargo.

#### *The Port of Antwerp*

The port of Antwerp has been divided into several smaller ports area. These smaller port areas will be used in the port model in the multiple barge exchange point option. The terminal cluster in figure 6.11 will now coincide with the smaller port areas. These areas are the Oosterweel port, the Wilmarsdonk port, the Linkeroever ports (Deurganckdok), the Lillo port and the Zandvliet port. These different port areas are adapted from figure 6.9.

Figure 6.9: Port areas of the port of Antwerp



Source: <http://www.antwerpportmobility.be/ENG/homepagina.htm>

The starting-point from where all the distances are determined in this port is the entrance of the Albertkanaal. All the different port areas have their own specialization in ship handling. The Oosterweel port is a port area with a lot of bulk terminals and chemical industries, while the Linkeroever port area has large container terminals.

#### *The Port of Rotterdam*

Figure 6.10 gives an overview of the port of Rotterdam. This port is divided into smaller port areas. These areas will represent the terminal groups in the MBEP of figure 6.7. These areas are the Waal/Eemshaven (1), Botlek area (2), Pernis area (3), Rozenburg Area (4), Maasvlakte I (5) and Maasvlakte II area (6).



Figure 6.10: Port of Rotterdam



Source: Adapted from the port of Rotterdam

All the distances are determined on the basis of the reference point chosen at the Willemsbrug in the centre of Rotterdam.

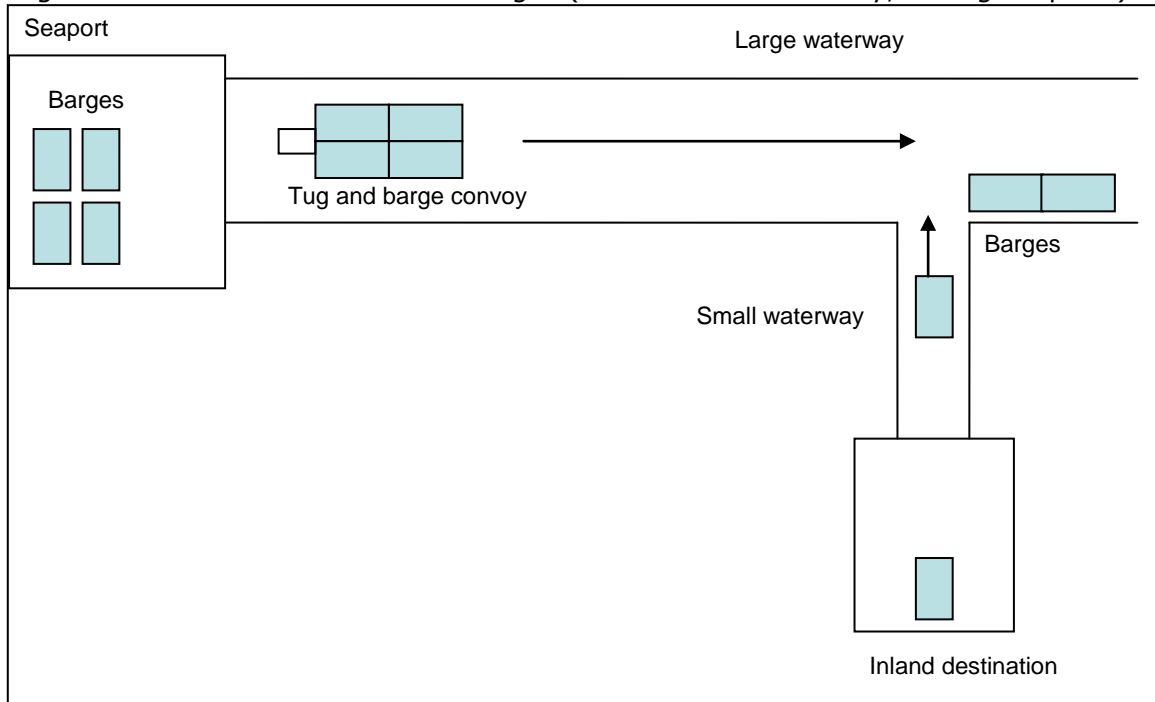
#### 6.4 Number of barges in the system

In section 6.2 of this chapter the different logistics options have been described. In the option where the tug will also sail on the small waterway, the number of pushed barges is equal to one, due to the lock and fairway restriction on the small waterway. For the other two logistics options the number of pushed barges must be given in the model. The model allows us to choose to push one, two, four or six barges in one convoy pushed by one tug. It is also possible to change the barge formations if more routes are added. So the total model can design and calculate the transportation costs, for a tug and barge convoy that can, for example, push two barges on the first selected route and four barges on the second selected route.

The minimum number of barges needed is equal to three times the number of barges that are in the convoy if the tug is sailing to one selected small waterway. If more waterways are selected, the minimum number of barges is equal to two times the number of pushed barges, times the number of selected waterways. On every waterway a set of barges must stay behind, while in the port only one set is needed (at a minimum). The schematic overview of minimum number of barges is given in figures 6.11 and 6.12.

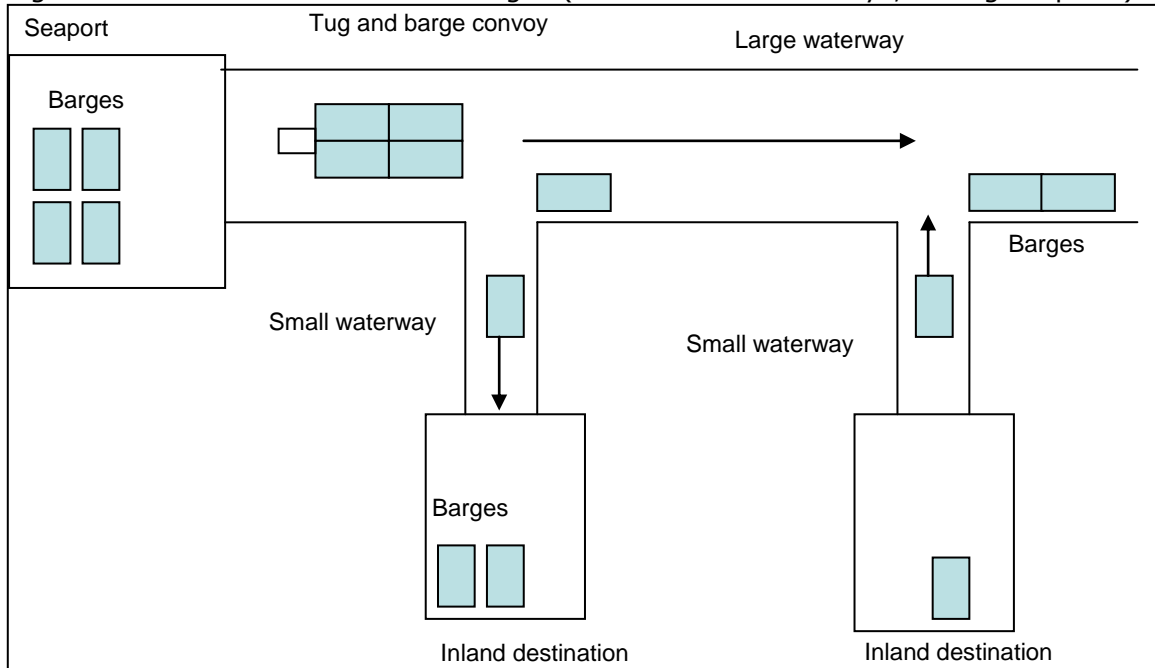


Figure 6.11: Minimum number of barges (one selected waterway, 4 barges option)



Source: Own composition

Figure 6.12: Minimum number of barges (two selected waterways, 4 barges option)



Source: Own composition

The total number of barges needed is referred to as the *minimum* number of barges needed in the system. From a logistics and a reliability point of view, it may be better to have more barge sets than the minimum number of barges. The time spent by the barges in port can then be larger, resulting in higher flexibility in deploying the barges.

In the model it is possible to overrule the minimum number of barge sets that are needed on the selected waterways and the number of barge sets ( $N_{\text{Barge\_sets}}$ ) can be changed. A sensitivity analysis needs to be conducted in

order to determine the influence of adding more barge sets on the transportation costs related to the improved reliability of the small barge system (see chapter 14).

## **6.5 Summary**

This chapter has described a logistics and network model that is incorporated into the total model. In this model a logistic system will be chosen which will provide the data needed and the boundary conditions for the tug and barge design model (next chapter) and the transportation/external cost models (chapters 8 and 9).

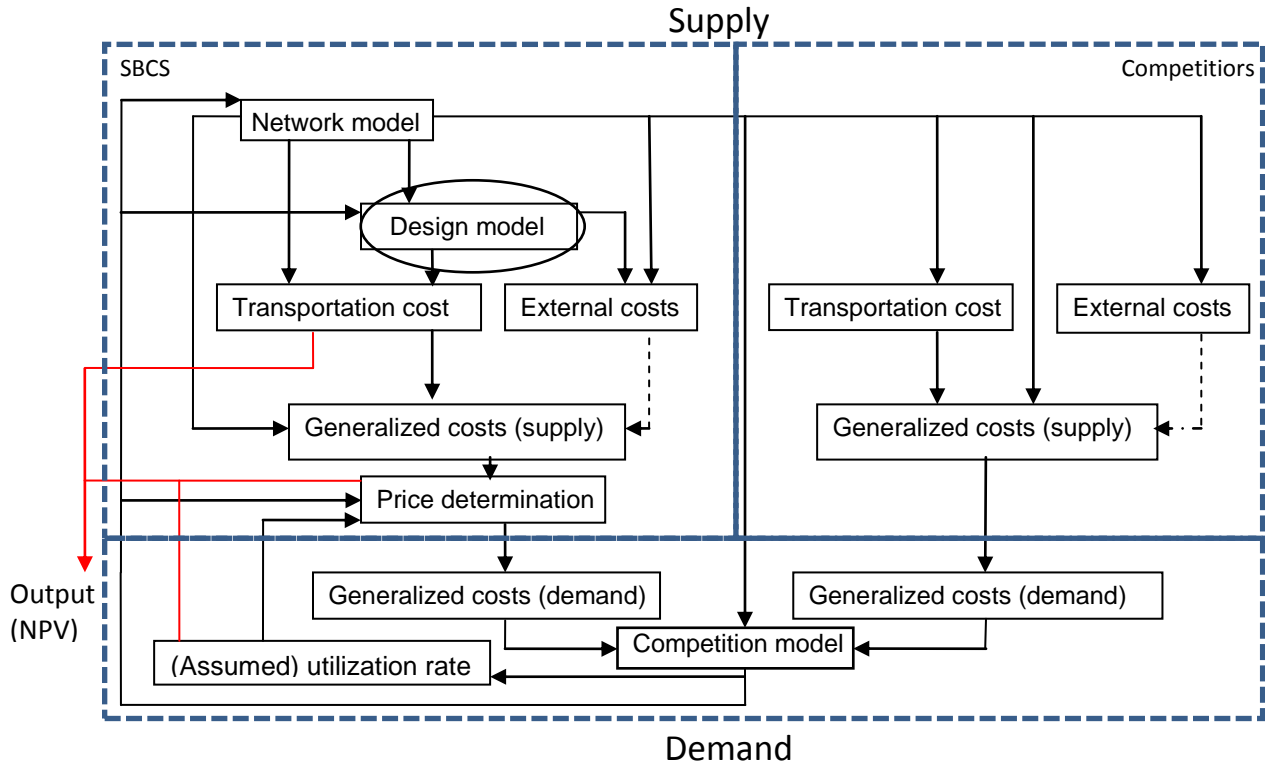
This chapter has also described the different port-hinterland systems for the developed small barge system and the potential advantage of the small barge system with regard to the existing problems of small call sizes at the deep sea terminals (see section 3.4).

## 7. Ship design model

### 7.1 Introduction

In this chapter the design model is described that has been added to the total model. The design model is used to design the barges and the tug for the selected logistics option described in previous chapter. Figure 7.1 shows the position of the design model in the total model.

Figure 7.1: Position of the design model in the total model



The design model will be built up from 3 different sub-models. The first sub-model is the barge design model in which the used barges are designed. The second sub-model is the barge train model in which the combined barge resistance is determined. The last sub-model is the tug design model in which the tug will be designed.

This chapter aims to give a general overview of the design made of the barges and tug. Also the possible design choices in the total model are explained in this chapter. For the detailed description of "non variable" design choices and detailed calculations the interest reader is referred to the appendices. References to these appendices will be made where the specific calculations and design choices are mentioned in this chapter.

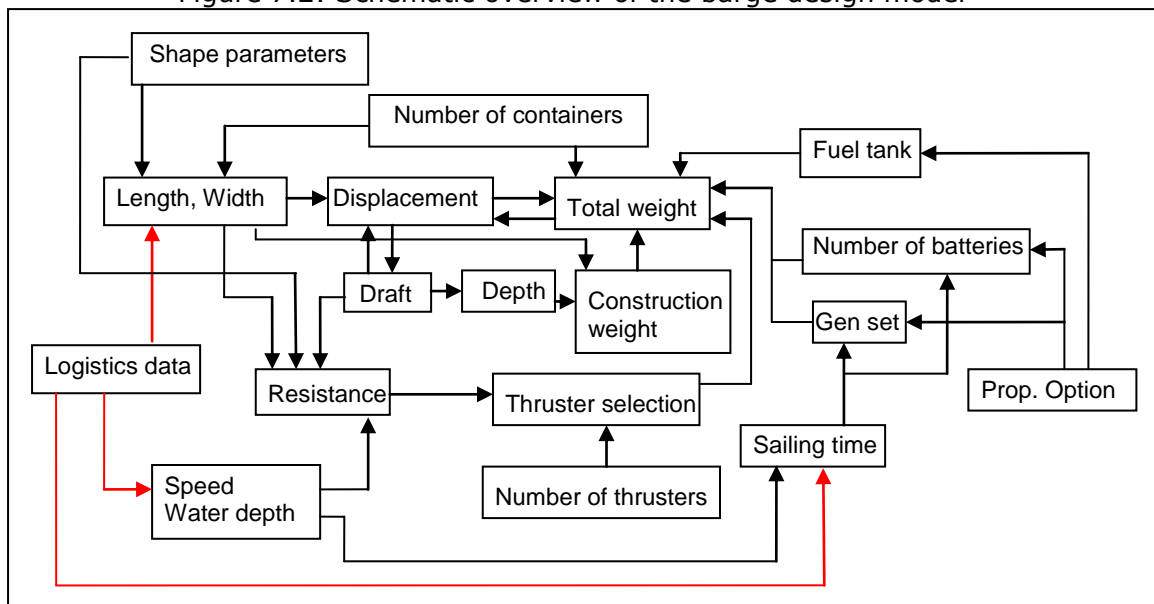
## 7.2 Barge design model

### 7.2.1 Introduction

This section of the chapter will describe the barge design model used to determine the design of the barge. In the design of the barge, the geometry, the construction and the resistance (propulsion) of the barge are important aspects.

Because the different components mentioned above depend on one another, the software program Quaestor has been chosen to program all the knowledge (design relations and formulations). The software is capable of solving all the different relations between all the components. The way the different components are related to each other is given in figure 7.2.

Figure 7.2: Schematic overview of the barge design model



The red lines indicate data taken from the chosen logistic option in the logistic model. For instance a change in the number of containers carried by the barge (payload) has an influence on all the other components. All the boxes in figure 7.2 with no arrows directed at them are parameters that need to be determined by the user of the model.

The different components are separately explained in more detail in the upcoming parts of this chapter. First, the position of the barge model in the total design model will be given. After that the geometry of the barge, the used resistance model and shallow water correction for the resistance calculation will be described.

The third aspect that will be described is the construction of the barge and the calculation of the construction weight of the barge. The next part will be the description of the propulsion of the barge (thruster selection and power generation).

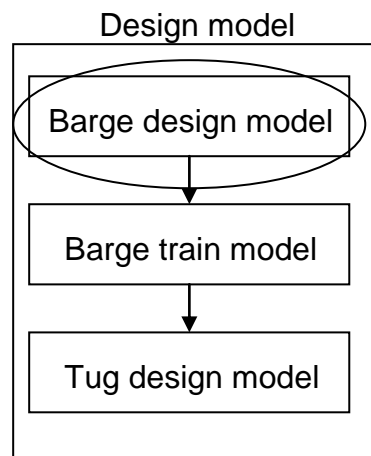
In the next paragraph the new building costs of the barge are determined. The last part of the chapter will deal with a sensitivity analysis of the chosen parameters shown in figure 7.2 in the design of the barge. For instance the effects of increasing speed and range of the barge on the newbuilding costs are analysed.

### 7.2.2 Position in the design model

This paragraph describes the location and the relation of the barge model within the design model.

The barge model must be able to design several barges (in dimensions and capacity) which are capable of sailing independently or to manoeuvre autonomously in and out of a lock. The new building costs for each design also needs to be determined by the barge model. When the barge is designed, the next model must be able to determine the total resistance of the selected barge train. The size of the barge train can be varied from 1 to 6 barges. When the total resistance of the barge train is known, the tug will be designed for a given speed of the total convoy. In addition, the new building cost needs to be calculated for the tug. The systematic representation of the design model and the position of the barge design model are given in figure 7.3.

Figure 7.3: Design model with the position of the barge design model



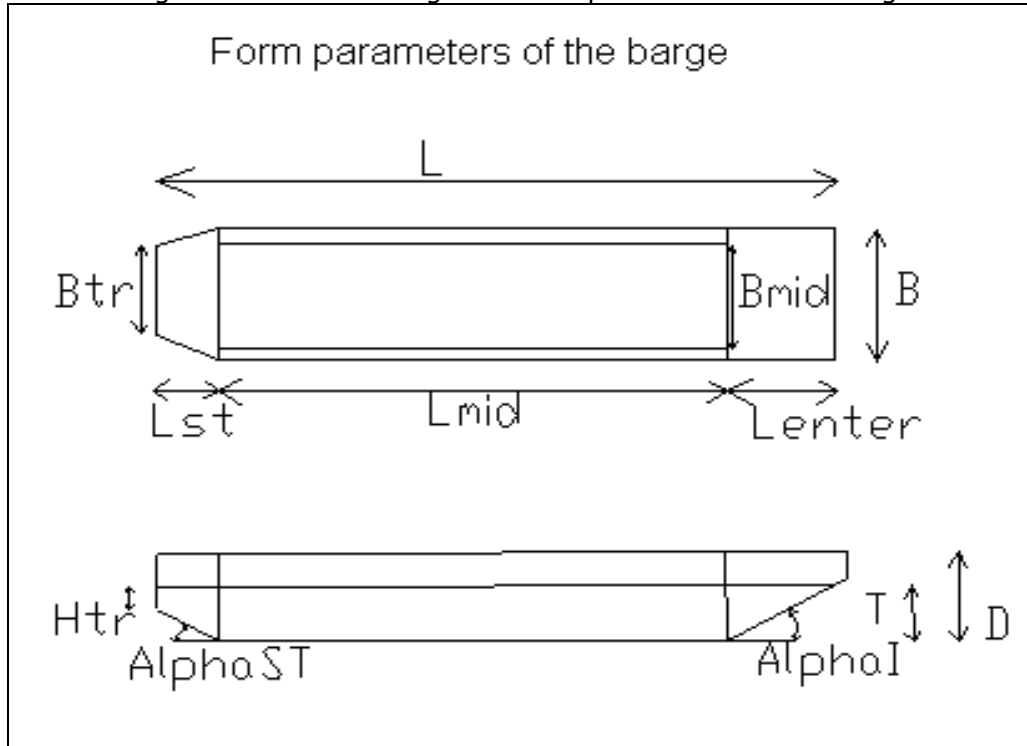
This design model wants to determine the main features of the barges and tug and the height of the building costs. The design model is also used to determine the transportation costs per TEU or tonne cargo, so that the competitiveness of the design can be determined.

### 7.2.3 Geometry

The geometry of the barge that is being used or the design of the barges is the same as the geometry that has been used in an empirical resistance model of barge (Holtrop *et.al.* 1990). The geometry is given in figure 7.4. A further description and explanation of how this geometry is embedded in the barge design model can be found in appendix A.

The reason for using this geometry for the barge is that the resistance model also uses this shape. The resistance calculation for the designed barge is the same in Holtrop *et.al.* (1990). A further explanation of the choice of this resistance model can be found in the next paragraph, which will deal with the resistance calculation of the barge.

Figure 7.4: Local and global form parameters of the barge



Source: Holtrop *et.al.* 1990

In the barge design model the maximum length and beam of the barge is restricted by the maximum allowable length on the selected waterway(s) that has been chosen in the network model (see chapter 6). The minimum beam of the barge will be determined by stability requirements of the barge (see section 7.2.8 of this chapter).

## 7.2.4 Resistance calculation

### Method

There are several methods to calculate the resistance of a barge in calm water.

In the past some simple empirical models were formulated, such as Latorre and Ashcroft (1981), in which the resistance was split into a frictional and a wave making part. The methods of Howe (1961) and Bronzini (1981) give relations to calculate the resistance of barge trains, including the push ship. These different resistance methods are given in appendix B.1.

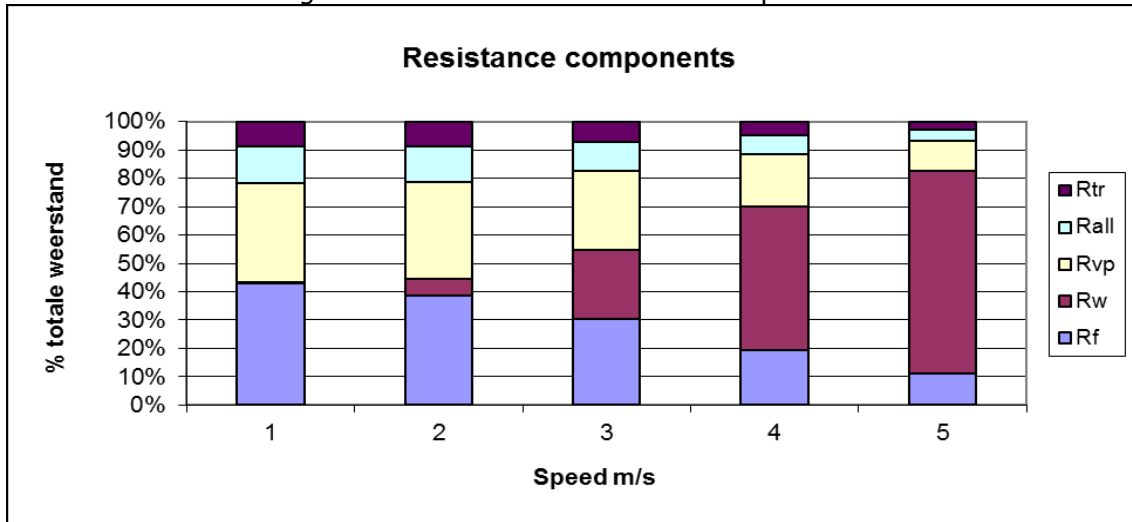
The downside of these formulas is that there is no very good description of the shape and form of the barge and that scale effects are not taken into account. Those formulas only hold for 'normal' large barges and not for small barges. That is why the resistance model of Holtrop *et.al.* (1990) is used in the barge design model.

The big advantage of this model is that it uses a regression model of a large set of resistance data of model barges (which have been towed in a towing tank), which is based on the hydro mechanical theory. Therefore, the data of the small barge models can be used in 1:1 scale if a correlation correction is applied. Another advantage is a better description of the shape of the barge, so that the influence of different shapes of barges can be analysed. Appendix B.2 offers an overview of the used resistance method. Because the barges are sailing on small waterways with a limited depth, the effect of the shallow waterway resistance also has to be added to the resistance model. Appendix B.3 gives the shallow water correction of Basin *et.al.* (1976), which will be added to the resistance method.

#### *Comparison of the different resistance calculations*

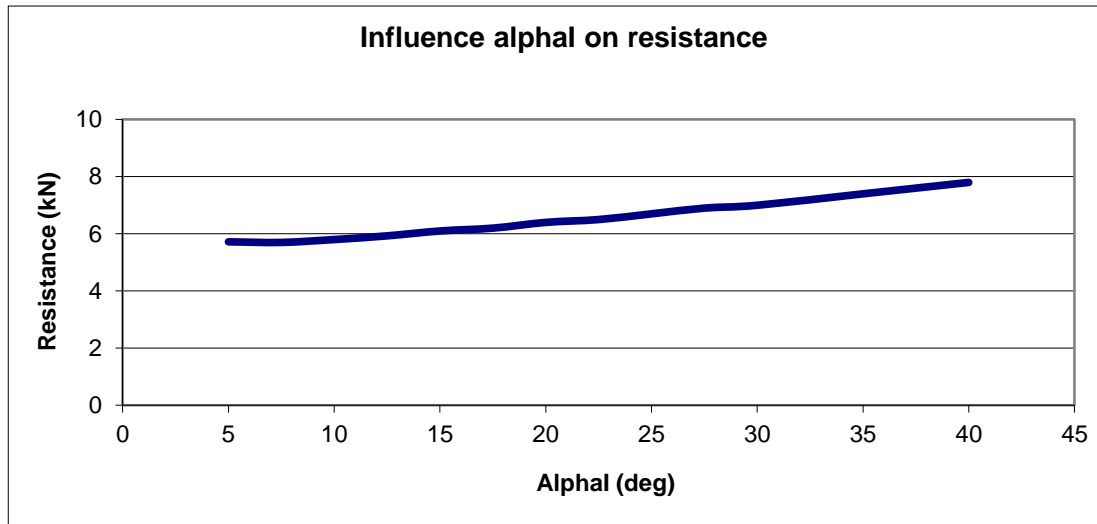
To check if the programmed calculations of the resistance give realistic values, several tests have been done. The first check is to take a close look at the different resistance components. The different resistance components for the barge on deep water by different speeds are given in figure 7.5.

Figure 7.5: Different resistance components



This calculation has been made with a barge with a length of 40 meters, a beam of 5.5 meters and a draft of 2 meters. It can be noticed that the frictional resistance at lower speeds is a large part of the total resistance and that the influence of the frictional resistance will become less if the speed is increased. On the other hand, the wave-making resistance gains in influence on the total resistance when the speed is increased. Further, it is clear that the viscous pressure resistance is an important resistance component. These conclusions are in line with the theory.

Another parameter with a large influence on the resistance is the angle  $\alpha_1$ . This influence is shown on figure 7.6. If that angle is varied and all other parameters are kept constant, the resistance will decrease when the angle becomes smaller. The reduction in resistance is not very important because when  $\alpha_1$  decreases, also the length of the barge will increase, so that the frictional resistance will increase. However, the general trend of reduction of the resistance is also something that can be found in theory (van Terwisga, 1989) (see also Appendix B.5).

Figure 7.6: Influence of  $\alpha_I$  on the resistance

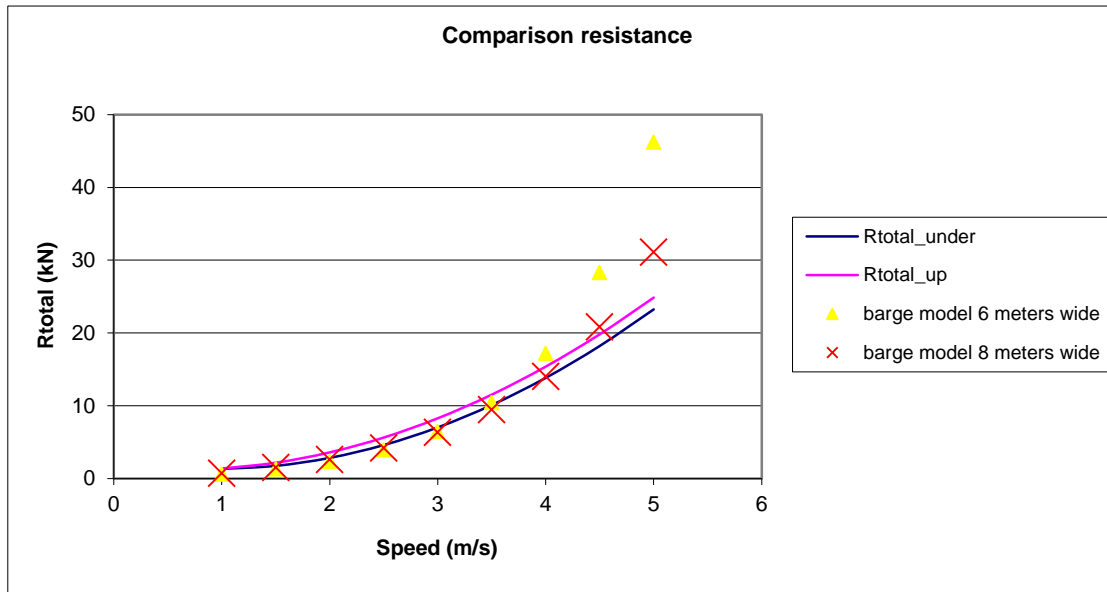
The last way to investigate if the calculated resistance is normal is to compare the calculated values with another resistance model, like the model of Latorre and Ashcroft. The choice has been made not to compare the used resistance model with the method of Howe and the method of Bronzini because those models will only deal with the total barge train resistance and including the push ship. Therefore those models will overestimate the resistance of a single barge.

If the resistance that is being calculated by the model is compared with the resistance of the model of Latorre and Ashcroft, it shows in figure 7.7 that the resistance the model calculates have the same order of magnitude as the model of Latorre and Ashcroft when the speed is smaller than 4 m/s. But when the speed is going up, the results of the model are much larger than the results of Latorre and Ashcroft. The difference will become smaller when the beam of the barge is increased.

This large difference is caused by the influence of the shape parameters of the barge model which are not used by Latorre and Ashcroft, which assumes standard hull form of the barge. The large difference at high speeds between the two methods is caused by the wave-making resistance of the used model which is very dependent on the Froude width number ( $Fn_b = V_s / \sqrt{g \cdot B}$ ) and on the parameter  $Q$  (see appendix B.2). The smaller the barge, the larger the wave-making resistance will be at higher speeds. Normally the wave-making resistance depends on the Froude number, based on length and not on the Froude number based on the width. The reason why the Froude width number is used is that the shape of the hull form of the barge is such that the wave-making resistance is more affected by the width of the barge than by its length.



Figure 7.7: Comparison resistance Latorre and Ashcroft with the barge model



The resistance calculated with the method of Latorre and Ashcroft is based on larger (and wider) barges. This could explain why there is such a large difference. This can also be seen when the model resistance of a wider barge ( $B = 8\text{ m}$  to  $B = 6\text{ m}$ ) is compared with the method of Latorre and Ashcroft. The difference will be smaller if the resistance calculated by the model is calculated for a wider barge. Furthermore, the model of Latorre and Ashcroft is only dependent on the length of the barge on not on the beam. This again leads to the idea that the model of Latorre and Ashcroft assumes fixed  $L/B$  ratios and deals with barges with a larger beam. This comparison also confirms that the model values of the resistance are realistic values and that they can be used for a reliable resistance calculation.

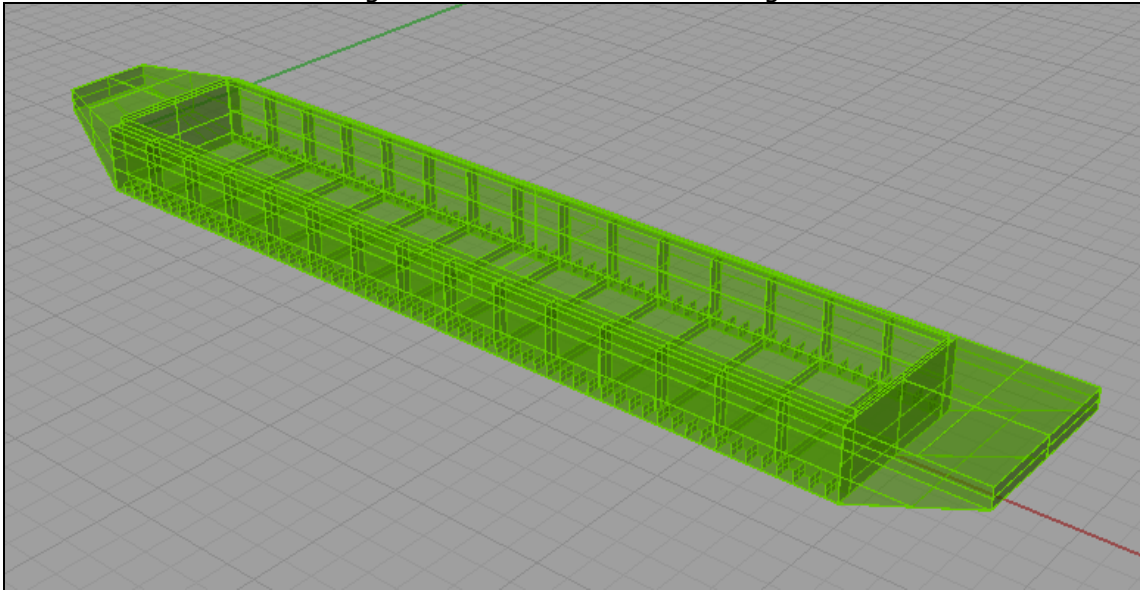
### 7.2.5 Construction

The construction of the barge will be described in this paragraph. Also the scantlings of the barge are shown and the calculated weight of the barge is being compared with other (existing) barges.

#### *Design of the construction*

In order to determine the construction weight of the barge, a design is made. The scantlings of the construction design are determined by the rules of the Germanischer Lloyd. If all the scantlings of all the different parts of the construction are known, then the weight of the construction can be calculated as the sum of the weight of all the different parts. Then it is also possible to determine the centre of gravity in height and length of the barge. Those values are needed to calculate the initial stability (GM) and the trim of the barge. Appendix C.1 shows the detailed description of the construction design, whereas figure 7.8 gives an overall picture of the total construction of the barge.

Figure 7.8: Total hull of the barge



### *Scantlings of the barge*

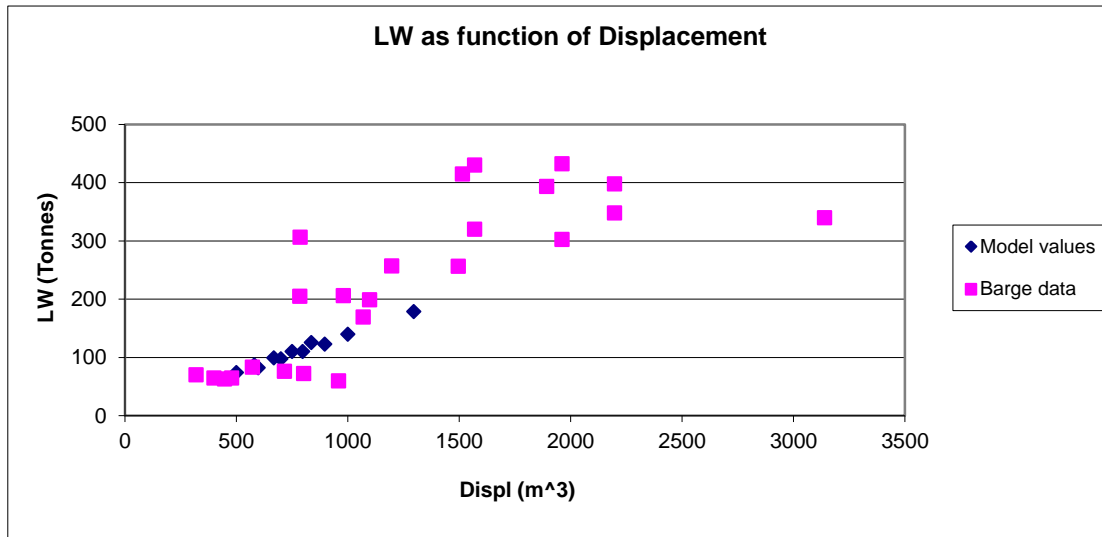
The scantlings of the barge are determined by the rules of the Germanischer Lloyd Inland vessels. The scantling rules are taken from Part B, Hull Design and Construction, Chapter 5, Hull Scantlings. The choice has been made to use the scantlings rules of the non-propelled cargo ships. In appendix C.2 a more detailed description of these calculations is given.

In order to investigate if the determined scantlings are not too small, the stresses at the deck and the tank top are calculated. First, the still water bending moment (SWBM) of the barge in the design condition and light-weight condition (empty) and the wave bending moment are determined. Based on the total moment (wave plus SWBM) and the scantlings of the main frame of the barge, the stresses can be calculated. In appendix D the calculation of the SWBM and the wave bending moment can be found. In the same appendix also the calculation of the stresses can be found.

### *Validation construction weight calculation*

In order to validate whether the calculated construction weight of the barge design model has realistic values, the model weights will be compared with the weights of existing barges. At first the light weight of the barge is analysed as a function of displacement. Because the shape of the barge is different from the shapes of normal barges (smaller length and beam), it is a better way to compare the weight as a function of displacement. The calculated and known values of the construction weight are given in figure 7.9.

Figure 7.9: Comparison between model values and known data



Source: barge data taken from Thill et.al. 2005; model values own calculation

Figure 7.9 indicates that the construction weights for small displacements (until 1000 – 1250 tonne) are in same range of known data. But when the displacement grows, the model values are too small compared with the known data. In other words, the larger the barge becomes, the more the construction weight will be underestimated.

The same figure also indicates that there is a large range in the light weight of the existing data. Therefore it is also analysed how well the model values of the construction weight compare with the weight estimation based on the equipment number developed by Watson (1998). The equipment number is an estimation parameter used to estimate the light weight of a ship. The formula for calculating the equipment number is given here below.

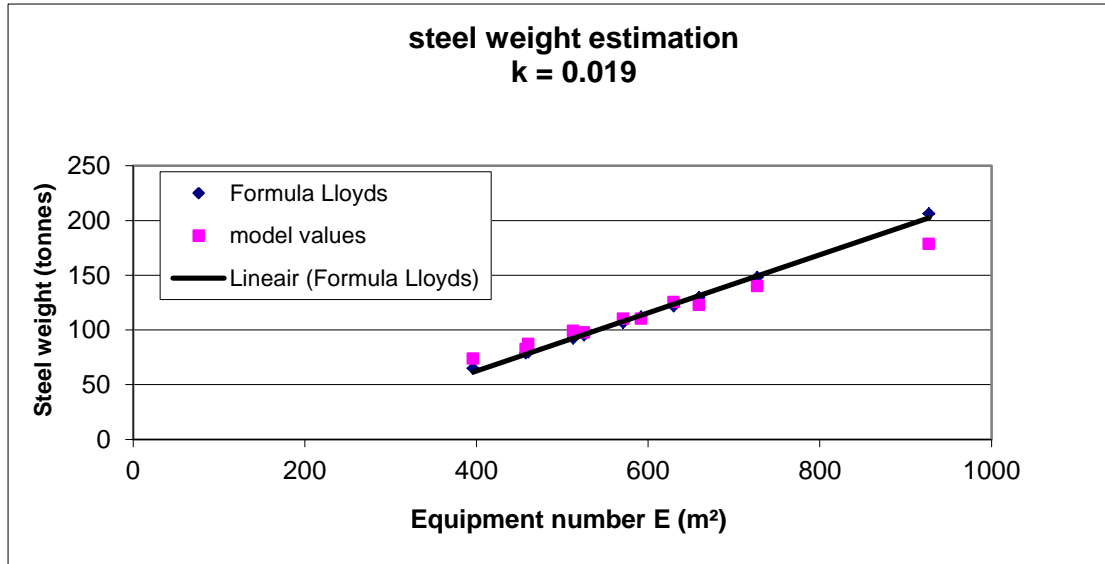
$$E = L(B+T) + 0.85L(D-T) + 0.85[(l_1.h_1) + 0.75(l_2.h_2)] \quad (7.1)$$

In this formula  $L_{1,2}$  and  $h_{1,2}$  are the length and the height of the superstructure on the barge. Because they are not present, those values are set at zero. The light weight of the barge can then be determined with the following formula:

$$W_{si} = K.E^{1.36} \quad (7.2)$$

The parameter K is a constant which is dependent on the type of ship. In the literature there is no value of K for inland ships or barges. The K-value of container ships gives an over estimation of the construction weight when the value of  $W_{si}$  is compared with the data set of barges. Therefore, a new value of K must be determined. The new value of K is determined by fitting  $W_{si}$  on the model values of the construction weight. The result is given in figure 7.10.

Figure 7.10: Equipment number compared to the model values



Graph 7.10 shows that the model values are a good estimation for the light weight. The trends of the theoretical line and the model values are the same and the deviation between the model and the theory is small. It can also be seen that the model values of the steel weight are smaller for larger barge, so that this model only can be used for small barges ( $E < 700 \text{ m}^2$ ).

The reason for this deviation, with increasing barge size, can be found in the scantlings of the barge which are determined by the rules from the Germanischer Lloyd. In those rules the thickness of the plates and the section modules of the stiffeners are determined by the largest value of three different formulas. As an illustration, the formulas for determining the thickness of the bottom plating of the barge are given.

$$\begin{aligned}
 t_{\text{bottom}} &= \text{MAX} \langle t_{1\text{bottom}}, t_{2\text{bottom}}, t_{3\text{bottom}} \rangle \\
 t_{1\text{bottom}} &= 1,85 + 0,03 \cdot L \cdot \sqrt{k} + 3,6 \cdot s \\
 t_{2\text{bottom}} &= 1,6 \cdot s \cdot \sqrt{k \cdot p_e} \\
 t_{3\text{bottom}} &= 68 \cdot \frac{s}{k_2} \cdot \sqrt{\frac{M_{\text{hog\_design}}}{Z_b}}
 \end{aligned} \tag{7.3}$$

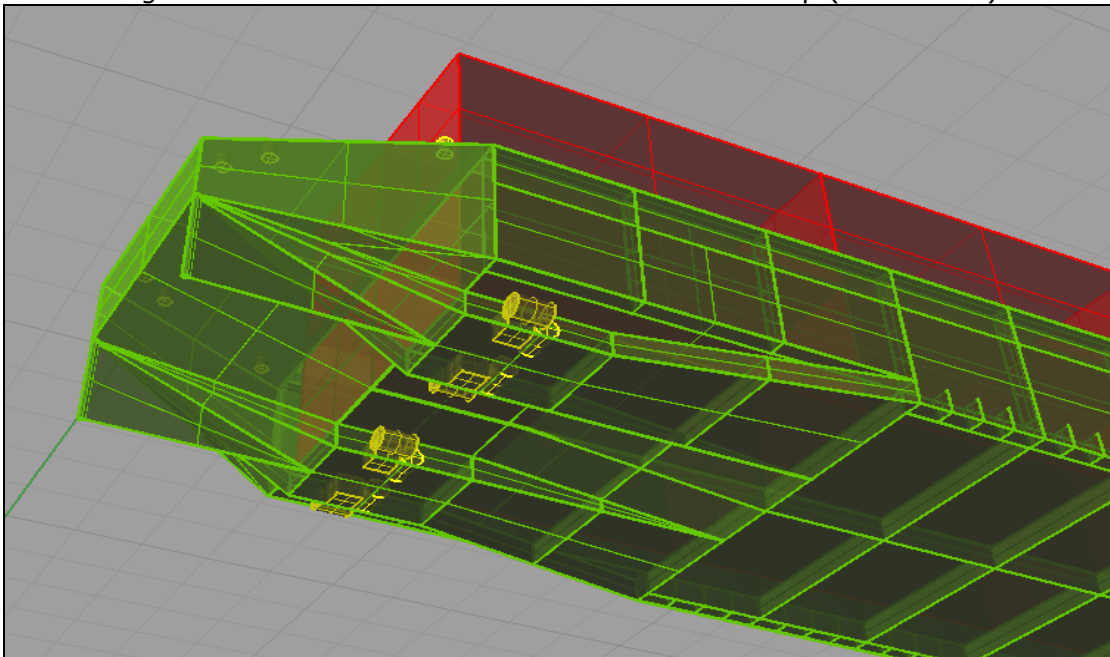
The formulae in 7.3 show that the relation  $t_{3\_bottom}$  is a function of the bending moment in hogging condition (BM) of the barge (global load). In order to determine that value, the scantlings of the barge must be known (weight distribution), so that another iterative problem will occur (besides solving the weight / displacement relation of the barge). If the latter criterion ( $t_{3\_bottom}$ ) is loosened, the software can solve all the relations that are programmed. However, the latter criterion becomes of great importance if the length of the barge (and the size) is increased. Therefore, the BM will become the most dominating factor in determining the scantlings. If the length of the barge is limited (small barges), then the latter criterion is not the most important one and the other two relations are sufficient (local load). Because the model gives good results for construction weight of small barges, it can be concluded that this model is suitable for the design of the

small barges. For the larger barges the results are not good and a manual adjustment has to be made. The model makes it possible to calculate the value of the third relation and a manual check is necessary if that value is smaller than the other two values.

### 7.2.6 Propulsion

If the barge must be able to sail independently, thrusters are added to the barge. There is a choice to install 0, 2 or 4 thrusters in the aft ship. These thrusters will be placed in the x-direction of the ship. Another thruster will be placed in bow of the ship. This bow thruster, along with the thrusters in the aft ship, will enable the barge to turn and manoeuvre. Figure 7.11 shows the thrusters in the aft ship of the barge.

Figure 7.11: Location of the thrusters in the aft ship (4 thrusters)



The thrusters are located in the double bottom of the barge (yellow cylinders) so that the thrusters do not stick out under the bottom of the barge. It is important to avoid this problem, especially when the barge is sailing in shallow water. The big advantage of installing thrusters is that these are capable of delivering thrust in two directions. That can be useful if the barge has to sail on a small narrow canal where the barge cannot be turned. In that case the barge could sail in reverse to a location where it can turn. For this, a steering installation must be placed on the aft ship, so that the captain can manoeuvre the barge from that position

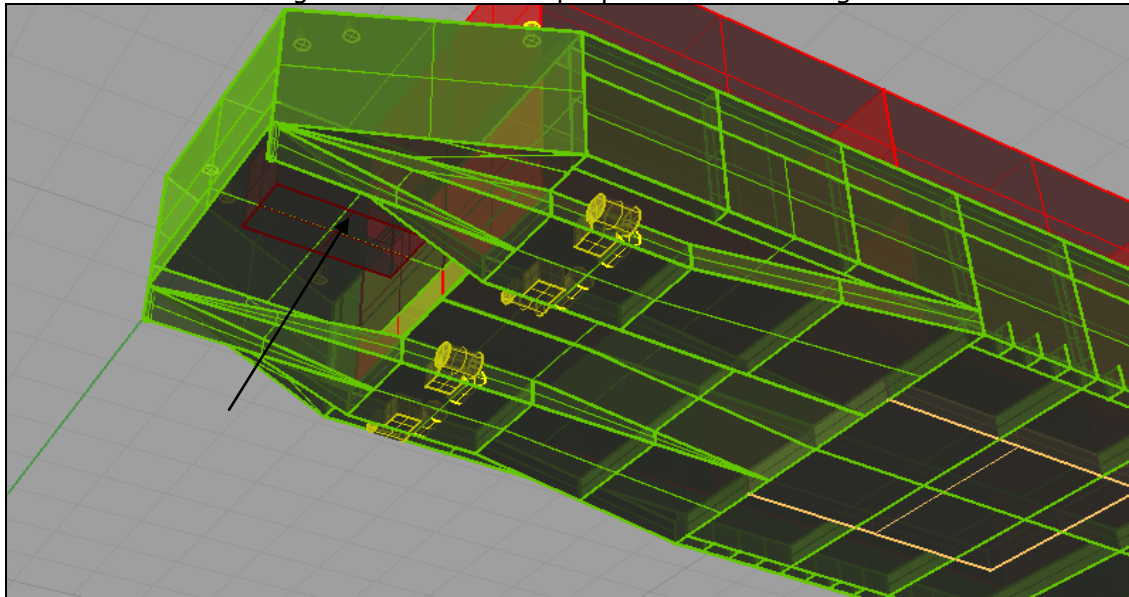
The thrusters that are used will be hydraulic thrusters that are being driven by a hydraulic pump powered by an electric engine. Such a system is more suitable for intensive use and long runs than electric thrusters.

The selection of the specific thrusters and the allocation of those thrusters on the barge will be further described in appendix E.

### 7.2.7 Power generation

The electric engines can be powered by one or two small generator set installed in the aft part of the barge. If the required power will be delivered by the gen sets, the aft ship of the barge has to be adjusted so that the gen sets can fit inside the hull. The installed gen sets are not greater than 400 kW per gen set and the number of installed gen sets (one or two) can be chosen in the model. The data of the gen set(s) will be taken from product information of a gen set manufacturer<sup>16</sup>. The fuel tank will be placed in the double bottom of the barge and that tank will be large enough to sail on the selected waterway(s) ten times back and forwards. Figure 7.12 shows the gen set propulsion of the barge. For this option two gen sets are installed.

Figure 7.12: Gen set propulsion in the barge



The electric engines can also be powered by the batteries that are installed in the double bottom of the barge. They are centred in the mid ship of the barge around the centre of gravity in length.

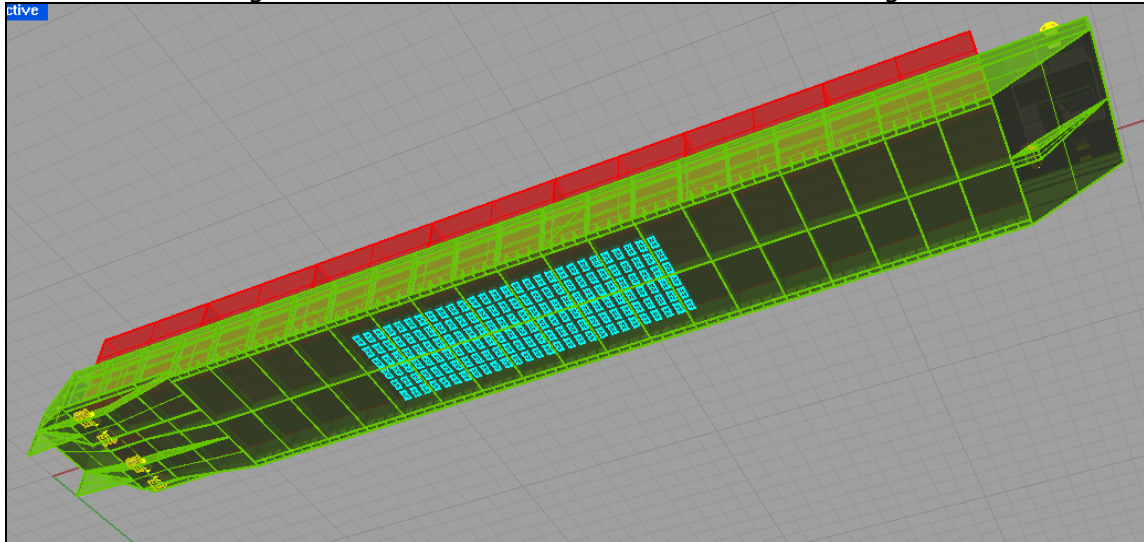
In appendix F.1 the design choices and necessary calculations for the battery propelled barge are given.

The result of the design choices and calculations regarding the allocation of the batteries is given in figure 7.13, where the batteries are the light blue blocks. The design below is a design where the barge will sail at a speed of 6 km/h and has to travel a distance of 45 km. There are also 4 thrusters in the aft.

<sup>16</sup> [www.wartsila.com](http://www.wartsila.com)

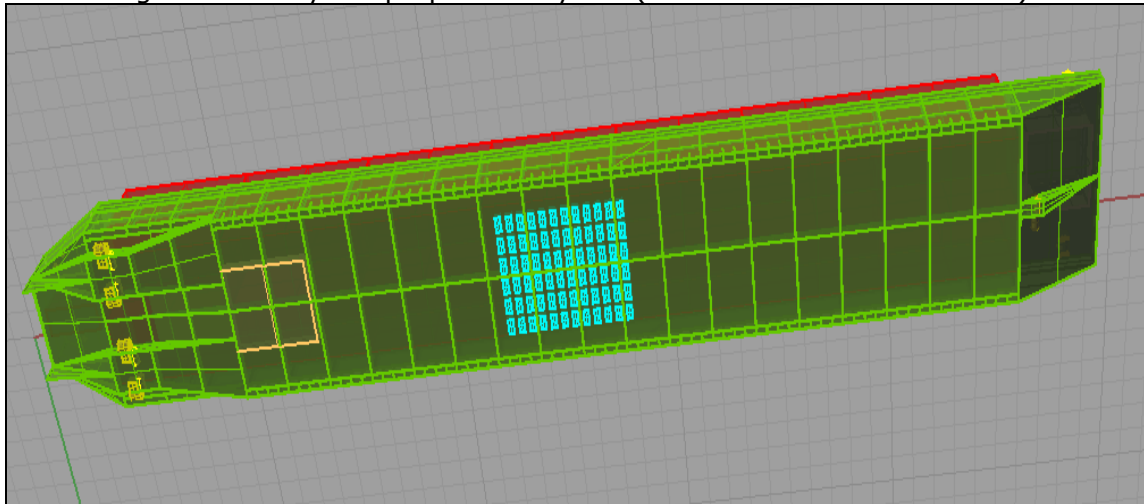


Figure 7.13: Allocation of the batteries in the barge



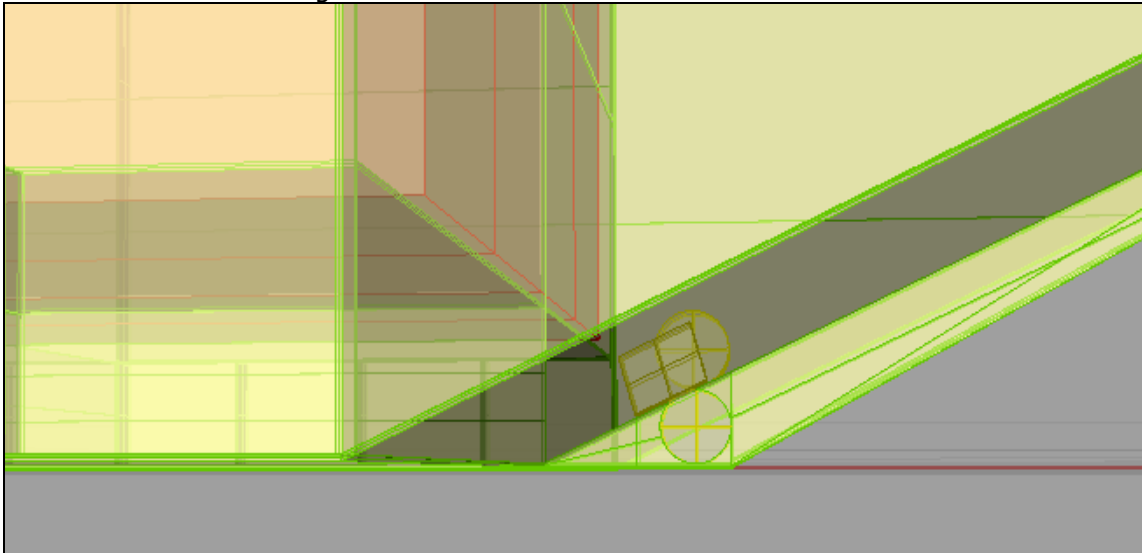
The design model has also room for a hybrid option, i.e. a combination of the previous two propulsion options. A gen set will be installed to power the barge for sailing at the required nominal cruising speed. The batteries are used to power the barge when top power is needed to, e.g. when passing a lock or in order to overcome strong currents. The gen set installed in the barge will also be used to recharge the batteries installed in the barge. Figure 7.14 shows the hybrid propulsion lay-out.

Figure 7.14: Hybrid propulsion lay out (with batteries and fuel tank)



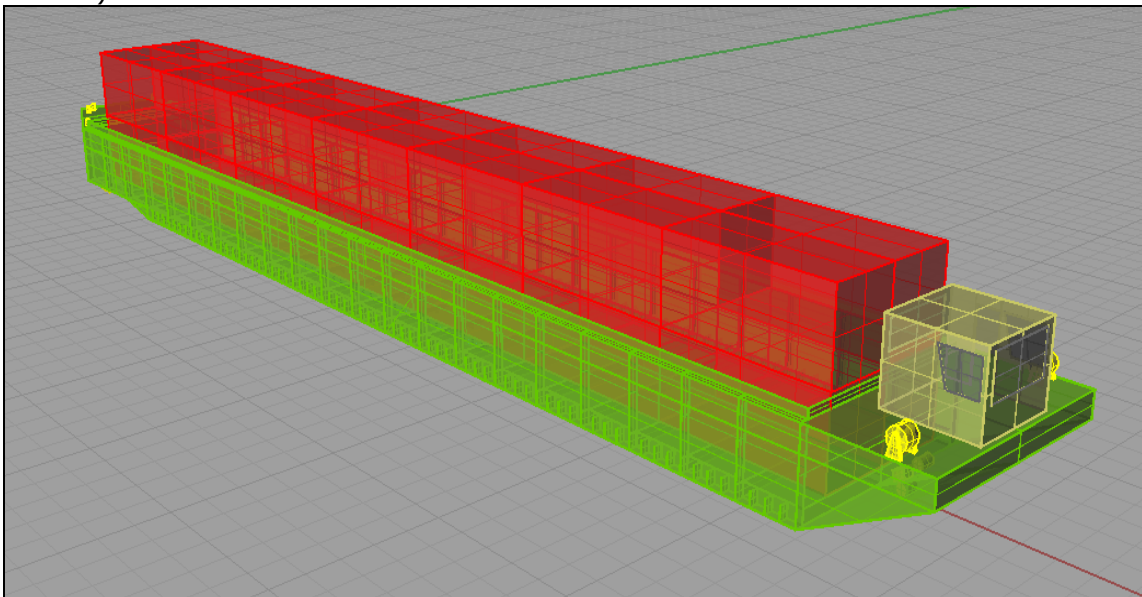
The bow thruster is placed outside the double bottom structure and in the bow section of the barge. That has been done because the thruster must not stick out under the barge, which suggests the best choice of the location. The location of the bow thruster is given in figure 7.15.

Figure 7.15: Location of the bow thruster



On top of the fore ship of the barge, the wheel house will be placed, from where the captain can sail his barge when it has to sail independently. The dimensions of the wheel house are taken from a comparable ship, i.e. the NeoKemp (Schip en werf de zee, 2000). If it has been preferred not to sail independently, the wheel house will not be placed on the barge. Figure 7.16 shows the total design of the barge when it has to sail independently on her batteries.

Figure 7.16: Top view of the barge (L = 50 meters, B = 6.8 meters, T = 1.91 meters)



### 7.2.8 Stability

The last design calculations that need to be made are the stability calculations. The initial stability of the barge will be determined by its GM-value. In Appendix G the stability calculations of the barge can be found.



In the rules of the shipping inspection it is pre-described that the value of GM must be larger than 50 cm if the containers are lashed. If the containers are not lashed, the GM must have a value of 100 cm.

For every design that has been made a stability check will be made to see if the barge is stable. If the calculations show that the barge is not stable enough, the design will be rejected and the design (or payload) has to be changed.

For the transportation of bulk cargo no stability criteria are given, but if the barge is stable enough to transport containers, no problems are expected with respect to transporting bulk cargo. The centre of gravity of the payload will be much lower than the VcG of containers, while the barge is still the same. Therefore KM will be equal as in the situation when containers are transported (if the draft is the same), so that the GM value will be larger and the barge will have a higher initial stability.

### **7.2.9 New building price of the barge**

In order to determine the transportation costs of the small barge system (see chapter 8), it is necessary to know the newbuilding price of the used barges. The newbuilding price, negotiated between the shipping company and the shipyard, will be a cost for the small barge system.

In order to determine the newbuilding price, first the newbuilding cost for the shipyard will be calculated. To calculate the newbuilding costs of the barge, first the two main outflows of money, which are the costs of the shipyard, will be determined. These two major cost components are:

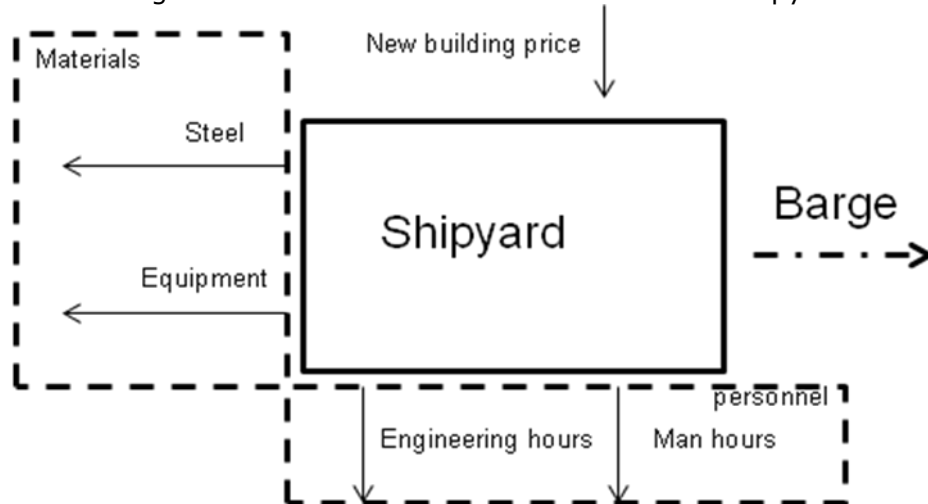
- Materials; defined as steel and equipment (engines, propellers, etc.)
- Personnel; defined as man-hours and engineering hours

The inflow of money will be the newbuilding price of the ship. The difference in newbuilding price and the newbuilding costs will be the profit margin of the shipyard. This profit margin will be fixed for the shipyard.

There is also a physical output of the shipyard. This will be the barge itself.

In figure 7.17 an overview is given of the different money flows from and to the shipyard. The calculation of the newbuilding costs of the barge within the barge design model will be further explained in this paragraph.

Figure 7.17: Overview of the cash flows of a shipyard



Source: own composition based on figure 3.7

The cost of the hull of the barge will be calculated on a basis of the total steel weight of the barge. In order to perform this calculation, a few assumptions have to be made. The first assumption is that the total amount of man hours needed to build one tonne of barge is equal to 25. A typical value of man hours is value between 20 and 30. The second assumption is that 85% of work on the barge is steelwork (building of the construction). The other 15% are costs made for painting, welding material and finishing the barge. The total costs to build the hull barge can be calculated with the following formula:

$$\text{Cost}_{\text{Barge\_construction}} = \text{LW} \cdot (25 \cdot \text{Cost}_{\text{man\_hour}} + \text{Costs}_{\text{steel}}) \cdot 1.15 \quad (7.4)$$

$\text{Cost}_{\text{Barge\_construction}}$  = costs to build the hull of the barge

[EUR]

LW = light weight of the barge

[tonne]

$\text{Cost}_{\text{man\_hour}}$  = overhead costs per person per hour

[EUR/h/person]

$\text{Cost}_{\text{steel}}$  = costs of one tonne of steel

[EUR/tonne]

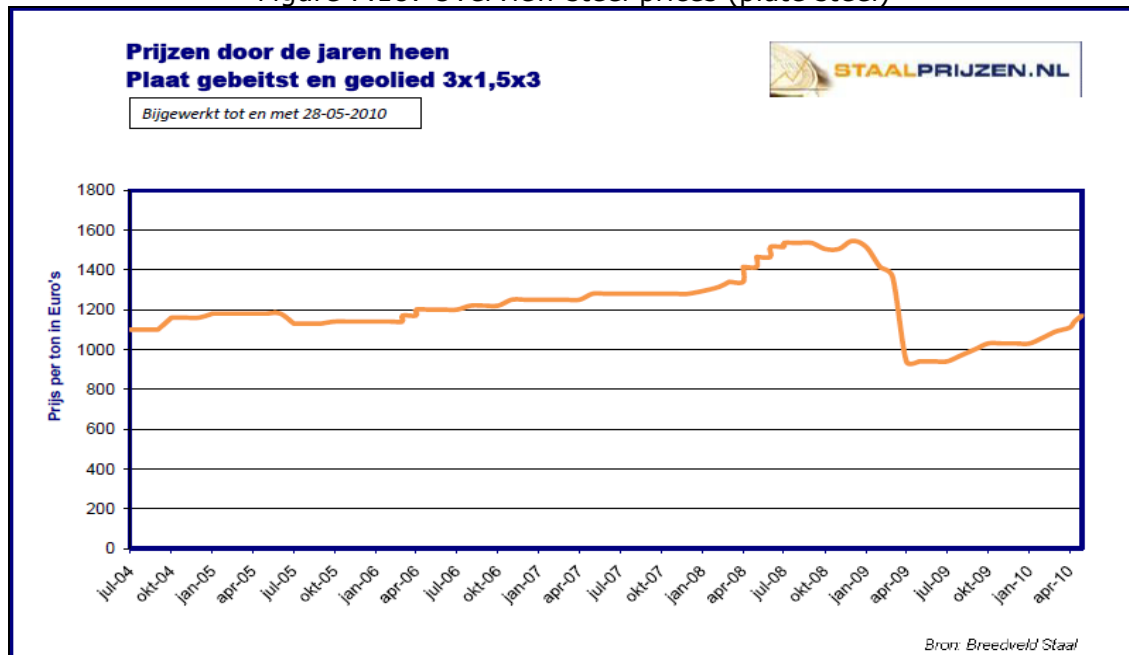
These costs are an estimation and are based on typical values for man hours and steel work costs. These costs are verified with a ship yard. It is essential to know that this is only an estimation of the costs and not a detailed calculation. The costs per man hour are 40 EUR/h, which is determined by the wages of the steelworkers (3300 EUR per month, before tax<sup>17</sup>) plus 40% as employers' costs. Also 5 EUR/h are added to incorporate engineering costs and 10 EUR/H to incorporate the fixed costs of the used equipment, docks, cranes ( $40 \approx 3300 \cdot 12/52 \cdot 1/40 \cdot 1.4 + 5 + 10$ ).

The costs for one tonne of steel (6 to 8 mm tick) are 1100<sup>18</sup> EUR (average 2009 value). In figure 7.18 an overview is given of the steel prices from 2004 to 2010.

<sup>17</sup> CAO klein metal 2009 (maximum working experience by 40 hours per week)

<sup>18</sup> [http://www.staalprijzen.nl/files/1\\_Bruto\\_%20prijslijst\\_platen.pdf](http://www.staalprijzen.nl/files/1_Bruto_%20prijslijst_platen.pdf) (2010)

Figure 7.18: Overview steel prices (plate steel)



Source: staalprijzen, 2010

The figure indicates that the steel prices are volatile and that there was a large drop in the price due to the economic crisis in 2008. As stated in chapter 5, the base year for all the costs calculations is the year 2009. In order to determine the steel costs for the year 2009, the average value is used. However, when taking the steel price of 2009 the newbuilding costs will be underestimated, which will have large impact on the transportation costs (see chapter 8). The newbuilding costs of the barge will affect the transportation costs of the small barge system through its entire life span and therefore the most actual price should be used. But in order to stay consistent in the cost calculations, the year 2009 will be used as base year.

The costs to install the electric engines, thrusters and batteries are given here below. The installation time of installing a battery is estimated at 1 man-hour per battery. In this time the batteries are placed and connected to the electrical system. The costs of the batteries itself come from the product info of the battery manufacturer and are given in appendix F.2 (2009 value).

$$\text{Cost\_Batt}_{\text{total}} = N_{\text{Batt}} \cdot (\text{Cost}_{\text{Batt}} + \text{Cost}_{\text{Man\_hour}}) \quad (7.5)$$

Cost\_batt<sub>total</sub> = costs of all the batteries [EUR]  
 Cost<sub>batt</sub> = costs of single battery [EUR]  
 Cost<sub>Batt\_installation</sub> = costs of installing the batteries [EUR]  
 N<sub>Batt</sub> = number of batteries [-]

The costs to buy and install the gen set are given in relation 7.28. The costs to install the gen sets are estimated at 100 man-hours per installed gen set. The costs per kW engine are equal to 330 EUR (Wartsila data 2005). Because no new or better information regarding the prices of generator sets are available, this cost is scaled with the inflation figures given in section 5.3. The value of the following relation will therefore be in 2009 values.

$$\text{Cost}_{\text{GEN\_SETS}} = (330 \cdot \text{Pb\_installed}_{\text{engine}} \cdot \text{index} + 100 \cdot \text{Cost}_{\text{Man\_Hour}}) \cdot A_{\text{Engines}} \quad (7.6)$$

$\text{Cost}_{\text{GEN\_SETS}}$  = costs for the installed gen sets [EUR]  
 $A_{\text{Engines}}$  = number installed gen sets [-]  
 $\text{Pb\_installed}_{\text{engine}}$  = installed power per gen set [kW]  
 Index = inflation index 2005 → 2009 = 115.4/106.5 (see 5.3) [-]

The time to install the thrusters is estimated at 25 man hours per thruster and the price of the thrusters is given in appendix G (2009 values).

$$\text{Cost}_{\text{Thruster}} = N_T \cdot (25 \cdot \text{Cost}_{\text{Man\_hour}} + \text{Cost}_T) \quad (7.7)$$

$\text{Cost}_{\text{Thrusters}}$  = total costs thrusters [EUR]  
 $N_T$  = number of thrusters [-]  
 $\text{Cost}_T$  = costs of a single thrusters [EUR]

The same relation as in 7.14 is used for the calculation of the costs of the electric engines. The prices of the electric engines are estimated at 100 EUR per kW power that is needed (Wartsila data 2005).

$$\text{Cost}_{\text{EMotor}} = N_{\text{EM}} \cdot (25 \cdot \text{Cost}_{\text{Man\_hour}} + 100 \cdot P_{\text{Emotor}} \cdot \text{index}) \quad (7.8)$$

$\text{Cost}_{\text{Emotor}}$  = costs to buy and install the electric engines [EUR]  
 $N_{\text{EM}}$  = number of electric engines [-]  
 $P_{\text{Emotor}}$  = power electric engine [kW]  
 Index = inflation index 2005 → 2009 = 115.4/106.5 (see 5.3) [-]

The cost of the control system needed is estimated at 10,000 EUR (2009 value). This control system is used to control and manoeuvre the barge when it has to sail in and out of the locks. If the choice has been made that the barge has to sail independently, these costs are set at 0 EUR because in that case the barge will be controlled by the captain.

The cost of the hydraulic coupling system is estimated at 9,000 EUR. These costs are given by a manufacturer of those systems and are an estimation of two 40 tonnes coupling systems (2009 values).

The wheelhouse price is determined at 40,000 EUR (2007 value). This figure is given by ALUBOUW de Mooy (manufacturer). This is only the price of an "empty" wheel house exclusive of equipment. If the price of the equipment is incorporated, the cost of the wheelhouse is doubled. To transform the 2007 values to 2009 values, again the inflation correction will be applied. So the total cost of the wheelhouse is €82,900 (2009 value). If it has been preferred to sail independently, the wheelhouse will not be placed and the costs are set at zero.

The total costs of the barge can now be determined as the sum of all the different components. On top of that an extra margin of 7% is added to incorporate the profit margin of the ship yard.

$$\begin{aligned} \text{Cost}_{\text{total}} = & (\text{Cost}_{\text{Construction}} + \text{Cost}_{\text{EM}} + \text{Cost}_{\text{whinches}} + \text{Cost}_{\text{Wheelhouse\_barge}} \\ & + \text{Cost}_{\text{Thrusters}} + \text{Cost}_{\text{Batt}} + \text{Cost}_{\text{Gen\_set}} + \text{Cost}_{\text{Control}}) \cdot 1.07 \end{aligned} \quad (7.9)$$

For deep sea shipbuilding also the costs related to the financing costs of the ship are to be taken into account (Hopman, Nienhuis, 2009). For these

small inland barges these costs are neglected. The barges are much smaller and so is also their newbuilding price, so that little pre financing is needed.

It is very difficult to determine the profit margin of ships and it is even harder to determine the newbuilding price. The shipbuilding market is a very volatile one, where prices fluctuate very much. In chapter 14 of this thesis the impact of a variation of the newbuilding price will be researched via a scenario analysis.

In the formula 7.9 the different parts are the costs of those parts inclusive of installation (man hours) and purchase price (steel costs, costs of the thrusters, ex.). Therefore  $Cost_{EM}$  is the cost of the installation and purchase price of the electric engines.

Table 7.3: Calculated barge new-building costs of different barges

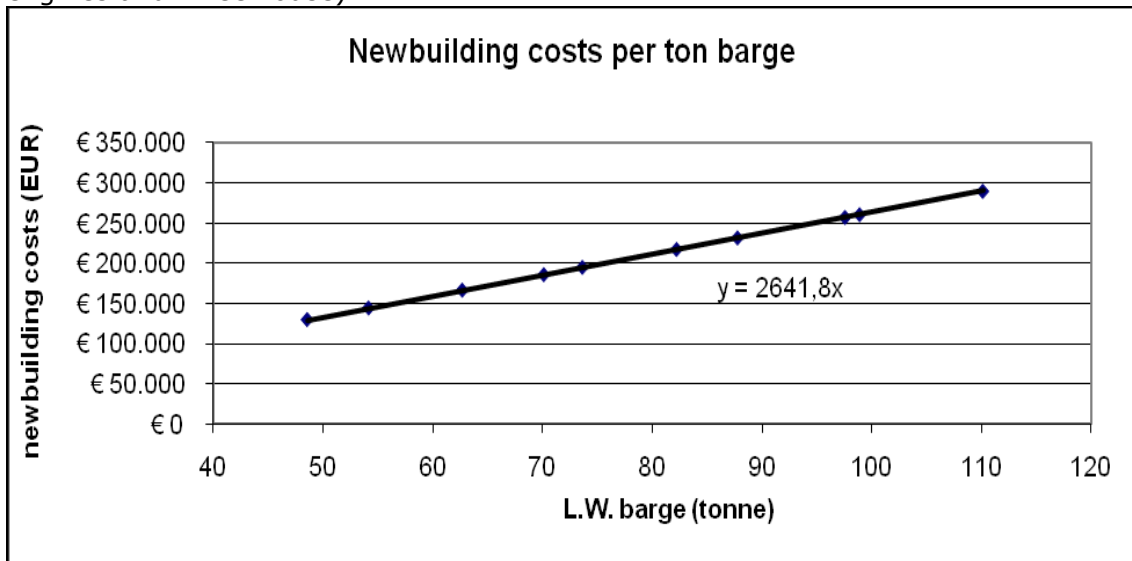
Displacement	L	B	T	LW	Payload	Costs
[m <sup>3</sup> ]	[m]	[m]	[m]	[tonne]	[tonne]	[EUR]
333.31	30.59	6.8	1.72	48.56	284.59	€ 130.304
418.33	36.8	6.8	1.77	62.69	355.74	€ 166.826
500.34	42.96	6.8	1.80	73.64	426.89	€ 195.117
585.62	49.13	6.8	1.83	87.78	498.03	€ 231.656
667.89	55.27	6.8	1.85	98.90	569.18	€ 260.395
398.54	30.52	8.3	1.69	54.16	344.26	€ 144.777
500.23	36.73	8.3	1.74	70.13	430.33	€ 186.038
598.40	42.89	8.3	1.77	82.23	516.39	€ 217.303
699.80	49.05	8.3	1.08	97.57	602.46	€ 256.958
798.43	55.19	8.3	1.81	110.13	688.52	€ 289.398

Note: 2009 values

The results of the costs calculations are given in the table 7.3. The costs in the table are the costs of the empty barge without equipment (without thrusters, batteries electric engines and wheelhouse). In fact, in order to compare the calculated values with known newbuilding prices of barges, the extra equipment must be left outside the calculation.

In figure 7.19 the new building costs are shown as a function of the light weight of the barges. The costs per tonne barge are determined at 2,642 EUR.

Figure 7.19: Costs per tonne barge without equipment (thrusters, batteries, electric engines and wheelhouse)



Note: 2009 values

For their calculation of new building prices of barges, Promotie Binnenvaart Vlaanderen<sup>19</sup> (PBV) uses €1300 per tonne. It has to be noticed that this figure dates from 2003-2004. Because the price of the barge very much depends on the steel price and the costs of employment, the new building price will be corrected. The steel price has increased very much from 2003 to 2009. The index from 2003 to 2006 (2006 has the same value as the 2010 values of figure 7.20) is equal to 1.55 (UK steel, 2008). The correction factor is now determined with the help of formula 7.26. In that formula the newbuilding costs are determined for 55% by the steel costs and for 45% by the costs for man-hours (€1200 steel and €1000 man-hours), so that the correction factor is equal to  $(0.55 \cdot 1.55 + 0.45 \cdot 1.13) \cdot 1.15 = 1.60$ . Therefore, the price per tonne barge, for the 2009 values is now 2,035 EUR per tonne.

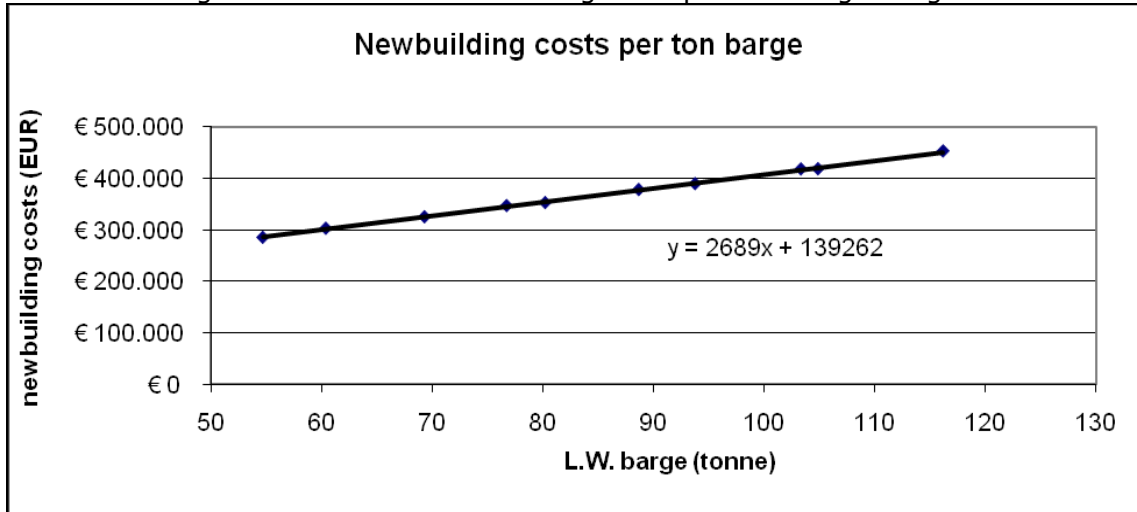
The calculated value is larger than the corrected values of PBV. This is most likely due to the incorporation of the costs of engineering and the costs capital. Therefore the rule of thumb used by the PBV is underestimating the costs of the barge by not including these costs items. They only use the costs of building the barge without considering the total costs made by the shipyard. In this research these costs will not be neglected, so that the calculated values will be used for the determination of the new building costs of the barge.

The total new-building costs are given in figure 7.20. These costs are also inclusive of the costs of the electric engines, thrusters, batteries and wheel house. These costs have a higher start value then the new-building costs of the "empty" barge. This higher start value is almost 140,000 EUR and is due to the investment costs of the equipment. The price per tonne barge also increases by 60 EUR per tonne more than the empty barge. The calculated values that are given here below are calculated for a barge that can sail at a speed of 6 km/h and can cover 2 times 35 km. If the barge has

<sup>19</sup> Promotie Binnenvaart Vlaanderen is an independent non-profit association for promoting the use of the inland waterways in Flanders ([www.binnenvaart.be](http://www.binnenvaart.be)).

to sail longer distances, the costs will increase due to the fact that more batteries are needed.

Figure 7.20: Total new-building costs per tonne lightweight



Note: 2009 values

### 7.2.10 Sensitivity analysis of the barge design model

To gain insight into different hull forms of the barge, several shape parameters will be varied, in order to find out what the most efficient barge shape is in terms of resistance. Besides the shape parameters, other parameters are varied in order to gain insight into which parameter has the biggest influence on the costs of the barge. Those parameters are the speed and the range of the barge and the type of propulsion system installed on the barge.

In order to make the calculations, some input parameters have been initially assumed. In table 7.4 an overview is given of those input parameters.

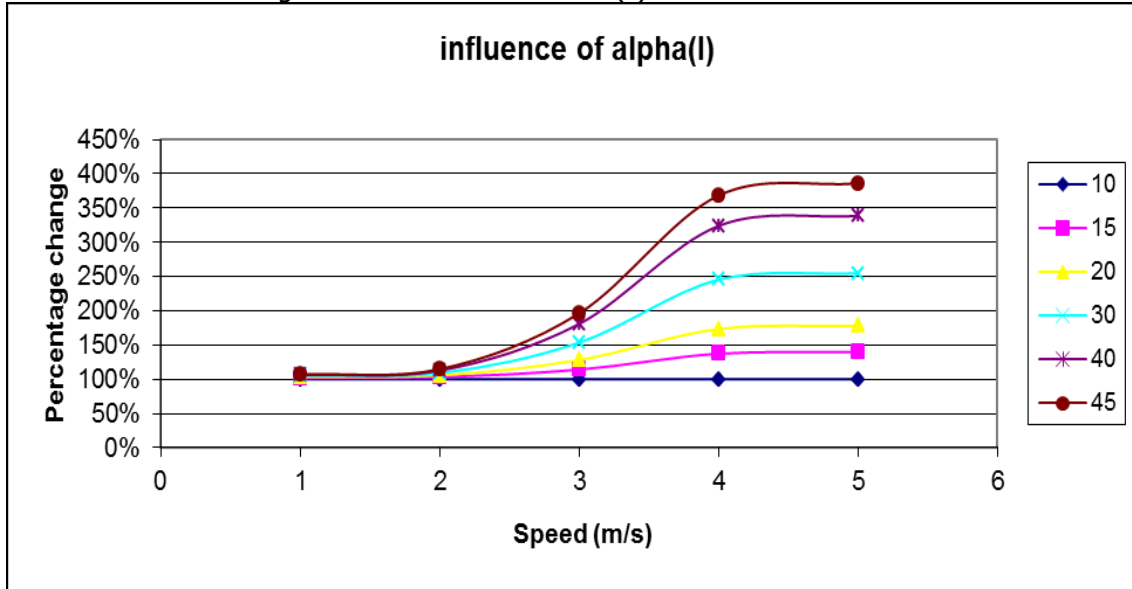
Table 7.4: Overview of predetermined design parameters

Input parameter	Value
$L_{\text{cargo hold}}$	7 TEU
B	6.8 m
Loading capacity barge	28 TEU or 550 tonne
Independent sailing barge	Yes

In all the upcoming calculations the water depth of the small waterway is set at 2.3 meters. This water depth will influence the shallow water resistance of the barges on the small inland waterways.

The first parameter that is analysed is the angle between the bottom and the bow of the barge ( $\alpha_I$ ). The influence of  $\alpha_I$  on the resistance is calculated and is shown in figure 7.21. In this figure the resistance when  $\alpha_I = 10$  degrees is set as the 100% value. When  $\alpha_I$  is small, the resistance is low in comparison with the other values of  $\alpha_I$ . This is because the length of the fore ship is related to the  $\alpha_I$  (see appendix A). The smaller  $\alpha_I$  is, the larger the barge will be, so that the draft will be reduced, which has an important

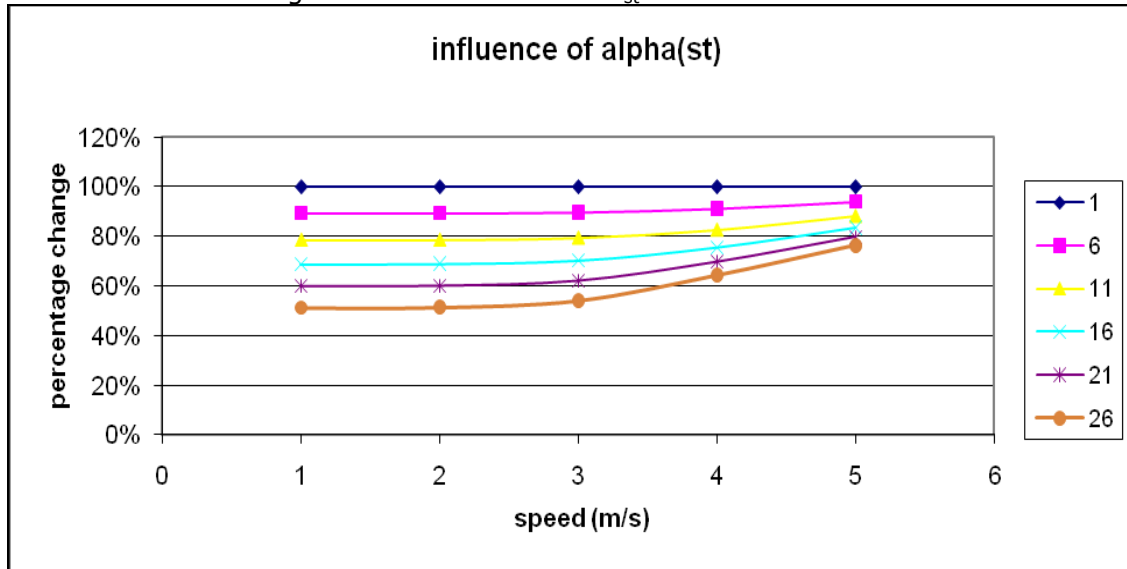
effect on the resistance, especially when the speed is high (high Froude numbers). This effect is increased by the shallow water resistance. If  $\alpha_I$  is increased, the barge will be shorter, and the draft and hence the resistance will increase. Figure 7.21 indicates that at higher speeds the influence of  $\alpha_I$  is larger than at lower speeds. So the effect of changing  $\alpha_I$  affects the main dimensions of the barge and therefore the choice of  $\alpha_I$  is also determined by the maximum length of the barge (limited by the lock dimensions) and the minimum length of the fore ship (enough space for the wheel house on the barge). In practice, it means that the  $\alpha_I$  has a value between 20 and 30 degrees. Therefore, a value of 25 degrees is advised because that will lead to the lowest resistance at the highest speeds.

Figure 7.21: Influence of  $\alpha_I$  on the resistance

The second parameter that will be analysed is the angle  $\alpha_{st}$ . The influence on the resistance of the barge will be analysed by varying  $\alpha_{st}$ . The variation of  $\alpha_{st}$  at different speeds can be found in figure 7.22, where the resistance at  $\alpha_{st}$  is one is given as 100% and all the other angles are given as a percentage change of that value.

From figure 7.22 it can be concluded that at low speeds of 1 to 2 m/s the largest value of  $\alpha_{st}$  gives the lowest resistance. When the speed is increasing, the influence of the angle on the resistance becomes less. The reason for that is in the shape of the barge. A large value of  $\alpha_{st}$  will result in a smaller transom area. Therefore the viscous pressure resistance is less. The viscous pressure resistance is hardly influencing the total resistance at higher speeds, where the dominant resistance component is the wave-making resistance. The size of  $\alpha_{st}$  is limited to 26 degrees. If that value is higher, the transom area will be smaller than zero and no results are obtained (see also appendix A: barge geometry). The transom area is determined by  $\alpha_{st}$  and the length of the aft ship of the barge ( $L_{st} = 4$  meters). The best choice for  $\alpha_{st}$  is then 25 degrees. If a generator is installed, set in the aft of the barge, then  $\alpha_{st}$  cannot be chosen freely, but it must be altered in order to create enough space to allocate the generator set ( $\alpha_{st} < 10^\circ$ ).



Figure 7.22: Influence of  $\alpha_{st}$  on the resistance

In figure 7.23 the influence of the width of the transom area will be investigated. In these calculations the angles  $\alpha_I$  and  $\alpha_{st}$  are set at  $25^\circ$ . The width of the barge is set at 6.8 meters. The resistance of the barge when the transom width is half the width of the barge is set at 100%.

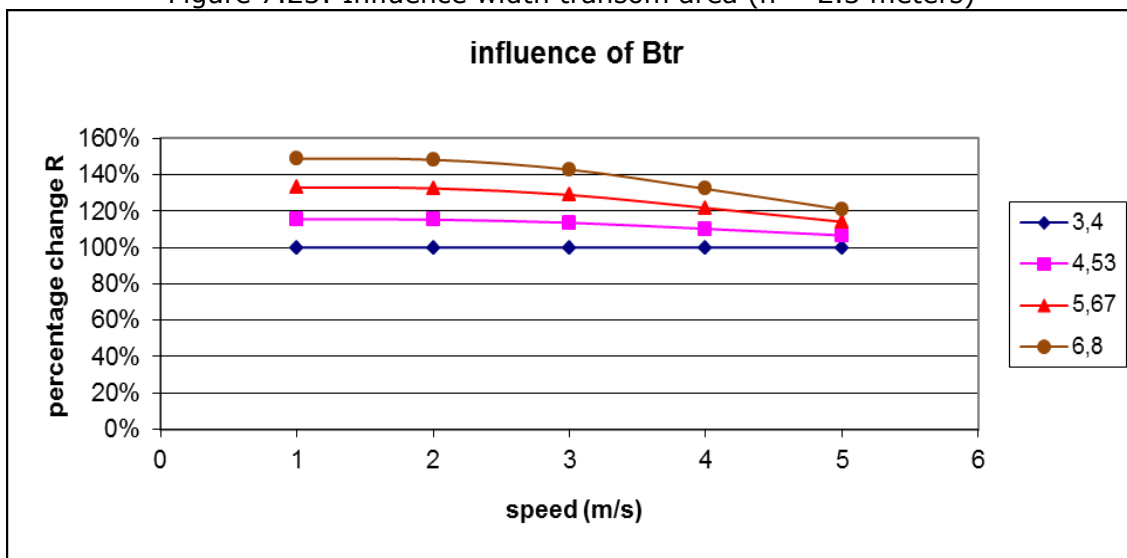
Figure 7.23: Influence width transom area ( $h = 2.3$  meters)

Figure 7.23 shows that the resistance will increase if the width of the transom area is increased. This is also due to the increase of transom area of the barge. The influence is decreasing when the speed of the barge is increasing, but the reduction is smaller than in figure 7.21, where the value of  $\alpha_{st}$  was varied. It is therefore advised that the width of the transom area will be reduced as much as possible. A limiting factor is that the barges have to be coupled, for which a minimum pushing area is needed. The minimum width of the barge is set at 0.5 of the total width of the barge. This will be used in the design because it leads to the lowest resistance of the barge when it is sailing independently.

In table 7.4 the width of the barge was initially set at 6.8 meters (maximum allowable width of the barge). But also the influence of the width of the

barge on the resistance is calculated and can be seen in the figure here below. The resistance curve is calculated for 5 different widths of the barge.

Figure 7.24: Influence of the width on the resistance ( $h = 2.3$  meters)

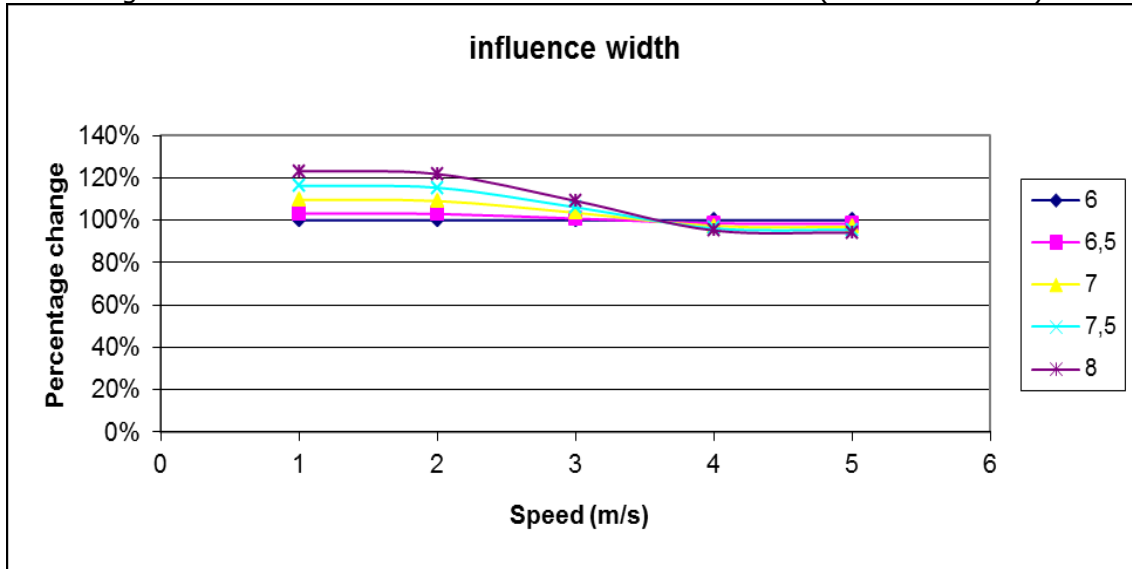
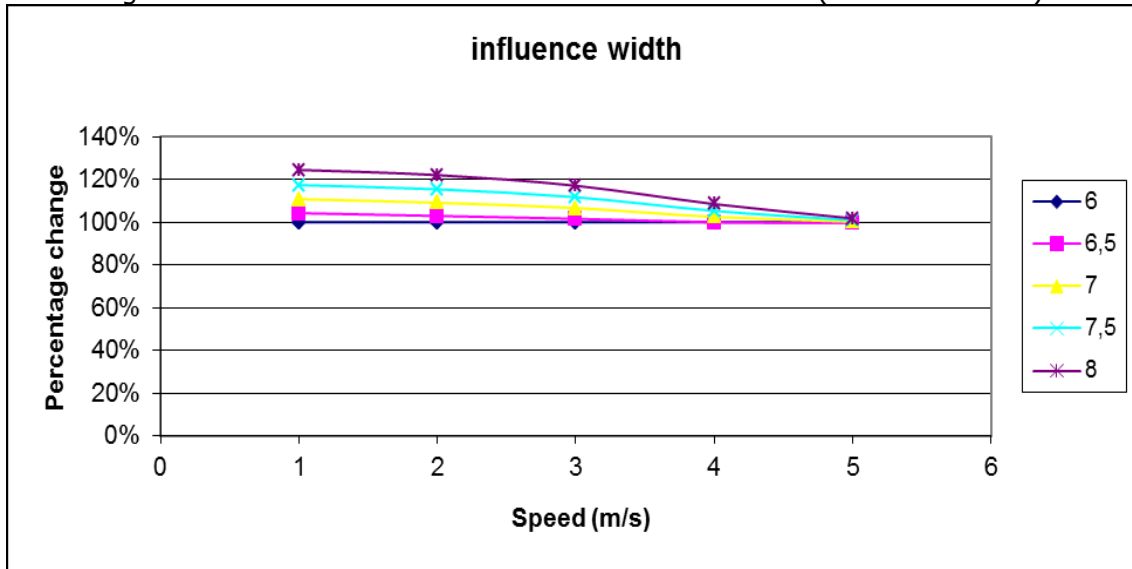


Figure 7.24 shows that the resistance will increase if the width is increased with a speed lower than 3 m/s ( $=11$  km/h). When the speed is increased, then the widest barge has the lowest resistance. This is because an increasing part of the total resistance is determined by the wave making resistance. That resistance component is dominated by the Froude width number ( $Fn_b = \frac{V_s}{\sqrt{gB}}$ ) when the speed is high. It can be seen in appendix

B.2 (formula B.2.4 to B.2.4.6) that the  $R_w$  is decreasing if  $B$  is increasing and all the other components are kept constant ( $R_w \sim C \cdot B^{-0.22}$ ). Therefore it could be concluded that at low speeds ( $<3$  m/s) the barge should be made as small as possible (keeping in mind stability and the number of containers that need to be placed inside the cargo hold) and at high speeds the barge should be made wider. But it has to keep in mind that the used resistance method of Holtrop *et.al* (1990) is based on a regression analysis. The factors in the formulas are thus determined to fit the model test data, so that the effect of the width on the resistance could also be due to the regression effect of the developed relations.

The same calculation as above has been made for a deeper waterway. In this case the water depth is set at 6 meters and if the two graphs are compared, the influence of the water depth on the resistance can be seen. Graph 7.25 shows that the resistance is decreasing when the width is increased. Only the resistance is reduced less than when the water depth is 2.3 meters. The shallow water effect is not present in figure 7.25, while there is a shallow water effect in graph 7.24. The effect of the wave-making resistance is increased when the water depth is reduced and therefore the influence of the width of the barge is magnified when the water depth is reduced.

Figure 7.25: Influence of the width on the resistance ( $h = 6.0$  meters)

Also the stability of the barge is influenced by changing the width of the barge. In order to understand this influence better, the width of the barge is changed. That influence is given in the figure 7.26. The calculations have been made for a barge that can sail independently and has a length of 50 meters (7 TEU in length). In the cargo hold 2 containers are placed aside. When the barge is wider than 7.5 meters, then the barge can store 3 containers wide. The containers are stacked two high in the cargo hold.

Figure 7.26: Influence of the width on the stability of the barge (independent sailing)

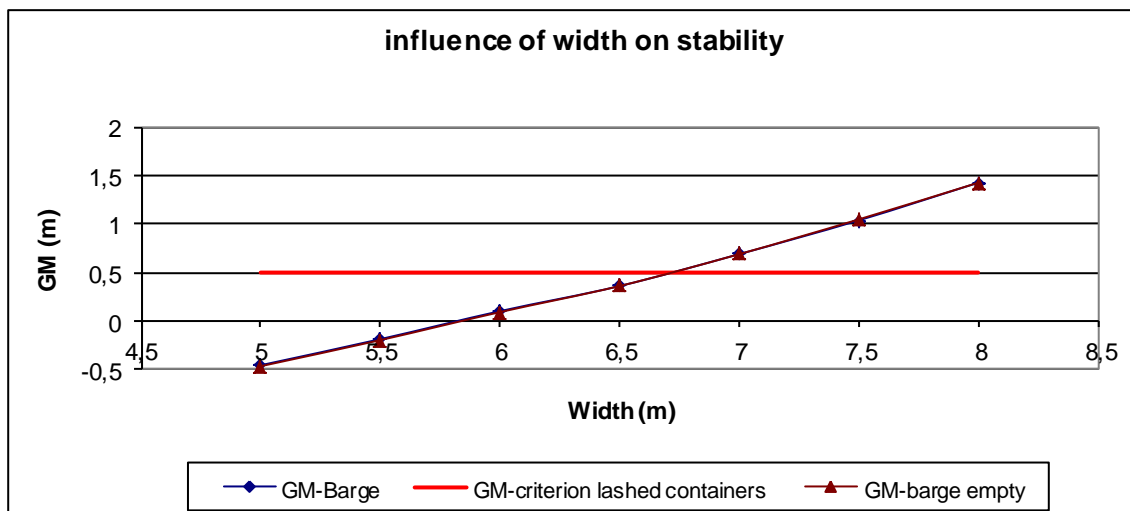


Figure 7.26 indicates that the GM-value is lower than 0 when the width is smaller than 5.8 meters. For barges wider than 6.7 meters, the GM value is larger than 0.5 meters and therefore the stability will be OK if the containers are lashed. If the containers are not lashed, the width of the barge must be increased to 7.5 meters to obtain a GM-value of 1 meter. Therefore the minimum width of the barges is 6.7 meters if containers are transported (see appendix A: barge geometry).

In the same figure the calculations are made for an "empty" barge (barge without propulsion equipment). The results for the two calculations hardly

differ if one only looks at the stability. The weight of the batteries and thrusters in the double bottom will lower the KG of the barge but that is being compensated by the increase in KG of the wheelhouse, which is placed on the deck of the barge. So the barge without the propulsion is just as stable as the barge with propulsion.

Now that the recommended values of the shape parameters are determined, the influence of speed and sailing distance on the newbuilding costs will be determined. In table 7.5 an overview is given of the values of the input parameters needed to make the calculations. The first parameters are the same as in table 7.4, with the addition of the parameters determined earlier in the sensitivity analysis plus the initial values parameters that will be varied in this section of the sensitivity analysis.

Table 7.5: Overview of the input parameters

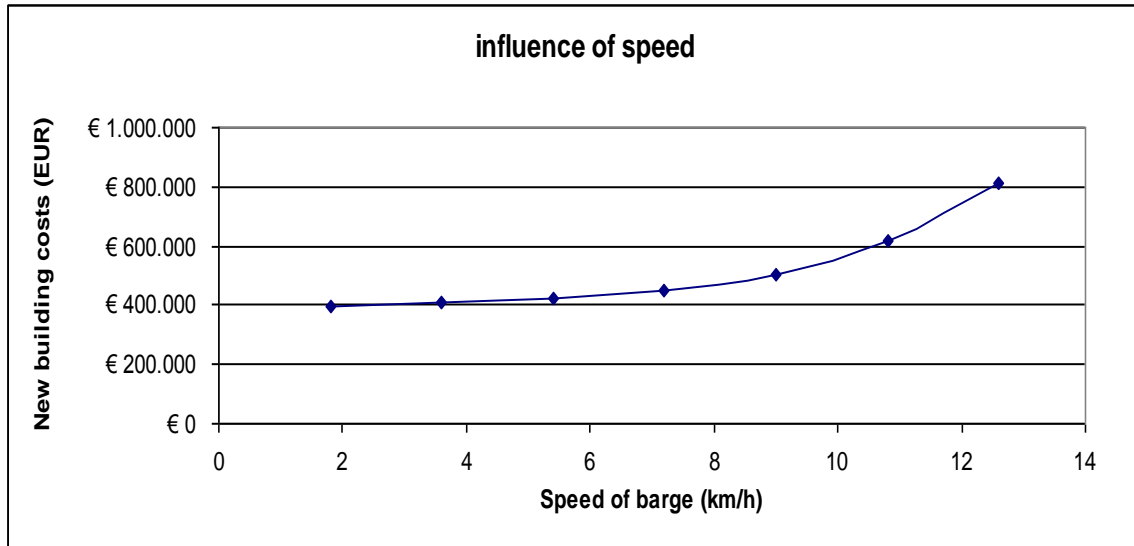
Input parameter	Value
$L_{\text{cargo hold}}$	7 TEU
$L_{\text{barge}}$	50 m
$B_{\text{barge}}$	6.8 m
Loading capacity	28 TEU or 550 tonne
Independent sailing barge	Yes
$\alpha_l$	25°
$\alpha_{st}$	25°
Design speed	7 km/h
$N_{\text{thrusters}}$	4
Max power installed	Yes
Propulsion system	Batteries
Sailing range	45 km

The input data shown in table 7.5 are the input data to design a barge that is capable of sailing on routes 1, 2 and 3 that were already predetermined in chapter 6 (see figure 6.5).

In figure 7.27 the influence of a variation of the required sailing speed from 2 km/h to 14 km/h on the newbuilding cost is shown.

This figure indicates there that the costs are increasing to a maximum value of €800.000 at a speed of 13 km/h. If the speed is increased more, the thrusters are not able to deliver more power to sail faster. Another observation is that at lower speeds the newbuilding costs do not change much. The power required is low and therefore not many batteries are needed. The thrusters are also the same and do not need to change.

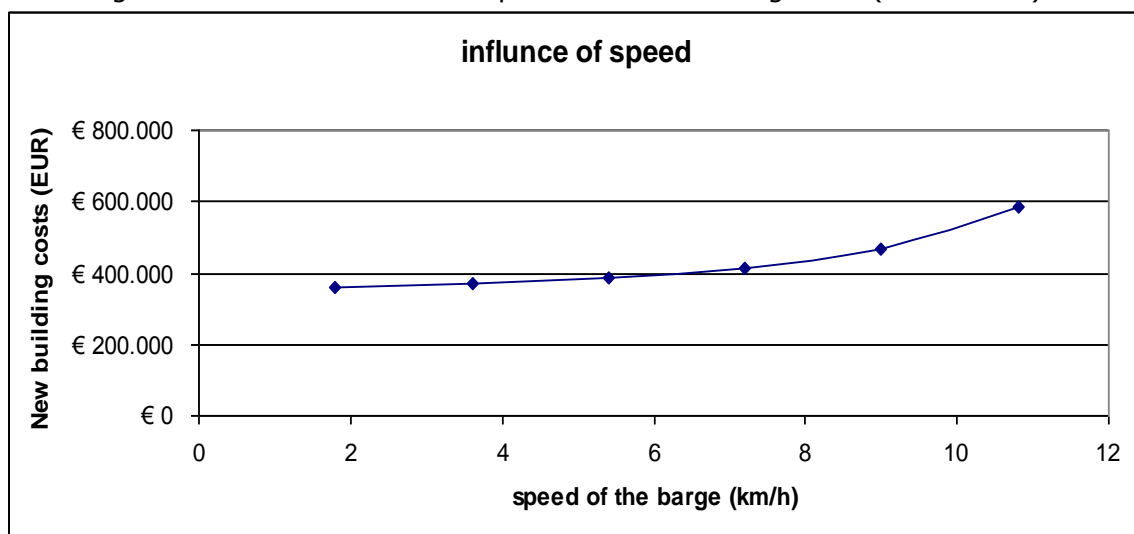
Figure 7.27: Influence of the speed on new building costs (4 thrusters)



Note: 2009 values

The influence of the number of thrusters will be analysed by making the same calculations as above, but now there are two thrusters installed instead of 4. This analysis is given in figure 7.28.

Figure 7.28: Influence of the speed on new building costs (2 thrusters)



Note: 2009 values

Figure 7.28 indicates that the maximum costs (and maximum speed) are now obtained at a speed of 11 km/h. The costs are lower if they are compared with the costs if there are 4 thrusters installed. If a speed higher than 11 km/h is required, at least, 4 thrusters are needed.

It is also possible not to install the power needed to sail at a certain speed, but to install the maximum power available. This may be because more power could be required for special manoeuvres of the barge such as sailing in and out of a lock. On certain locks a large current can occur and a lot of power is needed. The influence of installing maximum power on the barge is given in table 7.6.

Table 7.6: Influence of max power

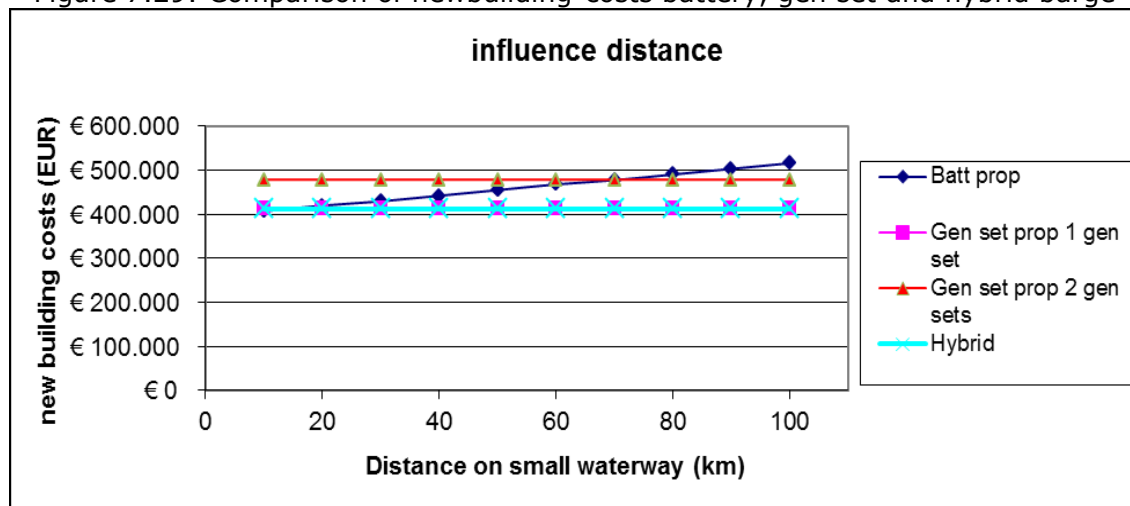
	Max power	No max power
Price	€ 448,877	€ 410,518
Power E-engine	169.20 kW	32.40 kW

Note: 2009 values

In the table also the effective power that the barge can deliver is given. Because the distance that the barge has to sail is kept the same, the only difference is obtained by the size of the thrusters and number of batteries needed.

The new-building costs of the barge when one or two gen sets are installed will also be compared with the new-building costs of the barge when it is equipped with batteries and with the hybrid version as a function of the required sailed distance. This comparison is given in figure 7.29. The reason to incorporate the distance in the analysis is that by increasing the sailed distance more energy is required and, in case of a battery propelled barge, more batteries are needed, or, in case of gen-set propelled barge, more fuel is needed.

Figure 7.29: Comparison of newbuilding-costs battery, gen set and hybrid barge

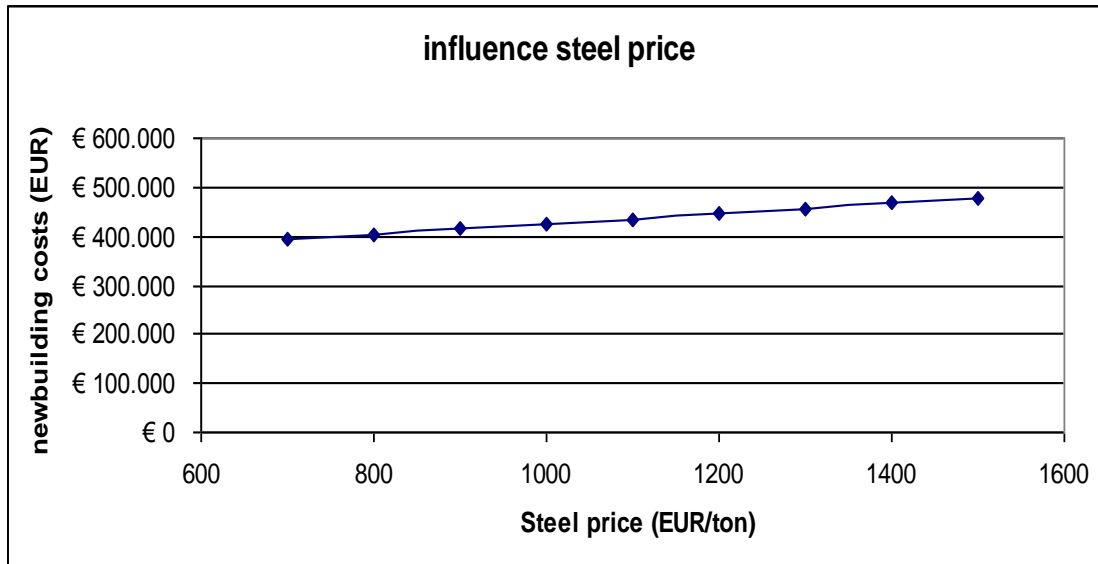


Note: 2009 values

Figure 7.29 shows that, when the barge has to cover more than 100 km (100 km one-way and 100 km back = 200 km in total), a double gen set propelled barge is as expensive as a battery propelled barge. If the barge is equipped with a single gen set, that option is the less expensive one, when it is compared with the battery-propelled barge, if the sailed distance is larger than 20 km. If the required sailed distance is increased more batteries are needed and therefore the new-building costs are increased for the battery propelled barge. The hybrid-propelled barge is as expensive as a single gen set propelled barge. The reduction in costs for a smaller gen set is completely covered by the costs of the batteries that are installed. It can also be seen that the new-building costs of the hybrid, the single gen set and the battery-propelled barge are almost equal when the required range is between the 35 and 40 km.

The last parameter that will be researched is the influence of the steel price on the new-building costs of the barge. In figure 7.30 the results are given.

Figure 7.30: Influence of the steel price on the new-building costs



Note: 2009 values

In this case, the barge is capable to sail on independently on routes one, two and three. Figure 7.30 indicates that if the steel price doubles the price for the barge increases with 17%. Therefore, it can be concluded that the new-building price of the barge is dependent on the steel price. This dependency becomes larger when the barge does not have to sail independently. The reason for that is that the price of the independent sailing barge is being determined for half by the costs of the batteries, electric engines, wheelhouse, etc. Therefore, the influence of the steel price becomes less.

## 7.3 Barge trains

### 7.3.1 Introduction

In this part of chapter 7 the barge trains of the small barge convoy system are further analysed. First, an overview will be given of how the barges will be coupled. When the selection has been made how the barges should be coupled the total resistance of the barge trains will be determined. Finally, the calculated total resistance of the barge train will be compared with the resistance model of Howe (van Terwisga, 1989).

### 7.3.2 Position in the design model

In this paragraph the position of the barge train model in the total design model is given. The position is given in figure 7.31.

Figure 7.31: Position of the barge train model in the total design model

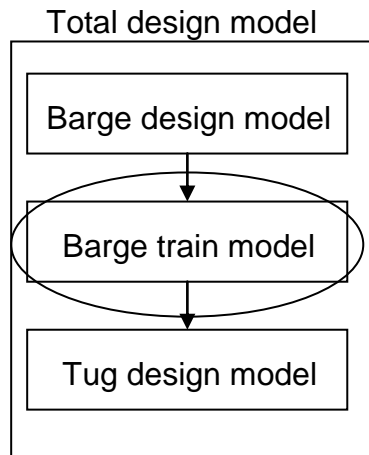


Figure 7.31 shows that the barge train calculations will be based on the design of the barges.

### 7.3.3 Coupling of barges

To couple the barges to one single unit to be pushed on the large waterways by the tug several known system could be used.

The first option of coupling the barges into a single unit can be done with the hydraulic coupling arms that are developed by TNO (fig 7.32). These arms can couple the barges very quickly without the need of labour. These arms can also be placed side ways to couple the barges that are placed aside.

The downside of this system is that if there is a large difference in draft between barges then such a system cannot work. That problem can be solved if the arms are not placed at the deck of the barge but at the side. The disadvantage is that the beam of the barge will increase so that the clearance between the barge and the side of the lock doors is very small. It is also not possible to couple 2 barges a side if those arms are placed at the side of the barge.



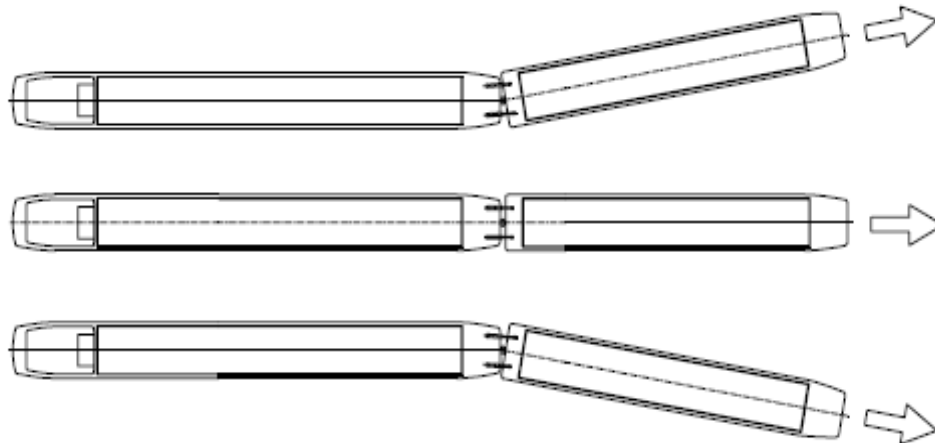
Figure 7.32: Hydraulic coupling arm



Source: TNO

The second option is to use a hinged coupling system. An example of such a system is given in figure 7.33 where a hinged coupling system is given. This system can be used if two barges are placed in line where the barges can move a little bit for each other to navigate through narrow bents. If a formation of 4 barges must be pushed then such a system can't be used.

Figure 7.33: Hinged system between barges



Source: Thill C. *et. al.*, 2005

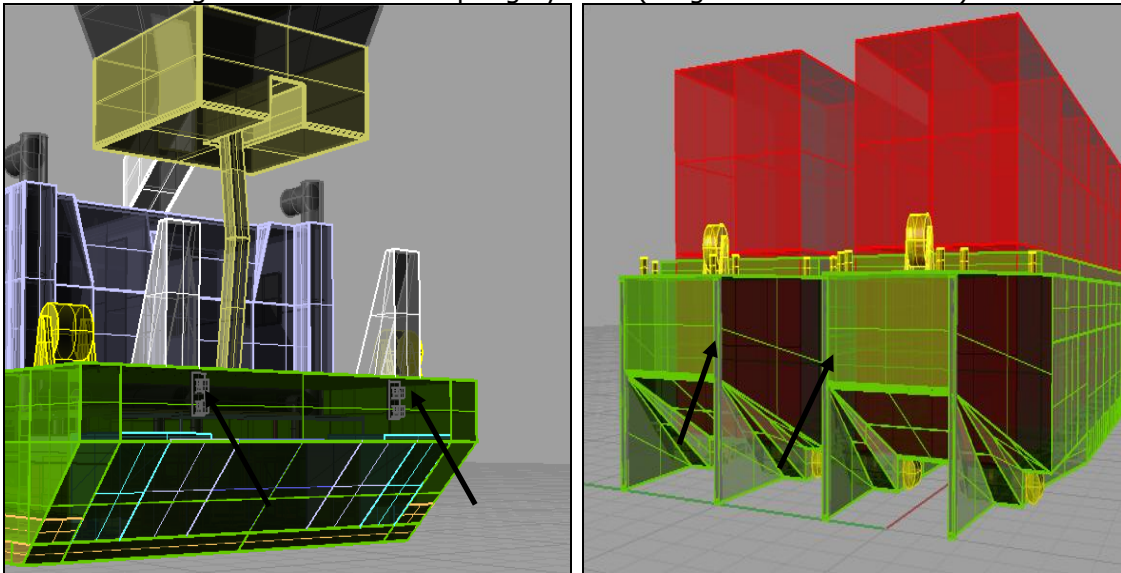
Another way of coupling the barge can be done by using "normal" hydraulic winches, which is given in figure 7.34. The advantage of the normal hydraulic winches is that there is a large flexibility in how the barges can be coupled. If there are differences in the draft of the barges then the barges can still be coupled. The disadvantage is that such a system requires a lot of manual (mussel) power to couple the barges and that it requires a lot of time (0.5 hours per barge (see chapter 6.2.5)) to couple the barges.

Figure 7.34: Normal hydraulic coupling winches.



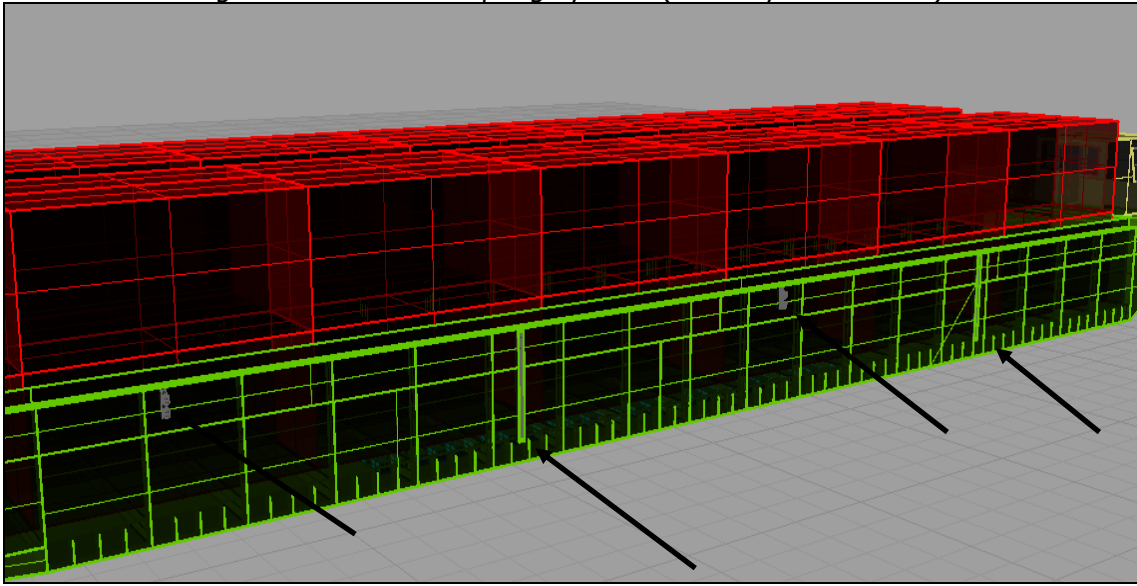
Besides existing coupling systems also a new system has been developed. The main reason to develop a new system is to decrease the coupling time. The system will be built up from connection rods which will connect the two units via coupling blocks. In the bow of the tug the system will be placed. In aft of the barge, in the push rods, the connection is made. The advantage of this system is that it can be used with different drafts of the tug and barges. In figure 7.35 the system is shown in the bow of the tug and in the aft of the barge.

Figure 7.35: New coupling system (longitudinal connection)



The system is aligned in such a way that if one barge is pushed the tug and barge will have a double connection and if two barges aside have to be pushed the one connection per barge is made. The same system is applied in the side of the barges to couple the barges sideways. There are four connection points installed over the total length of the barge. The coupling block and the connection rods are installed in an asymmetrical way. In figure 7.36 the sideways connection points are indicated with arrows.

Figure 7.36: New coupling system (sideway connection)



If there is only one barge in the convoy or the barges are coupled with the longitudinal connection, then the sideways coupling system will not be installed. In Appendix H (coupling system) the developed coupling system will be further explained.

The choice has been made, for now, to couple the barges with the normal hydraulic winches because of the flexibility and that such a system has proven in practice that it works. If a reduction in coupling time will lead to significant reduction the transportation cost (see chapter 8.3) then the new coupling system will be chosen. If the influence of the coupling time is limited then the simplest (cheapest) system will be chosen.

#### 7.3.4 Barge train coefficient

When the barges are coupled they will form, together with the tug, a single unit. If the barges are coupled then the resistance of that new unit must be determined. The resistance of a barge train is lower than the resistance of the sum of all the single barges. The total resistance can be determined by the resistance of the single barges and the so called barge train coefficient. This barge train coefficient is given in formula 7.10 which is taken from Thill *et. al.*(2005).

$$BTC = \frac{R_{total}}{\sum_n R_{barge}} < 1 \quad (7.10)$$

BTC = barge train coefficient	[-]
$R_{total}$ = total resistance of the barge train formed of n barges	[kN]
$R_{barge}$ = resistance of a single barge	[kN]
n = number of barges in the barge train	[-]

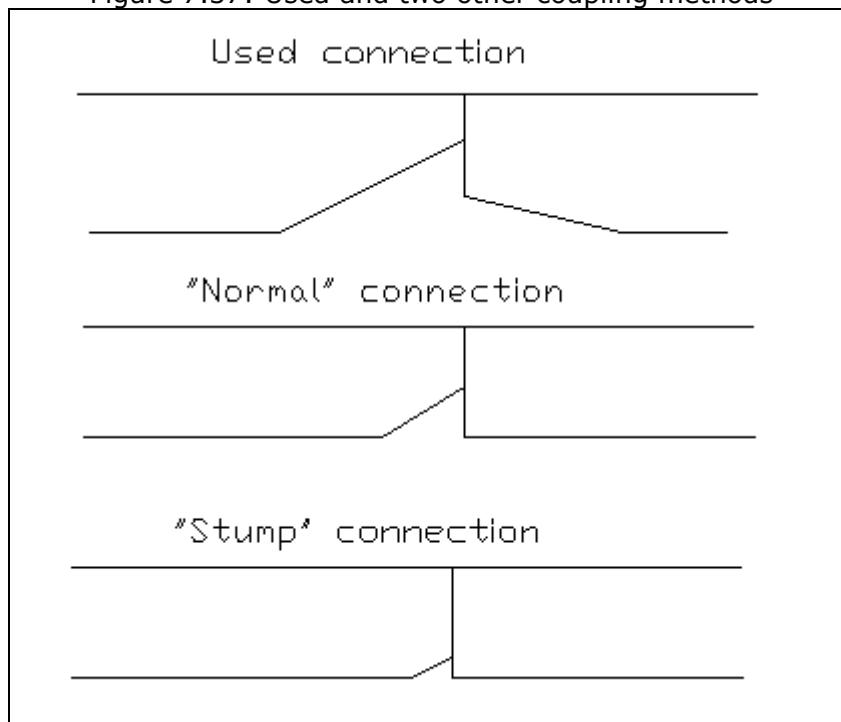
The reason for this effect is that if the barges are placed aside the wetted surface is reduced and therefore the frictional resistance. If the barges are coupled in length then there will be only one bow wave instead of two. If a 2x2 formation is applied both effects will happen. In order to determine the resistance of a barge train the following procedure had been followed. The

barge design model has been used to determine the resistance of a barge with a length of 52 meters and width of 6 meters. Then the resistance of a barge with the same length but with the double width (12 meters) has been calculated. The barge with the double width has been adjusted so that the draft is the same and the displacement is doubled if it is being compared to the single barge. Therefore from those two values the barge train coefficient for several speeds can be calculated.

The same has been done for the same width and doubled length. Also in this case the total resistance of the doubled barge is lower than the sum of the two single barges. The results of the barge train coefficient calculation for this case (two barges in length) have been adjusted because there is a difference between the doubled barge and the two single barges. The two single barges don't align perfectly in length due to the shape of the aft ship of the barge. The used connection is given in figure 7.37 along with two other coupling methods.

The stump connection is the best option if the barges have to be coupled. The total resistance can be reduced with 10% (Thill C. *et. al.* 2005) if such a coupling is used instead of the normal connection. Therefore the barge train coefficient in length (BTC) has been increased with 10% to incorporate the effect of not aligning as in the stump connection. But there is difference between the normal push convoys and the convoy that is used in this model. The barges can sail independently so that the resistance of the barges in single mode is also important. The sharper the aft ship of the barge (reduced transom area) the lower the resistance of the single barge is (see section 7.1: barge model) but the worse the connection is between the barges and therefore the higher the resistance is of the convoy.

Figure 7.37: Used and two other coupling methods



Source: based on Thill C. *et.al.* 2005

The sharper aft and fore ships of the barge will also lead to a longer barge and also to a lower draft of the ship (with the same payload). The "stump" barges will lead to a better BTC but those barges are shorter and therefore the draft is larger so that the single resistance of those barges will be greater (due to shallow water resistance). The connection of the barges that are designed to sail independently and the connection between two normal barges is given in figures 7.38 to 7.40 along with the main dimensions and the resistance of the barges at 5 km/h.

Figure 7.38: Connection between two independent sailing barges with push bars

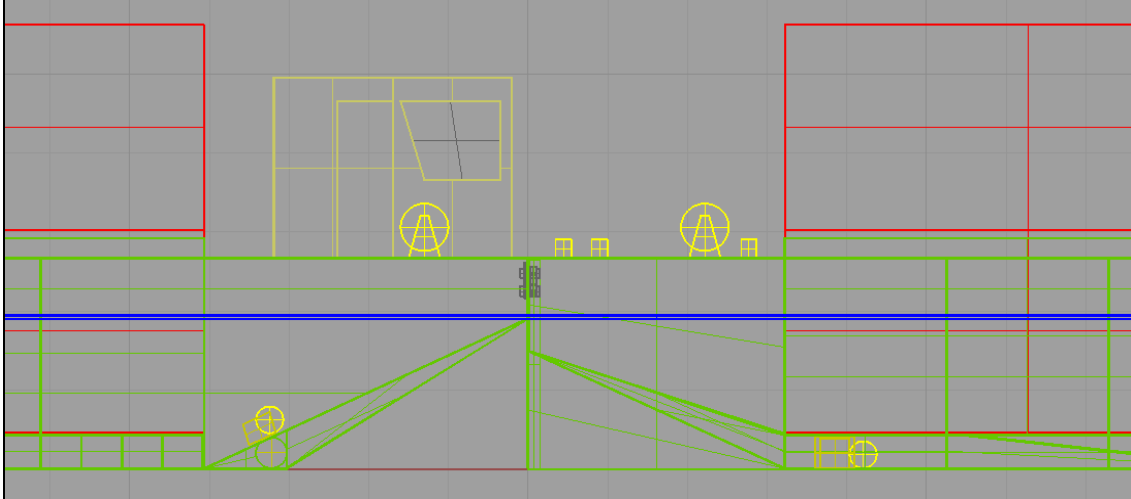


Figure 7.39: Connection between two independent sailing barges with push bars (3D)

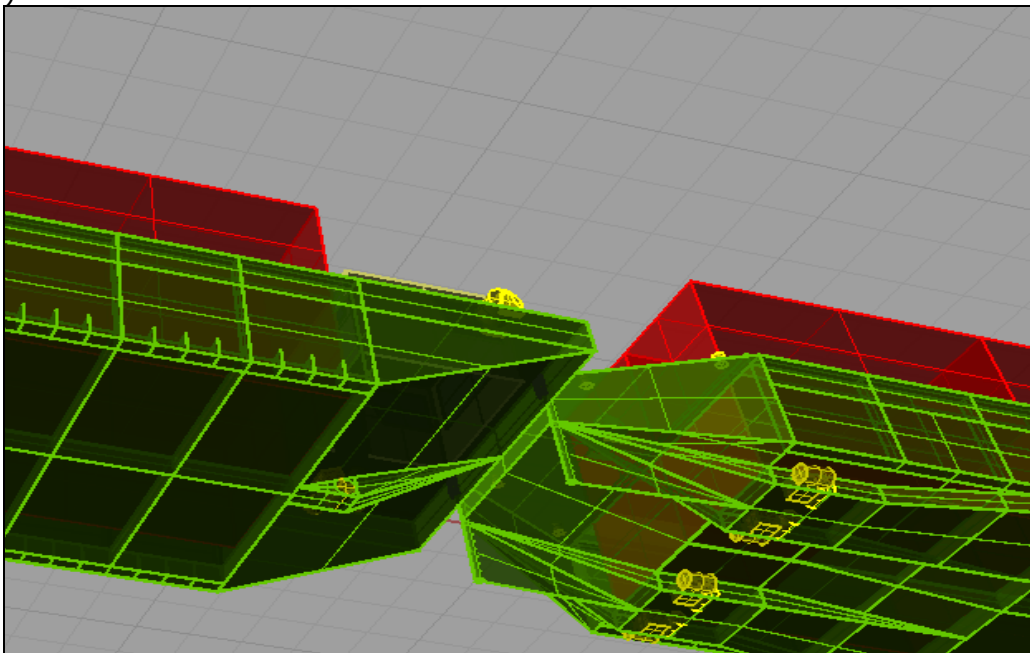


Figure 7.40: Connection between two "normal" barges

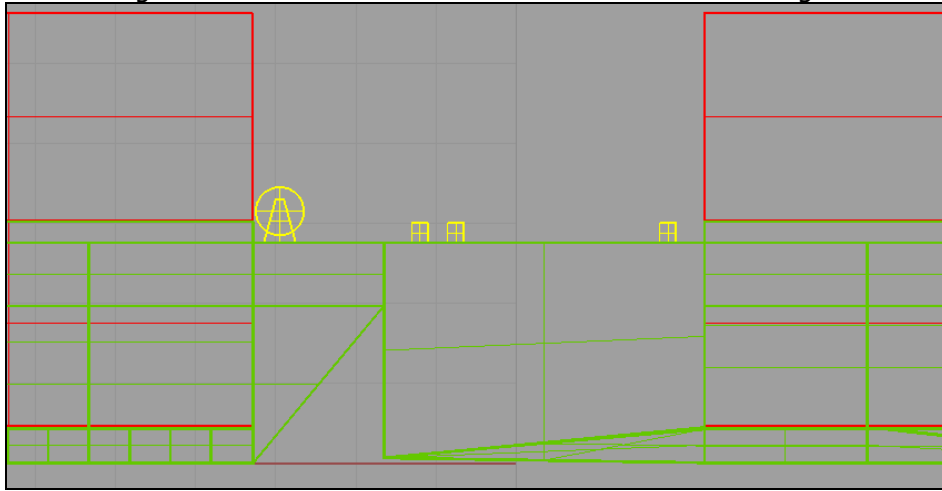


Table 7.7: Main dimensions and resistance of the two barges

		"Sharp" barge	"Stump" Barge
L	[m]	51.9	48.35
B	[m]	7.3	7.3
T	[m]	1.89	1.96
Displ	[m <sup>3</sup> ]	645.59	641.97
Cb	[-]	0.9	0.93
Rt	[kN]	2.73	3.97

From table 7.7 can be concluded that the sharp barge has a lower resistance than the stump barges. The resistance of a single stump barge is much larger than resistance of the sharp barge and that difference can't be made up by the better BTC of the stump barges.

The BTC for the situation that there are 3 barges in line is also determined. It shows that the BTC is lower than the BTC of 2 barges in line. Because there are now two connections between the barges the calculated BTC will be adjusted with another extra 10% correction.

The BTC for the situation of 2 barges in line and 2 barges aside is calculated as the product of the BTC of 2 barges in line times the BTC of 2 barges a side. The same procedure has been followed to calculate the BTC for the 3x2 formation where the BTC of the 3x1 formation is multiplied with the 2 wide formation. The results of the BTC calculations are given in the figure 7.41 for a barge with a width of 6 meters.



Figure 7.41: Barge train coefficient barge width of 6 meters

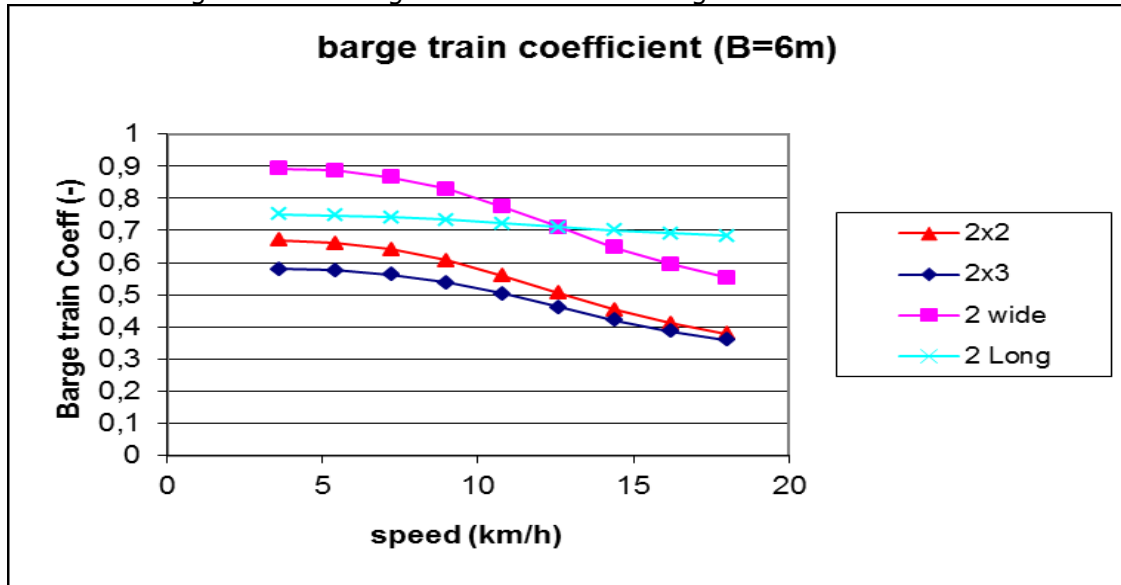


Figure 7.41 shows that the BTC of the 2-long formation is hardly dependent of the speed. That BTC stays almost the same for every speed, while the BTC of the formations with 2 barges a side is very much influenced by the speed. The higher the speed the lower the BTC will be and the larger the convoy the smaller the BTC. The BTC is dependent of the width of the convoy and therefore also on the width of the barge. Therefore the BTCs are determined for different widths of the barge. In figures 7.42 and 7.43 the BTC for barges width 7 and 8 meters width are given.

Figure 7.42: Barge train coefficient barge width of 7 meters

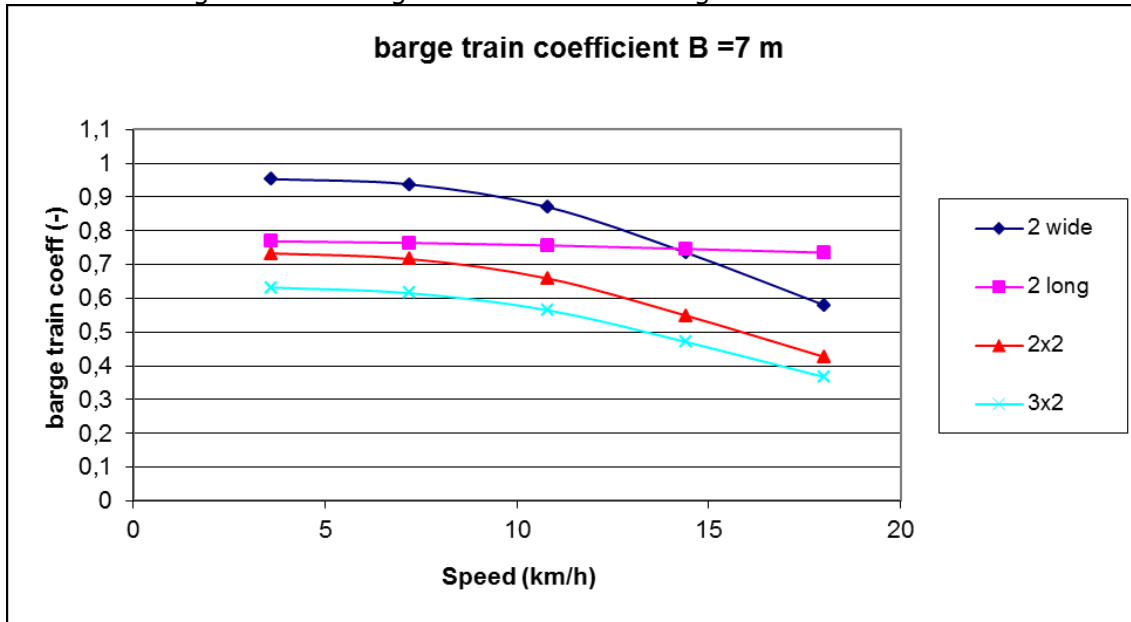
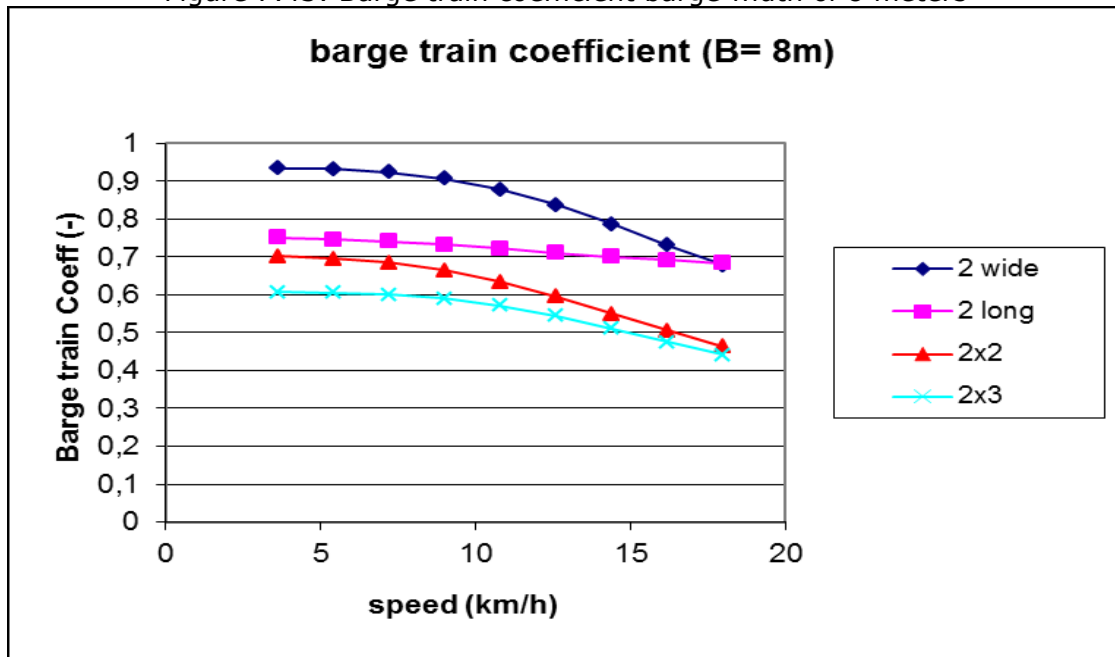


Figure 7.43: Barge train coefficient barge width of 8 meters



Figures 7.41 to 7.43 indicate that the reduction of the BTC is less if the width of the barges is increased. This is caused by the influence of the width of the barge on the resistance. The barge with a width of 8 meters will be less dependent on the wave-making resistance than a 6 meter- wide barge (see part of resistance model barge). The BTC is thus a result of the chosen resistance model of the barge. In Thill *et. al.* (2005) typical values of the BTC are estimated between 0.65 and 0.85, where the lower values occur for the slender forms of the barge train. If the speed is lower than 10 km/h, then the calculated values are in the same range. If the speed is higher, the BTC are lower than the typical values, due to the used resistance model of the barges (see Appendix B.2). Section 7.2.9 already demonstrated that by making the barges wider, the resistance drops at high speeds. This effect is amplified when the width of the barge is doubled.

The BTC will now be determined by the following formulas, which are the trend lines of the lines in figures 7.41 to 7.43. If a barge is 6.5 meters wide (or smaller), the lines for a barge of 6 meters will be used. If the barges are 6.5 to 7.5 meters wide, the BTC of 7 meters is used; for wider barges the BTC of barges of 8 meters will be used. The derived formulae for determining the barge train coefficients are given in appendix J.

### 7.3.5 Resistance of the barge train

The total resistance of the barge train will now be calculated and they will be compared with the resistance of a barge train calculated with the method of Howe (van Terwisga, 1989). In these calculations the resistance of the push ships needs to be taken into account. The size of the barge train is relatively small so that the influence of the tug is rather high. The main dimensions of the push ships are estimated at  $L = 13$  meter,  $B = 6$  meter and  $T = 1.3$  meter. These values are typical values for push ships pushing 4 to 6 barges. The total resistance is given in the figures 7.44 and 7.45, where the calculations are made for formations of 4 and 6 barges with a



barge width of 7 meters. In the appendix I a comparison is made with the case of 6 and 8-meter wide barges.

Figure 7.44: Comparison resistance between barge train model and Howe for barges of 7 meters wide

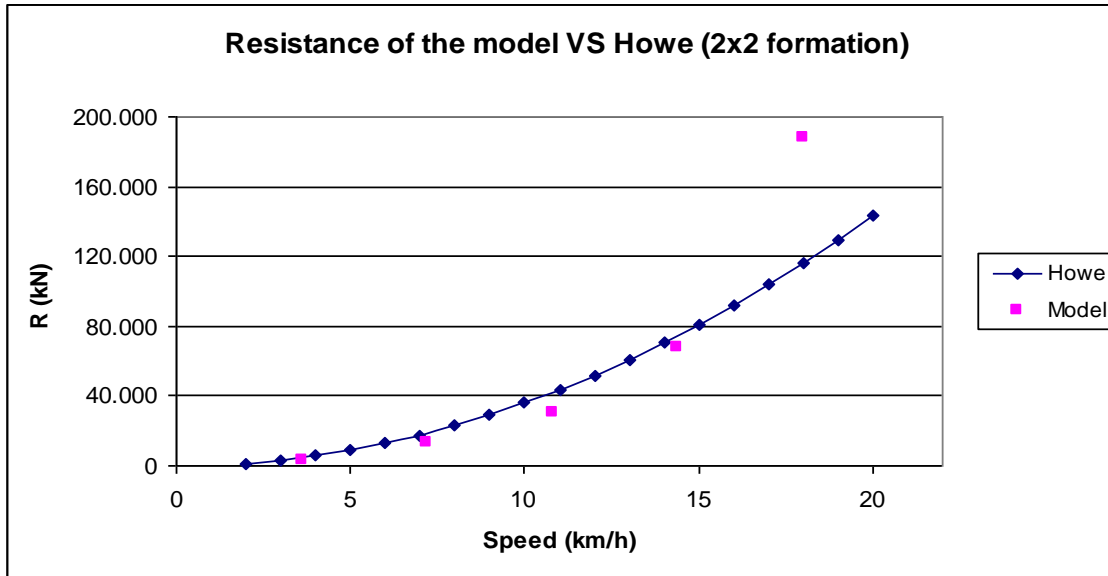
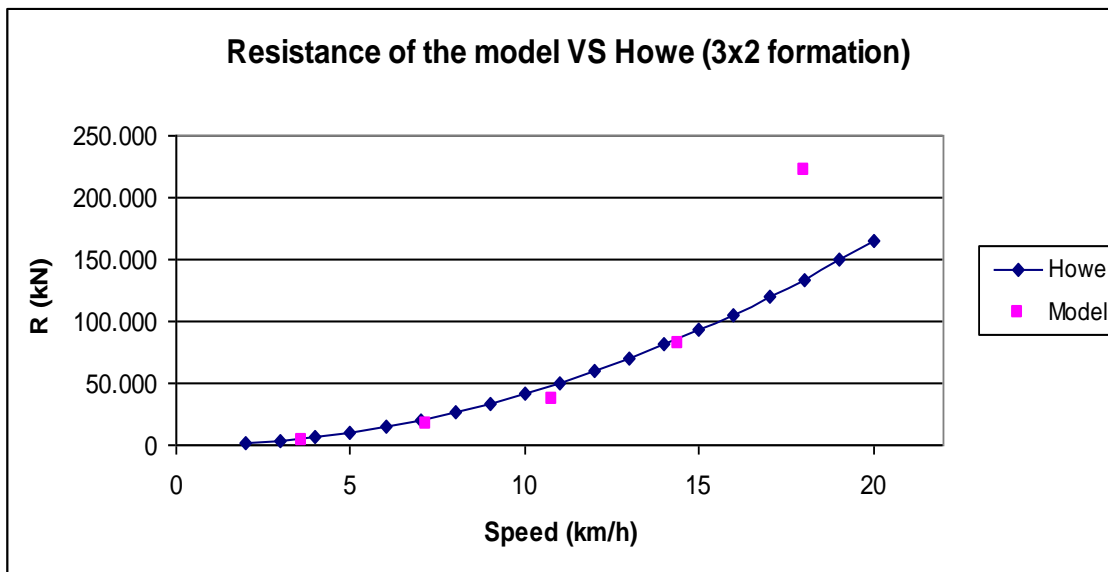


Figure 7.45: Comparison resistance between barge train model and Howe for barges of 7 meters wide



Figures 7.44 and 7.45 show a large similarity between the model values and the method of Howe for speeds smaller than 15 km/h. Only if the speed is larger than 15 km/h, the model values are much larger than the values of Howe. The reason for that can be found in the used resistance model. The formula of Howe is a second power function of speed, while the method of Holtrop *et.al.* (1990) is a higher power function of speed. If in appendix I the resistance of the other barges is compared, the difference between the model values and the values of Howe is shown to be getting smaller if the width of the barge is increased. This was also seen in figure 7.7, where the resistance of single barges was compared with the method of Lattore.

If the barges are equipped with thrusters then the resistance of the thrusters is also added to the total barge train resistance. This resistance can be calculated with the following relation (MacKenzie, Forrester, 2007):

$$R_{\text{thruster}} = \frac{1}{2} \cdot \rho \cdot V^2 \cdot A_t \cdot C_d \quad (7.11)$$

$R_{\text{Thruster}}$  = resistance of one thruster [N]

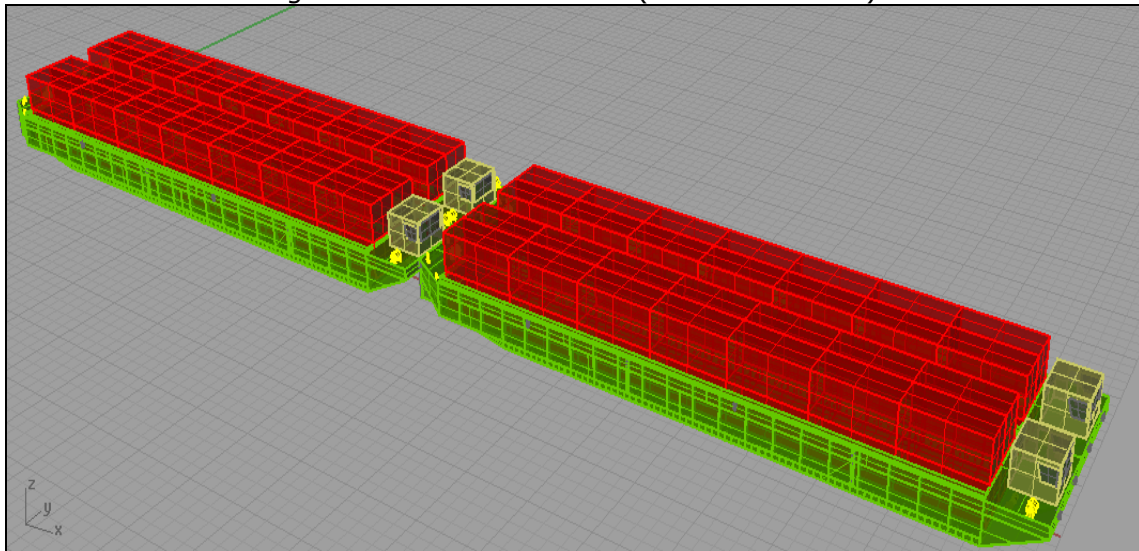
$A_t$  = Thruster diameter [m]

$C_d$  = drag coefficient (0.3) for free trailing thrusters [-]

The added resistance of the thrusters is assumed not be affected by the water depth, so the resistance can be added to the total calculated barge train resistance.

In figure 7.46 an example of a barge trains is given as a formation of 4 barges. All the barges are 52 meters in length and have a beam of 6.8 meters. The capacities of the barges are 28 TEU (or 550 tonne). All the barges that are drawn can sail independently.

Figure 7.46: 2x2 formation (total 4 x 28 TEU)



## 7.4 Tug design model

### 7.4.1 Introduction

In this section of chapter 7 the Queastor design model of the tug will be described. The main “components” of the design model are the geometry of the tug, the resistance, the construction (weight) and the propulsion installation of the tug. In addition, the layout of the superstructure will be described in this chapter.

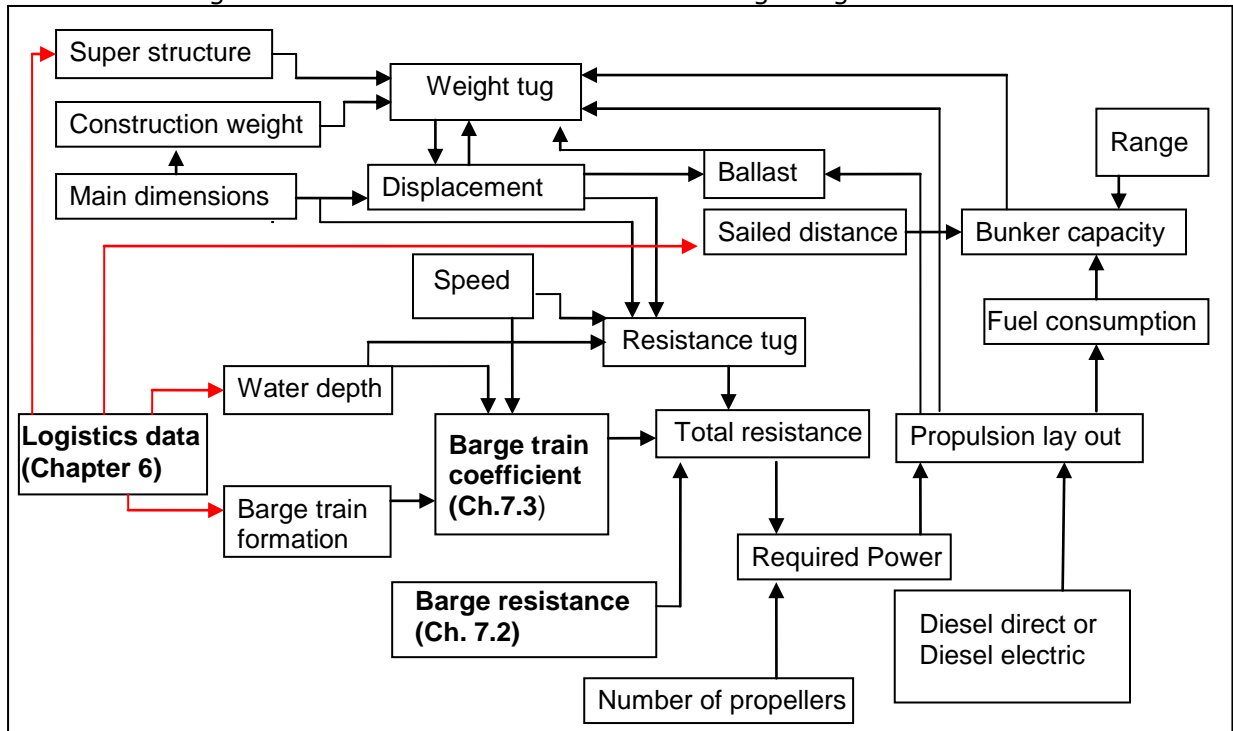
Because of the dependence of the components mentioned above and because the barge design model was also programmed in Quaestor, the program Quaestor has been chosen to solve all the different relations between the components in the tug design model.

The way the different components are related to one another is given in figure 7.47. The red lines indicate data that is taken from the chosen

logistics option in the network model (chapter 6). A change in the number (or the dimensions) of barges that have to be pushed will influence the design of the tug because the resistance will be changed and therefore the type of engines will change. As a result, the dimensions of the engines will change and that will have a large impact on the design of the tug.

Figure 7.47 shows that the design algorithm could opt for a diesel electric or a diesel direct propulsion lay out. So it can be analysed whether a diesel electric propulsion system will have an advantage over the diesel direct option. All the boxes in figure 7.47 without arrows directed at them are to be determined and are therefore design choices.

Figure 7.47: Schematic overview of the tug design model



All the different components mentioned in figure 7.47 will be further explained and described in the next paragraphs. In the first paragraph the position of the tug design model will be given in the total model that has been developed. The design paragraphs will start with the description of the hull form and geometry of the tug. After that the resistance calculations will be given in deep and shallow water, as well as the description of the construction and the calculations of the construction weight of the tug. The most important part of the tug, i.e. the power and propulsion systems, will be explained in the next part of this chapter, followed by the stability calculations. In the second to last paragraph the new building costs of the tug will be determined. The last paragraph is used to investigate the effects of changes in the design will have on the new building prices.

### 7.4.2 Position in the design model

In this paragraph the position of the tug design model in the total model will be given. This position is given in figure 7.48 with a schematic overview of the total model.

Figure 7.48: Position of the tug design model in the total model

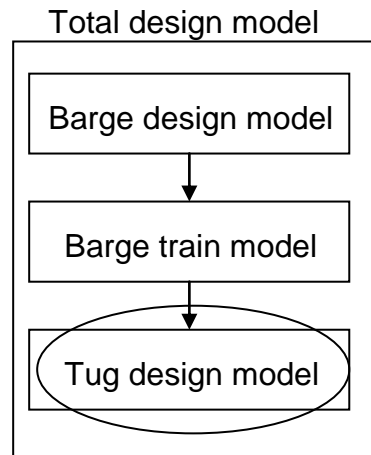
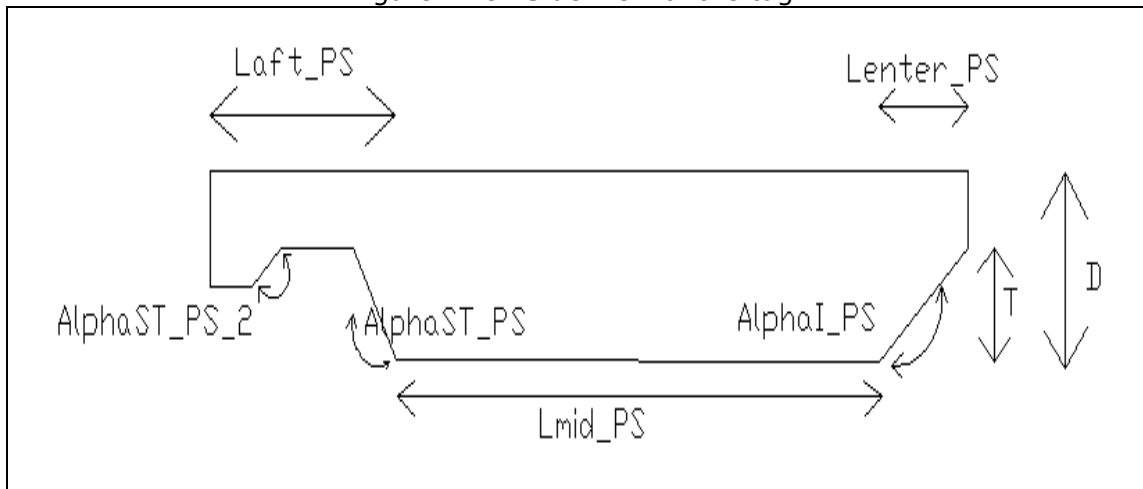


Figure 7.48 indicates that the design of the barges and the barge train calculations will have a direct influence on the design of the tug. So the tug will be specially designed for the designed barges.

### 7.4.3 Geometry

The geometry of the tug will be taken from van Terwisga (1989). In van Terwisga (1989) a literature study has been done for the hull forms of barges and tugs. Figure 7.49 gives a schematic overview of the tug.

Figure 7.49: Side view of the tug



Source: van Terwisga, 1989

In that study design relations are given for the design of a tug. These (generic) design relations are used in the design model. Appendix K deals with the developed tug hull form design relations.

### 7.4.4 Resistance calculation

The resistance of the tug will be determined in the same way as has been done with the barge. This is possible because the geometry of the tug and the barge are almost the same. In the resistance model of the tug only  $L_{enter}$ ,  $L_{mid}$  and  $L_{st}$  have been taken into account. The parameter "length" will

affect the wave making resistance of the tug, while  $L_{aft1}$  and  $L_{aft2}$  do not, as the aft part of the tug does not affect the displacement.

In the resistance model, the resistance of the length will be based on the parameters  $L_{enter}$ ,  $L_{mid}$  and  $L_{st}$ . This means that the influence of the length of the aft ship of the tug ( $L_{aft1}$  and  $L_{aft2}$ ) will be neglected. This has no real implications because the aft part of the tug does not influence the displacement, with only a small influence on the resistance as a result. The transom area of the aft part of the tug will be taken into account as well as the real wetted surface of the tug.

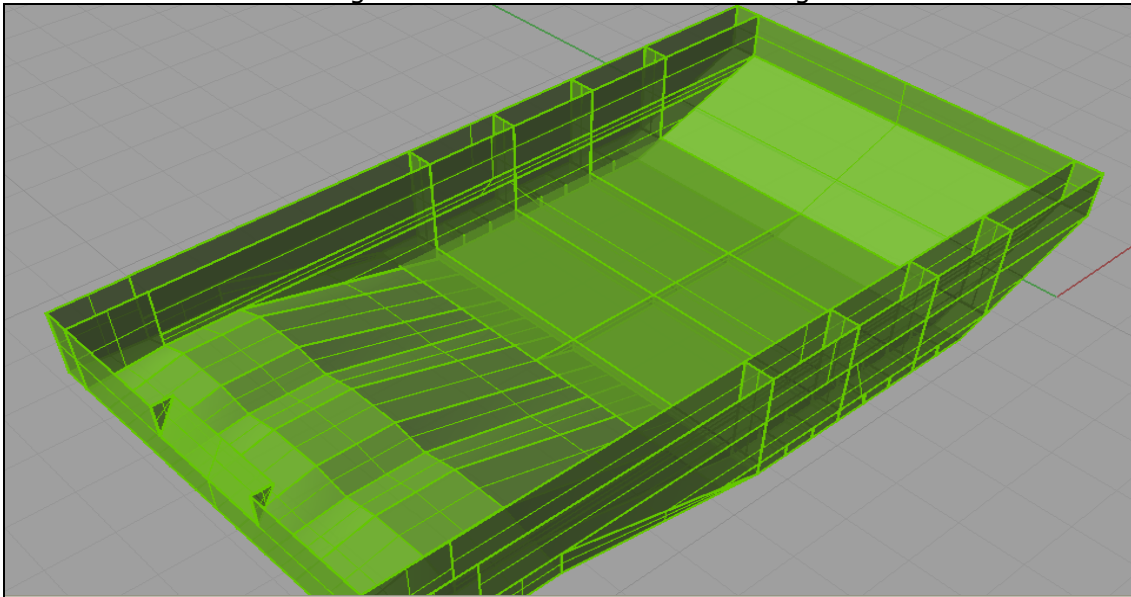
A shallow water correction has also been applied with this resistance calculation. This is the same correction as has been applied by the barge.

There is still another adjustment to the resistance calculation of the tug: the width of the barge train will be used in the calculations instead of the actual width of the tug. The wave making resistance will be determined by the width of the barge train and therefore that same width is used in the resistance calculation of the tug.

#### 7.4.5 Construction

The construction of the tug is analogous to the construction of the barge. The same rules are applied and the same spacing is used between the floors and girders. The construction of the tug is shown in figure 7.50.

Figure 7.50: Construction of the tug



The construction weight will be calculated as the summation of the different construction parts. For the total construction weight of the tug, an extra margin of 25% is added to the calculated construction weight. The extra 25% will represent the weight of the welds, paint, wiring, etc. All the weights that cannot be determined at this stage of the design will be incorporated in this margin.

### 7.4.6 Propulsion

In this section the propulsion lay-out of the tug will be described. First, the propeller calculations will be dealt with; then the total amount of installed power will be calculated. The third and fourth section will give the diesel-electrical and the diesel-direct propulsion systems. The final part of this section will deal with the fuel consumption calculations and the tank arrangements in the double bottom of the tug.

#### *Propeller calculations*

The propulsion calculations will begin with the determination of the total resistance (tug and barges) and based on that the needed thrust. The total resistance will be equal to the sum of the resistance of the barge train and the resistance of the tug. Normally the resistance of the tug will be neglected with respect to the total barge train. For this application the barges are relatively small and therefore the tug is relatively large, so that the resistance of the tug can't be neglected. The resistance of the tug has been taken fully into account into the barge train. Therefore the total resistance will be overestimated but the overestimation will incorporate the resistance of the propellers and rudders.

$$R_{\text{total}} = R_{\text{barge\_train}} + R_{\text{tug}} \quad (7.12)$$

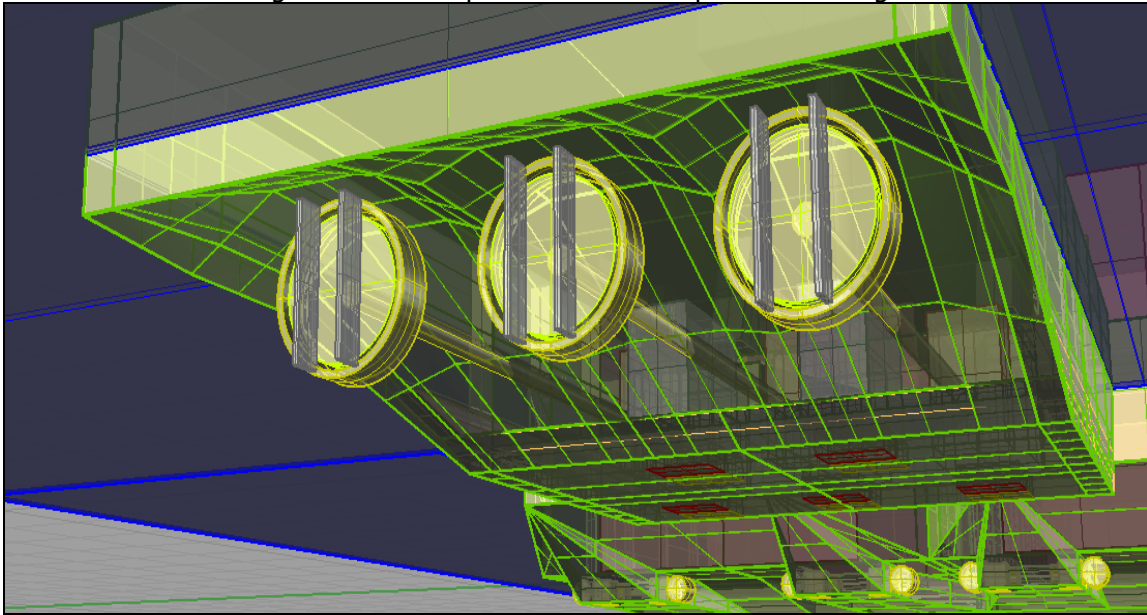
If the total resistance is known for the opted speed, the total required thrust can be determined. The calculation of the thrust can be found in appendix L.1.

When the thrust is known, the propeller calculation can be done. The decision has been made to install ducts around the propellers. These ducts will reduce the propeller loading because the ducts will generate a part of the needed thrust.

The diameter of the propeller ducts are set equal to the draft of the tug (van Terwisga, 1989). The thrust delivered by the ducts is taken from the K-19A nozzle. This  $K_t$  line is added to the  $k_t$  line of the propeller. Although this nozzle is specially designed for the Ka4.70 propeller, it is assumed that this nozzle can also be applied to "normal" B series propellers. In appendix L.1 the propeller calculations can be found.

The propellers are allocated in the aft part of the tug, where they are equally distributed over the width of the tug. It has been decided to install double rudders after every propeller. A large rudder area can be applied in shallow water situation. The rudders can also contribute to an increase in propeller efficiency as the rudders can reduce the rotation of the water that leaves the propellers. In Appendix M the calculations can be found to determine the dimensions and the weight of the rudders. Figure 7.51 shows the propellers as well as the rudders.

Figure 7.51: Propellers in the aft part of the tug



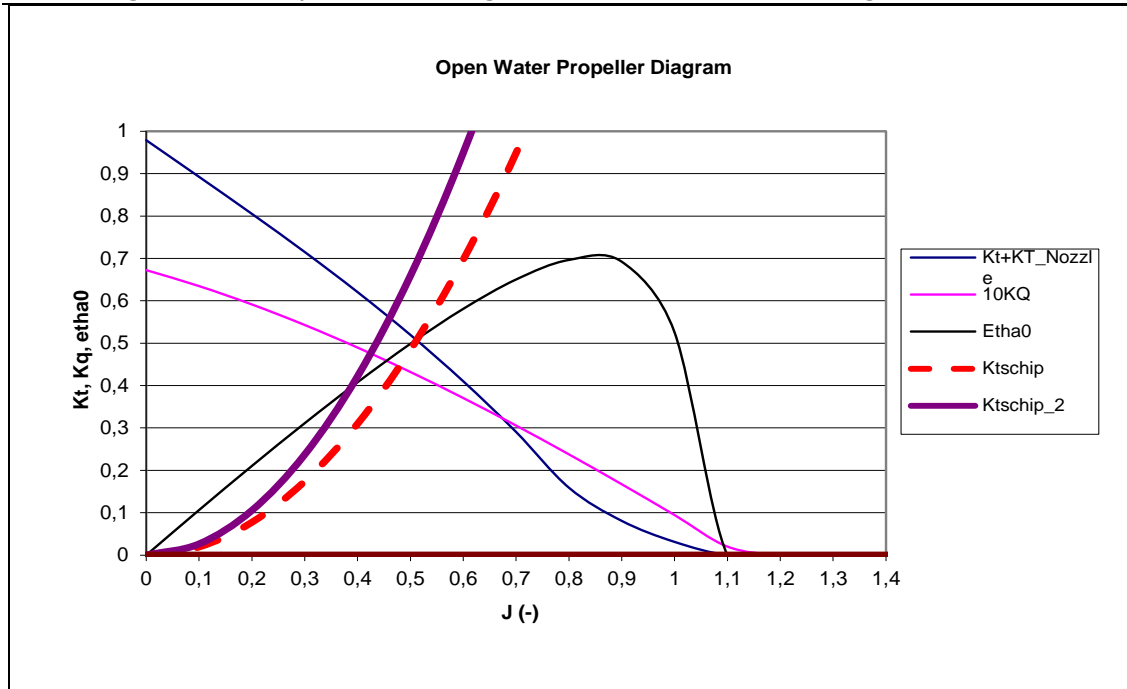
### *Power calculations*

When the propellers are designed and the required thrust is known, the needed amount of installed power can be calculated. First, the operating point of the propeller must be determined. In appendix N.1 the calculation of the working point of the propellers can be found, whereas figure 7.52 offers the result of that calculation.

In the model it is possible to determine the operating point of the propeller for two different design conditions. These conditions can be different speeds, different number of barges that need to be pushed or different water depths. These different lines will result in two different efficiencies and propeller RPMs. The propeller will be designed for the heaviest condition. Figure 7.55 shows that there are two different working points of the propellers. In the network model (chapter 6) it is also possible to opt for a situation in which the tug will sail on the small waterway pushing a single tug. Also for that situation a separate working point will be calculated ( $K_{t_{ship\_SR}}$ ).

If the working point of the propeller is known, also the propeller efficiency is known and therefore the total propulsion efficiency can be determined. In Appendix N.2 the calculation of the total propulsion efficiency ( $\eta_d$ ) and required installed power can be found ( $P_b$ ).

Figure 7.52: Open water diagram with two different design conditions



The installed power will be different for the two different design conditions, not only because the resistance is different (different speed or different number of pushed barges) but also because  $\eta_d$  will change.

Besides the needed power to sail at a certain speed with a given number of barges, there is also power needed to re-charge the batteries in the barges if a battery powered barge is opted for. The amount of power needed to do that can be calculated with the following relation:

$$P_{batt} = N_{Barges} \cdot \frac{N_{Batt} \cdot E_{batt}}{T_{LR}} \quad (7.13)$$

$N_{Barges}$  = number of barges [-]  
 $N_{Batt}$  = number of batteries in one barge [-]  
 $E_{batt}$  = energy per battery [Wh]  
 $T_{LR}$  = time sailed on the large waterway [h]

The batteries will be charged when the tug is pushing the barges from the entrance of the small waterway to the port or vice versa. If the barges are equipped with a gen set or if the option is for a barge that does not have to sail independently,  $P_{batt}$  will be set to zero.

The electrical power demand ( $P_{elec}$ ) is the last power demand that needs to be determined. The electrical power demand is estimated at 150 kW, which is a value that has been taken from an example ship (NeoKemp).

It is also decided that an extra (inland waterway) margin of 25% will be added to the required propulsion power, so that extra resistance due to fouling, as well as extra resistance due to currents in the rivers and wind can be overcome.



The total installed power for the two different conditions can now be calculated with the following relations:

$$P_{b\_installed} = P_b \cdot 1,25 + P_{Batt} + P_{elec} \quad (7.14)$$

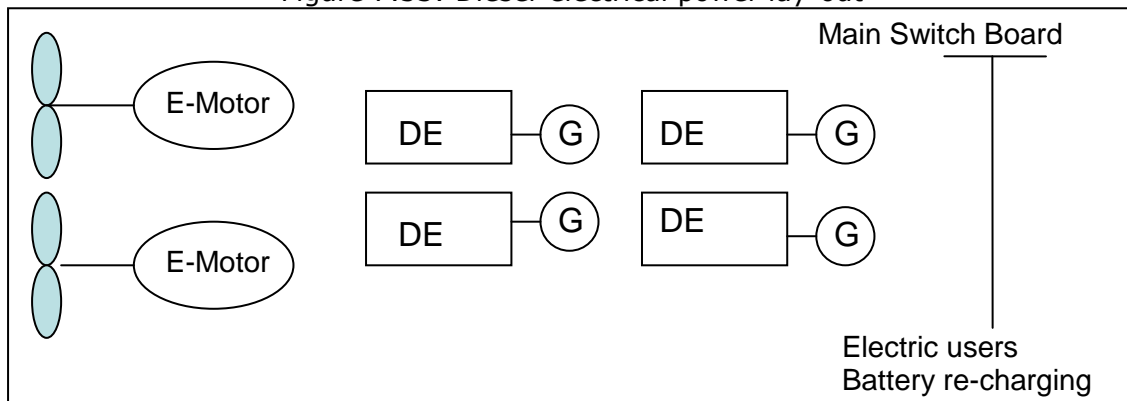
$$P_{b\_installed\_2} = P_{b\_2} \cdot 1,25 + P_{batt} + P_{elec} \quad (7.15)$$

The reason for only increasing the propulsion power and not the power needed for charging the batteries and the electrical power demand is that the last two powers are not related to the extra resistance due to currents and wind.

### *Diesel-Electrical power lay-out*

In the model it is possible to choose between a diesel-electrical power lay-out and a diesel-direct power lay-out. In this section the diesel electrical power lay-out of the tug will be described. The main advantage of the diesel electrical option is that all the different power demands can be incorporated in one power generation system. This advantage would even be bigger if the tug had to push the barges at two different speeds or two different numbers of barges, etc. If in that situation a diesel-electrical option is chosen, generator sets could be switched off so that fuel could be saved. In figure 7.53 a conceptual power generation lay-out is given.

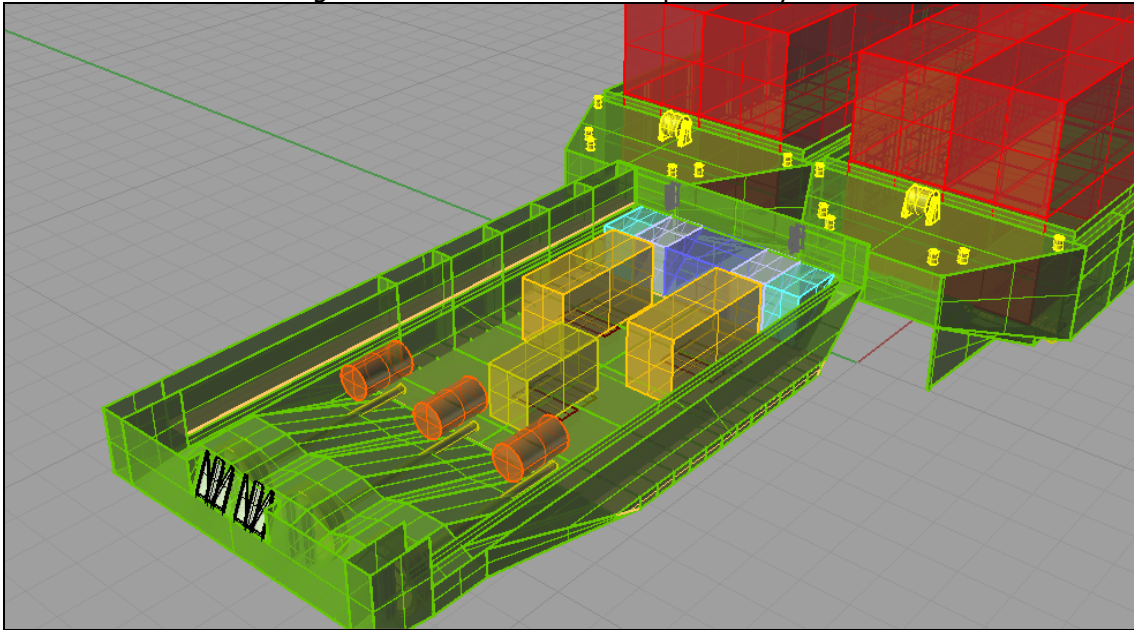
Figure 7.53: Diesel-electrical power lay-out



The tug design model may vary the number of installed propellers (1 to 4) and the number of installed gen-sets from one to four per design condition. It is possible to install two gen-sets to sail with 2 barges and one extra gen-set to sail with four barges (in total 3 gen-sets will be working). The choice of the gen-sets will be based on the calculations from the sections 7.6.1 and 7.6.2. The gen-sets are selected from a gen-set data-base that has been added to the tug design model. The data from that data-base is taken from gen-set manufacturers and gives the weight, dimensions and the fuel consumption of the gen-sets (see appendix O).

The electric engines, needed to deliver the torque and RPM to the propellers, are dimensioned at the highest value of  $P_b \cdot 1.25$  or  $P_{b\_2} \cdot 1.25$ . The product information of the electric engines can be found in appendix E. In figure 7.54 the diesel-electrical power lay-out is given.

Figure 7.54: Diesel-electric power lay-out



The electric engines are placed after the propeller shafts if there is enough space available in the engine room. If there is not enough space available, electric engines are placed above the propeller shaft so that the electric engines drive the propeller shafts with a drive belt.

If a diesel electrical power lay out is chosen, then an extra efficiency is added. This efficiency is set to be 90% so that 10% efficiency loss is incorporated for the diesel- electrical option. This loss is used to incorporate the losses for the electrical components of the power generation systems.

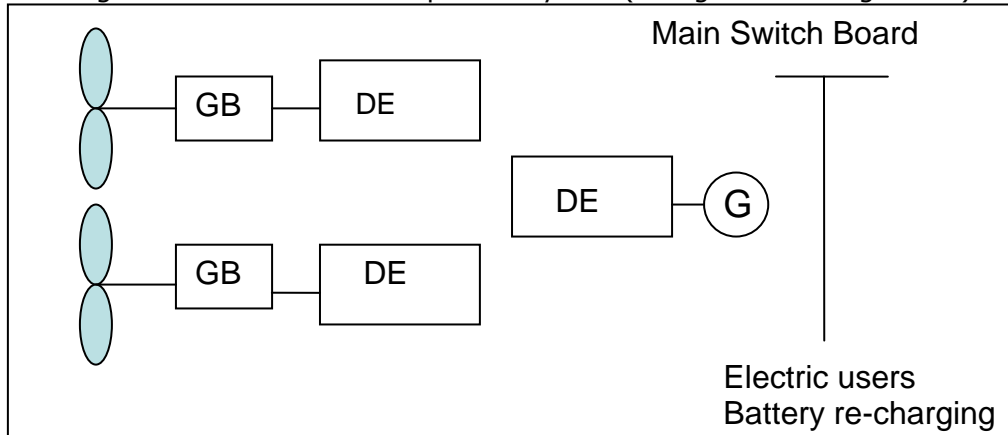
The gen-sets are allocated in such a way that the heaviest engines (or sets of engines) are placed as much forward as possible in order to reduce the trim of the tug (see also section 7.4.9 trim calculations).

#### *Diesel-Direct power lay-out*

The diesel direct system is a simpler system than the diesel electrical option. The model only has to define the number of propellers. The number of installed engines is set to be equal to the number of propellers. Owing to the fact that the engine RPM and the propeller RPM are not the same, a gear box needs to be installed between the engine and the propeller shaft. The gear box will be taken from a data-base and will be selected on basis of the needed reduction of RPM and engine power (see appendix Q).

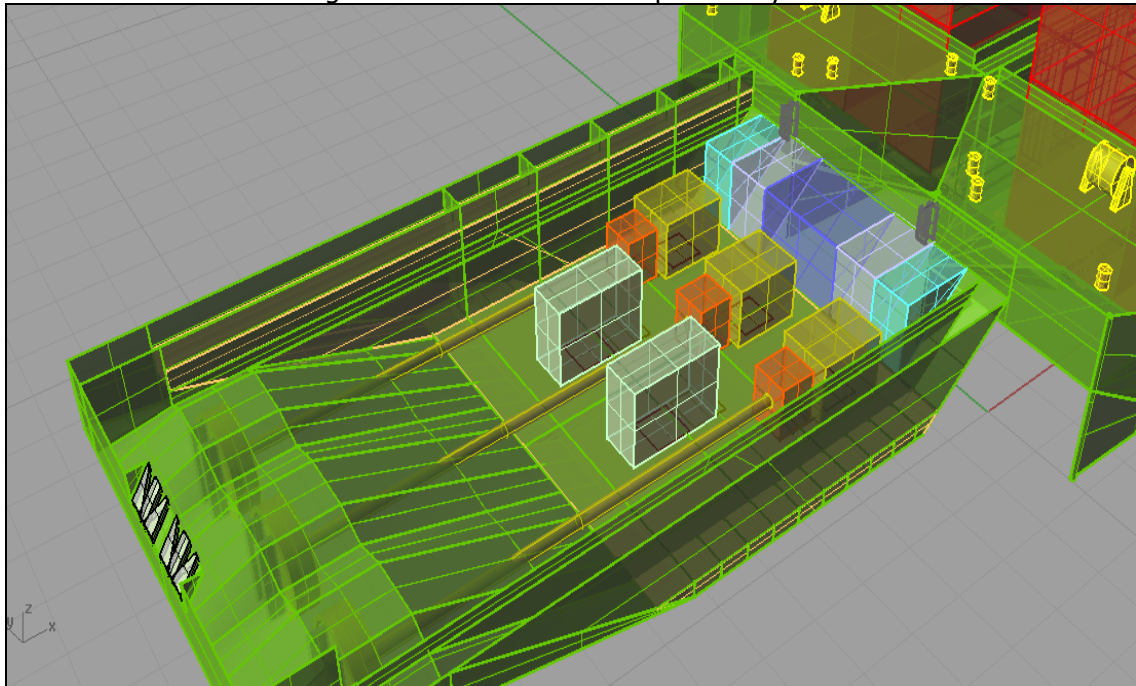
The propulsion power and the power needed to charge the batteries (via the power take off of the gear box) will be delivered by the installed diesel engines. The data of the diesel engines can be found in appendix P. The electrical power will be delivered by gen-sets. When it has been chosen to install two propellers, the tug design model will install one gen-set and in all the other situations there are two gen-sets installed. In figure 7.55 the schematic diesel direct lay-out is given.

Figure 7.55: Diesel-direct power lay-out (2 engines and 1 gen-set)



If a diesel direct power lay-out is opted for and two different design conditions are entered, the model will design the power lay-out for the heaviest condition. In figure 7.56 the 3D-model of the diesel direct power lay-out is given. The engines are placed as much forward as possible in order to reduce the trim of the tug.

Figure 7.56: Diesel-direct power lay-out



#### *Fuel, dirty and lubrication oil tanks*

The amount fuel oil that has to be allocated in the tug depends on the range of the tug. The number of trips that have to be made by the tug has to be defined. A trip is defined here as sailing from a seaport to the small waterway and back. In appendix R the more detailed calculations and design choices are given.

#### **7.4.7 Accommodation**

The accommodation of the tug will be determined by the number of required crew members and consequently the amount of needed cabins and

the required space for the galley. The total amount of crew members will be given by the rules of the shipping inspection and depends on the chosen sailing regime, i.e. semi or full continues and the total size of the tug and barge convoy (see chapter 8).

In the accommodation a distinction will be made between captain cabins and sailor cabins. The cabins of the captain will be equipped with a personal shower and toilet, while the other crew members have to share common facilities. The dimensions of all the cabins are set at 2.5 meters width, while the length of the captains' cabin is set at 3 meters and the height of the accommodation is set at 2.3 meters. The superstructure will be made of aluminium. In appendix S the lay-out design and the weight calculation of the accommodation are given.

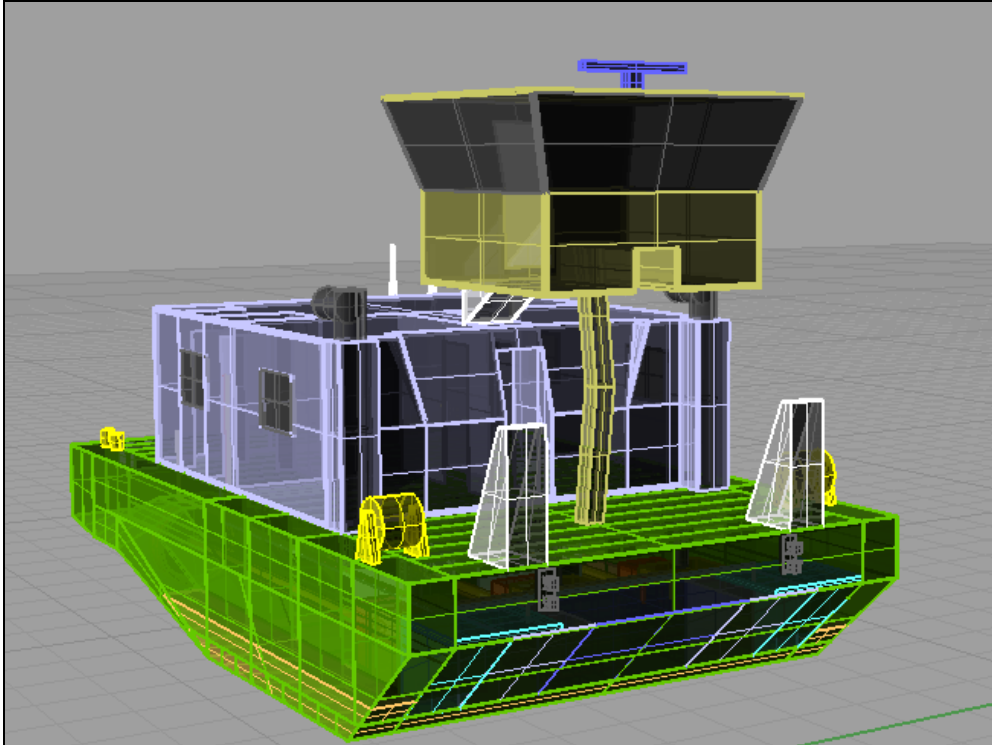
#### **7.4.8 Wheelhouse**

On the tug a moveable wheelhouse will be placed. The big advantages of this type of wheelhouse is that it can be placed above the containers when the tug and barges convoy is sailing on a large waterway. This gives the captain a good overview of the barges, but the wheelhouse can also be lowered so that the tug and barge convoy can pass low bridges. The wheelhouse will be entered from the aft part via a flight of stairs on the accommodation when the wheelhouse is higher. When the wheelhouse is lowered, the wheelhouse will be entered from the inside of the accommodation.

The dimensions of the wheelhouse are taken from an example inland ship (CompocaNord) that has been developed as a composite inland ship. The dimensions are determined at 3 meters in length, 3 meters in width and with a height of 2.3 meters.

The lowest point of the wheelhouse, in the upwards condition, will be placed on the highest of the containers so that the captain can look over the containers. In figure 7.57 a total overview of the tug is given when the accommodation and the wheelhouse are placed on the tug.

Figure 7.57: Overview of the tug with the wheelhouse and accommodation



The weight of the wheelhouse will be determined in the same way as has been done for the weight calculation of the accommodation. It is assumed that the calculated weight is the total weight of the wheelhouse, inclusive of the equipment weight of the wheelhouse.

#### **7.4.9 Stability and trim**

In this part of this chapter the stability and trim calculations will be described that are added in the model. First the stability of the tug will be determined. After that the trim of the tug will be calculated as well as the allocation of the ballast tanks.

##### *Stability calculations*

The stability of the tug will be determined by its GM-value. In appendix T the calculations of the GM-value are given.

No formal criteria are formulated by the shipping inspection concerning the stability of the push and tug ships on inland waterways (RAAD VOOR DE TRANSPORTVEILIGHEID, 2004). It is only prescribed that the ships must be sufficiently stable. In this research a minimum value of GM of 1 meter is taken as sufficient initial stability for the tug.

For every design that has been made, a stability check will be made to see if the tug is stable. If the stability is not high enough, the design will be rejected and should therefore be adjusted.

*Trim calculations*

Besides the calculation of the initial stability of the tug, also its trim will be determined. In appendix T also these trim calculations can be found.

If the initial trim of the tug is not equal to zero, the design model will automatically add ballast to the tug, so that the tug will have zero trim. The way that has been done can also be found in appendix T.

**7.4.10 New-building price tug**

The new building costs of the tug will be determined in the same as has been done for the barge. Therefore the newbuilding costs of the shipyard are determined and on top of that a profit margin is added, so that the newbuilding price is determined (recall figure 7.20). The costs of the hull of the tug are calculated in the same way as the barges. The reason for that is that there is not a big difference between the shape of the hull of the barge and the tug. But there are some additional costs for the hull, such as rudders, ducts, pumps, ballast tanks, etc. Therefore, the following relation is used to calculate those costs:

$$\text{Cost}_{\text{Tug\_Hull}} = \text{SW}_{\text{tug}} \cdot (25 \cdot \text{Cost}_{\text{man\_hour}} + \text{Cost}_{\text{steel}}) \cdot 1.25 \quad (7.16)$$

$\text{Cost}_{\text{Tug\_Hull}}$  = Costs of the hull of the tug [EUR]  
 $\text{SW}_{\text{Tug}}$  = total steel weight of the tug [tonne]

The costs of all the installed generator sets and or diesel engines are related to the installed power. The costs per installed kW of generator set are 330 EUR / kW<sup>20</sup>. For diesel engines the costs are 200 EUR / kW<sup>21</sup>. It is assumed that these costs are the total costs to install the equipment (including the costs of all the ducts, pumps, etc that are related to the engines). The total costs for the engines can then be determined with the following relations:

$$\text{Cost}_{\text{GEN\_SETS}} = \text{Pb\_installed}_{\text{engine}} \cdot 330 \cdot A_{\text{Engines}} \cdot \text{index}_{2005} \quad (7.17)$$

$\text{Cost}_{\text{GEN\_SETS}}$  = costs for the installed gen sets [EUR]  
 $\text{Pb\_installed}_{\text{engine}}$  = installed power per gen set [kW]  
 $A_{\text{Engines}}$  = number installed gen sets [-]  
 $\text{Index}_{2005}$  = inflation index 2005 → 2009 = 115.4/106.5 (see 5.3) [-]

$$\text{Cost}_{\text{Diesel\_Direct}} = \text{Pb\_installed}_{\text{engine}} \cdot 220 \cdot A_{\text{Engines}} \cdot \text{index}_{2005} \quad (7.18)$$

$\text{Cost}_{\text{Diesel\_Direct}}$  = costs for the installed diesel engine [EUR]

The costs for the installed electrical engines for the diesel electrical option are set at 100 EUR/kW. The total costs can be calculated with the following relation:

$$\text{Cost}_{\text{EMotor}} = N_{\text{EM}} \cdot 100 \cdot P_{\text{Emotor}} \cdot \text{index}_{2005} \quad (7.19)$$

$\text{Cost}_{\text{Emotor}}$  = costs of the electrical engines [EUR]  
 $N_{\text{EM}}$  = number of electrical engines [-]

<sup>20</sup> Data given in 2005 (TU delft lecture Wartsila data)

<sup>21</sup> Data given in 2005 (TU delft lecture Wartsila data)

$P_{\text{Emotor}}$  = power per electrical engine [kW]

The costs of the gear boxes are taken from product data of Reintjes<sup>22</sup> and are given in the following relation:

$$\text{Cost}_{\text{GEAR\_BOX}} = \frac{25.000}{0.243} \cdot \frac{\text{Installed}_{\text{power}}}{\text{Engine}_{\text{RPM}}} \cdot A_{\text{gear\_boxes}} \cdot \text{index}_{2008} \quad (7.20)$$

$\text{Cost}_{\text{GEAR\_BOX}}$  = costs of the gearbox [EUR]  
 $\text{Installed}_{\text{power}}$  = installed power per engine [kW]  
 $\text{Engine}_{\text{RPM}}$  = rpm of the installed engine [1/min]  
 $A_{\text{gear\_boxes}}$  = number of installed gear boxes [-]  
 $\text{Index}_{2008}$  = inflation index 2008 → 2009 = 115.4/115.4 (see 5.3) [-]

In the formula above the number 0.243 is the ratio of installed power and engine rpm of the example gear boxes and the number 25.000 EUR is the price for a single gear box inclusive of the PTO, braches, etc. In relation 7.34 the costs may be very low if the installed power is low. But a gear box will not be very cheap if the size of the gear box is decreased; therefore a minimum price of 20.000 EUR is assumed.

The costs for the propellers are determined at 100 EUR/ kW<sup>23</sup> for fixed pitch propellers. These costs also have to be indexed with the  $\text{index}_{2005}$ .

The costs to install the engines, gear boxes and propellers are estimated with the following relation:

$$\text{Cost}_{\text{Installation}} = [A_{\text{Engines}} \cdot 100 + (A_{\text{Prop}} + A_{\text{gear\_boxes}} + A_{\text{EM}}) \cdot 50] \cdot \text{Cost}_{\text{Man\_Hour}} \quad (7.21)$$

$\text{Cost}_{\text{Installation}}$  = costs for the installation of the propulsion equipment [EUR]  
 $A_{\text{engines}}$  = number of installed engines (gen-sets or diesel engines) [-]  
 $A_{\text{Prop}}$  = number of propellers [-]  
 $A_{\text{gear\_boxes}}$  = number of gear boxes [-]  
 $A_{\text{EM}}$  = number of Electrical engines [-]

It is estimated that the installation time of a single engines is 100 man-hours. This time is used to install the engines, connect the ducts and pumps, etc. The required amount of man-hours for the instalment of the propellers, gear boxes and electrical engines are set at 50 manhours. The costs of the exhaust system (exhaust pipes and ventilation of the engine room) are estimated at 30,000 EUR (2009 value). The costs of the electrical components (converters, switch boards, etc) are estimated at 50,000 EUR (2009 value).

The costs of the wheelhouse are 40,000 EUR<sup>24</sup> (inclusive installation). These costs are given by the firm ALUBOUW de Mooy. These costs are an estimation based on the used dimensions of the wheelhouse. The costs of the equipment that have to be installed in the wheelhouse (radar, communication equipment, etc) are 100,000 EUR<sup>25</sup>. All these costs have to be updated to 2009 values with  $\text{index}_{2007}$ . The costs for the finishing of the

<sup>22</sup> Data given in 2008 (personal contact Reintjes)

<sup>23</sup> Data given in 2005 (TU delft lecture Wartsila data)

<sup>24</sup> Data given in 2007 (personal contact alubouw de mooy)

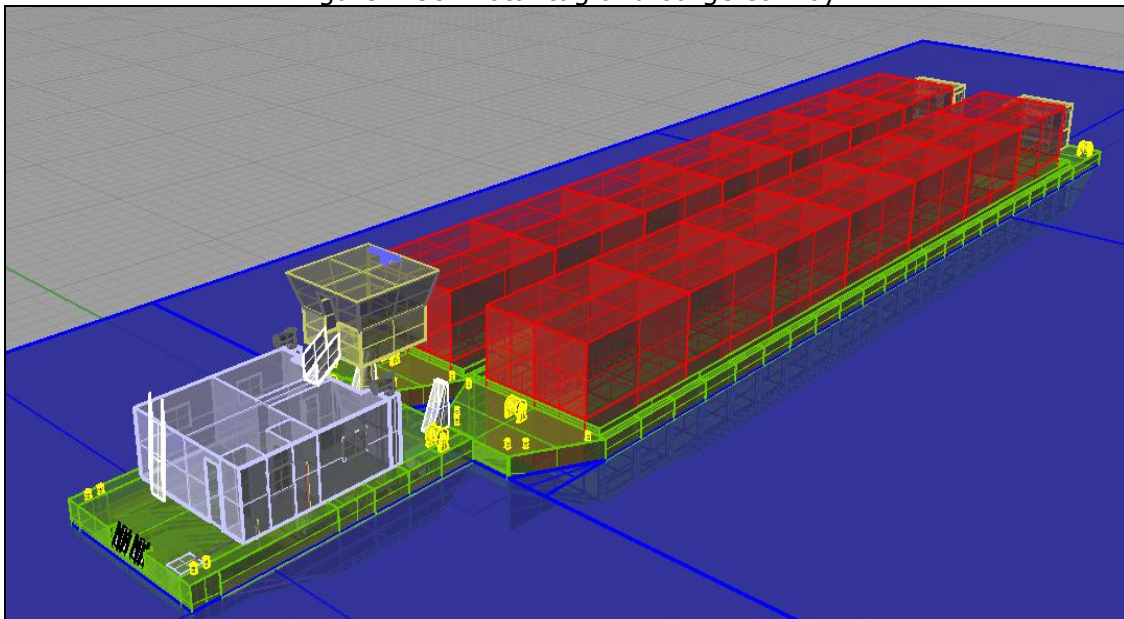
<sup>25</sup> Data given in 2007 (personal contact alubouw de mooy)



wheelhouse and superstructure are estimated at 225,000 EUR (Ecotrans 2002<sup>26</sup>), which will have to update to 2009 with index<sub>2002</sub> (115.3/100).

The costs of the hydraulic lifting system of the wheelhouse are set at 40,000 EUR<sup>27</sup>. This figure is given by Van der Velde marine systems. The costs are related to the required lifting height of the wheelhouse, but for these costs a lifting height of 5 to 9 meters can be achieved. The hydraulic winches that are also placed on the tug can be incorporated in the hydraulic lifting system of the wheelhouse. The extra costs for the hydraulic systems for the winches are in total 60,000 EUR<sup>28</sup> so that the total costs are 100,000 EUR. The costs of the steering equipment are determined at 65,000 EUR<sup>29</sup> per two pairs of rudders (see appendix K). The total installation costs of the rudders, lifting system and coupling winches amount to 40,000 EUR<sup>30</sup>. All these costs are valid for 2007 so that also these costs have to be indexed from 2007 to 2009 with index<sub>2007</sub> (115.4/111.3).

Figure 7.58: Total tug and barge convoy



The total new-building costs of the tug are now equal to the sum of all the different components plus a margin of 7%. That margin has been added to incorporate the profit margin of the ship yard and possible costs components that are not taken into account. In figure 7.58 a design has been made where a convoy can transport 2 x 28 TEU with a speed of 14.5 km/h on a large waterway. The total range of the tug is 5 x 200 km and there is space for 2 crew members on the tug.

#### 7.4.11 Emissions

The emissions of the tug and barge convoy will be based on the fuel consumption of the tug. It is known how much fuel will be consumed per

<sup>26</sup> Quaestor-model Eco-Trans developed by Dr. Ir. Van Hees ( the software developer of Quaestor)

<sup>27</sup> Data given in 2007 (personal contact Van der Velde marin systems)

<sup>28</sup> Data given in 2007 (personal contact Van der Velde marin systems)

<sup>29</sup> Data given in 2007 (personal contact Van der Velde marin systems)

<sup>30</sup> Data given in 2007 (personal contact van der Velde marin systems)



hour and therefore (with the known sailing time) per trip. The emissions will be expressed in CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub> and PM<sub>10</sub>. The total amount of emissions per gram of gas oil is given in table 7.8.

Table 7.8: Emissions per tonne fuel oil

	CO <sub>2</sub>	NO <sub>x</sub>	SO <sub>x</sub>	PM <sub>10</sub>
g/g	3.17	0.09	0.0013	0.0018

Source: Dijkstra, 2001

For the transportation of one TEU or tonne of cargo, it is possible to calculate the total emissions. Chapter 9 shows that the emissions costs will be calculated on the basis of the values given in table 7.6. Also the emissions in g per t\*km will be calculated, so that that value can be compared with other modes. When an independent sailing barge with a battery package is chosen, the emissions of the barge are set at zero, due to the electrical installation of the barge. In that case all the emissions are "produced" by the diesel engines (or generator sets) in the tug. If in the independent sailing barge a generator set is installed, also those emissions will be taken into account.

#### 7.4.12 Sensitivity analysis of the tug design model

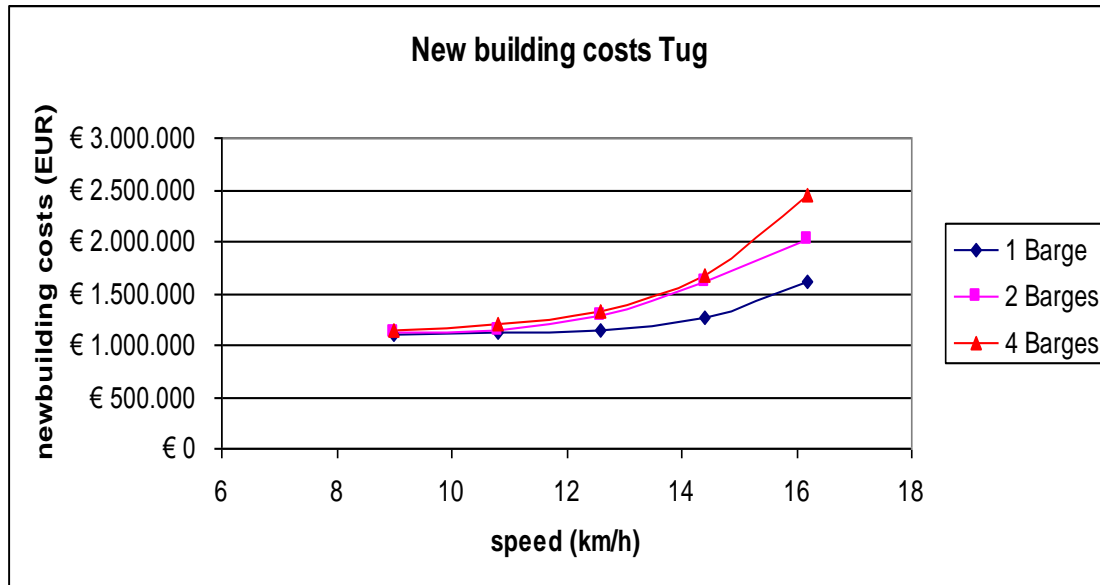
In order to make the calculations for the sensitivity analysis for the tug design model, some additional input parameters are needed. In table 7.9 an overview is given of the values of these additional input parameters. The number of barges pushed is the same for all the three waterways. All the other input parameters are the same as in table 7.5.

Table 7.9: Overview of the additional input parameters

Input parameter	value
Propulsion system tug	Diesel direct
N <sub>propellers</sub>	3
Sailing regime	Semi continuous

The first parameter that will be analysed is the influence of the speed on the new-building price of the tug. Also the influence of the number of pushed barges is analysed. In figure 7.59 the influence of a speed and barge train formation (btf) on the newbuilding costs of the tug is given.

Figure 7.59: Influence of speed and BTF on the new-building costs of the tug (DD)



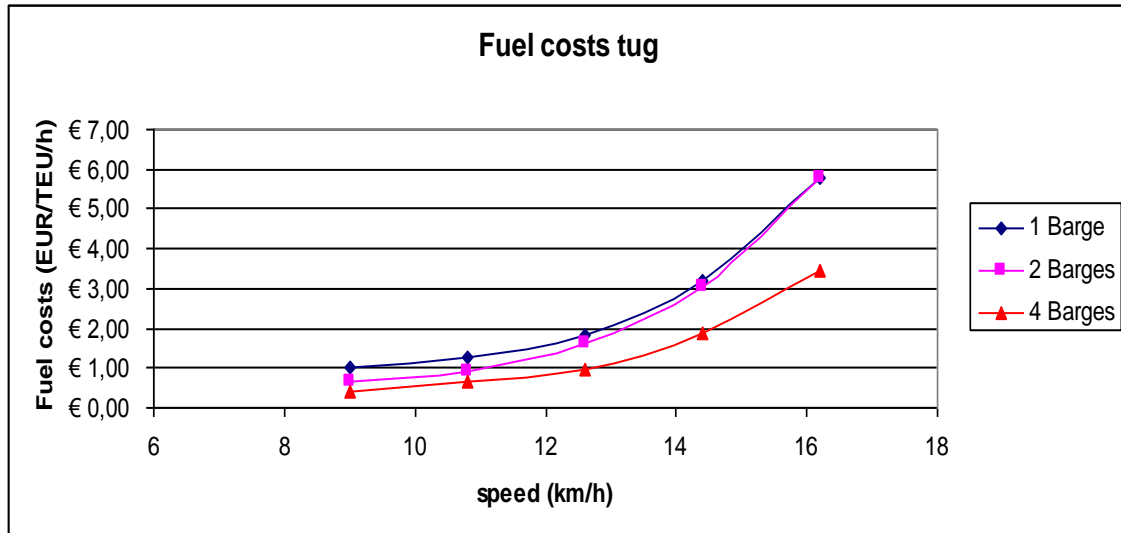
Note: 2009 values

Figure 7.59 shows that the new-building costs are (almost) the same for all three different designs when the speed of the tug is smaller than 11 km/h. The reason is a minimum engine size that will be installed in the tug. If the required power is lower than the smallest engine in the database, the model will always choose that smallest engine. Therefore, the designs of the tugs are the same and as a result also the new-building costs. From figure 7.59 it can also be concluded that, when the required speed goes up, the new-building costs also increase and that increase is the largest for the tug that has to push the most barges. Especially for tug that has to sail 16 km/h, the difference between pushing 1 or 2 barges is almost €500,000 (2009 values).

The second parameter that will be analysed is the fuel costs per TEU per sailed hour for different speeds and barge train formations. For these calculations the fuel oil price was set at 600 EUR per tonne fuel (2009 value, see chapter 8). In figure 7.60 the fuel costs per TEU are given.

It can be concluded from figure 7.60 that the fuel costs per TEU are larger (and increase more rapidly) for the smaller convoys. That effect is due to the economies of scale of the larger convoys. Figure 7.66 also allows us to conclude that when the speed of the tug (plus barges) is increased above 14 km/h, the fuel costs increase very rapidly. At 16 km/h, the difference per TEU per hour is 6 EUR if one compares the fuel costs if one barge has to be pushed or four. While the difference is less than 0.5 EUR if the speed is lower than 12 km/h. In the same figure can also be observed that the fuel costs per TEU for the 1 and 2 barge convoy are almost the same.

Figure 7.60: Influence of speed and btf on the fuel costs per hour of the tug (DD)



Note: 2009 values

Also the effect of the choice between a diesel direct and a diesel electrical system will be analysed. The same design as above has been made but now with a diesel electrical system. This is shown in figure 7.61.

Figure 7.61: Influence of speed and btf on the new-building costs of the tug (DE)

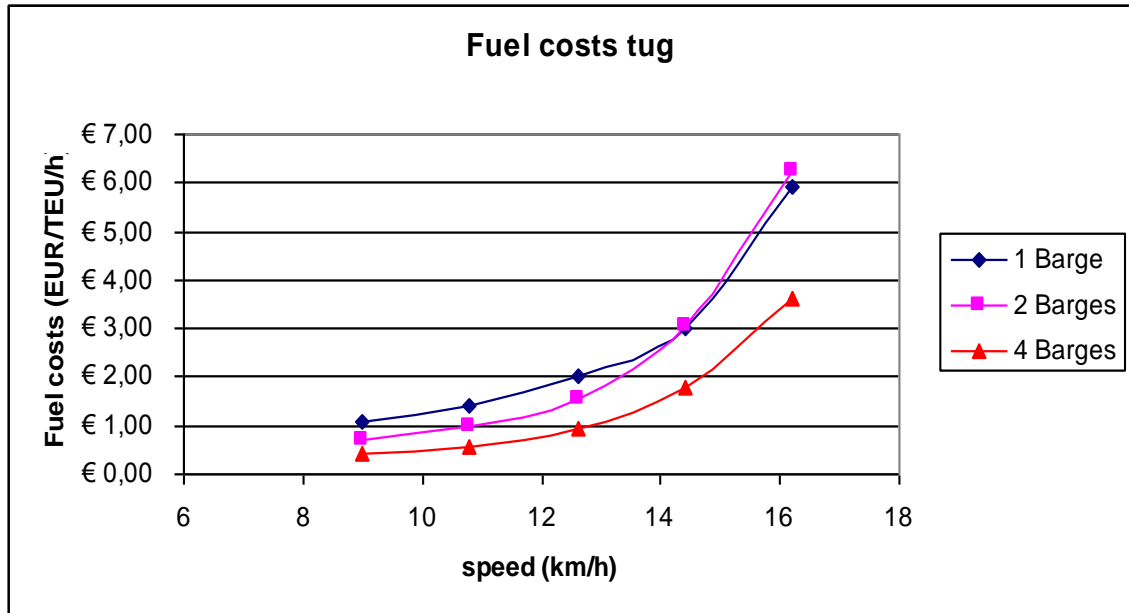


Note: 2009 values

Figure 7.61 shows that the new-building costs of the tug with a diesel electrical system are increasing with an increasing speed and size of the convoy. The new-building costs of the diesel electrical tug are higher than the costs for the diesel direct tug (except when the 4 barge tug convoy is sailing at 16 km/h). The reason for that is that, due to the installation of the generator sets, mechanical energy has to be transformed into electricity and from electricity transformed into mechanical energy. This loss of 10% will lead to a more expensive propulsion installation. The electrical engines and switch board will also have an upwards effect on the new-building costs.

In figure 7.62 the fuel costs per TEU are given for the situation that the tug is equipped with a diesel electrical propulsion system.

Figure 7.68: Influence of speed and btf on the fuel costs per hour of the tug (DE)



Note: 2009 values

If figure 7.62 is compared with figure 7.60, it can be concluded that the fuel costs do not differ much between the two propulsion systems.

The last parameter that will be analysed is the number of propellers on the tug. The numbers of propellers are varied from one to three propellers and for the different number of propellers the propulsion efficiency will be determined.

Figure 7.63: Influence of the number of propellers on the propulsion efficiency

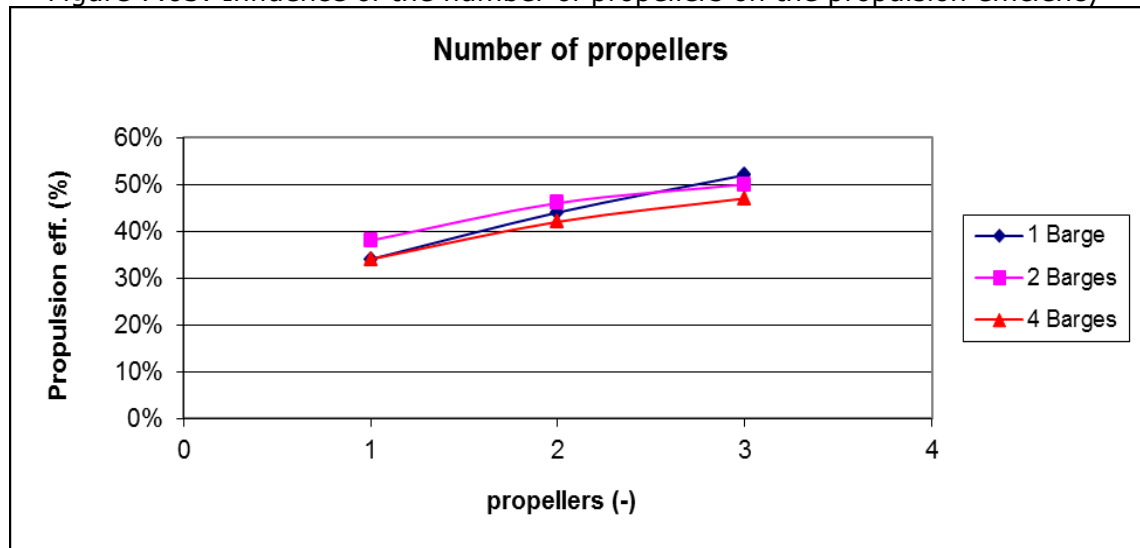


Figure 7.63 shows that the efficiency of the propellers increases with an increasing number of propellers. The load per propeller is reduced and the efficiency increases. It can also be seen that the difference between pushing one and two or four barges is very large. In fact, the tug has to push fewer

barges, the required amount of power needed is also reduced; therefore smaller engines are installed, resulting in a weight reduction of the tug. That weight reduction results in a reduction of the draft of the tug and thus a reduction of the propeller diameter and in an increase in propeller load per blade area.

## 7.5 Preliminary conclusion

In this chapter the design models for the used barges and tug have been developed. These design models use the input from the network model and will also provide data to the transportation and external cost models.

In this section of chapter 7 the preliminary conclusions regarding the design choices for the tug and barge design are presented (resistance influence, stability and propulsion). The influence of design choices on the newbuilding / transportation costs will be made in chapter 8 (transportation cost model) and in chapter 14 (Applying the small barge system in a real case). The reason to split these decisions is that the more logistics / cost research is needed before a choice can be made.

From the barge design model it can be concluded that  $\alpha_1$  should have a value between 20 and 30 degrees. If it is possible, the lowest value of  $\alpha_1$  (20 degrees) is advised because that will lead to the lowest resistance at the highest speeds.

It can also be concluded that at low speeds (1 to 2 m/s) the largest value of  $\alpha_{st}$  gives the lowest resistance. When the speed is increasing, the influence of the angle on the resistance is less. The best choice for  $\alpha_{st}$  is 20 degrees. If a generator set is installed in the aft of the barge,  $\alpha_{st}$  cannot be chosen freely, but it must be altered in order to create enough space to allocate the generator set ( $\alpha_{st} < 10^\circ$ ).

With respect to the width of the transom area, it can be concluded that the resistance of the independent sailing barge will increase if the width of the transom area is increased. The influence is decreasing when the speed of the barge is increasing, but the reduction is smaller than when the value of  $\alpha_{st}$  was varied. It is therefore advised that the width of the transom area will be reduced as much as possible. A limiting factor is that the barges have to be coupled, for which a minimum pushing area is needed. The minimum width of the transom is set at 0.5 of the total width of the barge.

The minimum width of the barge, with respect to its stability, should be at least wider than 6.7 meters so that the GM value is larger than 0.5 (minimum criteria if the containers are lashed). If the containers are not lashed, the width of the barge must be increased to 7.5 meters to obtain a GM-value of 1 metre.

It can also be concluded that an "empty" barge (barge without propulsion equipment) will be as stable as a fully equipped barge. The weight of the batteries and thrusters in the double bottom will lower the KG of the barge but that is being compensated for by the increase in KG of the wheel house, which is placed on the deck of the barge.

The number of thrusters installed on the barge will be set at 4 thrusters in the aft the barge and on in the bow. The four thrusters in the aft ship of the barge will enable it to sail at 13 km/h (for a short period of time if batteries are installed). This maximum speed will give the barge the ability to manoeuvre in sailing areas where there is a large current or if ships have to be passed.

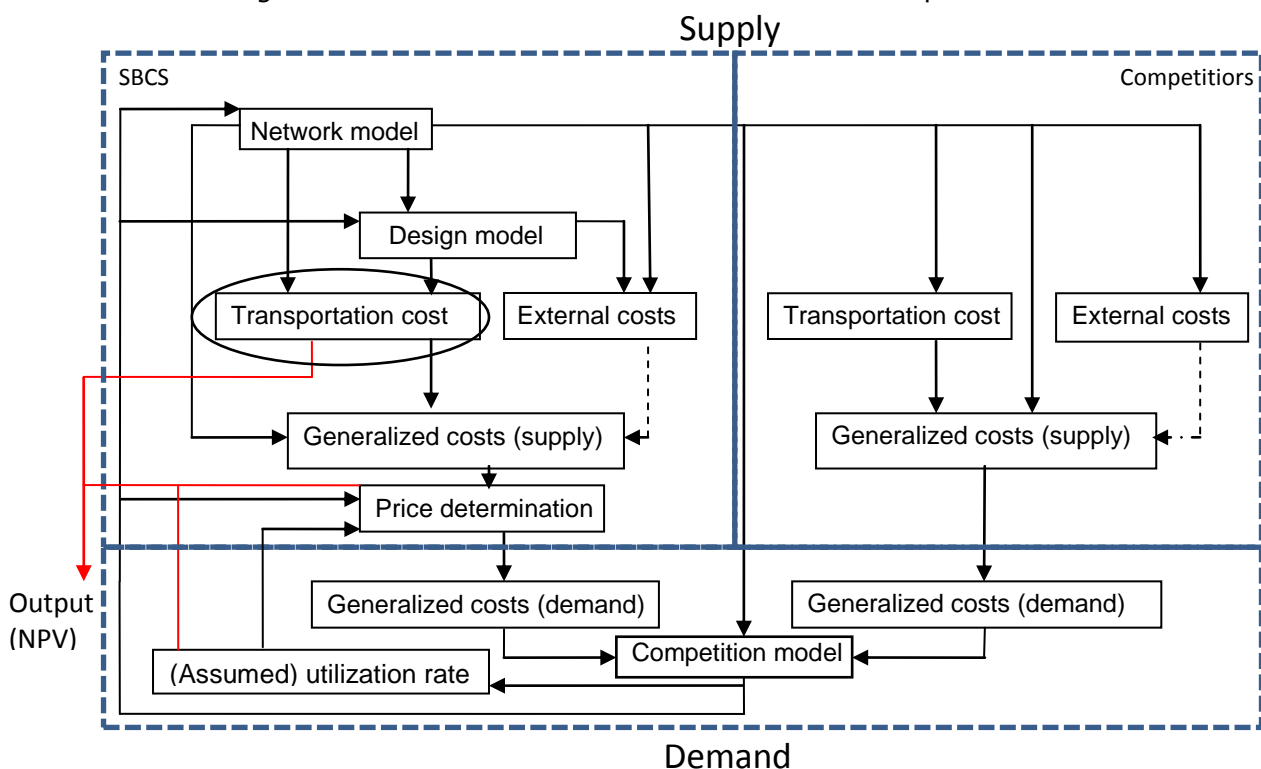
From the tug design model it can be concluded that the efficiency of the propellers increases with an increasing number of propellers. The load per propeller is reduced, so that the efficiency increases. It can also be concluded that the difference between pushing one or two or four barges is considerable. The reason for that is that, if the tug has to push fewer barges, the required amount of power needed is also reduced and smaller engines are installed, resulting in a weight reduction of the tug. That weight reduction results in a reduction of the draft of the tug and thus a reduction of the propeller diameter and in an increase in propeller load. This will decrease the propeller efficiency.

## 8. Transportation costs model

### 8.1 Introduction

In this chapter the transportation costs of the small barge convoy system will be determined. These transportation costs are determined as the sum of the fuel, crew, interest, repair and maintenance, insurance costs, depreciation and administration costs. This chapter will conclude with a sensitivity analysis of parameters that are influencing the transportation cost such as the number of barges and fuel oil price. This is justified by our interest in the effects of changes of those parameters on the total costs. Figure 8.1 shows the position of the costs model in the total model.

Figure 8.1: Position of the costs model in the concept model



### 8.2 Cost components

The transportation costs will be calculated as the sum of the fuel, crew, interest, repair and maintenance, insurance costs, depreciation. These different costs components are taken from NEA (2003). Also the costs to use the inland waterways (waterway costs) and the overhead costs are added.

#### 8.2.1 Fuel costs

The fuel costs are determined by the amount of fuel that is used on the selected trips and the fuel costs per tonne fuel. The amount of fuel used is already determined in chapter 7, where the fuel consumption is determined as a function of needed power to sail with a given number of barges and at

a given speed and the specific fuel consumption of the engine. In formula 8.1 the fuel costs per TEU per trip will be calculated.

$$\text{Cost}_{\text{Fuel\_trip}} = \frac{\text{Fuel}_{\text{consumption}} \cdot \text{Fuel}_{\text{costs}}}{N_{\text{Barges}} \cdot (N_{\text{containers}} + \text{Bulk})} \quad (8.1)$$

$\text{Cost}_{\text{Fuel\_trip}}$	= fuel costs per trip per TEU or tonne	[EUR/TEU or tonne]
$\text{Fuel}_{\text{consumption}}$	= fuel consumption (see chapter 7.3)	[tonne]
$\text{Fuel}_{\text{costs}}$	= costs for one tonne of gas oil (600 EUR/tonne) <sup>31</sup>	[EUR/tonne]
$N_{\text{Barges}}$	= number of barges in the convoy	[-]
$N_{\text{Containers}}$	= number of containers per barge	[TEU]
Bulk	= amount of bulk cargo in one barge	[tonne]

In this calculation, and also in the upcoming ones, the costs are calculated per unit load. This can either be in TEU if a barge is loaded with containers or in tonne if the barge is loaded with bulk cargo (sand, iron ore, etc). The loading degree of the barges is in this stage of the model not yet determined. This loading degree is a variable in the total model which will be determined with the feedback relation who will connect the competition model with the top of the model (see figure 8.1). So the competition will determine the maximum loading degree of the barges.

With this calculation the assumption has been made that the tug will sail at a constant (design) speed(s) and that the added resistance due to waves and wind are not taken into account.

If a barge has been chosen that is equipped with a generator set instead of batteries, the fuel costs of the barge are also added to the total fuel costs.

### 8.2.2 Crew costs

The crew costs of the different barge trains will be determined by the minimum number of crew members that should be present at the barge train. The rules for the number of crew members are given in table 8.1, where also a distinction is made between the full and semi-continuous sailing regimes. It needs to be mentioned that a push barge in this table can be seen as a combination of smaller barges if the total width does not exceed 15 meters and the total length does not exceed 76.5 meters. If a barge train is operated at a semi continuous regime, there are only 14 hours available per day.

<sup>31</sup> Costs in 2009 value which can be varied (December 2009, NEA 2010)



Table 8.1: Number of crew members

		Full continues S1	Semi continues S1
Dimensions of the barge train L < 37 m B < 15 m	Captain	2	1
	Quartermaster	-	-
	Sailor	1	1
	Ordinary sailor	1	-
	Machinist	-	-
Dimensions of the barge train 37 m < L < 86 m B < 15 m	Captain	2	1
	Quartermaster	-	-
	Sailor	2	1
	Ordinary sailor	-	-
	Machinist	-	-
Dimensions of the barge train 86 < L < 116.5 m B < 15 m	Captain	2	1
	Quartermaster	1	1
	Sailor	2	1
	Ordinary sailor	-	-
	Machinist	-	-
Tug + 2 barges	Captain	2	1
	Quartermaster	1	1
	Sailor	2	1
	Ordinary sailor	-	-
	Machinist	1	1
Tug + 3 or 4 barges	Captain	2	1
	Quartermaster	1	1
	Sailor	2	2
	Ordinary sailor	1	-
	Machinist	1	1
Tug + > 4 barges	Captain	2	1
	Quartermaster	1	1
	Sailor	3	3
	Ordinary sailor	1	-
	Machinist	1	1

Source: NEA, 2003.

The crew costs per hour will be determined by the number of crew members and the hour wages for the crew members. The wages are taken from the collective labour agreement and are given in table 8.2<sup>32</sup>. The costs are given as the before tax costs per month of a 40-hour work week. The costs per hour are then equal to the month wages times 12/52 divided by 40 hours. The wage costs per hour per TEU or tonne can be calculated with formulae 8.2 and 8.3 for the situation on the large and small waterways:

$$\text{Crew}_{\text{costs\_LR}} = \frac{\sum \text{Costs}_{\text{crew}}}{N_{\text{Barges}} \cdot (N_{\text{containers}} + \text{Bulk})} \quad (8.2)$$

<sup>32</sup> All costs are calculated for 2009. The table indicates that the costs are valid from the 1st of January 2010, which is only one day after the base year 2009 (31<sup>st</sup> of December).

$$\text{Crew}_{\text{costs\_SR}} = \frac{\sum_{\text{Crew}_{\text{SR}}} \text{Costs}_{\text{crew}}}{(\text{N}_{\text{containers}} + \text{Bulk})} \quad (8.3)$$

$\text{Costs}_{\text{crew}}$  = hour wages of the crew [EUR/h]

$\text{Crew}_{\text{LR}}$  = crew members on the large waterway [-]

$\text{Crew}_{\text{SR}}$  = crew members on the small waterway [-]

The number of crew members on the small waterway will differ per selected barge train. If a system is chosen in which the barge will not sail independently on the small waterway, the crew costs per hour are the same as for the total barge train. If the barge will sail independently, the minimum crew members will be set at 2, a captain and a mate. In the model is it possible to opt for only a single captain on the barge.

Table 8.2: Labour costs according to the labour agreement

<b>Wage table</b>		
<b>Tug and push ships</b>	Month wages	Hour wages
<b>Data of start 1 January 2010:</b>		
	<b>EUR</b>	<b>EUR</b>
<b>CAPTAIN</b>		
Engine power. > 1200 EPK	2,234.39	12.89
Engine power. 900-1200 EPK	2,153.87	12.43
Engine power. 600-900 EPK	2,073.04	11.96
Engine power. < 600 EPK	1,992.60	11.50
<b>ENGINEER</b>		
Engine power. > 1200 EPK	2,101.04	12.12
Engine power. 900-1200 EPK	2,020.17	11.65
Engine power. < 900 EPK	1,940.30	11.19
<b>SHIPPER</b>	1,876.77	10.83
<b>QUARTERMASTER</b>	1,705.94	9.84
<b>full SAILOR / SAILOR-engine mechanic</b>		
Age 23 yr. or older	1,642.59	9.48
Age under 23 yr.:		
3 function years	1,577.19	9.10
2 function years	1,432.45	8.26
1 function year	1,287.66	7.43
no function years	1,143.13	6.59
<b>SAILOR</b>		
Age 23 yr. or older	1,625.85	9.38
Age under 23 yr.:		
3 function years	1,417.10	8.18
2 function years	1,271.92	7.34
1 function year	1,127.18	6.50
no function years	982.56	5.67
<b>ORINARY SAILOR</b>		
Age 23 yr. or older	1,407.60	8.12

Age 22 yr.	1,196.45	6.90
Age 21 yr.	1,020.50	5.89
Age 20 yr.	865.65	4.99
Age 19 yr.	739.00	4.26
Age 18 yr.	640.45	3.69
Age 17 yr.	566.00	3.27
Age 16 yr.	485.60	2.80

Source: Kantoor binnenvaart, 2010

Table 8.3: Overview of the overtime and continues costs

<b>WAGE TABLE</b>	<b>SYSTEM SAILING</b>	
<b>TUG and PUSH SHIPS</b>	Overtime per hour	Continues sailing per day
<b>Data of start 1 January 2010:</b>		
<b>CAPTAIN</b>		
Engine power. > 1200 EPK	17.35	64.25
Engine power. 900-1200 EPK	16.71	61.90
Engine power. 600-900 EPK	16.09	59.60
Engine power. < 600 EPK	15.47	57.30
<b>ENGINEER</b>		
Engine power. > 1200 EPK	16.31	60.40
Engine power. 900-1200 EPK	15.69	58.10
Engine power. < 900 EPK	15.07	55.80
<b>SHIPPER</b>	14.57	53.95
<b>QUARTERMASTER</b>	13.24	49.05
<b>Full SAILOR</b>		
Age 23 yr. or older	12.74	47.20
Age under 23 yr.:		
3 function years	12.24	43.35
2 function years	11.12	41.20
1 function year	9.99	37.00
no function years	8.87	32.85
<b>SAILOR</b>		
Age 23 yr. or older	12.62	46.75
Age under 23 yr.:		
3 function years	11.00	40.75
2 function years	9.87	36.55
1 function year	8.75	32.40
no function years	7.63	28.25
<b>ORINARY SAILOR</b>		
Age 23 yr. or older	10.96	40.60
Age 22 yr.	9.32	34.50
Age 21 yr.	7.95	29.45
Age 20 yr.	6.74	24.95
Age 19 yr.	5.75	21.30
Age 18 yr.	5.00	18.50
Age 17 yr.	4.33	16.05
Age 16 yr.	3.78	14.00

Source: Kantoor binnenvaart, 2010

The total crew costs per trip will be determined by the crew costs per hour and the time that the crew on the tug (or the independent sailing barge) is working. In chapter 6 it could be seen that there are several time components defined in the logistics model (see section 6.2.5). These times are used to determine the crew costs. The crew on the tug will deal with the coupling and uncoupling of the barges from the total convoy. The crew who are sailing the barges on the small waterways will deal with the mooring of the barge. If a continuous sailing regime (24 hours a day) on the tug is opted for, 24 hours per day are taken as a basis for calculating the crew costs.

The crew on the tug will work in a system sailing regime, where the crew will be one week on board the tug and the next week off board. The amount of "normal" working hours per day is 12 hours. If the crew has to make more than 12 hours for a specific trip, the extra hours have to be charged as overtime. The overtime costs (along with the additional costs of a continuous sailing regime per day) are given in table 8.3. If a continuous sailing regime is chosen, the amount of overtime hours is set to zero because, if the 12 hour per day limit is exceeded, the next crew is already present and available.

When the total crew costs per hour are determined, an extra 100% of the costs are added to incorporate the total costs for the employer. These 100% are built up from 27% (Van Dorsser, 2004) for the employer costs and 8% costs to be contributed to the pension funds. The other 65%<sup>33</sup> of the additional costs are for the daily compensation for sailing in a system sailing regime on the tug. For the crew that is sailing on the small waterways, these daily compensation costs are not needed because they are not sailing in system sailing regime. For that crew an additional 20% is assumed, on top of the 35% additional costs of mandatory employer costs, to compensate for the travel expenses to and from the small inland waterways. The time that the captains of the barges are brought back to the starting-point of the small waterway are also taken into count as crew costs. As a result, the captains are being paid during the time that they are moved back to the start position of the barge.

### 8.2.3 Repair and maintenance

The repair and maintenance (R&M) costs are taken from NEA (2003). The R&M costs of small 18 TEU inland ships are 2.91 EUR/h. These R&M costs for the barges are estimated at 6 EUR/h. The costs are doubled when they are compared to normal small inland ships because of all the electrical components and thrusters that are installed in the barges which can sail independently. It is also assumed that the R&M costs for the tug are also 6 EUR/h. The total R&M costs per hour and TEU or tonne can be calculated with the following formula:

$$\text{Cost}_{\text{R\&M}} = \frac{(6 \cdot N_{\text{barges}} + 6)}{N_{\text{Barges}} \cdot (N_{\text{containers}} + \text{Bulk})} \cdot \text{index} \quad (8.4)$$

$\text{Cost}_{\text{R\&M}}$  = costs repair and maintenance [EUR/TEU or tonne]

<sup>33</sup> Based on table 8.3 (based on 5 days on the tug during one shift)

Index = index figure

[-]

 $N_{\text{Barges}}$  = number of barges in the system

[-]

As mentioned in section 5.3, all the costs components will be scaled to values of the year 2009. In table 8.4 the index figures are given from 2003 to 2009 for maintenance costs. Table 8.4 shows that the index figures increases by 16 percent points from 2003 to 2008, and from 2008 to 2009 the index figure decreased again. This drop is mainly due to the drop of the steel price in 2009 (see also figure 7.20) (European Commission, 2010).

Table 8.4 Index figures for maintenance inland ships

Year	2003	2004	2005	2006	2007	2008	2009
Index	100	106	107	111	113	116	111

Source: European Commission, 2010

The repair and maintenance costs, given in formula 8.4 increased by 11% according to table 8.4.

### 8.2.4 Insurance costs

The insurance costs of the small barge system per year are determined at 2%<sup>34</sup> (BCI, 2008) of the total new-building price of the tug plus the barges. The insurance costs per year can then be calculated with the following formula:

$$\text{Cost}_{\text{Insurance}} = \frac{2\% \cdot P_{\text{newbuilding}}}{N_{\text{trips}} \cdot N_{\text{barges}} \cdot (N_{\text{containers}} + \text{Bulk})} \quad (8.5)$$

 $\text{Cost}_{\text{Insurance}}$  = insurance costs

[EUR/TEU or tonne]

 $N_{\text{trips}}$  = number of trips per year of the tug and barge convoy

[-]

 $P_{\text{newbuilding}}$  = new building price of the barges and tug

[EUR]

The insurance costs per TEU are reduced if the number of trips is increased. Also the insurance cost need to be updated to 2009 values. The index figure from 2008 to 2009 is 0% (see table 5.3), so that the 2008 value is equal to the 2009 value.

### 8.2.5 Depreciation

The depreciation of the total system will be determined by the new-building price of all the barges and the tug. The equipment will be fully depreciated with a linear method over 20 years. The depreciation costs per trip per TEU or tonne can then be calculated with the following formula:

$$\text{Depreciation} = \frac{P_{\text{Newbuilding}}}{20 \cdot N_{\text{trips}} \cdot N_{\text{barges}} \cdot (N_{\text{containers}} + \text{Bulk})} \quad (8.6)$$

If the tug can be used as much as possible, the number of trips can be increased and therefore the depreciation per TEU can be reduced. If the tug

<sup>34</sup> Insurance costs are 1% to 1.5% of the new building price according to Buck consultancy int. (2008). To be safe, insurance costs of 2% of the total new building price is taken here.

is used more, the number of barges must also be increased, to make sure that the barges have enough time in the port to unload and load them.

### 8.2.6 Interest costs

For the calculation of the interest costs, the percentage of equity needs to be given as an input parameter. The other part of the total investment needs to be borrowed by a bank or an investment company. The interest rate of the loan is set at 4.6 percent. The average interest rate varies from 5.5% in 2005 to 4.6% at the end of 2009 (NEA, 2010). In this thesis 4.6% interest rate is used as default setting (due to the fact that 2009 will be the base year) which can be adjusted. The period in which the loan must be paid back is set at 20 years. The interest costs will become less because the outstanding loan will become less. Therefore the interest costs will be determined as an average cost over the loan period. The average is determined on the basis of the first interest payment and the last interest payment. The interest costs can then be calculated with:

$$\text{Cost}_{\text{Interest}} = \frac{\text{Loan}_{\text{start}} \cdot \text{interest}}{2 \cdot (\text{N}_{\text{containers}} + \text{Bulk}) \cdot \text{N}_{\text{trips}} \cdot \text{N}_{\text{barges}} \cdot 20} \quad (8.7)$$

$\text{Cost}_{\text{Interest}}$ = interest costs	[EUR/TEU or tonne]
$\text{Loan}_{\text{start}}$ = amount of loan at the start of the 20 years	[EUR]
Interest = interest rate of the loan (4.6 % default setting)	[-]

### 8.2.7 Costs of crew logistics

The next cost component that will be taken into account are the costs made to bring the crew of the independent sailing barges back from the end point of the barge to the starting-point. If barges are chosen that cannot sail independently, these costs are set at zero. In the model the calculation of costs will be based on the following formula, where it is assumed that the crew of every barge will be picked up by car. Consequently, there are no consolidations of crew members because it cannot be determined a priori when the different barge captains are finished with their work.

$$\text{Cost}_{\text{crew\_log}} = \frac{\text{Cost}_{\text{Driver}} + \text{Cost}_{\text{Fuel}} + \text{Cost}_{\text{Rest}}}{(\text{N}_{\text{containers}} + \text{Bulk})} \quad (8.8)$$

$\text{Cost}_{\text{crew\_log}}$ = costs crew logistics per TEU	[EUR/ TEU or tonne]
$\text{Cost}_{\text{driver}}$ = costs of the driver of the car	[EUR]
$\text{Cost}_{\text{Fuel}}$ = fuel costs of the car	[EUR]
$\text{Cost}_{\text{Rest}}$ = depreciation and other costs of the car	[EUR]

The costs of the driver are set at 14<sup>35</sup> EUR per hour. The total time needed to drive from the start point to the end point of the small waterway and back are determined by the distance and a fixed speed of 60 km/h.; on top of that an extra hour is added to incorporate delays. The fuel costs are determined by the fixed fuel consumption of the car (1L of fuel for 15 km) and a fuel price of 1 EUR per litre. The other costs are set at 10 EUR per

<sup>35</sup> Based on minimum wages of a 40 hour week + 80% employment costs (2009)

trip and these costs must cover the costs of the depreciation of the car and insurance.

### 8.2.8 Waterway infrastructure costs

The costs to use the waterways are shown in table 10.5. Two different tariffs are used, one for an independent sailing barge and one for the push barge convoy. The tariff for the push barge convoy is related to the installed power in the tug. Because all the designed tugs will have an installed power larger than 295 kW (400 PK) that specific tariff of 0.00017 EUR/tonne\*km is used the most.

Table 10.5: Costs to use the inland waterways

Loaded ship	Loaded push barge convoy	
[EUR/tonne*km]	(installed power tug)	[EUR/tonne*km]
0,00025	0 to 60 PK	0.00075
	61 to 150 PK	0.00050
	151 to 400 PK	0.00037
	> 400 PK	0.00017

Source: de scheepvaart, 2010

For each design the covered distance on the waterways and transported tonnage will be used to calculate the waterway infrastructure costs. These costs will be added as a costs component to the total costs.

### 8.2.9 Overhead costs

The overhead costs are the costs that the tug and barge company has to make to process the different orders of transportation. These costs are determined by the costs of the rent for an office, the wages of the personnel, computers, etc.

It is assumed that two personnel members are needed at the office, one fte (full time equivalent) for the administration and one fte for the planning of the barges. The yearly costs are estimated at €75,000<sup>36</sup>. This is €37,500 per fte per year. The costs for renting an office space plus material (computers, etc.) are set at €25,000 per year. The management fee of the director of the small Barge Company is set at €50,000, so that the total overhead costs per year are estimated at €150,000 (2009 values).

## 8.3 Sensitivity analysis of the transportation cost model

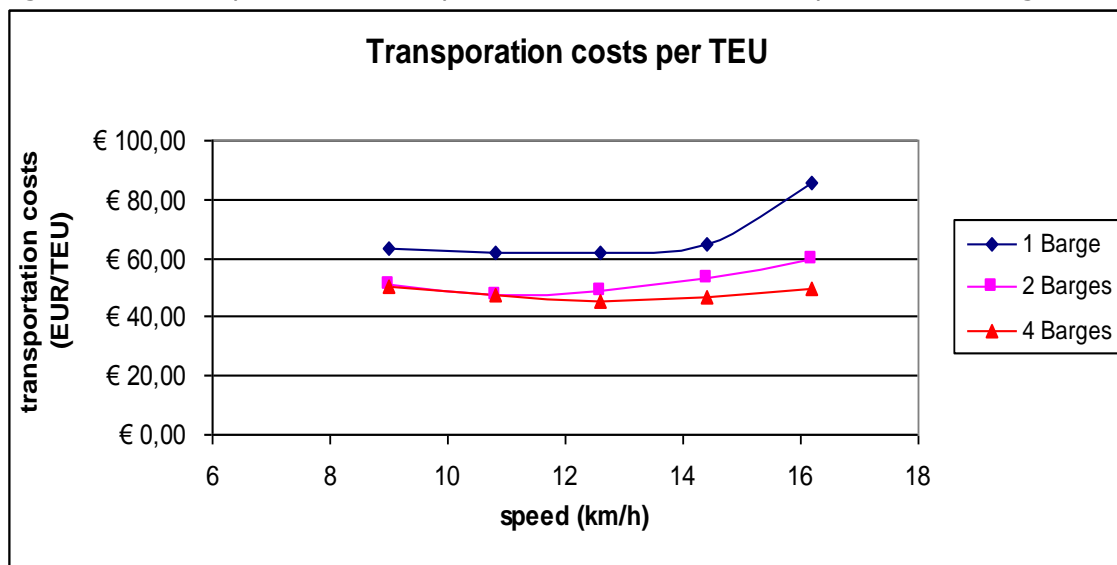
In this part of the chapter the influence of different design and logistics parameters have been analysed. The first parameters that will be varied to investigate their influence on the transportation costs are the speed of the tug and the barge train formation. These calculations use the same input parameters from table 7.5 and 7.9. There is one additional parameter, i.e. the barge will be operated by a single captain on the small inland waterway (in chapter 14 the influence of operating the barge by a captain and a mate will be further examined). In figure 8.2 the influence of the speed of the tug

<sup>36</sup> 2009 value

and barge convoy and the barge train formation on the total transportation costs is given.

Figure 8.2 shows that the transportation costs will have a minimum around a convoy speed of 12.5 km/h. It can also be seen that there only is a small variation in the transportation costs from 9 km/h to 13 km/h. This is because the decrease in fuel costs (due to a lower speed) will be cancelled out by an increase in crew costs. The difference in the transportation costs between the 2 and 4 barge convoy is very small in the speed area between 9 km/h to 11 km/h. Due to a higher speed, the sailed time is reduced so that all the barges can be coupled and uncoupled in 14 hours. The speed is lower than it is not possible to complete a trip (including the coupling and uncoupling) and therefore the number of round trips is reduced, so that the same fixed costs have to be divided over less transported cargo per year. The figure also implies that the transportation costs are increased by an increase of the speed of the tug and barge convoy. The fuel costs are increased too much in comparison with the other costs components, at a speed higher than 14 km/h. In this case, the number of trips made by the tug and barge convoy will not be increased if the speed is increased from 14 km/h to 16 km/h because the sailed distance is too short for the small increase of speed to have an effect.

Figure 8.2: Transportation costs per TEU as function of the speed of the barge train

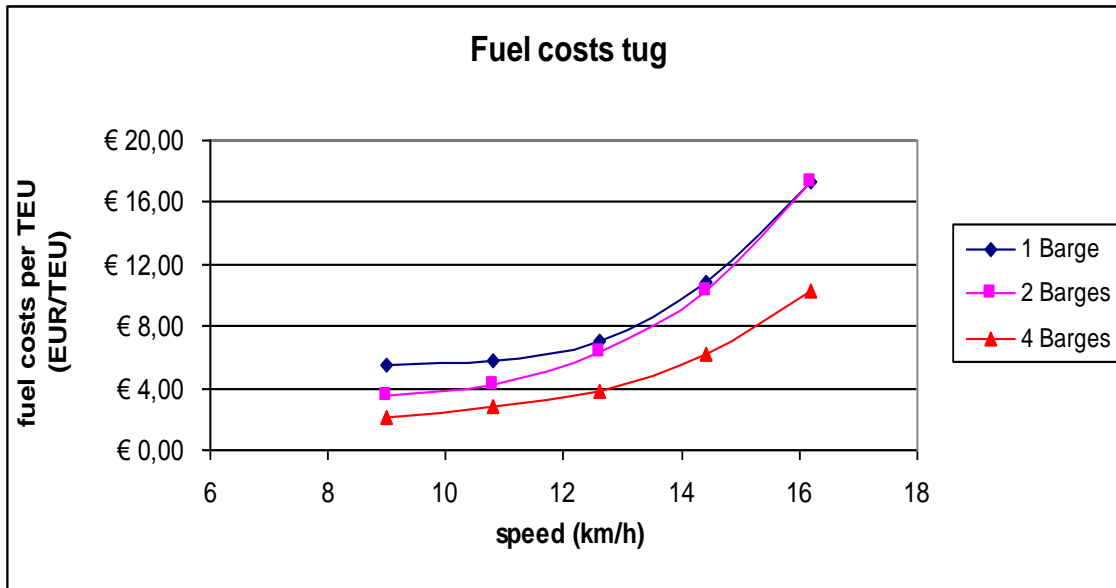


Note: 2009 values

In figure 8.3 the fuel costs per TEU are given as a function of the speed of the convoy. In that figure shows an increase of 2 km/h (from 14 to 16 km/h) will costs 12 EUR per TEU for the 1-barge option and 2.5 EUR per TEU for the 4-barge option.



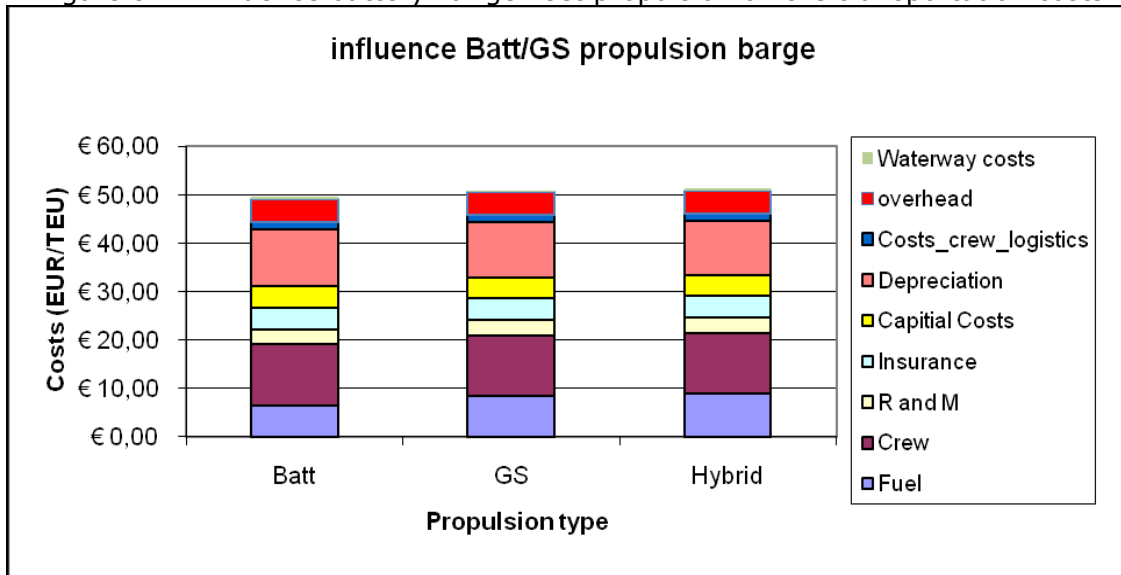
Figure 8.3: Fuel costs per TEU as function of the speed of the barge train



Note: 2009 values

The second parameter to be analysed is the choice for the propulsion concept of the barges (battery, the generator set(s) or hybrid propulsion system). To investigate the effect of this choice on the transportation costs, the same routes are selected as in the previous case. Only, now 2 barges are pushed in one convoy by a tug with a diesel direct propulsions system at a speed of 12.5 km/h on the large waterway. Figure 8.4 shows the cost structures of different barge propulsion systems.

Figure 8.4: Influence battery- or gen set propulsion on the transportation costs



Note: 2009 values

Figure 8.4 shows that the overall transportation costs are slightly lower for the battery propelled barge than for the gen-set driven barge (2.7%) and the hybrid barge (3%). The largest difference is the fuel cost. The battery propelled barge will be recharged by the main engines of the tug, where the power needed to push the barges and to re-power the batteries is combined. The power production of larger engines is more efficient than the

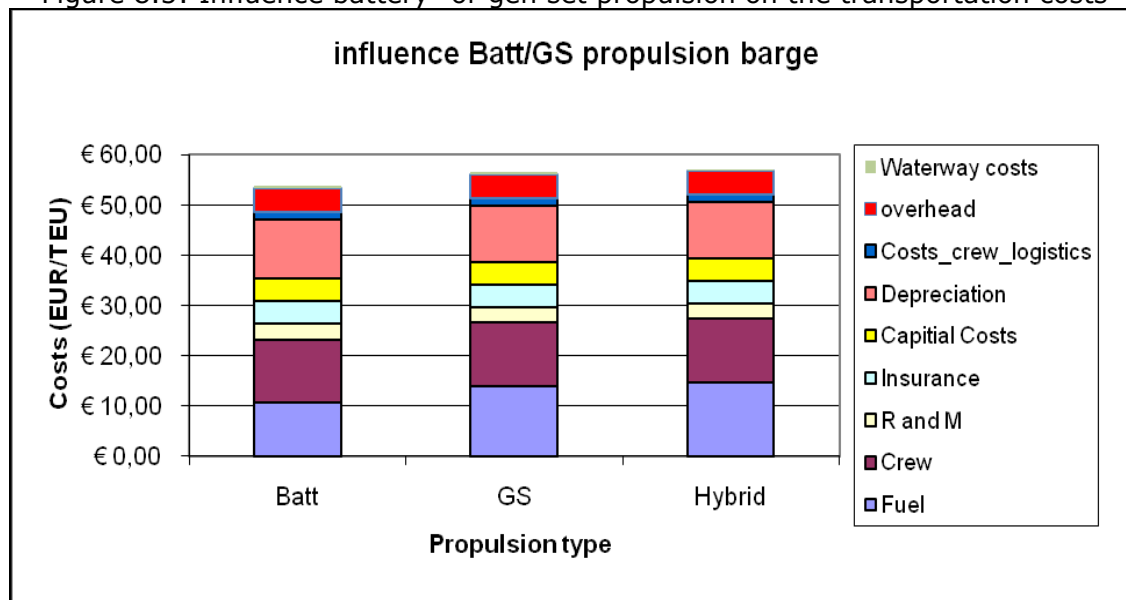
smaller installed generator-set in the barge (economies of scale for power generation). Another important aspect is that the barge must be able to sail faster (for a short period) than the required 6 a 7 km/h in order to overcome strong currents or winds. Therefore, the installed generator-set is much larger than needed to sail at its nominal condition. Therefore the gen set will work most of the time in an off-design condition, so that the SFC will be a higher.

The third aspect that will influence the fuel costs is that the aft ship of the two compared barges is not the same. In order to accommodate the gen-set in the aft ship, it must be adjusted so that the transom area will be greater for the gen-set and hybrid propelled barge than for the battery-propelled barge. Consequently, the independent sailing resistance of the gen-set and hybrid barge is larger, resulting in higher fuel consumption when the barges are sailing independently.

The costs related to the new building costs of the barge (depreciation, insurance and capital costs) are higher for the battery-propelled barge and the hybrid barge. This can be understood by the fact that the new-building costs are higher for those barges than for the generator-set-propelled barge. The increase in new-building costs is almost completely compensated for by the reduction in fuel costs of the battery-propelled barge compared with the gen-set and hybrid-propelled barge.

The calculations made were done with a fuel price of 600 EUR per tonne<sup>37</sup>. In figure 8.5 the same costs calculations are made but now with a fuel price of 1,000 EUR per tonne so that the influence of the fuel price can be determined.

Figure 8.5: Influence battery- or gen set propulsion on the transportation costs



Note: 2009 values

From figure 8.5 it can be concluded that the difference in total transportation cost of the different propulsion systems is rather small. As such, the influence of the fuel price on the selection of propulsion system on

<sup>37</sup> 2009 value

the barge is not large. However, by increasing the fuel price the battery propelled barge becomes more competitive compared with the other barges. The transportation costs per TEU are now 5% lower compared to the generator-set-propelled barge, and 6% lower than the hybrid-propelled barge.

Accordingly, the barges will be propelled with a battery pack in the double bottom of the barge. However, if that solution is too much of a technical challenge, the other alternatives could also provide suitable options.

The last parameter to be investigated is the influence of the coupling time on the total transportation costs. If a reduction in coupling time has a serious impact on the transportation costs, a new coupling system could be implemented (see chapter 7.2).

In table 8.5 the total transportation costs are mentioned for the situation that the coupling time is ½ hour (normal case) and ¼ hour (new coupling system). The costs are an average of the three different waterways.

Table 8.5: Influence coupling time on transportation costs (EUR/TEU)

		1 Barge		2 Barges		4 Barges	
		1/2 hour	1/4 hour	1/2 hour	1/4 hour	1/2 hour	1/4 hour
<i>Fuel</i>	[EUR/TEU]	6.13	6.13	5.06	5.06	3.10	3.10
<i>Crew</i>	[EUR/TEU]	15.33	14.55	12.48	11.52	12.84	11.32
<i>R&amp;M</i>	[EUR/TEU]	4.06	4.06	2.96	2.96	2.47	2.47
<i>Insurance</i>	[EUR/TEU]	5.40	5.40	4.67	4.67	4.87	4.22
<i>Capital Costs</i>	[EUR/TEU]	6.23	6.23	5.39	5.39	5.62	4.88
<i>Depreciation</i>	[EUR/TEU]	13.49	13.49	11.67	11.67	12.17	10.56
<i>Costs crew logistics</i>	[EUR/TEU]	1.50	1.50	1.50	1.50	1.50	1.50
<i>Overhead</i>	[EUR/TEU]	1.79	1.79	4.71	4.71	1.03	0.90
<i>waterway costs</i>	[EUR/TEU]	0.31	0.31	0.31	0.31	0.31	0.31
<b>Total</b>	<b>[EUR/TEU]</b>	54.24	53.47	48.75	47.80	43.92	39.26
<i>Difference</i>	[%]		1.44%		1.97%		10.69%

Note: 2009 values

Table 8.5 implies that reducing the coupling time per barge from ½ hour to ¼ hour will have small influence if only one or two barges are coupled into one convoy. But if the convoy size is increased to 4 barges, the reduction in coupling time will have a large impact (decrease of 10.7%) on the transportation costs. This decrease is due to a reduction in transportation time (2 hours per trip ( $\frac{1}{4} \times 4 \times 2$ )) so that more trips per year can be made (from 216 to 249 per year), which will lead to a reduction of the fixed costs per TEU. The time that the crew on the tug will work per trip will also be reduced (2 hours per trip), which will decrease the crew costs per TEU. Thus, it can be concluded that implementing the new coupling system is useful if the barge train is built up of 4 barges (see also chapter 7.3) and if the coupling time can be reduced from ½ hour to ¼ hour.

But the new coupling system does not exist yet, it is very difficult to determine the reduction in coupling time. Therefore, in the rest of this thesis the coupling time will be kept at ½ hours per barge.

The savings per year for the 4 barge option, if the coupling time is reduced to  $\frac{1}{4}$  hours, is €217,965 per year (€4.66 (€43.92 - €39.26) per TEU times 46,771 TEU). If a discounting factor of 4% is used and if the life-time of the small barge system is 20 years, the total savings in 2009 values are €2,960,000. The new system must cost less than €2,960,000 (development, installing and 20 years maintenance) and reduce the coupling time from  $\frac{1}{2}$  hour to  $\frac{1}{4}$  hour, in order to be justified. These maximum coupling unit costs are the total costs. In the 4 barge convoy to 3 different waterways option, in total, 24 barges are deployed. Therefore, in total, 25<sup>38</sup> coupling systems are needed so that the maximum allowable costs per coupling system are €118,500 (2009 value).

## 8.4 Preliminary conclusion

This chapter has developed the transportation cost models of the small tug and barge system. This cost model use the input from the network model and design model and will also provide, among the external cost and network model, data to a generalized cost model.

From the transportation costs model it can be concluded that the transportation costs will reach a minimum around a convoy speed of 12.5 km/h. It can also be concluded that there is only a small variation in the transportation costs if the speed of the tug and barge convoy is increased from 9 km/h to 13 km/h.

If the propulsion system of the independent sailing barge is researched, it can be concluded that the overall transportation costs are slightly lower for the battery propelled barge than for the gen set-driven barge (2.7%) and the hybrid barge (3%).

If the fuel price per tonne is increased from €600 to €1000, it can be concluded that the difference in total transportation cost of the different propulsions systems is still rather small. However, by increasing the fuel price the battery-propelled barge becomes more competitive compared with the other barges. The transportation costs per TEU are now 5% lower, compared to the generator-set- propelled barge and 6% lower than the hybrid-propelled barge.

Consequently, the barges will be propelled with a battery pack in the double bottom of the barge. However, if that solution presents too technical a challenge, the other alternatives could also provide suitable options.

The last parameter researched is the implementation of a new coupling system. It can be concluded that reducing the coupling time per barge from  $\frac{1}{2}$  hour to  $\frac{1}{4}$  hour will have small influence if only one or two barges are coupled into one convoy. But if the convoy size is increased to 4 barges, the reduction in coupling time will have a large impact (decrease of 10%) on the transportation costs. It can thus be concluded that implementing the new coupling system is useful if the barge train is built up of at least 4 barges and if the coupling time can be reduced from  $\frac{1}{2}$  hour to  $\frac{1}{4}$  hour.

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<sup>38</sup> 24 barge +1 tug

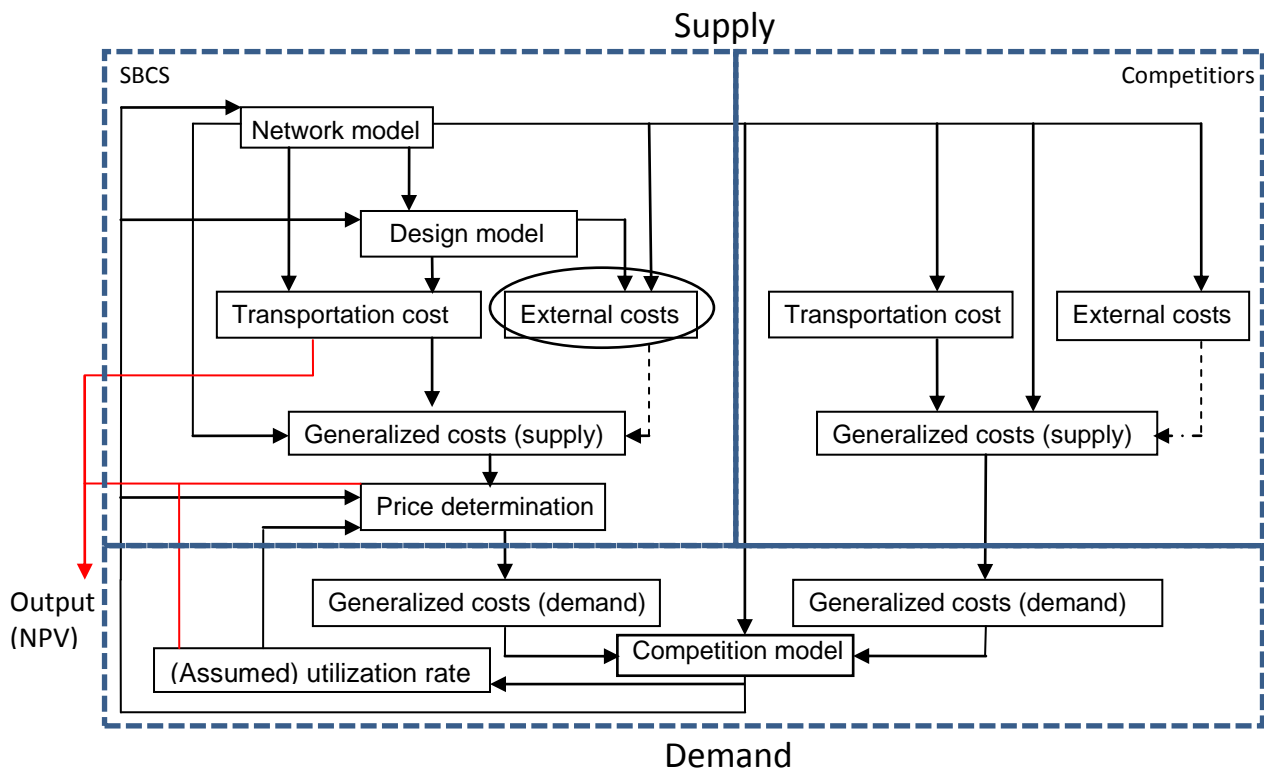
But the new coupling system does not exist yet, so it is very difficult to determine the reduction in coupling time and the cost of the new system. Therefore, in the rest of this thesis, the coupling time will be kept at  $\frac{1}{2}$  hours per barge and an existing coupling system will be used. If the maximum costs per coupling system is less than €118,500 (2009 value), investment in such a new system is justified if a 4-barge convoy needs to be formed on the large waterway and if the coupling time is reduced from  $\frac{1}{2}$  to  $\frac{1}{4}$  hour.

## 9. External costs

### 9.1 Introduction

In this chapter the external costs of the small barge convoy system will be calculated. These external costs are the costs that are caused by the small barge convoy system to a third party and for which it does not pay. These external costs will be determined by air quality costs, CO<sub>2</sub>-costs, accident, noise-cost and congestion costs. In figure 9.1 the position of the external costs calculations in the total model is given.

Figure 9.1: Position of the external costs determination in the model

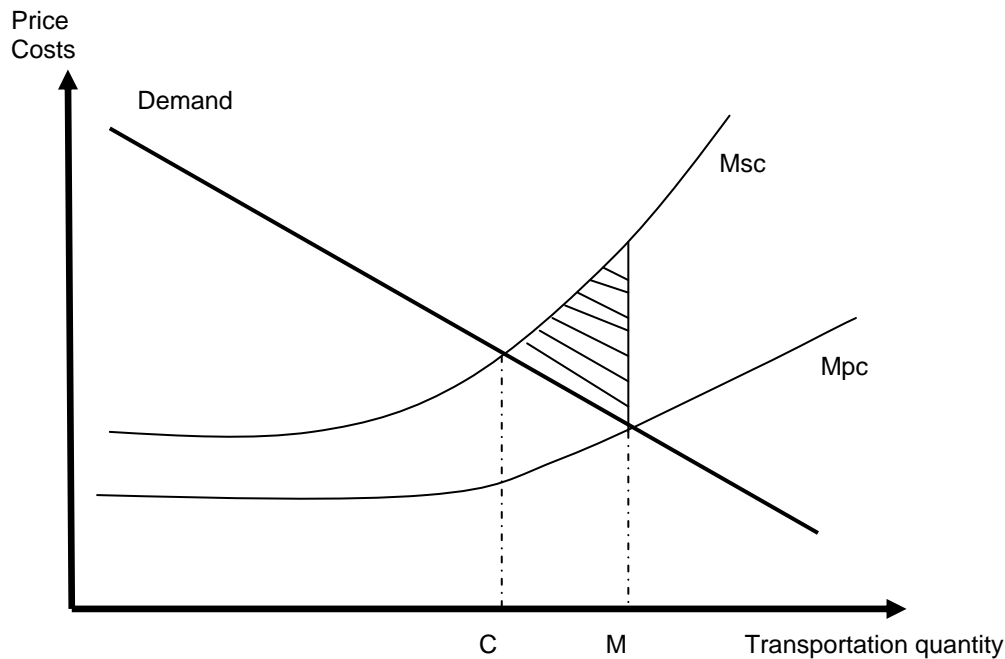


### 9.2 Justification of external costs

The reason why the external costs would be internalized is that the transport user is confronted with the entire social costs that he is causing. Only when the external costs are internalized, can the transport user make the right decision (Blauwens *et.al.*, 2008). In other words: is the transport user (cargo owner) willing to pay more money for a chosen mode or is he willing to switch to modes that have fewer external costs?

The effect of not internalizing the external costs can be found in figure 9.2, where the marginal social costs (Msc) and the marginal private costs (Mpc) are indicated. Figure 9.2 shows that the Msc are higher than the Mpc. The transport provider, who does not have an incentive to include the external costs, can offer a price which is lower than when the external costs are included. As a result, the market equilibrium is not reached at C, but at M. The overproduction M-C causes a welfare loss equal to the shaded area in figure 9.2.

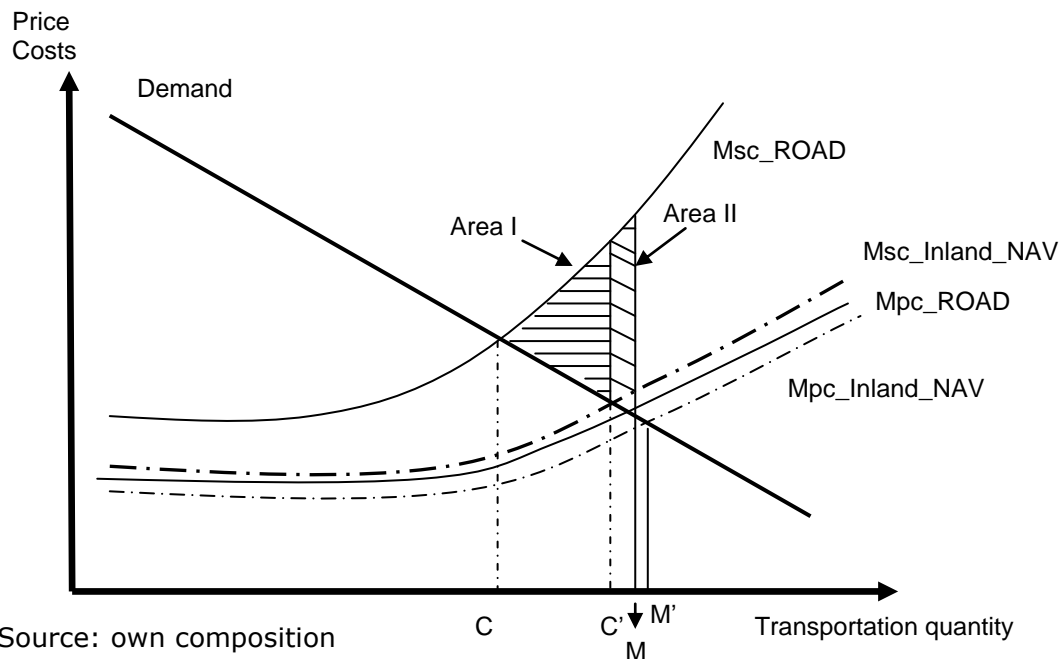
Figure 9.2: Overview of the market and social equilibrium



Note: Blauwens *et.al.*, 2008 p. 382

In figure 9.3 the Msc and Mpc of two different modes (road and inland navigation) are given.

Figure 9.3: Overview of the Msc and Mpc of two different modes



Source: own composition

Figure 9.3 shows that the Msc of inland navigation are lower than the Msc of the road transport (CE Delft, 2004 and see also section 12.2 for the external costs of road transportation and inland navigation). Consequently, a big part of the total welfare losses (total shaded area) can be reduced (shaded area I). Even if the Msc is higher for road transport, for inland navigation a transport user may still be opting for road transportation. In that case the transport user is willing to pay more if he believes that the extra costs are worthwhile (Blauwens *et.al.*, 2008). This condition could be

fulfilled in the case of higher flexibility or reliability of road transport. The next chapter about generalized costs will deal in more detail with those non- monetary cost components.

### 9.3 External costs components

The external costs of the concept and the competitive modes will be calculated on the basis of the following components taken from Blauwens *et. al.* (2008):

- Congestion costs
- Infrastructure costs
- Environmental costs:
  - Air quality costs
  - Climate costs
  - Noise costs
- Accident costs

#### 9.3.1 Congestion costs

The first cost component is the marginal congestion cost. This cost represents the hindrance of one additional ship (or other transportation unit) to the other. Because an additional transportation unit is imposing costs to another, it can be regarded as an external cost. The congestion costs consist mostly of time costs and an increase in fuel costs: an additional transportation unit on the existing (and limited) infrastructure is causing others to lose time and it will lead to more stop-and-go traffic, which will increase the fuel consumption (Blauwens *et. al.*, 2008).

The total inland waterway network does not have capacity problems. However, some bottlenecks occur at locks. If the number of ships passing a lock is higher than the number of ships that can be handled by that lock, a queue will start to be formed. Besides lock capacity, the availability of sufficiently deep water levels to operate all vessel types is a problem, particularly in summer time. Based on the Low Water Surcharge, which has to be paid on the river Rhine when water levels fall below a certain value, scarcity costs could have to be paid (CE Delft, 2004).

For the small-barge convoy system there is not a lot of congestion to be expected on the small inland waterways (see part I for reduction of small inland fleet). There is enough capacity left on the inland waterways, so that the small barge convoy system are unlikely to face infrastructure considerable capacity problems on the small inland waterways. Only at the locks on the main large waterways can congestion occur. On the large main waterways all the inland ships are sailing (small, medium sized and large). So, the number of ships having to pass the locks on the large waterways is higher than on the small ones, where only small inland ships can sail.

In order to determine the increase in total service time to pass a lock, the locks on the large waterway will be modelled as an M/M/1 queue model. This is a queue model with an exponential arrival distribution of the ships, an exponential distribution of the service distribution and with a single



server. The total waiting at a lock can be determined with the following formula:

$$W = \frac{1}{\mu - \lambda} \quad (9.1)$$

W = waiting time [h]  
 $\mu$  = handling rate of the lock [ships/h]  
 $\lambda$  = arrival rate [ships/h]

In 2009 28,150 ships have sailed on the Albert canal in Flanders (NV de scheepvaart, 2010). All these ships have to pass the locks on the waterway. The small barge convoy system will add an additional 150 passages per year (based on 83 departures to 3 different waterways) to the grand total of ship movements through those locks. Then the total number of ships is increased by 0.5%. The arrival rate of ships will also increase by 0.5%. We are interested in the increase in waiting time caused by the increase of the small barge convoy system. The difference in waiting before the addition of the new concept and the waiting time when the barge convoy system is implemented will yield the increase in waiting time. The handling rate of the lock will be considered constant. Therefore the increase in waiting time is equal to:

$$\Delta W = W_{II} - W_I = \frac{1}{\mu - 1.005\lambda} - \frac{1}{\mu - \lambda} = W_I \frac{\frac{\mu}{\lambda} - 1.005}{\frac{\mu}{\lambda} - 1} = W_I \frac{0.005}{C - 1.005} \quad (9.2)$$

$W_I$  = waiting time before addition of small barge convoy [h]

$W_{II}$  = waiting time after addition of small barge convoy [h]

C = constant =  $\frac{\mu}{\lambda}$  [-]

As stated earlier, in total 28,150 ships sailed in one year on the Albert canal. If the locks are operated 250 days per year and 16 hours per day, on average 7 ships per hour will arrive. On the Albert canal 6 lock complexes are placed. Each complex has 3 locks which on average can accommodate 6 ships<sup>39</sup>. The handling rate of a lock was set at 1/2 hour (see chapter 6) so that, on average, the locks can handle 12 ships per hour. Then the increase in waiting time will be equal to 0.7%. The increase in waiting time is 0.21 minutes (=13 seconds) per lock complex. The increase in the total transportation time will be rather small and therefore also the increase in transportation costs. Thus it can be concluded that the marginal congestion costs of the small barge convoy can be neglected, so that these costs are set at €0 / vehicle kilometre.

### 9.3.2 Infrastructure costs

The second costs component is the marginal infrastructure costs. These costs are determined by the wear and tear on the infrastructure (road, rail or inland waterway) caused by an additional user of that infrastructure. The general maintenance costs of an inland waterway are considered not dependent on the number of ships sailing on the waterway (CE Delft,

<sup>39</sup> Based on available dimensions of the locks (2x 136 by 16 and 1x 200 by 24) and the dimensions of the average ship (see figure 3.4) (L = 85 m , B = 9.5 m)

2004). If the number of ships sailing on the waterway increase, the costs of maintaining the waterway are not increased. The reduction of water-depth of the waterway depends on passing of time and not on the number of ships passing through. It can even be considered that the water-depth is maintained if a lot of ships are sailing on that waterway. As a result, the marginal infrastructure costs can even be negative (there will be a reduction in maintenance costs of maintaining the water depth of the waterway). The banks of the waterways could be damaged more if more ships are passing. However, a lot of canals have concrete water banks, so that the deterioration of those banks is not influenced by the passing of ships.

If user-dependent maintenance costs of inland waterways are considered, those costs are dependent on management costs, such as lock guards, waterway police, etc. But those management costs can also be considered not directly dependent on the number of passing ships on the specific waterway. If a lock has to be operated for 24 hours a day, those costs do not increase by more passing ships through that lock. Only if the number of passing ships is reduced very much, the locks may not be operated for 24 hours per day. The locks itself do not need more maintenance either if more ships are passing. Only the moving parts of the locks are effected and not the lock door itself for instance.

Therefore the infrastructure costs are estimated to be €0/vehicle kilometre.

### **9.3.3 Environmental costs**

A third cost component consists in marginal environmental costs. These costs are built up of noise and emission costs. The marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because emission factors are comparably low and most of the activities occur outside densely populated areas. For that reason, noise costs of shipping are not taken into account (CE Delft, 2008). For the small barge convoy system the noise level can even be reduced in comparison with "normal" inland shipping because the barges are equipped with electric engines which produce less noise. Therefore, for the transportation of cargo on the small inland waterways the noise level will be reduced. Thus the total noise costs of the small barge system will be lower than "classic inland shipping and so these costs are considered to be €0 /vehicle kilometre.

The climate costs are calculated bottom-up for the small barge convoy system. In the design model the selection of the engines is based on the design requirements (sailing at 13 km/h with 4 barges for instance). When the engine types are known, also the fuel consumption of the engines is known and, based on the selected design and network of the small barge system, the amount of consumed fuel and produced emissions can be calculated (see section 7.4.11). The air quality and climate costs are based on the monetary costs of one kilogram produced substance which will be taken from table 9.1.

Table 9.1: Air quality and climate costs per weight unit (2020 projection)

Air quality				Climate
CO	SO <sub>2</sub>	NO <sub>x</sub>	PM <sub>10</sub>	CO <sub>2</sub>
[EUR/kg]	[EUR/kg]	[EUR/kg]	[EUR/kg]	[EUR/tonne]
0.0008	6.38	1.328	103.49	25

Source: Arcadis *et.al.* 2009

The amount of fuel used for the small barge system is already calculated in order to determine the fuel costs (7.4.11). The composition of the fuel is known, so that it can be determined how much emissions there will be produced.

Because the marginal environmental cost of the small barge system will be influenced by the chosen network and by the design specifications of the used tug and barges, no 'general' environmental cost table can be constructed. All the environmental cost will be calculated for each design.

### 9.3.4 Accident costs

The last cost component that is taken into account is the marginal accident cost. These are the costs that an additional ship is imposing on others on the inland waterway network. The external accident costs are those social costs of traffic accidents which are not covered by risk-oriented insurance premium. The level of external costs does therefore not only depend on the level of accidents, but also on the insurance system. The most important accident cost categories are material damage, administrative costs, medical costs, production losses and the risk value as a proxy to estimate pain, grief and suffering, caused by traffic accidents in monetary values. Mainly the latter is not covered properly by the private insurance systems (CE Delft, 2008).

The marginal accident costs can be calculated with the following relation (CE Delft, 2008):

$$EAC = ACC_{\text{figures}} \cdot \text{Costs}_{\text{Accident}} \cdot \text{Ext}_{\text{part}} \quad (9.3)$$

EAC = External accident costs [EUR]

ACC<sub>figures</sub> = Accident figures [veh]

costs<sub>Accident</sub> = unit costs per accident [EUR/veh]

Ext<sub>part</sub> = percentage of the costs that can considered to be external [%]

In CE Delft (2008) no figures were found for calculating the external accident costs of inland navigation, so that these costs were set at €0 /vehicle kilometre. In Arcadis *et.al.*(2009) the marginal costs of accidents caused by inland ships were taken at €0.0001/vehicle-kilometre. Because the small barge convoy will not cause more accidents than the other inland ships, the marginal accident costs are set at €0.0001 /vehicle kilometre.

## 9.4 Summary

As stated in section 9.3.3, the model only allows calculating the environmental cost for a concrete network and tug and barge design. Therefore an example calculation will be made. The input parameters are

again the same as previously stated in tables 7.5 and 7.9 with some additional input values given in table 9.2

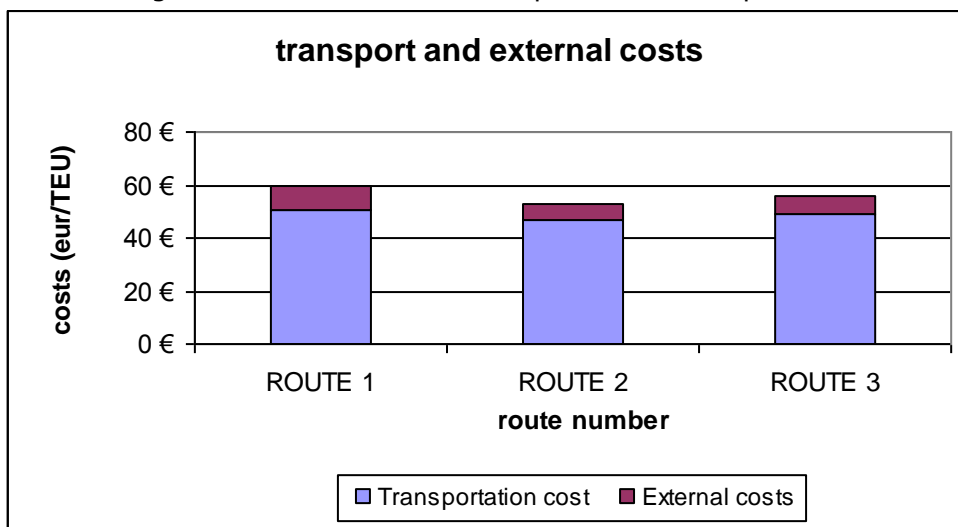
Table 9.2: Overview of the additional input parameters

Input parameter	Value
$N_{\text{barges}}$ per waterway	2
$V_{\text{convoy}}$	3.5 m/s

In this example the designed tug and barge system will be sailing in a convoy of 2 barges. The speed of the tug and barge convoy is set at 3.5 m/s and the barges are equipped with batteries (see section 8.3).

In figure 9.4 the external costs per TEU are given per route as well as the total transportation costs.

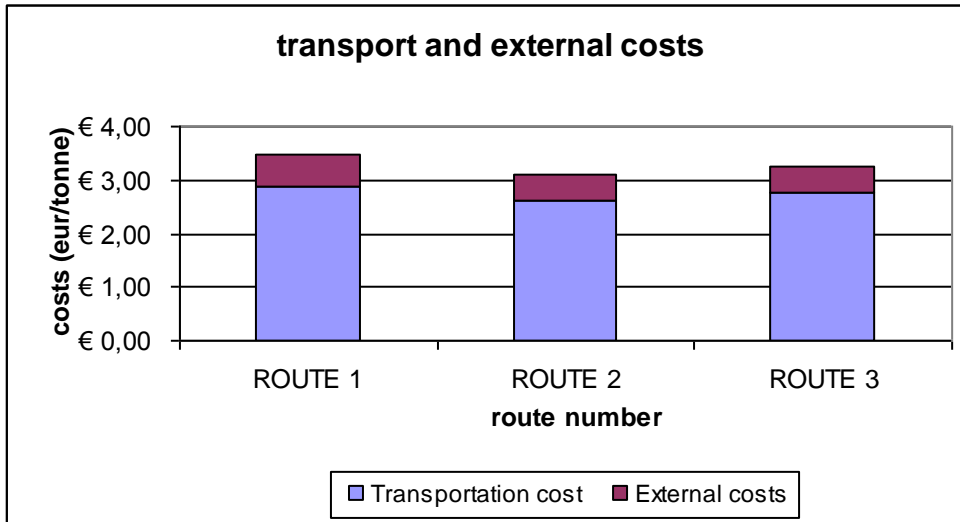
Figure 9.4: External and transportation costs per TEU



Note: 2009 values

In figure 9.5 the transportation and external costs per tonne are given. From those figures it can be concluded that the external costs are much smaller than the transportation costs (14% of the total costs per TEU and 17% per tonne).

Figure 9.5: External and transportation costs per tonne



Note: 2009 values

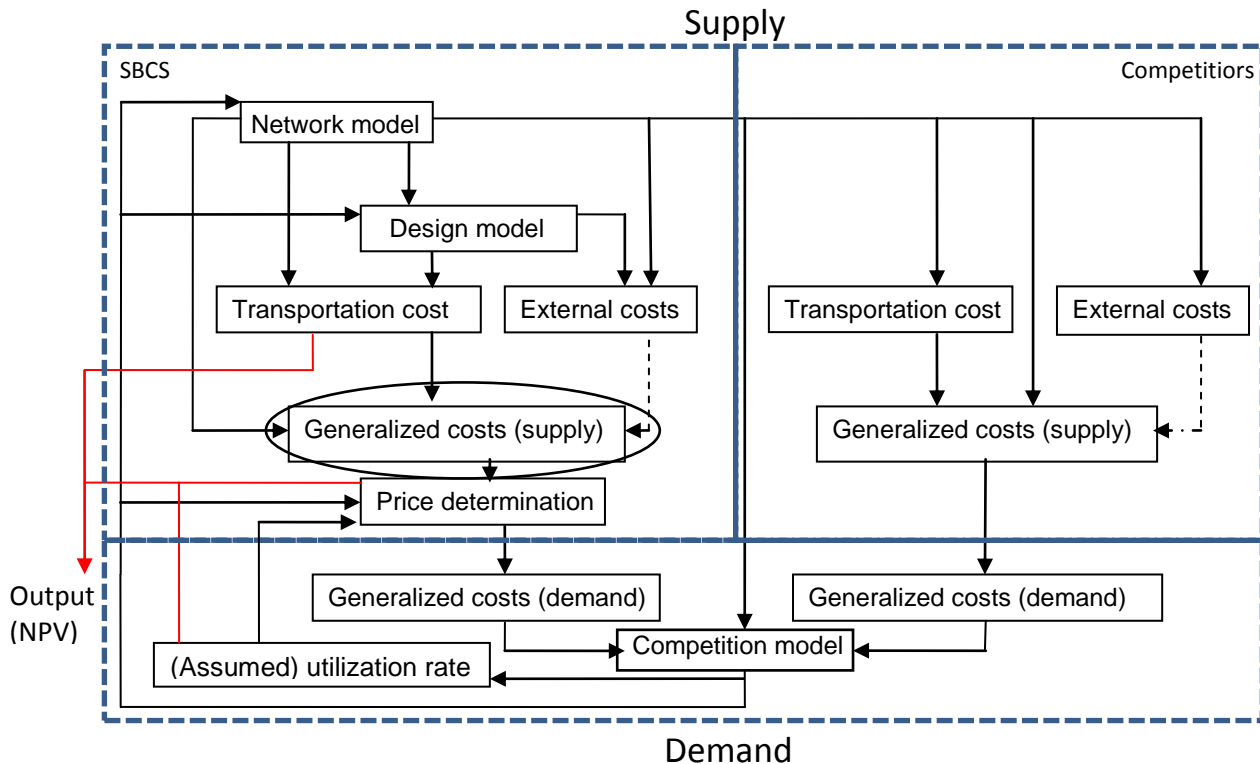
All the external costs are almost completely determined by the marginal environmental costs and only by a small part by the marginal accident costs. The total external costs are therefore influenced by the design of the tug (speed and number of pushed barges) and the chosen network (covered distance).

# 10. Generalized costs

## 10.1 Introduction

In this chapter the generalized costs of the small barge convoy system will be calculated. These costs, among other parameters, will be used later on in this thesis to determine the competitiveness of the small-barge system towards the other modes (chapter 11). The generalized costs of the small barge system will be minimized, so that the most competitive price can be offered or that the profit margin would be maximized. In figure 10.1 the position of the generalized costs model is given.

Figure 10.1: Position of the generalized costs model in the total model



From figure 10.1 it can be concluded that, in order to calculate the generalized cost, the transportation and external costs per TEU (or tonne) must be known, as well as some logistical data such as the total transportation time. In this chapter the components to determine the generalized costs of the small barge convoy will be elaborated further on.

The generalized costs consist of the out-of-pocket costs, the external costs plus the value of time of transporting cargo with the small barge convoy system and the costs of reliability and flexibility. The generalized costs can be calculated with formula 10.1.

$$GC = TC + CHC + EXT + ITI + REL + FLEX \quad (10.1)$$

GC = Generalized costs [EUR/TEU or tonne]  
TC = transportation costs (chapter 8) [EUR/TEU or tonne]  
CHC = Cargo handling costs [EUR/TEU or tonne]  
EXT = External costs (chapter 9) [EUR/TEU or tonne]

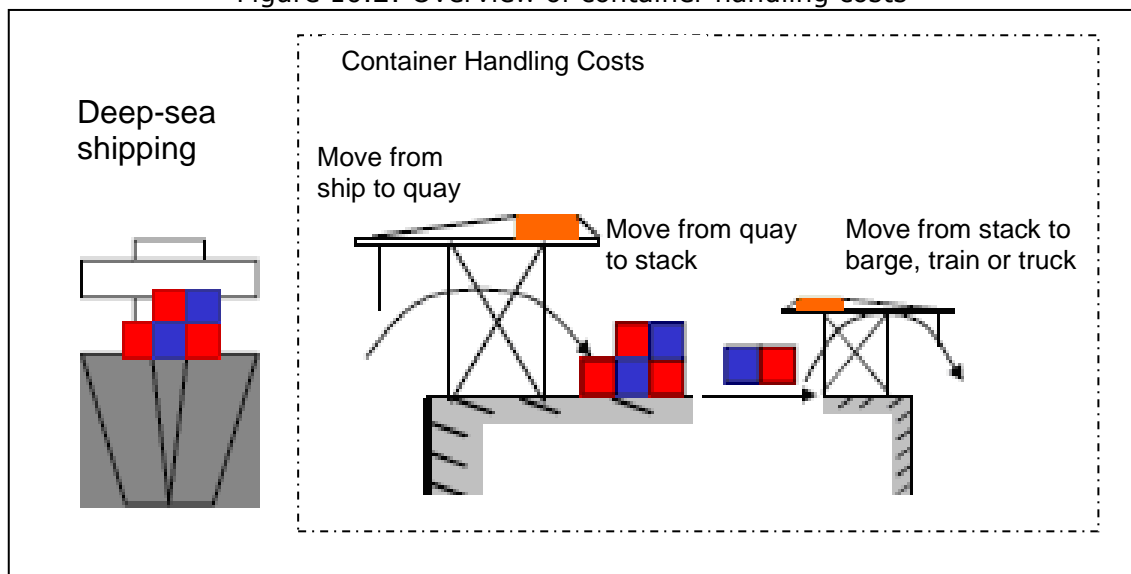
ITI = in transit inventory costs	[EUR/TEU or tonne]
REL = Reliability costs	[EUR/TEU or tonne]
FLEX = Flexibility costs	[EUR/TEU or tonne]

## 10.2 Cargo handling costs

The first part of the generalized cost is the transportation costs, which were already determined in chapter 8. The second cost component, which will be incorporated in the generalized costs, is the cargo handling cost.

These costs are the costs made by the transportation firm for loading or unloading a container or bulk cargo from a barge in a seaport or inland terminal. The costs of a container moved to or from a deep-sea vessel are incorporated because these costs will be made anyway, regardless of the chosen transportation mode in the hinterland. The container handling costs are then the costs to unload a box from deep-sea ships and to move it to the stack. From the stack (and an average dwell time of 3 days) the box is collected and it will be placed on a barge, train or truck. The costs related to lashing the containers and to removing hatch covers are incorporated into the freight rate and not in the terminal handling costs (EC, 2009). In figure 10.2 an overview is given of what is incorporated in these container handling costs.

Figure 10.2: Overview of container handling costs



Source: own figure based on CBRB, 2003

These container handling costs can differ a lot. Unloading a container in a seaport can be charged at €70 (Konings, 2007) up to €85 (Gerrits, 2007) (2003 values) per move plus €14-16 for the other container call costs (Gerrits 2007) (2003 values). Thus the total container handling costs in a seaport will be equal to 85 to 100 EUR per container. In EC (2009) the CHC in the port Antwerp in the year 2008 varied between €80 and €174 per box. The range in container handling rates is quite large and therefore difficult to determine. The CHC will normally be negotiated between shipping lines and container terminals. However, for inland ships the negotiation power is very limited, due to their limited amount of containers that will be handled, so that the costs will be higher than the average costs for deep sea liners. In

this research therefore, a container handling cost of €100 (2009 value) is used for the further calculations.

Handling a container in an inland port can be moved for €15<sup>40</sup>. In Konings *et.al.* (2006) the handling costs of a container are €16 if a gantry crane is used and €12 if a reach stacker is used. The costs for loading bulk material are €0.80 per tonne<sup>41</sup> (2007 value). The costs for loading and unloading a tonne of bulk cargo have to be indexed with  $\text{index}_{2007}$  (+3.6%). It can be concluded that there is an important difference between the handling costs of containers and bulk material.

### 10.3 In-transit inventory costs

To incorporate time effects of transporting cargo with different modes, the in-transit inventory costs are also added to the generalized costs. These costs are estimated as the willingness to pay for a reduction of one day in transportation time (VoT). This VoT (Value of time) is approximated as the daily loss on capital for the receiver of the cargo in transit. The in-transit inventory costs can be calculated with the following formula.

$$\text{ITC} = \text{VoT} \cdot (t + t_{\text{dwell}}) \quad (10.3)$$

VoT = Value of time [EUR/TEU/day or EUR/tonne/day]

t = time needed to complete a shipment [day]

t<sub>dwell</sub> = dwell time of cargo [day]

The VoT per TEU and tonne are adapted from Dekker (2005); they are given in the table 10.1 and are based on an interest rate of 15% per year.

Due to the different commodity types and values transported with the containers, there is a large spread in the values of VoT.

The dwell time of cargo will be the time that a container (or a bulk cargo) is stored at a terminal in a deep-sea port (or at an inland destination). This time is needed because, when the deep-sea vessel arrives at the deep-sea port, the inland transportation modes are not always present at the same time at that terminal. Therefore the cargo has to be stored a few days (3 days in Rotterdam and Antwerp, Gerrits, 2007) before the cargo is moved again.

Table 10.1: Different VOT values of the two commodity types

Commodity type	VOT [EUR/TEU/Day]	VOT [EUR/tonne/day]
<b>Containers</b>		
NTSC (1)	8.44	-
NTSC (9)	75	-
NTSC (0,2,4,5,7,8)	8.73	-
<b>Bulk</b>		
NTSC (6)	-	0.02

Source: RAND, 2002

<sup>40</sup> This figure is given by a transport expert and is valid for 2008

<sup>41</sup> N.V. de scheepvaart 2007 estimation



For each developed network, tug and barge design in the total model, the total transportation time of a commodity type, from loading in a seaport terminal to unloading at the destination at the small inland waterway, is determined (see chapter 6). So that the in-transit-carrying costs per TEU or tonne can be calculated for the small barge convoy system.

## 10.4 Reliability costs

The next parameter in the generalized costs is reliability. Reliability can be interpreted as the probability that a transportation mode is not capable of delivering the transported cargo on time. This can either be too late or too early. The receiver, in the hinterland, experiences as total delivery time the time that is needed to transport the cargo from the seaport to their company. This is the dwell time of cargo in the deep seaport plus the time that is needed to transport the cargo from the seaport to the final destination (including the congestion time). Reasons for unreliability can be due to either logistical problems (unexpected congestion, cargo not available, etc.) and/or mechanical problems of the transportation equipment. In figure 10.3 the two different parts of the total experienced transportation time are given.

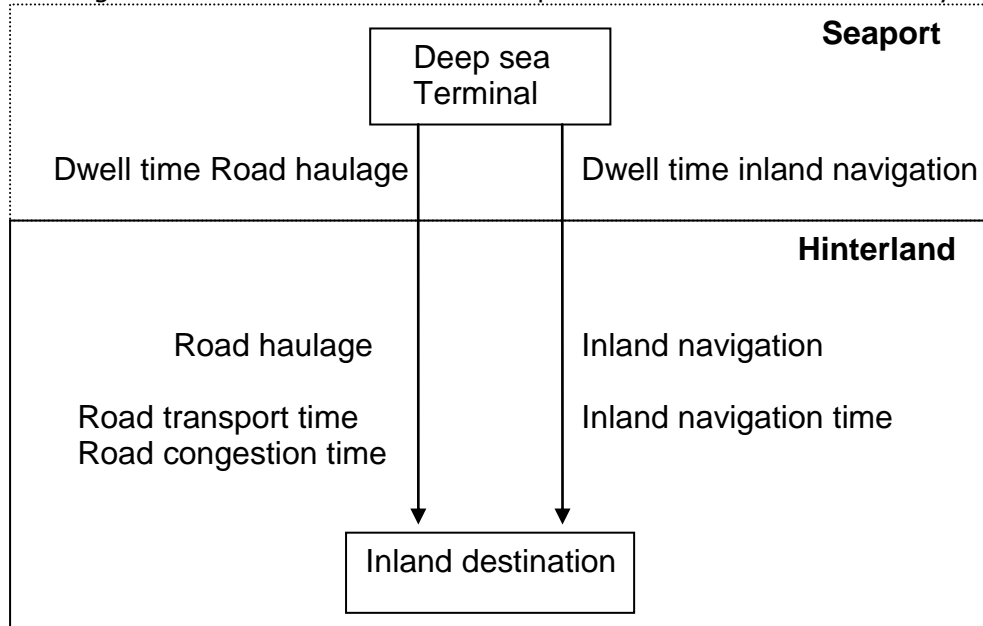
The congestion costs of the cargo in the seaport will be determined by the dwell time of the cargo on the deep sea terminal multiplied by the value of time of the cargo plus the costs caused by the variance in the dwell time. This variance will lead to a large spread of delivery times, which will affect the logistical process of the receiving companies and therefore the costs. In relation 10.4 the reliability costs in the deep sea terminal are calculated.

$$REL_{\text{dwell}} = VoT \cdot t_{\text{dwell}} \cdot \alpha + LOG_{\text{costs}} \cdot VAR(t_{\text{dwell}}) \quad (10.4)$$

REL_dwell = reliability costs due to dwell time	[EUR/TUE or tonne]
$\alpha$ = average increase in dwell time due to unreliability	[%]
LOG_costs = logistical costs for receiving companies	[EUR/day]
VAR( $t_{\text{dwell}}$ ) = variance in dwell time	[days]

The extra transportation time, due to congestion during the actual movement of the cargo, will increase the transportation time and therefore the in-transit inventory costs. Also, due to the increased transportation time and dwell time, the level of safety stock increases. With the next relation the reliability costs are calculated.

Figure 10.3: Overview of different parts to determine unreliability



Source: own composition

$$REL_{\text{hinter}} = VOT \cdot t \cdot \mu + LOG_{\text{costs}} \cdot VAR(t) \quad (10.5)$$

$REL_{\text{hinter}}$  = reliability costs hinterland [EUR/TEU or tonne]

$\mu$  = average increase in transportation time due to unreliability [%]

Then the value of reliability (VoR) could be calculated with:

$$VoR = REL_{\text{dwell}} + REL_{\text{hinter}} \quad (10.6)$$

It is very difficult to determine (quantify) the value of reliability in general for cargo transportation (RAND 2004, RAND 2005). It is also not possible to determine the different variations in dwell times and transportation times for the small barge convoy system.

Therefore it will not be possible to calculate the value of reliability for the small barge convoy directly. In chapter 12 another approach will be used to determine the value of reliability indirectly.

If the developed barge convoy is considered, no capacity problems on the small inland waterways are expected. Blocking of inland waterways and locks hardly occur. On the large waterways some delays could be expected at the locks, due to increase in shipping movements and ship size. The small barge convoy the barges will also have a loading and unloading window, which can also be used to deal with delays in a seaport. If a barge has a time window of 3 days to be unloaded and loaded again, a delay in the seaport of 1 day does not affect the departure time of the barges and therefore the barge convoy system could be considered reliable, so that the costs of reliability will be lower than road transportation.

## 10.5 Flexibility cost

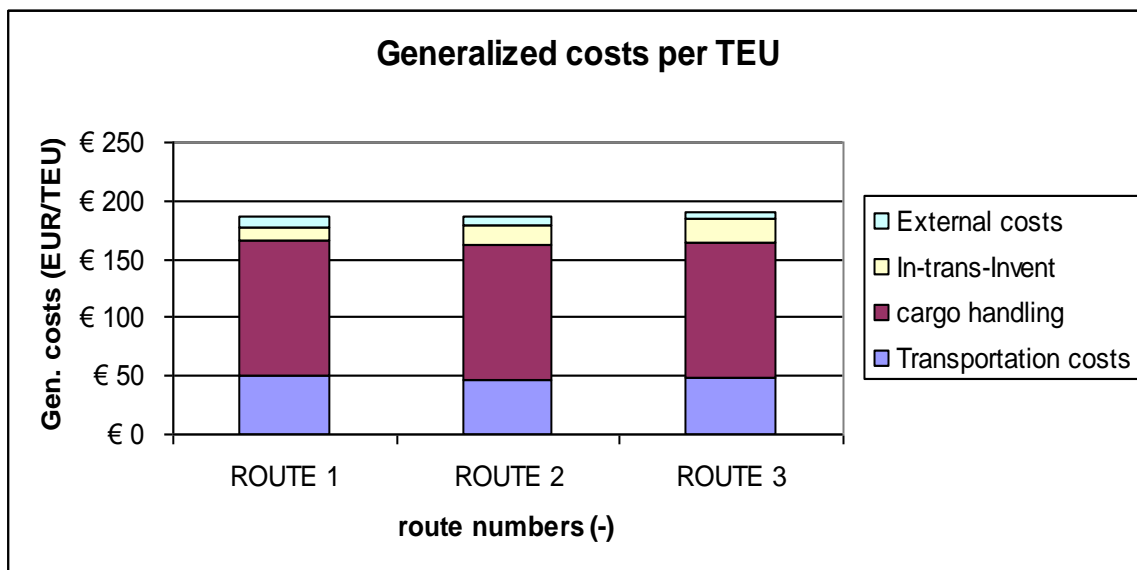
The flexibility cost for small barge convoy system is really difficult to determine. Because of the characteristics of the small barge convoy system

(fixed departures at fixed waterways), it can be expected that these costs can be rather high. If there is a lot of volatility in the cargo flows which cannot be predicted, this will be very difficult for the small barge system to deal with. So, if a company wants to ship additional cargo within a very short time, the small barge convoy system cannot cope with those changes because more barges are needed than there are available. The concept could be very reliable because of the fixed sailing regime, but due to the set-up of the system (fixed departures from fixed waterways), the flexibility will be low and therefore the costs will be high. These costs cannot be calculated directly either and therefore these costs will be determined indirectly in chapter 12.

## 10.6 Preliminary conclusions

In this chapter the generalized costs of the small barge system were determined. It was not possible yet to determine all the costs components (REL and FLEX). As could be seen in figure 10.1, the generalized depend on the chosen network, the design of the barges and tug and the transportation and external costs. For this reason the same example calculation as in chapter 9 will be made (input parameters of table 7.5, 7.9 and 9.2). In figure 10.4 the generalized costs are shown per TEU.

Figure 10.4: Generalized costs per TEU

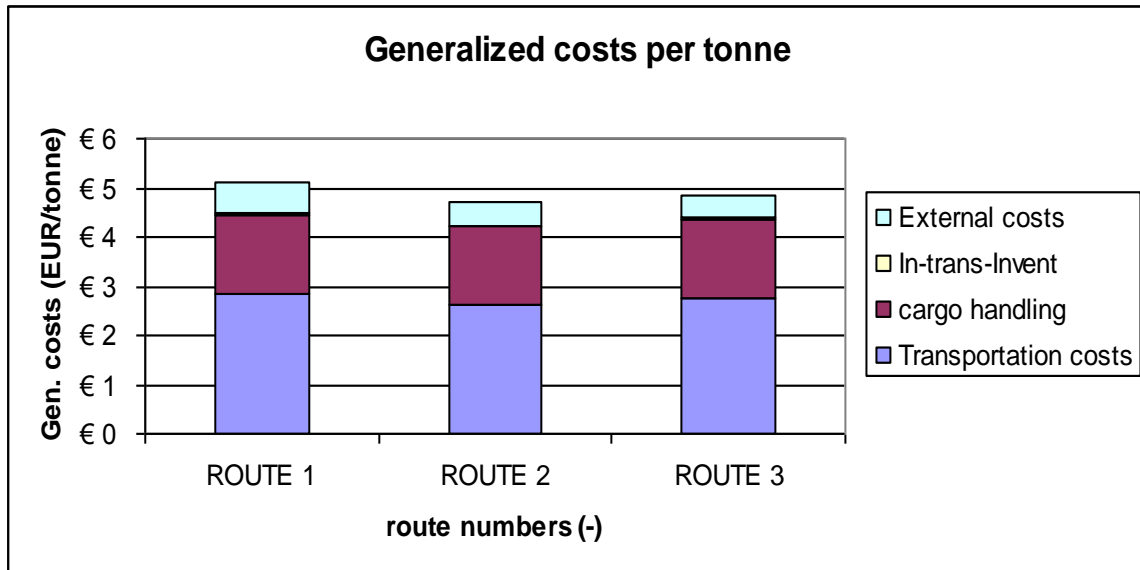


Note: 2009 values

From figure 10.4 it can be concluded that the biggest part (60%) of the generalized will be determined by the handling costs of the containers. Also the in-transit-inventory costs add a considerable contribution to the generalized costs (6%). So 66% of the generalized costs are determined by costs that cannot (or only marginally) be affect by the small barge system. It is therefore necessary that the deep sea container terminals are incorporated in the implementation of the small barge system. The implementation of the small barge system could also be beneficial for the container terminals by reducing the number of calls with a small amount of containers (see chapter 6.3).

In figure 10.5 the generalized costs per tonne cargo are presented.

Figure 10.5: Generalized costs per tonne



Note: 2009 values

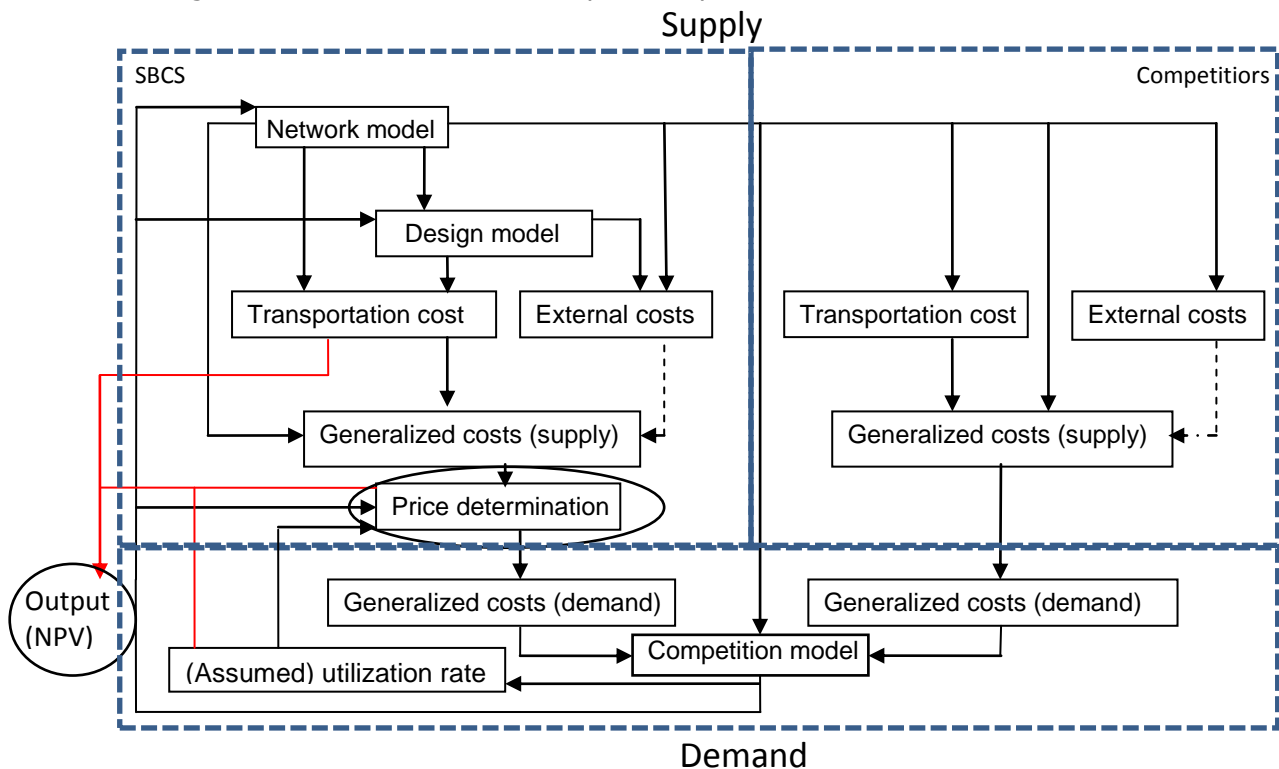
Figure 10.5 shows that the generalized cost per tonne are predominantly determined by the transportation and external costs (66%) and not by the cargo handling or in-transit-inventory costs (33%). The influence of the in-transit-inventory costs are marginal for bulk cargo (<0.5%) due to the low value of the transported cargo type, which will result in a low VoT.

# 11. Net present value calculation

## 11.1 Introduction

In this chapter the net present value, of investing in the SBCS, will be determined. This NPV is also the output of the model. In order to determine the NPV also the total income of the SBCS needs to be known. These earnings will be determined by the utilization rate of all the barges and the transportation price. In this chapter also the way how these utilization rate and transportation price are incorporated in the NPV calculations is explained. In figure 11.1 the position of the price determination model and the output of the total modal are shown.

Figure 11.1: Position of the output and price model in the total model



The first part of this chapter will deal with the calculation of the cash flow of the small barge convoy system. The second part will deal with the calculation of the IRR and the NPV. The third section will deal with the investment decision criteria. The last section will give a summary of this chapter.

## 11.2 Cash flow statement

A cash-flow statement will be made in order to determine the IRR (and the NPV). This cash-flow statement will be based on the earnings and the different cost components mentioned in chapter 8. As the occupation rate of the barges is not known a priori, a utilization rate has been assumed (see chapter 5 and chapter 13). From the assumed utilization rate and the number of deployed barges and the transportation price, the earnings can be calculated.

In order to determine the cash-flow, a cash-flow calculation will be made. In table 11.1 the calculation method can be found.

Table 11.1: Calculation of the free cash flow

<b>Earnings</b>	1
Operational costs	2
Insurance	3
Overhead	4
<b>EBITDA</b>	5 = 1-2-3-4
Depreciation	6
<b>Operational result</b>	7 = 5-6
Interest costs	8
<b>Result before tax</b>	9=7-8
Tax (25.5%) <sup>42</sup>	10
<b>Result after tax</b>	11 = 9-10
<b>cash flow</b>	12 = 11+6
payback loan	13
<b>Free cash flow</b>	14 = 12-13

In this calculation there are two unknowns: the occupation rate of the barges and the profit margin. As can be seen in figure 11.1 an initial occupation rate will be determined in order to start the calculation (see also chapter 5). In chapter 13 (competition modelling) will further explain how the occupation rate will be determined via an iterative relation. In the same chapter also the determination of the transportation price will be further explained.

The earnings are related to the transportation price per TEU (or tonne). The transportation price is determined by the total costs per unit plus a profit margin. This profit margin is a variable that is dependent on the competition of the other modes and it will be determined in such a way that a competitive price can be obtained (see chapter 13 for completion modelling). Furthermore, the earnings are, as mentioned before, also dependent on the occupation rate of the barges. A low occupation rate will therefore lead to lower earnings and therefore a lower free cash flow. With formula 11.1 the total revenue per year can be calculated.

$$EAR = \sum_{N_{\text{Trips}}} \sum_{N_{\text{Barges}}} (TP \cdot Occ_{\text{rate\_barge}} \cdot CAP_{\text{barge}}) \quad (11.1)$$

EAR= earnings per year	[EUR]
TP = transportation price per barge	[EUR/TEU or tonne]
N <sub>Barges</sub> = number of barges in the system	[-]
N <sub>Trips</sub> = number of trips per year	[-]
Occ <sub>rate_barge</sub> = occupation rate per barge	[%]
Cap <sub>barge</sub> = loading capacity of the barge	[TEU or tonne]

The transportation price can be calculated with formula 11.2.

<sup>42</sup> Corporate tax rate in the Netherlands

$$TP = (TC + OC) \cdot (1 + PM) \quad (11.2)$$

TC = total transportation costs (see chapter 8) [EUR/TEU or tonne]  
 OC = Overhead costs (see chapter 8) [EUR/TEU or tonne]  
 PM = profit margin [%]

The overhead costs per year are divided by the total amount of transported cargo per year in order to determine the costs per TEU or tonne. The PM will be determined in such a way, that a price will be obtained, that can compete with the SBCS competitors. More on the determination of the PM will be given in chapter 13. It can be possible that the PM becomes smaller than zero (heavy competition or high cost of the SBCS for example). This means that a loss will be made. This will result in a negative NPV and therefore also in a negative investment decision (see also section 11.3).

This costs plus pricing method has three main advantages over the profit maximizing rule  $MR = MC$  (marginal revenue = marginal costs) (Lipczynski, Wilson and Goddard, 2005).

- 1) It is easier to implement because less information is needed. For the costs plus profit approach, only the average costs function needs to be determined, along with the size of the mark-up, while for the  $MR=MC$  rule the MC, MR and demand function are needed to be known.
- 2) The costs plus pricing approach will lead to greater price stability. For the profit-maximizing rule the price should vary with changes in demand.
- 3) The costs plus pricing method appeals to a sense of fairness: in determining its mark-up, the firm can claim to allow for a reasonable profit margin, rather than the maximum profit. Price changes can be attributed solely to changes in costs, rather than fluctuations in market demand.

The statements presented here can be made because the AVC (average costs) are quite stable for a given network design of the small barge system. Only when the several options are calculated (for instance 2 barges per waterway or 4), is it necessary to know the demand function to determine the price. If a specific design has been made, it is safe to use the costs plus pricing method to determine the transportation price.

Price stability can also be obtained because almost all the costs components are stable over a given period (crew costs, payback of the loan, insurance, etc.). Only the fuel costs can vary quite considerably in a relative short period. The fuel costs are not the most dominating cost for the small barge system (see chapter 8), so that fluctuations in the fuel price will not lead to large fluctuations in the transportation costs. Furthermore, a fuel price clause can be added, stating that a fuel-price increase (or decrease) will be paid for by the clients of the small barge system (or when there is a decrease, they will get a discount). The cash-flow statement will be made for the 20 years, all the operational costs such as fuel oil, crew costs being

indexed with an inflation rate of 1.8%<sup>43</sup> per year. The same inflation correction has been applied to the earnings.

In table 11.3 the cash flow calculation is based on the input parameters stated previously in tables 7.5, 7.9 and 9.2. The additional input parameters are added in order to make the calculations are given in table 11.2.

Table 11.2: Input parameter

Input parameter	Value
Fin. Structure	20%equity / 80%loan
Inflation	1.8%
Profit TAX	25.5%

Table 11.3: Cash flow statement (all figures in base year)

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4
<b>Fixed costs</b>		<b>€ 780,164</b>	<b>€ 761,251</b>	<b>€ 754,407</b>	<b>€ 747,655</b>
Interest		€ 239,566	€ 215,610	€ 203,631	€ 191,653
pay back loan		€ 260,398	€ 260,398	€ 260,398	€ 260,398
Insurance	Index	€ 130,199	€ 132,543	€ 134,928	€ 137,357
Overhead	Index	€ 150,000	€ 152,700	€ 155,449	€ 158,247
Depreciation		€ 325,498	€ 325,498	€ 325,498	€ 325,498
<b>operational costs</b>		<b>€ 650,500</b>	<b>€ 662,209</b>	<b>€ 674,129</b>	<b>€ 686,263</b>
Fuel (600 EUR/tonne)	Index	€ 141,026	€ 143,565	€ 146,149	€ 148,779
Crew	Index	€ 375,805	€ 382,569	€ 389,456	€ 396,466
Repair and Maintenance	Index	€ 91,757	€ 93,409	€ 95,090	€ 96,802
Costs of_crew_logistics	Index	€ 41,912	€ 42,666	€ 43,434	€ 44,216
<b>Earnings</b>	Index	<b>€ 1,456,492</b>	<b>€ 1,482,709</b>	<b>€ 1,509,398</b>	<b>€ 1,536,567</b>
<b>EBITDA</b>		€ 525,793	€ 535,258	€ 544,892	€ 554,700
<b>Operational result</b>		€ 200,296	€ 209,760	€ 219,394	€ 229,203
<b>Result Before Tax</b>		-€ 39,271	-€ 5,850	€ 15,763	€ 37,549
<b>TAX (25.50%)</b>		€ 0	€ 0	€ 4,020	€ 9,575
<b>Result After Tax</b>		-€ 39,271	-€ 5,850	€ 11,743	€ 27,974
<b>Cash flow</b>		€ 286,227	€ 319,648	€ 337,241	€ 353,472
<b>free cash flow</b>		€ 25,829	€ 59,250	€ 76,843	€ 93,074
(Investment t=0)	€ 1,301,991				

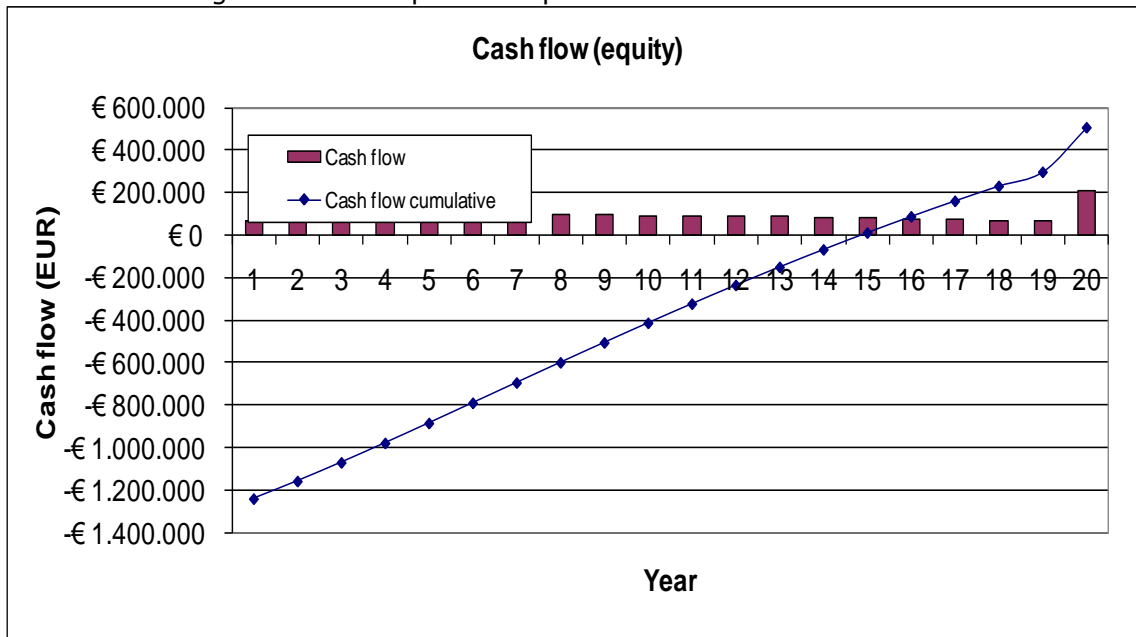
Note: Year 0 = 2009 values

With the data calculated in the previous table, a graphical output of the cash flow can be made. This is indicated in figure 11.2.

<sup>43</sup> The target inflation rate of the ECB is below 2% so that a value of 1,8% is used in this research



Figure 11.2: Graphical output of the cash flow statement



Note: base year 2009

From figure 11.2 it can be concluded that in the last year there is a big increase in income. The rest value of the barges and tug is indeed added to the free cash flow. It is estimated that the rest value of the tug and barges is 15% of the original new-building price. This value can be adjusted. There are now two different ways to calculate the NPV (and IRR<sup>44</sup>), one based on the equity perspective and one on the enterprise perspective. The NPV (IRR) based on the equity perspective will be calculated over the free cash flow for the upcoming 20 years (Higgins, 2007), in which 2009 will be the base year. If the NPV will be based on equity, also the risk of the financing structure must be taken into account in determining the appropriate discount rate. The higher the leverage, the higher the discounting factor (and also the IRR) should be. The NPV can be calculated with the following formula:

$$NPV = \sum_{t=0}^n \left[ \frac{\text{Cash Flow}(t)}{(1+r)^t} \right] \quad (11.3)$$

Cash Flow (t) = cash flow in year t

[EUR]

t = year

[Year]

r = discounting factor

[%]

n = maximum life span of the investment (20 in this case)

[-]

In figure 11.2 the IRR of the free cash-flow is equal to 10%. It is up to the decision of the investor (Investment Company) to determine the minimum amount of IRR, so that the investment decision will be positive.

There are two ways of determining the discounting rate. First, there is the discounting rate based on the government bonds. The government bonds are (or at least were before the crisis of 2008) considered being safe and therefore the return on government bonds can be considered a minimum level of return. On average a return of 4% could be expected (corrected for

<sup>44</sup> The IRR is the discounting rate at which the Net Present Value is equal to zero.

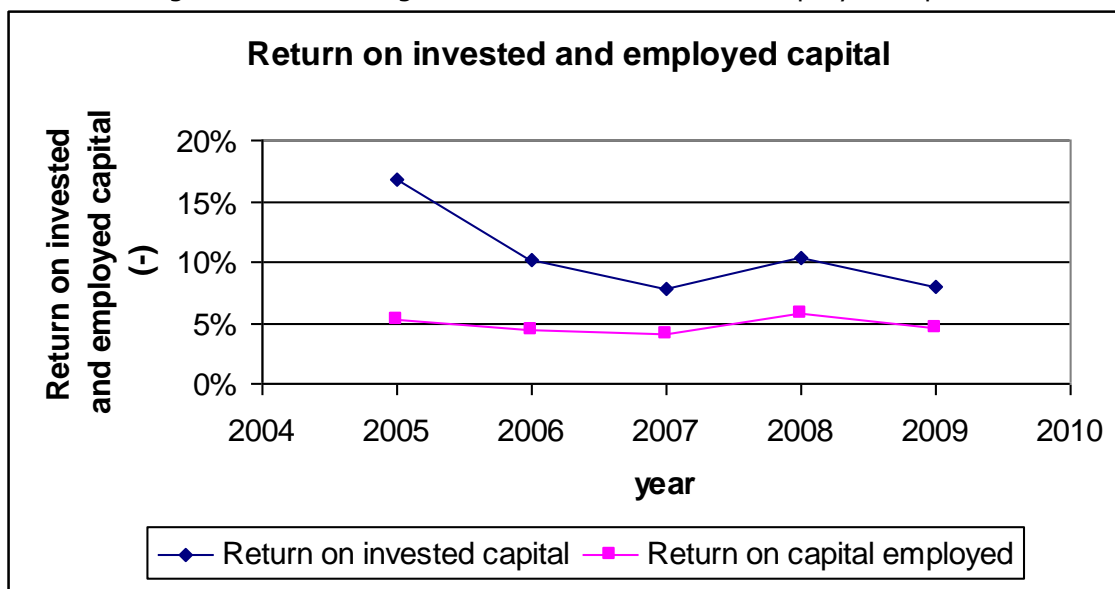
inflation). The downside of applying this discounting rate is that the opportunity cost of capital is not incorporated.

If the discounting factor reflects the expected return forgone by withdrawing capital from the private sector, it will be called the corporate rate of return. This rate is higher than the rate based on government bonds and will include risk compensation, and the tax rate that has to be paid (Blauwens *et.al.* 2008).

In this research the corporate rate of return (costs of equity) will be used as a criterion because the small barge convoy system wants to become a profitable business. Therefore the total opportunity costs of capital should be taken into account. The question is: how large should the corporate rate of return be?

In order to determine the rate of return, the following reasoning is followed. In 2009 the rate on government bonds in the Netherlands and Belgium was close to 3.5% (CBS, 2010). If the risk compensation is equal to 5%, the nominal dividend should be 8.5%. The corporate tax rate was equal to 25.5%, resulting in an interest rate before tax equal to 11.41% ( $8.5\% / (1 - 0.255)$ ). 2009 saw an EU average inflation of 1% and therefore the real return should be equal to 10.3% ( $1.114 / 1.01$ ). Consequently, a default criterion of 10% is used in this thesis. In Deloitte (2009) it was found that the return on invested capital was 7.9% in 2009. The 10% used in this thesis is higher than the sector average. This is shown in figure 11.3. In part III of this thesis the influence of changing the level of costs of equity will be further researched via a sensitivity analysis.

Figure 11.3: Average return on invested and employed capital



Source: Deloitte, 2009

As mentioned before, besides the calculation of the IRR based on the free cash flow (equity based), there is also the possibility to calculate the IRR based on the enterprise perspective (Higgins, 2007). In the latter the total investment will be considered (equity and debt) and not only the amount equity needed for the investment. Therefore the free cash flow is not used,

but the free cash flow plus the interest costs and yearly payback of the loan (= EBITDA - TAX). When the enterprise perspective is used, the IRR must not be compared to the opportunity costs of equity but to the weighted average costs of capital (WACC). In relation 11.4 the formula to calculate the WACC is given.

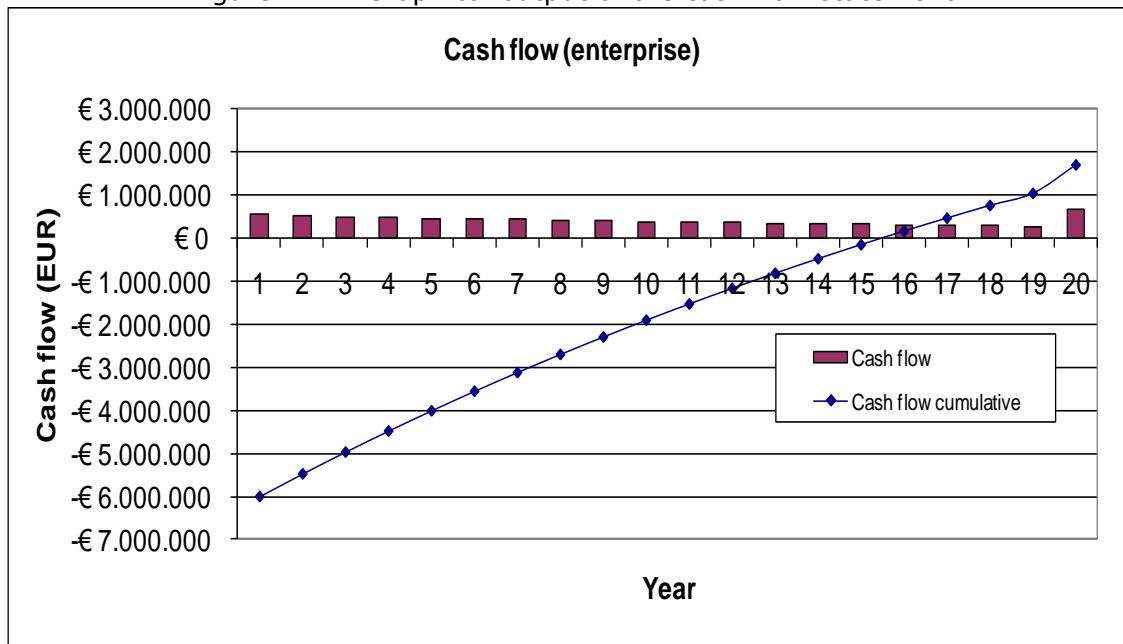
$$\text{WACC} = \frac{(1-\text{TAX}) \cdot D \cdot C_{\text{INTER}} + C_{\text{equity}} \cdot E}{D+E} \quad (11.4)$$

WACC = weighted average costs of capital [%]  
 TAX = tax rate (25.5%) [%]  
 D = total debt [EUR]  
 E = equity [EUR]  
 $C_{\text{inter}}$  = Interest costs (4.6%, see chapter 8) [%]  
 $C_{\text{equity}}$  = equity costs (10%) [%]

If the IRR based on the enterprise perspective is larger than the WACC, the investment can be justified. The return on employed capital can also be seen in figure 11.3. In 2009 this was 4.6% on average in the transport sector.

In figure 11.4 the cash-flow based on the enterprise perspective is given.

Figure 11.4: Graphical output of the cash flow statement



Note: base year 2009

Basically, using the enterprise or equity perspective should lead to the same conclusion. It is just a matter of comparing the right criterion to the appropriate IRR. Normally the enterprise perspective could be considered to be the easier way to calculate the investment because the risk-adjusted costs of equity can be ignored. Just the usual (non-risk adjusted) costs of equity can be used.

### 11.3 Investment decision criterion

In order to determine the minimum level of return of different design options of the small barge system the choice has been made to aim for a minimum level of IRR (enterprise perspective). Therefore the minimum level of IRR must be larger than the calculated WACC, in which the cost of equity is set to be equal to 10% (see formula 11.5).

$$\text{IRR}(i) \geq \text{WACC}(i) \quad (11.5)$$

IRR(i) = internal of rate of return of design option I [%]

WACC(i) = weighted average costs of capital of design option I [%]

If the IRR is used to rank different design options the use of the IRR has a disadvantage because the IRR does not give insight into the magnitude of the return. Therefore it is better to use the NPV rule to rank different design options. If, for the determination of the minimum rate of return, a minimum amount of NPV is set instead of IRR, the problem is that a priori the order of magnitude of the NPV of a selected design is not known. It is easier to set a minimum level of return in terms of a percentage.

In the NPV investment criterion, an investment decision will be positive if the NPV is larger than zero. If several different (network) designs options are calculated, the following maximization relation will be used (Blauwens *et.al.* 2008, p.499):

$$\max(Z) = \sum_{i=1}^n \text{NPV}_i \cdot X_i \quad (11.6)$$

NPV<sub>i</sub> = net present value design i [EUR]

X<sub>i</sub> = 1 if design is selected or 0 if not selected [-]

I = design options [-]

The formula in relation 11.6 indicated that one should invest in the design that has the highest level of NPV. The minimum level of return is incorporated in the net present value calculations by means of the discounting factor  $r$  (see formula 11.3) which will be set equal to the WACC (=minimum level of IRR). This means that if the NPV is larger than zero, then also the IRR will be larger than WACC. The NPV (and thus the investment decision) will thus be determined by the minimum level of IRR and by the maximum allowable earnings, which is determined by the maximum allowable transportation price and utilization rate. The maximum transportation price and utilization rate are limited by the competitors of the SBCS (this will be explained in chapters 12 and 13). If the investment budget is limited, an additional criterion has to be applied:

$$\sum_{i=1}^n C_i \cdot X_i \leq C \quad (11.7)$$

C<sub>i</sub> = investment of design I [EUR]

C = maximum investment budget [EUR]

If there is no limit on the investment budget, relation 11.7 will not be applied and only the value of NPV will be used to rank the different designs according to relation 11.6.

## **11.4 Summary**

This chapter has described how the transportation price per TEU and tonne will influence the earnings of SBCS and therefore also the NPV. This chapter also describes how the total NPV of the SBCS will be determined by a required of a minimum IRR and by the maximum allowable transportation price (earnings) under completion of other transportation modes. In the next chapter this completion of the competitors of the small barge system will be modelled.

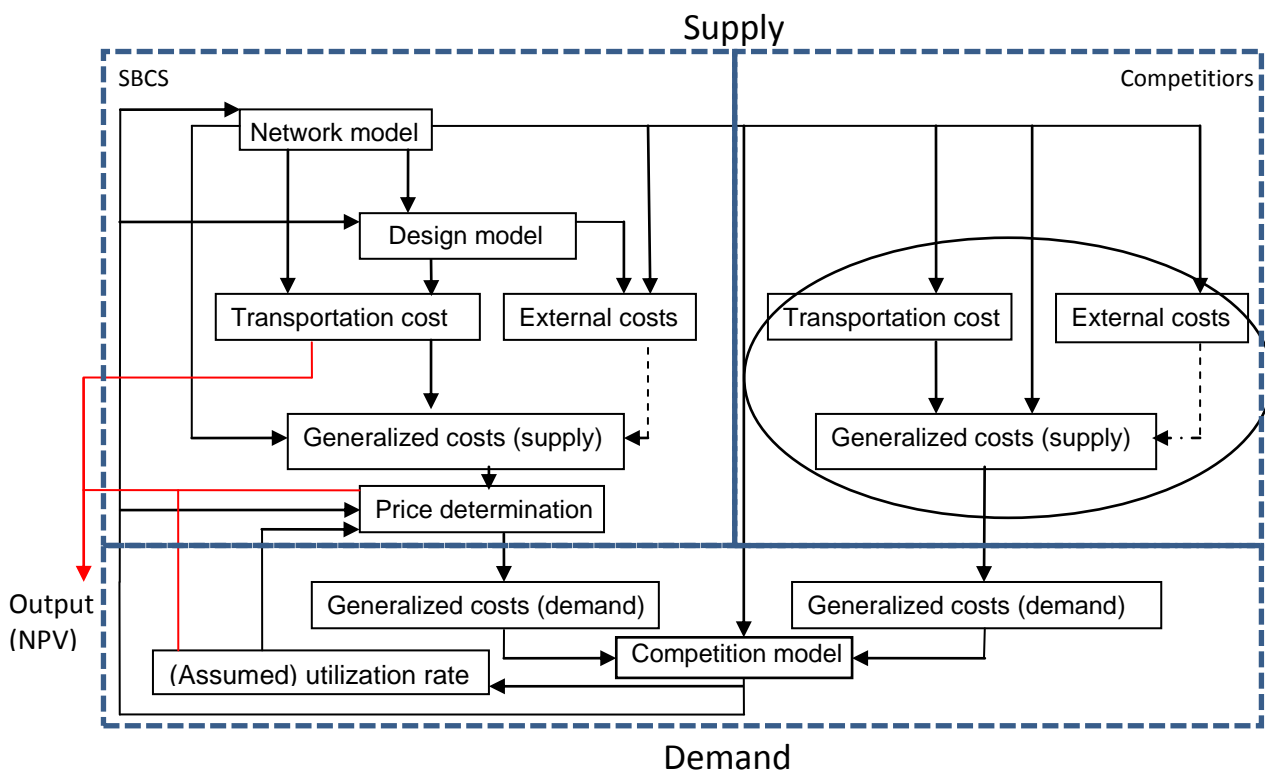
In chapter 13 the competition model will be explained in which the determination of the maximum transportation price and occupation rate of the barges is explained.

## 12. Competitor modelling

### 12.1 Introduction

Besides the generalized costs of the small barge convoy system, the generalized costs of the competing alternative modes are also important to know because they will determine the maximum price that can be obtained by the small barge convoy system. The competitors for the market where the barges have to operate are trucking companies, trains and classic inland ships. When a specific route for the barges has been selected, the transportation costs of the competitors are also calculated. From the out-of-pocket costs and the time costs the generalized costs are determined. This generalized costs approach is needed because the choice for a mode is not only determined by the out-of-pocket costs, and therefore also non-monetary costs components such as the value of time costs (VoT) and the reliability and flexibility costs (REL/FLEX) are to be taken in to account. In figure 12.1 the sub-models are shown which will be dealt with in this chapter.

Figure 12.1: Position of the competitors in the total model



The first parts of this chapter will deal with the determination of the transport and external costs of the competing modes. Moreover, the generalized costs of the competing modes are calculated (supply of the competitors) (right side of figure 12.1)). The first competitor that will be modelled is road transportation. The second part of this chapter will deal with the modelling of classic small inland shipping. This chapter will conclude with a summary.

## 12.2 Road transportation

The main competitors of the small barge system are road transportation and classic small inland ships, which must be taken into account as well. First, the transportation, external and the generalized costs will be determined for road transportation.

### 12.2.1 Transportation costs

The transportation costs of road transport will be determined when a truck has to drive fully loaded with bulk material from the selected origin (seaport or inland company) to the destination, with an empty backhaul. The reason for this assumption is that the truck will start its journey from the depot of the transportation firm. From this location the truck will drive to the port to load the cargo, from where the truck will drive to the client to discharge the cargo. Then there are two options: the truck will either go back to the depot of the transportation firm or will drive to the next client. In the last case a part of the costs to drive to the next destination will be taken into account. But because the distance from the transportation firm to the port and inland destination are not known, and neither are the distance from one client to the other, the known distance and travelled time, from the seaport to the inland destination, will increase by (an assumed) 50% in case of bulk transport (van Dorsser, 2004). If the truck transports containers, it is assumed that the truck will take the empty container(s) back, so that there is no distance (and time) between the previous trip and the new one.

The road transportation costs will be built up from the following major costs components:

- the covered distance
- the time needed to perform the transportation
- the fixed costs per day

The relation that will be used to calculate the transportation costs is given in the next formula (Beelen *et.al.* 2008).

$$Costs_{Road\_haulage} = \frac{(Distance.A + time.B + C \cdot \frac{time}{time_{Available}})}{Cargo_{capacity\_truck}} \cdot index_{2008} \quad (12.1)$$

Costs <sub>ROAD_HAULAGE</sub>	= costs per TEU for road transportation	[EUR/TEU]
A	= distance costs coefficient = 0.35 (based on 28 tonne truck or 2 TEU)	[EUR/km]
B	= time costs coefficient = 22 (based on 28 tonne truck or 2 TEU)	[EUR/h]
C	= day costs coefficient = 112	[EUR/day]
Distance	= covered distance of road transportation	[km]
Time	= time needed to perform the transportation task	[h]
time <sub>Available</sub>	= time available per day set at 10 hours	[h]
Cargo <sub>capacity_truck</sub>	= cargo capacity of the truck	[tonne or TEU]
Index <sub>2008</sub>	= 3.6%	[-]

As the cost calculation dated from 2008, the costs must be updated to 2009 values. The index figure for road transportation is 3.6% between 2008 and 2009 (ITLB, 2010).

The time that a truck will spend to transport its cargo to a given destination is based on an average speed of the truck of 50 km/h. This speed is based on the average speed as function of the travelled distance and a congestion parameter. For covered distances between the 50 and 100 km, the average speed is 45 to 55 km/h (Van Dorser, 2004). So an average of 50 km/h is taken for the further calculations. Furthermore, one hour extra time is added to incorporate the time loss in the seaport where the cargo must be picked up (or unloaded) (Beelen *et.al.* 2008). One hour is also added to take care of loading and unloading the truck at the inland destination. If the truck is transporting containers, these times are doubled because the empty container must also be loaded and unloaded at the seaport terminal.

### 12.2.2 Terminal handling costs

The terminal handling costs are set at the same level as for inland ships. Loading or unloading a container in the seaport will cost €100 per container. These costs are the same as for inland ships because the majority of the costs are the same (unloading or loading a deep-sea vessel, moving the container to the stack and loading the container to a land based transportation mode). In EC (2009) the terminal handling costs are all the costs from receiving a container from a deep-sea vessel to placing it on a land-based transport mode. In that study no distinction is made whether the containers are transported via inland waterways, rail or road. Therefore no large differences between the modes are expected. In Konings (2006) the loading costs per TEU for barges is determined at 35 EUR in a deep-sea terminal. In Konings (2010) 40 EUR per container move is used for the calculation of the loading costs of a container on to a truck in a sea terminal. It can be concluded that there is a small difference in actual loading (and unloading) costs between road and inland shipping.

Handling a tonne of bulk cargo is set at €0.80 (plus indexation) in a seaport and at an inland destination. The handling costs of a container at inland destination are therefore set at €15.

### 12.2.3 External costs

The external costs for road transportation are summarized in table 12.1, where the costs are based on total costs per tonne-kilometre and vehicle-kilometre (Arcadis *et.al.*, 2009). The same external cost parameters are used as with the small-barge convoy system. In this thesis, a sector average is used in order to determine the external costs of road haulage.

Table 12.1: External costs per tonne kilometre in other modes (2020 projection)

	Air quality	Climate	Accidents	Noise	Congestion	Infrastructure
	[EUR/tonne* km]	[EUR/tonne* km]	[EUR/tonne* km]	[EUR/tonne* km]	[EUR/vehicle* km]	[EUR/vehicle* km]
Road Haulage	0.0015	0.0023	0.0032	0.0006	0.4233	0.0015

Arcadis *et.al.* 2009

One remark has to be made. The external congestion cost of road transportation is much larger than the external congestion cost for inland navigation (see section 9.3.1). The reason for this is that road traffic has increased dramatically, while the infrastructure capacity hasn't increased



with the same pace. This has led to an increase in congestion. There are two main questions. The first question is whether the marginal congestion cost is completely external? The second question is whether public intervention is needed?

In a pure sense, an external cost is a cost which is caused by one person but is imposed to another (Blauwens et.al., 2008). The congestion costs are caused by the first vehicle in front the other vehicles. The second vehicle causes a cost to the ones behind him, etc. Therefore, the congestion costs are external and therefore also, by definition, they are not internalized. As mentioned in section 9.1, all the costs (including all external cost) must be taken into account in order to choose the correct mode of transportation to reach the maximum level of social welfare. So, not including the external costs is a form of market failure, which must be compensated by government interference (Leijssen, Korteweg and Derriks, 2009).

However for the congestion cost, there is a difference with the other external cost components. As mentioned before, the congestion cost appears to be external. The costs are caused by a first party and then imposed to others. Or in other words, if someone has made the choice to drive on a specific highway, he does not take into account the cost he inflicts to others who also want to use the same highway. But the reason why there is congestion on motorways is not due to market failure. Other sectors (the hotel sector for example) show that if the suppliers can set their own price, no congestion will occur. On motorways, this does not happen. The infrastructure supplier prices inefficiently. This means that the market is not failing but the infrastructure supplier itself is (Leijssen, Korteweg and Derriks, 2009).

In the work of Rothengatter (1994), it is argued that the congestion costs do not have to be compensated for by means of public intervention. It states that if private management is involved, there are sufficient incentives to reduce these congestion externalities without government interventions. Private road network operation and financing companies would differentiate user charges according to the congestion level inverse demand elasticities and therefore tend to reduce congestion externalities. So, the institutional solution would be the natural way to cope with congestion (Rothengatter, 1994).

Now that we have determined that the congestion costs are a bit different than the other external cost elements, the question remains whether government interference is needed to reduce congestion. Strictly, it is not necessary for the government to internalize the congestion cost because this cost is not caused by market failure. However the same government is also causing this congestion cost due to its inefficient price regime of infrastructure use, so it can also be argued that the one who is causing this error is also responsible for correcting it. If one considers the hotel business again, it can be observed that by an increasing demand, the prices will increase. This corresponds with a pricing structure in which the congestion costs are internalized with a tax which is variable in time and location (Leijssen, Korteweg and Derriks, 2009).

Therefore, in this research, the congestion cost of road transportation will be incorporated into the external costs so that the government can intervene. This is because by incorporating the congestion cost, the available road capacity will be priced more efficiently, which was ultimately the goal (Leijssen, Korteweg and Derriks, 2009).

#### 12.2.4 Generalized costs

The generalized costs of road haulage will be calculated with formula 12.2.

$$GC_{road} = TC_{road} + CHC_{road} + EXT_{road} + ITI_{road} + REL_{road} + FLEX_{road} \quad (12.2)$$

$GC_{road}$	= generalized costs road transportation	[EUR/TEU or tonne]
$TC_{road}$	= Transportation costs road transportation	[EUR/TEU or tonne]
$CHC_{road}$	= Cargo handling costs road transportation	[EUR/TEU or tonne]
$EXT_{road}$	= External costs road transportation	[EUR/TEU or tonne]
$ITI_{road}$	= In-transit-inventory costs road transportation	[EUR/TEU or tonne]
$REL_{road}$	= Reliability costs road transportation	[EUR/TEU or tonne]
$FLEX_{road}$	= Flexibility costs road transportation	[EUR/TEU or tonne]

The terminal handling costs of this transportation mode are the same as for the small barge convoy system (see section 10.2.2). The time costs are determined by the transportation times of road transport, which have already been determined in 6.3.1. The increase of transportation time for road haulage due to unreliability is set at 10% of the transportation time. The flexibility costs for road haulage are set at zero Euros because flexibility of deploying trucks is very large. If a customer wants to ship cargo within a very short time, a trucking company can offer that service.

### 12.3 Traditional inland shipping

The second main competitor of the small barge system is road classic small inland ships, which must be taken into account as well. Also for this transportation mode, the transportation, external and the generalized costs will be determined.

#### 12.3.1 Transportation costs

There are two sources that can be used to calculate the transportation costs of traditional inland ships. The first source indicates the total transportation costs as the transportation costs per sailing hour and the costs for waiting in a seaport or inland destination (NEA 2003). The transportation costs are determined as the sum of the crew costs, fuel oil costs, repair and maintenance costs and material costs, interest costs, depreciation and insurance. Because the costs data is relatively old (2003), the figures need to be updated. In table 12.2 the index figures of the costs components are given.

Table 12.2: Index figure costs development inland shipping costs

	2003	2004	2005	2006	2007	2008	2009*
Fuel	84	100	130	145	148	181	122
Crew	98	100	101	103	105	108	111
Other costs	100	100	100	132	170	163	161

Source: CCNR, 2009, \*estimation of the CCNR

The fuel and crew costs are indexed by 1.45 (122/84) and 1.13 (11/98) and all the other costs components are indexed by 1.61 to determine the costs for the year 2009. The transportation costs per hour as a function of the payload of the inland ship are given in figure 12.3.

The transportation costs per tonne per hour can be calculated with the following formula:

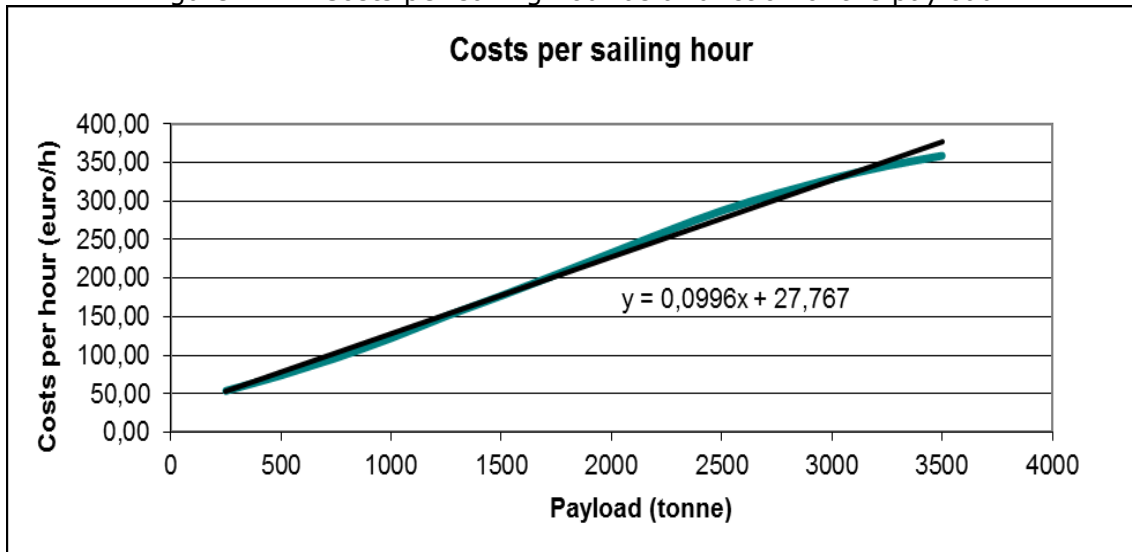
$$\text{Cost}_{\text{sailing\_hour}} = \frac{0.0996 \cdot \text{size}_{\text{ship}} + 27.767}{\text{transported}_{\text{cargo}}} \quad (12.3)$$

$\text{Cost}_{\text{sailing\_hour}}$  = Costs per sailed hour [EUR/tonne]

$\text{size}_{\text{ship}}$  = Cargo capacity of the ship (350, 600 or 1350 tonne) [tonne]

$\text{transported}_{\text{cargo}}$  = amount of cargo that is transported per shipment [tonne]

Figure 12.2: Costs per sailing hour as a function of the payload



Source: original NEA 2003 updated to 2009 figures by using table 12.2

The distance that needs to be covered at a given average speed of 10 km/h on a large waterway and 6 km/h at a small waterway will determine the time that is needed to sail. The distance will be doubled because the inland ship is assumed to have an empty return voyage to the seaport. Inland ships sailing on the waterway Dender are on average 49% empty (ECORYS, 2009). In table 12.3 an overview is given of the number of ships sailing on the small inland waterways in Flanders. In the overview a distinction has been made between the empty and loaded ships that are sailing on the considered waterways.

Table 12.3: Overview of the loaded and empty ships on the small inland waterways

Waterway	full [-]	empty [-]	full/empty [-]
Dender	336	312	1.08
Leuven-Dijle	16	34	0.47
DTS	2,659	2,690	0.99
Bochelt-Herentals	3,140	3,115	1.01
Total	6,151	6,151	1.00

Source: own calculation based on traffic figures NV de scheepvaart 2008)

Table 12.3 indicates that on average all the ships that are sailing on the small inland waterways do not take any return cargo. The ships sail fully loaded to a destination and back empty (or empty to a destination and loaded back). There is potential back haulage but the time needed to wait for that could be too long, so that the barge owners will sail back empty to another destination. Based on this table and ECORYS (2009), it can be concluded that small inland ships will cover double the distance to transport a shipment to and from small inland waterways.

Besides the time needed to sail, also the time of passing the locks on selected routes are taken into account. Therefore the costs per tonne can then be calculated as:

$$\text{Cost}_{\text{sailing}} = \text{Cost}_{\text{sailing\_hour}} \cdot \left[ \frac{2 \cdot \text{Distance}}{V_{\text{barge}}} + 2 \cdot N_{\text{locks}} \cdot \text{time}_{\text{lock}} \right] \quad (12.4)$$

$\text{Cost}_{\text{sailing}}$  = costs per transported tonne [EUR/tonne]

Distance = covered distance on large and small waterways [km]

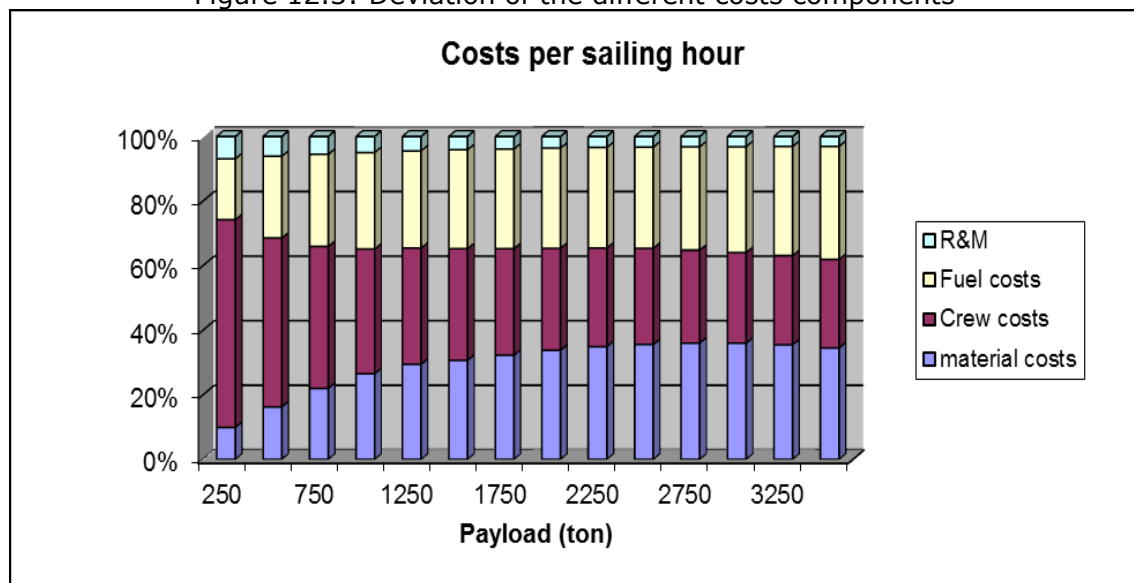
$V_{\text{barge}}$  = average speed of the inland ships estimated at 10 km/h on the large waterway and 6 km/h at the small waterway [km/h]

$N_{\text{locks}}$  = number of locks on the route [-]

$\text{Time}_{\text{lock}}$  = time to pass a lock (0.5 hours) [h]

Figure 12.3 indicates that the larger part of the costs for small ships (<600 tonnes) depends on the crew costs and that the influence of the fuel oil costs increases with the growing size of the ship. The material costs of the small ships play a smaller role in the total costs when they are compared to large ships. This can be understood by the age of the small ships that are now sailing (>50 years), which are fully depreciated and free of mortgage (see chapter 3.3). Normally mortgages on ships will have an expire time of 20 to 25 years, so that the majority of the small ships are completely depreciated.

Figure 12.3: Deviation of the different costs components



Source: NEA 2003 updated to 2009 figures by using table 12.2

The costs in figure 12.3 are based on a minimum number of crew members, on their minimum wages and on the costs for repair and maintenance and

depreciation. In practice, the crew costs are not fully taken into account. This is because the small inland ships are operated by a family, where the crew cost of (in most cases) the wife will not be taken into account. Therefore, in practice, the costs per tonne cargo of the small ships will be less than the figures that are given here.

Therefore the calculated costs are corrected on the previously mentioned costs components. Figure 11.2 shows that for the smallest inland ships (<400 tonne) 60% of the total costs are crew costs. These costs will be reduced by the wages of the mate. Roughly 2/3 of the total crew costs are made up by the captains' wages, so that the crew costs will be reduced by 33%. As a result, the total transportation costs are lowered by 20%. For the 600-tonne ship, 50% of the costs are crew costs, so that the reduction of the costs for those ships is smaller compared with the smallest ships (16%).

The second way to calculate the transportation costs of inland ships is a calculation- method based on distance and hour-costs (Blauwens *et.al.* 2008). In relation 12.5 the transportation costs can be calculated for ships with different loading capacities.

$$\text{Cost}_{\text{sailing}} = \frac{U \cdot u + D \cdot d}{\text{Transported}_{\text{cargo}}} \quad (12.5)$$

U = time coefficient [EUR/h]  
D = distance coefficient [EUR/km]  
u = sailed time [h]  
d = covered distance [km]

In table 12.4 an overview of the different time and distance coefficients are given for different ship sizes.

The cost coefficients are valid for the year 2004 and are based on the wage levels of the labour agreements and the interest and depreciation costs are based on the newbuilding prices of new vessels. The problem with the small ships is that, as mentioned before, the total costs of all the crew members are not taken into account, and that these ships are almost completely depreciated. Therefore the hour costs coefficient can be halved to take these effects into account (Blauwens *et.al.* 2008).

Table 12.4: Overview of the costs coefficients

Loading capacity	U [EUR/h]	U <sub>cor</sub> [EUR/h]	D [EUR/km]
300 t	54.50	27.25	1.20
600 t	77.26	38.63	1.62
1000 t	104.27	52.14	2.91
1350 t	127.24	63.62	4.02

Note: 2004 figures

Because these costs also date from 2004, an update is needed for these costs figures. Because it is not known how these costs coefficients were built up, it is not possible to update the figures. Therefore the updated hour costs coefficient of NEA is used to calculate the transportation costs of the

small inland ships. The transportation costs per hour for the smallest ships (Spits and Kempenaar) are given in table 11.5.

Table 12.5: Corrected costs coefficients inland ships

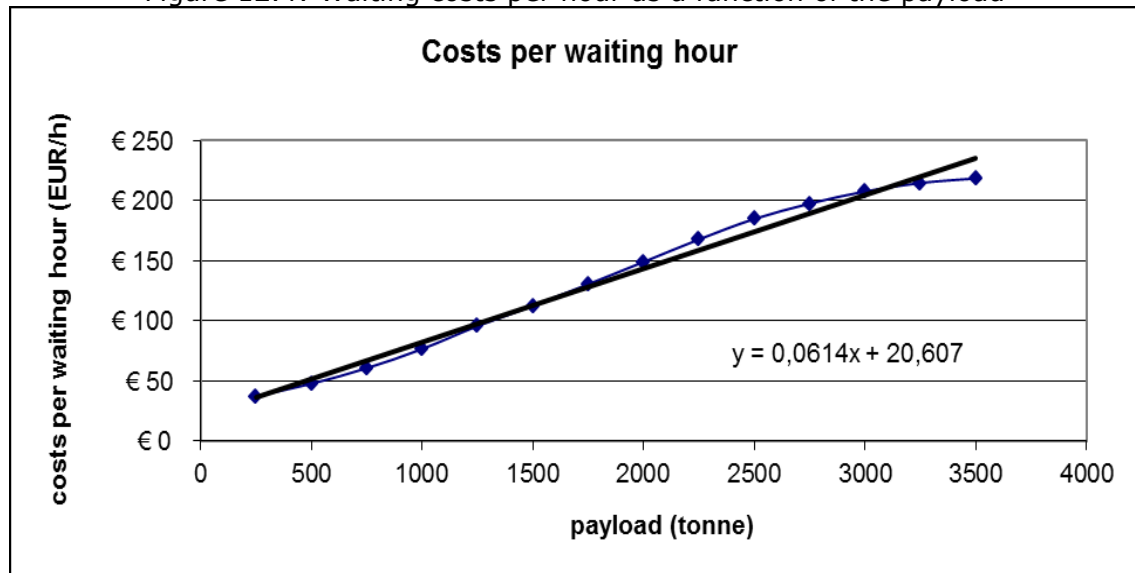
	Capacity [tonne]	actual loading [tonne/TEU]	costs coef [EUR/h/tonne]	costs coef [EUR/h/TEU]
Spits	450	450/14	0.129	4.15
Kempenaar	600	550/20	0.133	3.67

Note: updated to 2009 figures by using table 12.2

### 12.3.2 Port residence costs

Besides the costs for sailing from a seaport to an inland terminal, the costs for waiting in the seaport and costs made during loading and unloading needs to be taken into account. For container transport the waiting time at the seaport terminal is taken from the actual waiting times in the port of Antwerp and Rotterdam and is set at 7 hours per terminal (rhinecontainer, 2009, see appendix U). The time that an inland ship has to wait at an inland terminal before it can be handled is set to be zero hours. For container transport, the time that a ship has to wait at a terminal while loading and unloading is 20 cont/h in a seaport and inland terminal. The average loading and unloading time at a bulk terminal is set at 100 tonne/h. These extra times are used to calculate the costs of the waiting times. These extra costs are added to the costs of sailing in order to determine the total transportation costs. The costs per hour for waiting are also given in NEA (2003). These costs feature in figure 12.4, where only the material costs and the crew costs are taken into account. Also these costs are updated to 2009 values.

Figure 12.4: Waiting costs per hour as a function of the payload



Source: NEA updated to 2009 values by using table 12.2

The waiting costs per hour per tonne of cargo can be calculated with the following formula:

$$\text{Cost}_{\text{waiting\_hour}} = \frac{0.0614 \cdot \text{size}_{\text{ship}} + 20.607}{\text{transported}_{\text{cargo}}} \quad (12.6)$$

The costs made by inland ships in the seaport for waiting at the terminals and the costs made for waiting at terminals while the ship is being loaded and unloaded can be calculated with the next relation:

$$\text{Cost}_{\text{waiting}} = \text{Cost}_{\text{waiting\_hour}} \cdot (2 \cdot T_{\text{loading}} + T_{\text{terminal}}) \quad (12.7)$$

$T_{\text{Loading}}$  = time spent at a terminal during loading and unloading [h]

$T_{\text{terminal}}$  = time spent at a seaport terminal while waiting [h]

The total inland shipping costs made are the summation of the two costs components, i.e. sailing and waiting.

### 12.3.3 Terminal handling costs

In these costs the terminal handling costs of this mode are the same as for the small barge convoy system because the same terminals are visited and the same equipment on those terminals is used. The time needed to complete a shipment will be based on the time components mentioned in part 6.2.5 (including lock passing, waiting at deep-sea terminals, etc).

### 12.3.4 External costs

The costs are given in table 12.6, where the costs are based on total costs per tonne-kilometre and vehicle-kilometre.

Table 11.6: External costs per tonne kilometre other modes (2020 projection)

	Air quality	Climate	Accidents	Noise	Congestion	Infrastructure
	[EUR/tonne* km]	[EUR/vehicle *km] <sup>45</sup>	[EUR/tonne *km]	[EUR/tonne *km]	[EUR/vehicle* km]	[EUR/vehicle* km]
"classic" Inland ships	0.034	0.87	-	-	-	-

Source: Acradis *et.al.* (2009)

The climate and air quality costs are calculated with the figures given in table 12.7 (emissions data) and the monetary costs per costs item given in table 9.1.

Table 12.7: Emissions per tonne kilometre for small inland ships (2020 projection)

	Air quality			Climate
	Pm <sub>10</sub>	NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub>
"Kempenaar" 550 tonnes	0.0235	0.565	0.037	63

Source: CE, STREAM (2008)

The reason to calculate these figures "bottom up" is that a sector average figure is not sufficient. The small barge convoy system will compete with small inland ships and therefore only the external costs of small inland ships should be considered. If a sector average is used, the influence of the large ships is too big. The emissions per tonne of large inland ships are much

<sup>45</sup> Based on a 550 tonne loading capacity

lower than the emissions of smaller ships. The reason is that the larger ships use their economies of scale. The power needed to propel a tonne of cargo is lower for larger ships than for smaller ones, which also reduces the emissions.

### 12.3.5 Generalized cost

The generalized costs of inland shipping, as well as the generalized costs of small barge convoy, are also determined with formula 12.8 (repeat of formula 10.1 but then applied for inland shipping).

$$GC_{is} = TC_{is} + CHC_{is} + EXT_{is} + ITI_{is} + REL_{is} + FLEX_{is} \quad (12.8)$$

$GC_{is}$ = generalized costs inland shipping	[EUR/TEU or tonne]
$TC_{is}$ = Transportation costs inland shipping	[EUR/TEU or tonne]
$CHC_{is}$ = Cargo handling costs inland shipping	[EUR/TEU or tonne]
$EXT_{is}$ = external costs inland shipping	[EUR/TEU or tonne]
$ITI_{is}$ = in transit inventory costs inland shipping	[EUR/TEU or tonne]
$REL_{is}$ = Reliability costs inland shipping	[EUR/TEU or tonne]
$FLEX_{is}$ = Flexibility costs inland shipping	[EUR/TEU or tonne]

The VoR for classical inland ships could be assumed to be rather high due to the large and volatile waiting times at the seaport terminals (see appendix Q). It is, however, not possible to determine this value directly (RAND 2004, RAND 2005). It can also be argued that for classical inland ships the VoF is rather high compared with road haulage. It is very difficult for inland ships to be flexible. If a ship is needed within a very short period of time, it could take quite long for the barge to be available due to the low sailing speed of the barges. Trucks can be available much faster. The next part of this chapter will deal more in detail with the flexibility and reliability costs.

## 12.4 Generalized costs demand side

Now that the supply side of figure 12.1 has been determined, it is the turn of the demand side. In the demand side the generalized costs of all the modes (SBCS, road and classic small inland ships) will be determined for the cargo owners. They are the ones who decide which mode to choose. First, those generalized costs are determined for all the mentioned modes.

### 12.4.1 Small barge convoy system

The generalized costs of the small barge system from the demand perspective will be equal to the generalized costs of the supply side (chapter 10) plus the profit margin.

$$GC_{demand} = TP + CHC + EXT + ITI + REL + FLEX \quad (12.9)$$

$GC_{demand}$ = generalized costs demand perspective	[EUR/TEU or EUR/tonne]
TP = transportation price of the SBCS (see chapter 11)	[EUR/TEU or EUR/tonne]

The transportation price offered by the small barge convoy will now be interpreted as a costs item for the transport customers. As such, for the determination of the competitiveness of the small barge system, the transportation price must be incorporated.



### **12.4.2 Road transportation**

For road transportation there are a lot of small and medium-sized companies, while for the demand side of road transport (container shipping lines, forwarders and shippers) there are numerous customers, many of whom are large international operating companies with a strong market position. This particularly applies to shipping lines and forwarders. These companies also have a strong interest in controlling the logistics chain, including the cost of landside transport services (Konings, 2009). As a result of the competition between all the trucking companies and the large bargaining power of the transport customers, the road transportation companies will behave as price-takers instead of price-setters (Konings, 2009). This is why no additional profit will be incorporated for road transportation, so that the transportation costs will be equal to the transportation price. The generalized costs of road transportation firms (supply perspective) will therefore be equal to the generalized costs from the demand perspective.

### **12.4.3 Classic small inland shipping**

The generalized costs (demand perspective) for classic small inland navigation are also equal to the generalized costs from the supply perspective. As mentioned in chapter 3, the small inland ships facing a large competition, both internal and from other modes. This will result in a price that will be equal to their costs (no additional profit).

## **12.5 Summary**

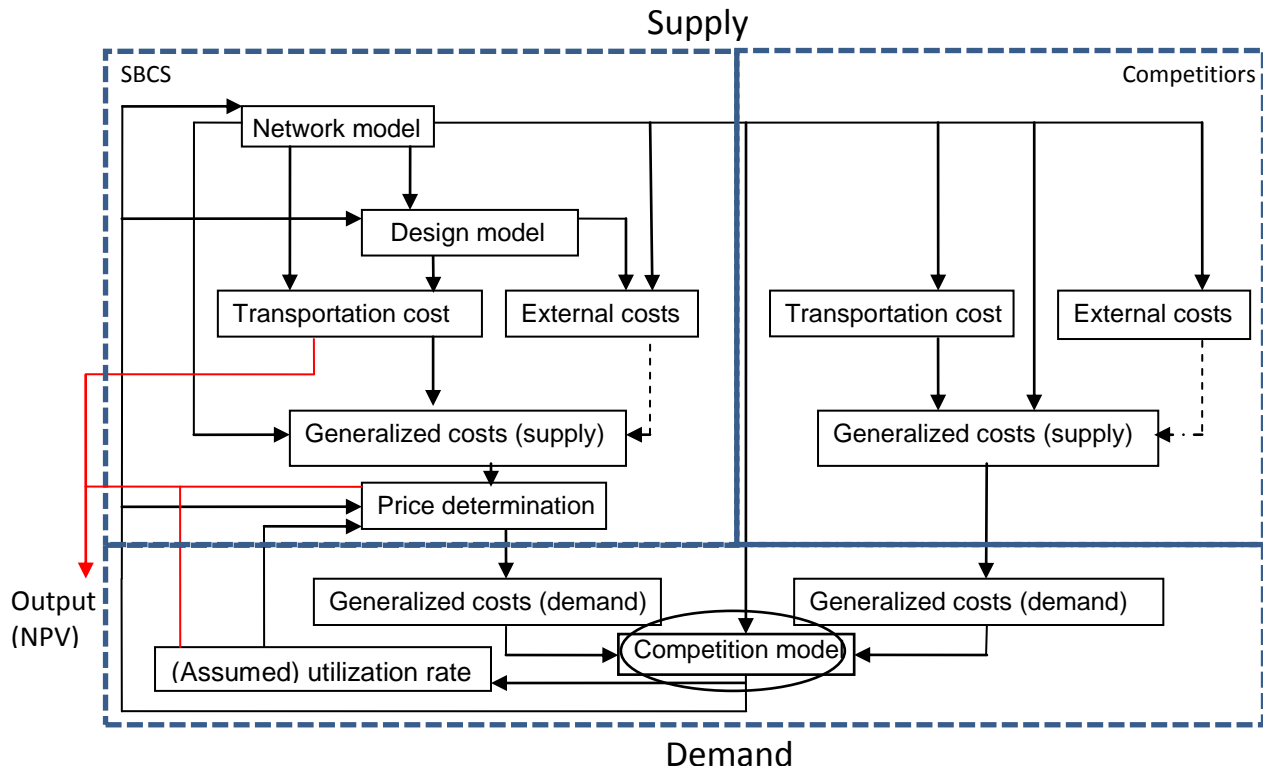
In this chapter the competitor modelling is taken into account in the total model. The generalized costs (demand side) of the small barge system and its competitors are calculated. These costs will now be incorporated into the competition modelling in the model.

## 13. Total competition modelling

### 13.1 Introduction

Now that the generalized costs are determined for both the small barge system and its competitors the competition between them will be modelled, by combining two different approaches. The first approach is a logit approach. The second approach is a total logistics costs approach (TLC) (cf. figure 13.1).

Figure 13.1: Overview of the location of the competition model in the total model



The first part of this chapter will deal with a comparison of the two different models. The second part will deal with the calculation of the total logistics cost. The third part will deal with the logit model. In the fourth part a sensitivity analysis will be made to research the influence of changes of some parameters in the competition model. Also a section has been added to research the intermodal application of the small barge system by adding additional road transportation. This chapter will end with the conclusions.

### 13.2 Competition modelling

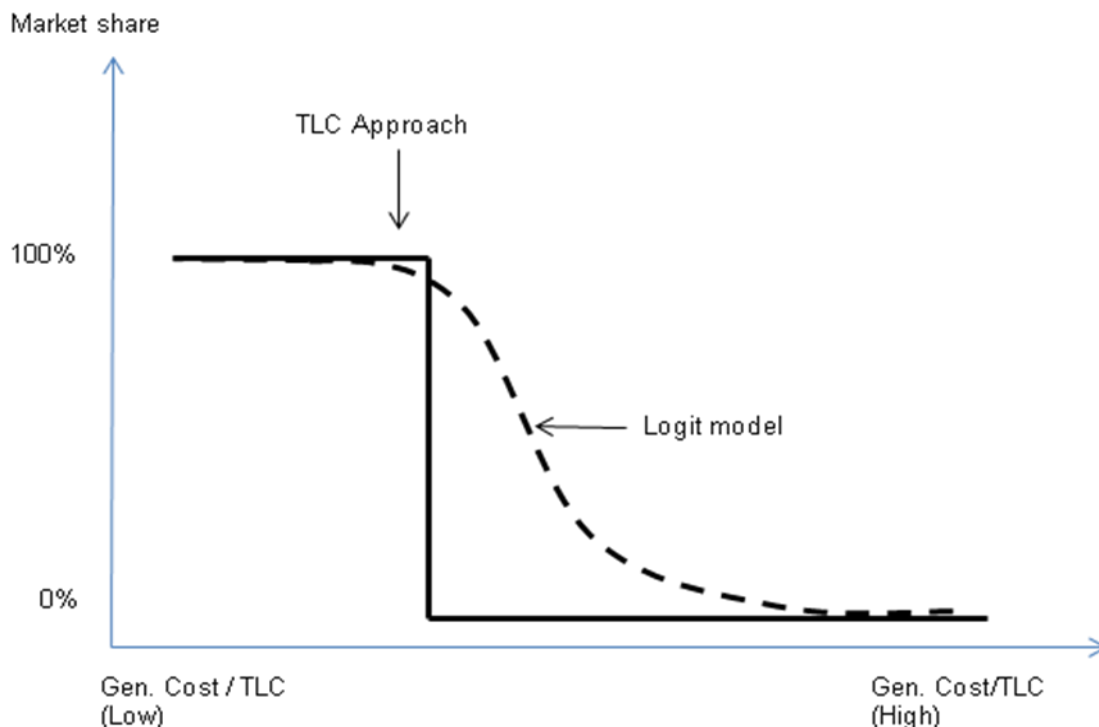
The first competition model that is applied is the total logistics cost approach. One of the aims of this thesis is research the conditions when current day road transport cargo flows can be shifted to the small inland waterways. Therefore, the modal shift will be researched from the perspective of the companies located at the small inland waterways. If a company is using road transport for its daily transport, shifting its cargo flows to the small barge convoy system will affect the internal logistics in

the considered company (longer transit times and more inventory cost). In order to take these effects into account, the total logistic cost approach will be applied.

In this total logistics cost (TLC) all the relevant cost, such as transportation cost, total travel time and inventory cost are taken into account for the small barge system and its competitors. Companies located at the small inland waterways will opt for the small barge system if the TLC of the small barge system are lower than the TLC of competing modes. The problem with this approach is that it's like an "all or nothing" criteria. If the TLC are only slightly smaller than its competitor than one opts for that mode or if they are only slight larger than one opts for the competitor. There is also no link to the demand. Changes in demand will not affect the mode choice. If the TLC for the small barge system are smaller than the TLC of its competitors, than all the demand will be available for the small barge system or if the TLC are higher than no demand will be available for the small barge system.

That is why the logit model is incorporated. A logit model is a statistical application to determine the probability that a specific mode of transport will be chosen. This choice will be influenced by the generalized cost of the different modes. This approach allows constructing a "smooth curve" between a very high values and low values of the TLC. Another advantage of the logit model is that there is a link with demand (section 13.4). In figure 13.2 the comparison between the TLC approach and the logit approach is shown.

Figure 13.2: Comparison between TLC and Logit approach



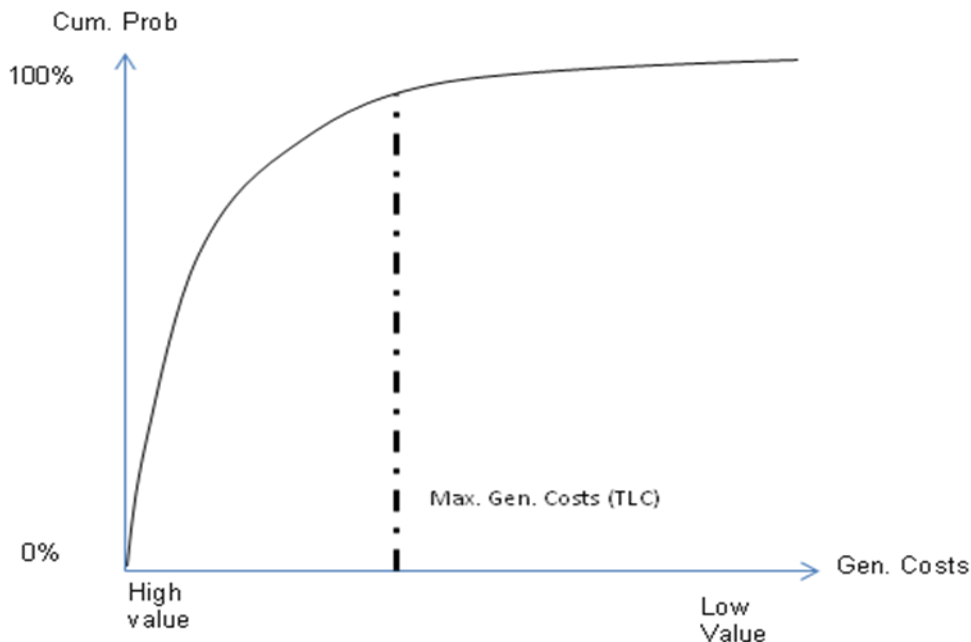
Source: own composition

The Y-axis in figure 13.2 represents the probability that one opts for a specific mode (in this case for the small barge system) and the X-axis

represents the generalized (or TLC) cost. The figure indicates that by only using the TLC approach the shift from one mode to the other is quite rigid. The logit model will function in the area between high and low values of generalized cost (or TLC).

On the other hand, if only the logit model was used to calculate the competition between the small barge system and its competitors, very high values of generalized cost could be accepted if only a small percentage of the total demand is needed. This is, for example, the case when only one barge will be pushed to three different waterways. The amount of cargo needed to fill the barges is small, so that high values of generalized cost can be accepted. These generalized cost (including the transportation price per TEU or tonne) can be too high if the total logistics cost are calculated and compared to the competing modes. Therefore the maximum value of generalized cost will be determined by the total logistics cost. This is graphically shown in figure 13.3.

Figure 13.3: Cumulative probability function logit model as function of the generalized cost



Source: own composition

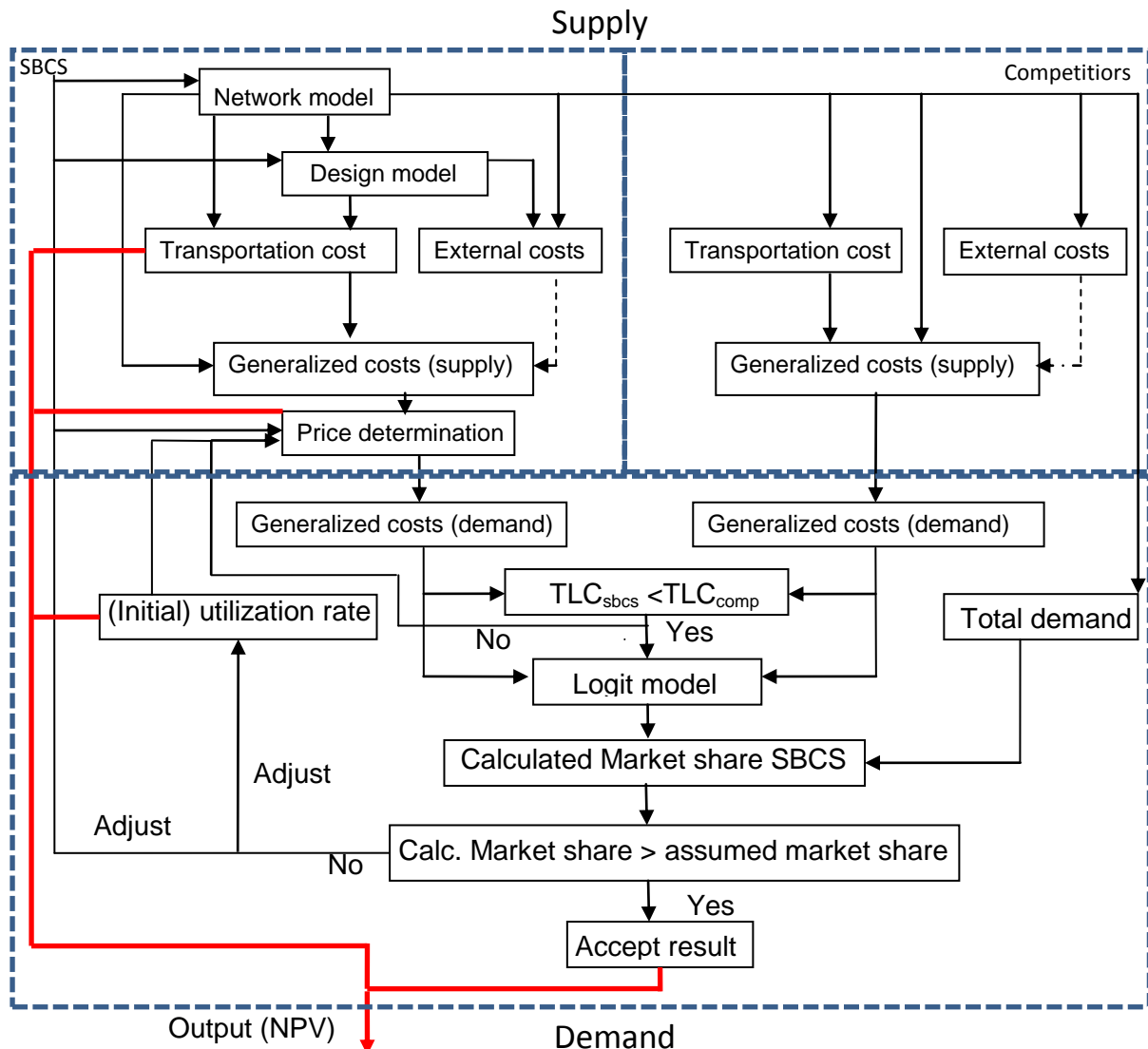
Figure 13.3 shows that by applying this TLC criterion the maximum allowable generalized cost of the small barge system will be determined by a mix of the TLC approach (maximum value) and the logit model (competing with the other modes). The TLC approach will make sure that the "edge of the logit model" will be eliminated.

All the different components in the developed model will come together in figure 13.4, where a schematic representation of the total model is given. In this model all the different relations of several sub-models are given.

The modelling approach of the small barge convoy system can be found in the top left corner. Figure 13.4 shows that from the network model a connection is made with the competing modes. If a certain route for the small barge convoy system is chosen, also the alternative routes of the

competing modes will be determined. For these competing modes the generalized costs are calculated. The total demand is also determined by the chosen routes (see chapter 6).

Figure 13.4: Total logistic cost criteria and the logit model in the total model



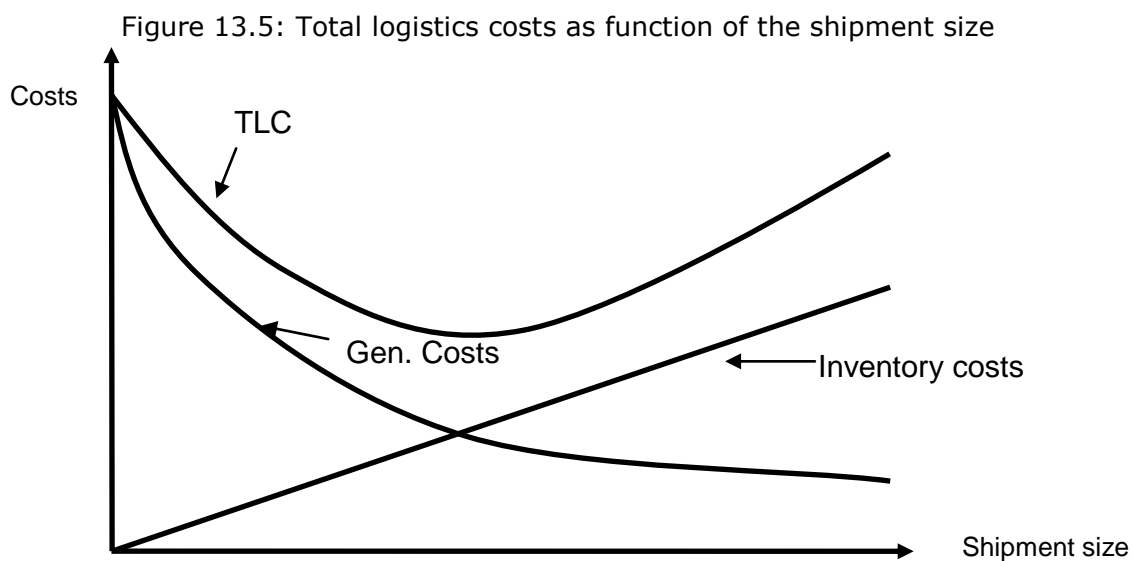
In figure 13.4 the position of the TLC approach and the logit model in the total model can be found. If the TLC of the SBCS ( $TLC_{SBCS}$ ) are larger than the TLC of its competitors ( $TLC_{comp}$ ) the solution cannot be accepted. There is a feedback relation back to the price determination model. The profit margin of the small barge system will be altered so that the TLC of the small barge system are lower than the TLC of the competitors (see also chapter 11). In order to fulfil this criterion it must be possible that the profit margin can become negative. This will result in a negative NPV which will eventually lead to a negative investment decision (see section 11.3).

Figure 13.4 also shows that after the TLC model the logit model is incorporated. If the  $TLC_{SBCS}$  are smaller than the  $TLC_{comp}$  then via the logit model and the total demand the market share will be calculated. The calculated market share will now be compared to the initial assumed utilization rate of the barges. If the calculated market share is larger than the initial assumed utilization rate than the calculated result can be

accepted. If not then the initial assumed market share has to be changed. A change in the utilization rate of the barges will in its turn have an impact on the price determination part of the model (see chapter 11). Figure 13.4 also indicates that both criteria have to be fulfilled before a result from the model can be accepted.

### 13.3 Total logistical cost

In this part the total logistics cost components are described. The cost components that have to be taken into account when a firm will make a choice between the different transportation modes are the out-of-pocket cost, the in-transit inventory cost and the total inventory cost. The total inventory cost is built up of the cycle stock and the safety stock cost (Blauwens *et.al.* 2008). The total logistics cost are presented graphically in figure 13.5.



Source: taken from Blauwens *et.al.* 2008 p.230

The biggest change for companies when changing from road haulage to inland navigation is the change from just-in-time logistics to a delivery once a week. This will lead to maintaining stock and require internal storage space at the sites of the companies. The requirement for the storage space at the companies is needed because of the increased shipment size. As a result, the inventory costs are increased compared with the situation where a just-in-time principle is used. So, in order to determine whether a company can shift its cargo flows, these costs must also be taken into account. Therefore, the total logistics costs must be lower when the small barge convoy system is chosen instead of road transportation or traditional inland ships.

The TLC can be calculated as the vertical summation of the two lines in figure 13.1. With relation 13.1 the TLC will be calculated.

$$TLC_i = GC_i + INVENT_i \quad (13.1)$$

$TLC_i$  = total logistical costs of mode i

[EUR/TEU or EUR/tonne]

$GC_i$  = generalized costs mode i

[EUR/TEU or EUR/tonne]

INVENT<sub>i</sub> = inventory costs mode i [EUR/TEU or EUR/tonne]

The GC was already calculated in chapter 10 and those costs are built up of the OPC and the ITC. The other component, i.e. inventory costs, will be further described in the next section.

### 13.3.1 Inventory costs

The inventory costs will be calculated with the following formula, which has been taken from Blauwens *et.al.* (2006). This formula is based on Baumol and Vinod (1970), where a Poisson distribution is assumed for the stochastic elements of the relation.

$$\text{Costs}_{\text{Inventory}} = \frac{\left[ \frac{s \cdot T}{2} + K \cdot \sqrt{(s+t) \cdot T} \right] \cdot I \cdot 365}{\text{Total}_{\text{cargo}}} \quad (13.2)$$

costs <sub>Inventory</sub> = inventory costs per unit	[EUR/tonne or EUR/TEU]
T = Shipment size per day	[tonne/day or TEU/day]
s = average time between shipments	[day]
t = time for one shipment	[day]
K = constant depending on no-stock probability	[-]
I = inventory costs per unit	[EUR/tonne/day or EUR/TEU/day]
Total <sub>cargo</sub> = total amount of cargo transported per year	[tonne or TEU]

The first part of formula 13.2 represents the average amount of cargo in stock. The second part, between brackets, gives the amount of safety stock. The factor K will be determined on the basis of the tolerated risk of stock-out. This tolerated risk is set at 5 % and K becomes 1.64<sup>46</sup>.

The inventory costs per unit are determined as the sum of (Blauwens *et.al.* 2008):

- Opportunity costs of the cargo stored
- Costs of the depreciation of the goods stored
- Insurance costs
- Warehousing costs

The interest and depreciation costs per day are set equal to the daily loss on capital for the receiver of the cargo in transit (VoT). These values are explained in 10.3. The costs of depreciation are set to zero for bulk cargo (sand, iron ore, etc). The insurance costs are neglected because those costs are small compared with the other costs. Those costs are also independent of the chosen transportation mode. The warehousing costs are determined as the annual warehousing costs which include the depreciation of the building, the interest paid for financing the building, the heating, the lighting, etc. These costs are constant and not dependent on the amount of cargo stored. They are also independent of the type of mode that is transporting the cargo. In order to calculate these costs, detailed data is needed for all the companies that are investigated. Because that is not

<sup>46</sup> This value is taken from Blauwens et.al. 2008 p. 213 table 8.2

possible and there is no influence of mode choice and transportation size, these costs are left out of consideration.

### 13.3.2 Assumptions made to calculate the inventory costs

In order to determine the TLC, two linearizations are made to perform the required calculations.

The first linearization is related to the required space on the site of the company. In most of the cases the tonnages of companies located at the small waterways are transported via the road, so that the companies can be replenished daily and that there is no need for a storage space. If such a company wants to shift its cargo flows towards the new concept, the number of deliveries are reduced; therefore stock must be kept and space is required to do that. Accordingly, it is assumed that there is enough space available.

The second linearization is that the delivery of cargo flows can be uniformly distributed in the time if the company wants to shift its cargo flows from the road towards the inland waterways, so that no sudden peaks are to be expected. If a company has a lot of volatility in its cargo flows, shifting towards inland navigation can be a problem due to a lack of flexibility.

### 13.3.3 Inventory costs for the small barge convoy system

In order to calculate the inventory costs for the small barge convoy system, a simplification is made. All the cargo flows from one waterway are considered to be at one location. In reality several companies are located at one waterway but then as many calculations have to be made as there are companies.

Table 13.1: Calculation of the inventory costs on route number one

	In [TEU]	Out [TEU]	In [ton]	Out [ton]
total per year	1,394	2,092	57,871	0
AV Shipment size	<b>16.8</b>	<b>25.2</b>	<b>697</b>	<b>0</b>
AV Shipment size per day	<b>5.58</b>	<b>8.37</b>	<b>231</b>	<b>0</b>
AV time between shipments (days)	3.01	3.01	3.01	3.01
time for one shipment (day)	1.45	1.45	1.45	1.45
STOCK				
Cycle	8	13	349	n.a.
Safety	8	0	106	0
K	1.64	1.64	3.3	3.3
total stock per day	16	13	455	n.a.
Costs per day stock	€ 144.78	€ 110.00	€ 9.09	n.a.
<b>Costs per unit</b>	<b>€ 37.38</b>	<b>€ 18.93</b>	<b>€ 0.06</b>	n.a.
Stock_costs_TEU	€ 26.31			
Stock_costs_tonne	€ 0.06			

Note: 2009 values

In chapter 10 on costs calculation, an example calculation has been made based on 2 barges sailing to routes numbers 1 to 3 (see figure 6.5 for the



waterways and tables 7.5, 7.9 and 9.2 for input data). In table 13.1 the calculations of the inventory costs are shown for the given case on route number one.

The amount of transported cargo is determined by the total competition model (see also chapter 12). The average shipment size is calculated, as well as the average shipment size per day. The average shipment per barge may be larger than the capacity of a single barge because two barges can be used. The time needed to complete a shipment and the time between shipments is determined by the chosen logistics system of the small barge convoy system. With that information it becomes possible to calculate the number of TEUs or tonnes in cycle or safety stock. Table 13.1 shows that the safety stock is set to zero when a company is exporting cargo. When the total volume of cargo in stock is known, the total costs per day and per cargo unit can be calculated. Finally, the average inventory costs are calculated for the incoming and outgoing cargo flows. In the total model these calculations will be performed for all selected waterways.

### 13.3.4 Inventory costs for road transport

The total inventory costs for road transportation are determined with the same formulas as given in section 13.3.1. The size of the shipment is adjusted for road haulage to 2 TEU or 28 tonnes. Table 13.2 shows the calculations for route number 1. The average time between shipments is set at one day, meaning that if on average 9 TEUs are needed, several trucks per day will be used. Because it is not possible to determine how many trucks are used to transport all the cargo, the costs per unit (TEU or tonne) are calculated by dividing the total inventory costs by the total market.

Table 13.2: Calculation of the inventory costs road transportation on route number one

	In [TEU]	Out [TEU]	In [ton]	Out [ton]
total per year	2,250	2,720	233,500	0
AV Shipment size	<b>2</b>	<b>2</b>	<b>28</b>	<b>28</b>
AV Shipment size per day	<b>9.00</b>	<b>10.88</b>	<b>934</b>	<b>0.00</b>
AV time between shipments (days)	1	1	1	1
time for one shipment (day)	0.38	0.38	0.38	0.38
STOCK				
Cycle	5	5	467	n.a.
Safety	6	0	119	0
K	1.64	1.64	3.3	3.3
total stock per day	10	5	586	n.a.
Costs per day stock	€ 89.75	€ 47.49	€ 11.71	n.a.
<b>Costs per unit</b>	<b>€ 14.36</b>	<b>€ 6.29</b>	<b>€ 0.02</b>	n.a.
Stock_costs_TEU	€ 9.94			
Stock_costs_tonne	€ 0.02			

Note: 2009 values

Table 13.2 indicates that the inventory costs are lower for road transportation than for the small barge convoy system. That is due to the reduction in cycle and safety stock. The stock can be reduced because the

cargo can be delivered daily instead of every three days. Also due to the high value of the cargo less stock will be maintained. The difference in inventory costs between road and inland navigation for bulk cargo is very small. That is due to the low value of the considered cargo.

### 13.3.5 Inventory costs for inland navigation

The total inventory costs for inland navigation are determined with the same formulas given in section 13.2. The size of the shipment is adjusted for inland navigation to 16 TEU or 350 tonnes for a Spits and 24 TEU and 500 tonnes (at 2.00 metre draft) for a Kempenaar. The time for one shipment is taken from section 12.4 (costs calculation inland ships). In table 13.3 the calculations are given for an inland ship of the Kempenaar type.

Table 13.3: Calculation of the inventory costs inland navigation on route number one

	In [TEU]	Out [TEU]	In [ton]	Out [ton]
total per year	2,250	2,720	233,500	0
AV Shipment size	<b>20</b>	<b>20</b>	<b>500</b>	<b>500</b>
AV Shipment size per day	<b>20.00</b>	<b>20.00</b>	<b>934</b>	<b>500</b>
AV time between shipments (days)	1.00	1.00	1.00	n.a.
time for one shipment (day)	1.21	1.21	1.21	1.21
STOCK				
Cycle	10	10	467	n.a.
Safety	11	0	150	0
K	1.64	1.64	3.3	3.3
total stock per day	21	10	617	n.a.
Costs per day stock	€ 182.39	€ 87.30	€ 12.34	n.a.
<b>Costs per unit</b>	<b>€ 29.18</b>	<b>€ 11.55</b>	<b>€ 0.02</b>	n.a.
Stock_costs_TEU	€ 19.53			
Stock_costs_tonne	€ 0.02			

Note: 2009 values

### 13.3.6 Total logistics costs of the different modes

As mentioned before, if a company located at a small waterway wants to shift its cargo flows from the road towards the small inland waterways, the TLC must be reduced in comparison with the old situation; otherwise there is no incentive to change transportation mode. Therefore the following relation will be applied.

$$TLC_{SCBS} \leq \min (TLC_{road}, TLC_{In_{nav}}) \quad (13.3)$$

$TLC_{SCBS}$  = total logistics costs small barge system [EUR/TEU or tonne]

$TLC_{road}$  = total logistics costs road transportation [EUR/TEU or tonne]

$TLC_{in_{nav}}$  = total logistics costs traditional inland navigation [EUR/TEU or tonne]

If all companies located at the small inland waterways are considered to be rational, the slightest difference in TLC will make them change transportation mode. It can also be considered that when the TLC of modes

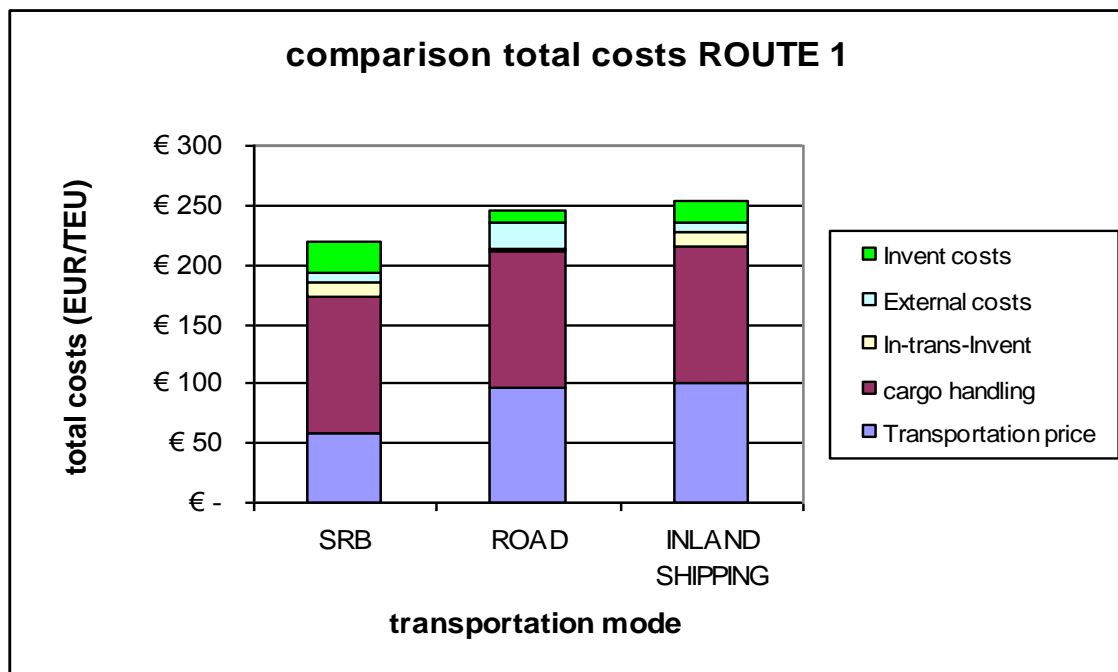
are equal one would choose for the transportation mode which will produce the lowest emissions.

In this analysis the calculated TLC per TEU of the small barge system must be at least 5% lower than the lowest TLC per TEU offered by the competitors. It is assumed that when taking the total logistics costs into account (including stock costs) a reduction of 5% will make the companies located at the small inland waterways shift from road transport to the small inland waterways.

For bulk cargo the difference must be larger than 30%. The reason why the required difference in TLC for bulk cargo is larger than the required difference for container transport is that bulk cargo is currently transported with trucks despite the fact that traditional inland shipping can offer a transportation price leading to almost the same TLC (also in generalized costs) of road transportation. Therefore a larger difference in TLC must be achieved (see also section 13.4).

In figure 13.6 the total logistics costs are given per TEU on route number one for the different modes.

Figure 13.6: Total logistics costs on route number 1 (TEU)

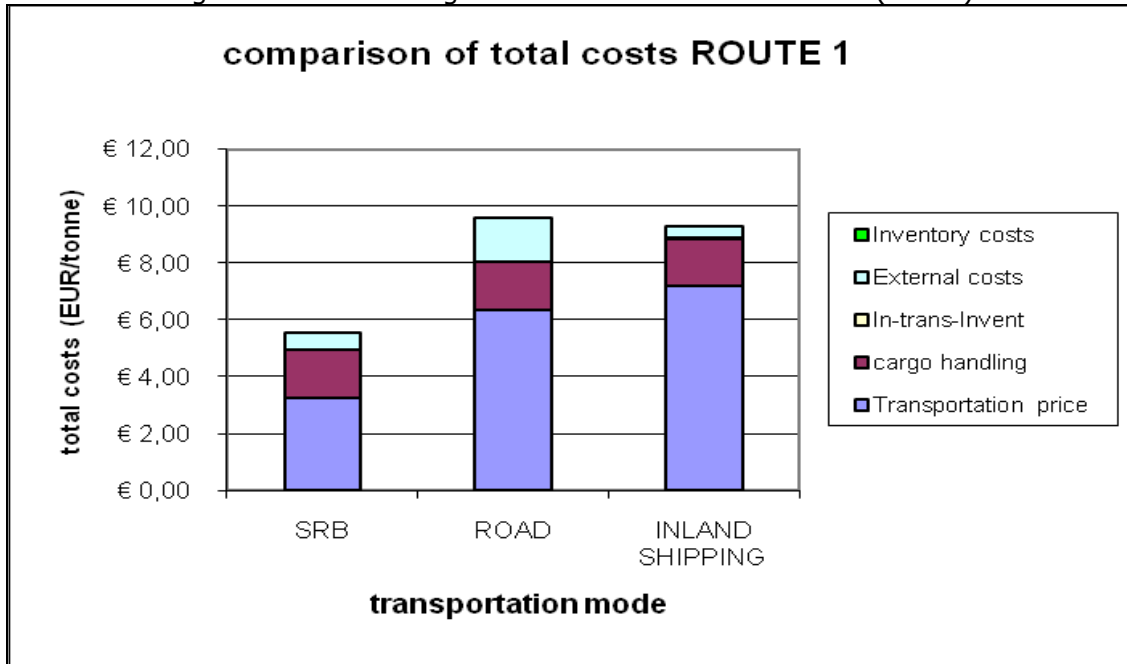


Note: 2009 values

Figure 13.6 shows that the total logistics cost for the small barge convoy system is smaller in this specific case (2 barges sailing to routes numbers 1 to 3). The in-transit inventory and "normal" inventory costs are higher for the small barge system but the decrease in transportation price is larger. Therefore the total logistics costs are decreased.

In figure 13.7 the TLC costs are given per tonne of bulk cargo. It shows that the inventory costs are low, due to the low value of the cargo. Therefore the TLC are predominately determined by the out-of-pocket costs.

Figure 13.7: Total logistics costs on route number 1 (tonne)



Note: 2009 values

From figure 13.7 it can also be concluded that the TLC of inland shipping are higher than the TLC of road transport (excluding external costs) but this difference is not large enough to explain the very large market share of road transportation. This could be due to the internal logistics at the companies located at the small inland waterways, which cannot be changed because of too large volatile characteristics of the cargo flows. Therefore the lack of flexibility and even reliability of supply on the small inland waterways can be a reason why road transportation is the dominating transportation mode. In section 13.4 is explained why and how an extra cost component is added to inland navigation and the small barge convoy system to deal with this.

### 13.4 The logit model

In this section the logit model will be incorporated into the total model as has been shown in figure 13.4.

#### 13.4.1 The model

In the logit model the different generalized costs are used to calculate the mode choice. When the probability of choosing a specific mode is known, the market share can be determined for the different modes with formula 13.4.

$$P_i = \frac{e^{-\mu GC_i}}{\sum_i^n e^{-\mu GC_i}} \quad (13.4)$$

$P_i$  = probability that mode  $i$  will be chosen

$GC_i$  = generalized costs mode  $i$

$\mu$  = spreading factor

[%]

[EUR/TEU or tonne]

[-]

In formula 13.4 the spreading factor  $\mu$  will be determined in such a way that the existing market share of the existing modes (road and classic small inland ships) is the same as the calculated values of formula 13.4. A distinction has been made between bulk cargo and container transport. Therefore each commodity type will have its own value of  $\mu$  ( $\mu_{\text{cont}}$  and  $\mu_{\text{bulk}}$ ).

In the generalized costs the values of REL and FLEX could not be determined due to a lack of data and interpretation difficulties of the considered costs components. Therefore only the transportation price, the cargo handling costs and the VoT are incorporated in the generalized costs.

### 13.4.2 Data for the logit model

The total demand, for transport with an origin (or destination) in the port of Antwerp and a destination (or origin) at the small inland waterways, was already given in table 2.6 but is repeated in table 13.4.

Table 13.4: Total potential cargo flows from the seaport Antwerp to companies located at the different waterways (recap of table 2.6)

	ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4
Small Waterway	Dender	Leuven-Dijle	Deseel – Turnhout - Schoten	Bocholt-Herentals
Cargo flow containers (in) [TEU]	2,250	7,500	8,140	-
Cargo flow containers (out) [TEU]	2,720	12,600	9,950	-
Cargo flow bulk (in) [tonne]	233,500	128,000	10,000	231,461
Cargo flow bulk (out) [tonne]	-	-	84,000	463,248

Source: Waterslag (2008), FISN data (2008), cargo flows WenZ and NV de scheepvaart (2009)

Note: all containers are loaded, no empty containers are in the data

In table 13.5 the current cargo flows transport via the small inland waterways with an origin or destination on the port of Antwerp are given.

Table 13.5: Current transport via the small inland waterways

	ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4
Small Waterway	Dender	Leuven-Dijle	Deseel – Turnhout - Schoten	Bocholt-Herentals
Cargo flow containers (in) [TEU]	-	4,500	-	-
Cargo flow containers (out) [TEU]	-	4,500	-	-
Cargo flow bulk (in) [tonne]	22,936	640	1,870	231,461
Cargo flow bulk (out) [tonne]	-	-	870	463,248

Source: FISN data (2008), cargo flows WenZ and NV de scheepvaart (2009)

### 13.4.3 Calibration of the logit model

In the current day situation only trucks and traditional small inland ships are present. Therefore the spreading parameters  $\mu_{\text{cont}}$  and  $\mu_{\text{bulk}}$  will be chosen so that the calculated market share, based on the generalized costs of the road transport and classic small inland ships, will be equal to the observed market share in table 13.5.

*Container transport*

In table 13.5 can be seen that there is no container transport from the port of Antwerp to companies located at small inland waterways via the small inland ships, except for one company located at the Leuven-Dijle canal (Cargill). This company is using the waterway despite the higher generalized costs of inland shipping, while all the other companies are not using the waterway. Therefore the company is considered as an outlier and therefore the spreading factor  $\mu_{\text{cont}}$  will be determined in such a way that the current market share, for container transport, for small inland ships at all the small inland waterways is zero. In that case the value of  $\mu_{\text{cont}}$  will be equal to 0.06.

By neglecting the current container transport of Cargill it is assumed that Cargill will shift their cargo to the small inland waterways only if the barges can offer a competitive generalized costs compared to road transportation while in reality they have already chosen to use inland navigation. So by neglecting the cargo flows of Cargill in determining the spreading factor  $\mu_{\text{cont}}$  we will determine a transportation price for the small barge system which will be lower than their current price. Therefore it doesn't matter that the cargo flow of Cargill is neglected.

*Bulk transport*

It could also be possible that the observed modal shift cannot be calculated with only the considered cost components (transportation price, cargo handling and VoT) in the generalized costs. The  $GC_{\text{demand}}$  of mode  $i$  could be smaller than mode  $j$ , while mode  $j$  has the largest market share in reality. This is actually the case for bulk transport on routes 1, 2 and 3. This is showed in formula 13.5.

$$P_i > MS_i \rightarrow GC_i < GC_j \quad (13.5)$$

$MS_i$  = observed market share mode  $i$  [tonne]  
 $GC_j$  = generalized costs of the competing mode [tonne]

Because the initially calculated GC of inland ships are slightly larger than the GC of road transportation, it would be rational that the modal split between road and inland navigation would be around 50/50. But in the observations road transport is the most dominant transportation mode. This could be because the lack of reliability or flexibility of the inland ships will direct the companies located at the small inland waterways to road transport. Therefore an extra cost component will be added to the generalized costs of inland shipping to correct for the difference in observed and calculated market share (rest costs).

$$GC_i = OPC_i + VoT \cdot t + REST \quad (13.6)$$

Rest = rest costs [EUR/ tonne]

The value of the rest value term will be adjusted in such a way that the calculated market share will be fitted to the observed market share.

$$P_i = MS_i \rightarrow P_i = \frac{Q_i}{\sum_{k=i}^n Q_k} \quad (13.7)$$

$Q_i$  = observed demand mode i [tonne]  
 $Q_j$  = observed demand mode j [tonne]

The rest-term of the relation 13.6 will be set at zero Euros for the mode that has the smallest calculated market share but also has the largest observed market share (road transportation). The value of the rest term will now be determined in such a way that the calculated market share of the logit-model will be the same as the real market share<sup>47</sup>.

The 'rest' costs will consists of the not yet determined cost components: costs for reliability (REL) and costs of flexibility (FLEX).

$$REST = REL_{in} + FLEX_{in} \quad (13.8)$$

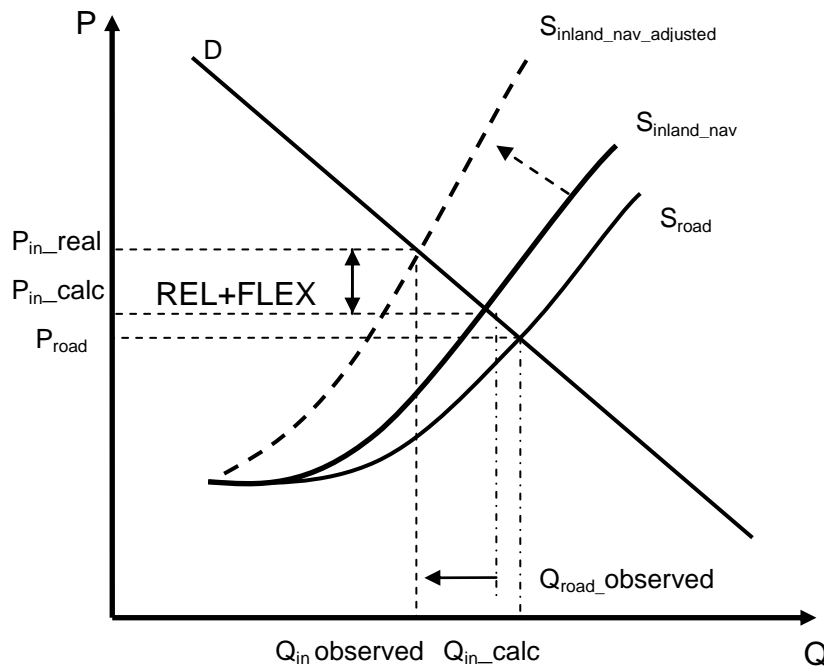
$REL_{in}$  = reliability costs for inland navigation [EUR/ tonne]  
 $FLEX_{in}$  = flexibility costs for inland navigation [EUR/ tonne]

Figure 13.8 shows the visual representation of this approach. The only way to calculate REL and FLEX is to determine the difference in adjusted generalized costs and initial calculated generalized costs of inland ships. In this approach only the combined values of REL and FLEX can be calculated and not the individual values. Because the REL and FLEX of road transport are set at zero Euros, the calculated values of REL + FLEX are the relative costs compared to road transport.

The problem of this approach is that there is one equation (logit equation) and two unknown parameters (rest-term and the value of  $\mu_{bulk}$ ). In order to overcome this problem, a value of  $\mu_{bulk}$  will be predefined. One option is to use a  $\mu$  from another modal split model. The problem is however that the problem at hand is very specific. If a general modal split model was to be used then, most likely, the total inland navigation sector will be taken into account (small, medium sized and large ships) while in this research only the small inland waterways are taken into account. If the value of  $\mu_{bulk}$  is set to be too small (<0.01), the influence of the generalized costs becomes very small. This will lead to a situation where the choice for a specific mode of transport becomes almost independent of the generalized costs of the considered modes.

<sup>47</sup> This approach allows us to determine a rest costs component for inland navigation relative to road transportation

Figure 13.8: Schematic overview of the 'rest' costs



Source: own figure

Trial and error with various combinations of  $\mu_{\text{bulk}}$  and "rest costs" for the considered small waterways, the best result for the total model split of the three waterways is achieved by applying a cost coefficient of 0.5 and a cost correction of 4 EUR/tonne<sup>48</sup>. For lower values of the  $\mu_{\text{bulk}}$  higher cost corrections are necessary to get the same result. This is undesirable because cost corrections have to be restricted as much as possible (Gerrits, 2007).

In the sensitivity analysis of the next section will be shown that a variation of the value of  $\mu_{\text{bulk}}$  will not have large influence on the total outcome of the model. This is due to the additional competition model (TLC approach) added to the model which has been described in the previous section (13.3).

For the small barge convoy system the 'rest costs' will consist of the REL and FLEX costs of the classical inland ships. Due to the set-up of the small barge convoy, it should be capable to deal with the delays and "shocks" in the system. There is a time-window in which the barges can be handled. The system is also designed to sail regularly between the selected waterways, so that the reliability (and frequency) will be higher than for regular small ships therefore the costs of reliability will lower. The REL+FLEX for the small barge convoy are assumed to be equal to half of the FLEX+REL costs of classic inland ships.

In tables 13.4 and 13.5 could also be seen that for route 4 all the cargo that is transported with an origin (or destination) in the port of Antwerp will be transported with inland ships. This is quite the opposite of what is observed for the other waterways. The main reason why all this cargo is

<sup>48</sup> This approach of calibrating logit model is also applied in Gerrits, 2007 where a logit application is made to determine port competition



currently transported with inland ships is that it is only one company who is responsible for this cargo flow. The company is a gravel pit who exports sand via the port of Antwerp. Sand is a traditional commodity flow for the inland navigation sector and therefore inland ships are still used. Although the company is located at a small inland waterway, also larger ships (up to 1100 tonnes loading capacity) are used on that waterway which will transport 50% of all the current cargo flows (cargo flows NV de scheepvaart, 2009). The reason why this can be done is that the waterway administrator allows bigger ships to enter the small waterway on the south (Lock B), via a bigger lock and to sail on the small waterway. This means that those ships must take a detour on their trip to Antwerp compared to small ships which can pass the small locks at the north entrance of the waterway (Lock A). In figure 13.9 an overview of this situation is given.

Figure 13.9: Accessibility of waterway number 4



Source: own figure based on Beelen.et.al, 2009

This means that for route 4 another calibration must be done. In this case the calculated market share of inland navigation is too small. This means that a negative “rest costs” must be added in order to calibrate the logit model for route 4. In this research is chosen not to add a negative cost component for the small barge system but to exclude the rest cost component which has been added to routes number 1 to 3.

In table 13.6 the different values of the  $\mu$  parameters and rest cost components are given for the Flemish case.

Table 13.6: Result of the calibration of the logit model

			Containers	Bulk			
	Routes	[-]	all routes	Route 1	Route 2	Route 3	Route 4
	$\mu$	[-]	0.06	0.5	0.5	0.5	0.5
Road	REL+FLEX	[EUR/tonne]	-	0	0	0	0
IN NAV	REL+FLEX	[EUR/tonne]	-	4	4	4	-4
SBCS	REL+FLEX	[EUR/tonne]	-	2	2	2	0

Source: own calculations

The data presented in table 13.6 are used in the logit model.

#### 13.4.4 Calculation of the market share per mode

The calculated amount of cargo that a mode will transport is equal to the probability that that mode is chosen times the total demand.

$$\text{Cargo}_i = P_i \cdot D_{\text{total}} \quad (13.9)$$

$\text{Cargo}_i$  = transported amount of cargo with mode i [tonne or TEU]

$D_{\text{total}}$  = total demand [tonne or TEU]

This calculated market share for the small barge system will now be compared to the initially assumed market share (recall figure 13.4). As mentioned before, if the calculated market share is larger than the initially assumed market share the solution will be accepted. Otherwise the occupation rate of the barges has to be changed or the design changes have to be made so that the transportation costs will be reduced.

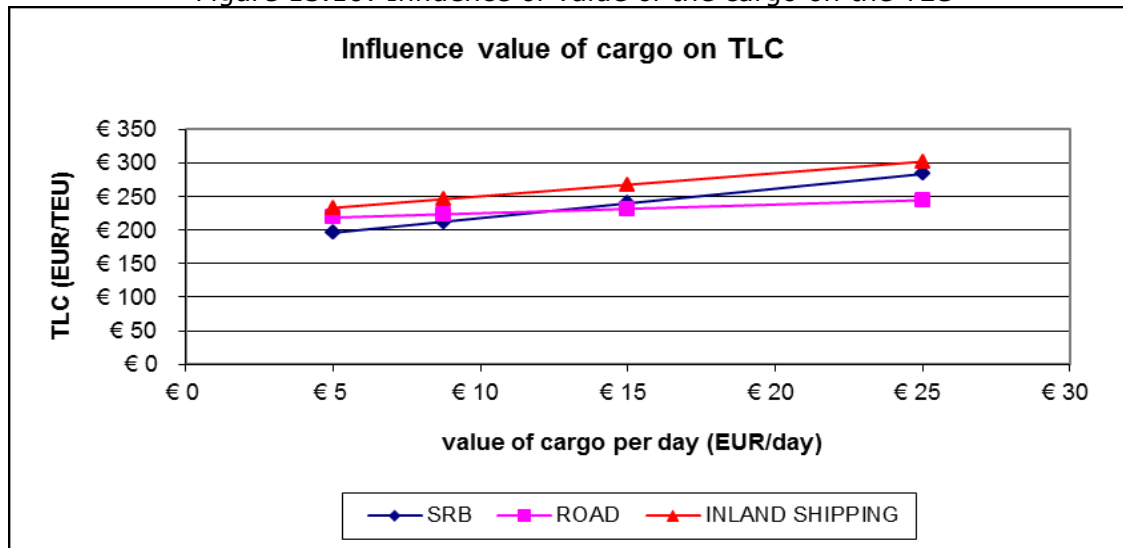
### 13.5 Sensitivity analysis of the total competition model

In this section of chapter 13 a sensitivity analysis will be made for the competition model. First the influence of the value of transported cargo on the TLC per mode will be researched. The second analysis will deal with the influence of  $\mu_{\text{bulk}}$  on the total outcome of the model.

#### 13.5.1 Sensitivity analysis TLC model

The value of the inventory costs is much dependent on the value of the transported (or stored) cargo, as could be seen in the large difference between the TEU and tonne values in the graphs above. In figure 13.10 the influence of the value of the cargo is further examined.

Figure 13.10: Influence of value of the cargo on the TLC



Note: 2009 values

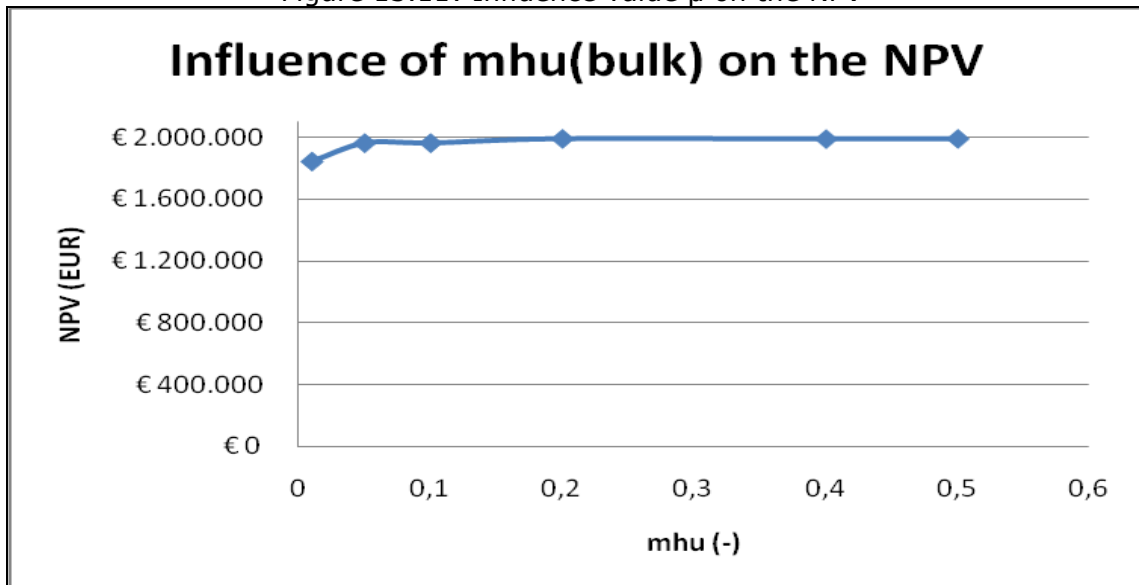
If the value per day of the transported cargo is larger than €12, then in this specific case road transport will have the lowest TLC. If the value of the transported cargo is too high, the small barge convoy system will most likely not be used due to too high costs. Consequently, containers with low value products and empty containers are most suitable for the small barge system.

### 13.5.2 Sensitivity analysis logit model

In the previous section a logit model was used to calculate the market share of the small barge system. In that logit model the value of  $\mu$  (the spreading factor) was chosen arbitrarily for the bulk competition model in order to determine the "rest costs". In this section the influence of the value of  $\mu_{\text{bulk}}$  will be further researched by means of a sensitivity analysis. For the analysis the input parameters of table 13.7 are used. In figure 13.11 the influence of the variation of  $\mu_{\text{bulk}}$  on the NPV will be given.

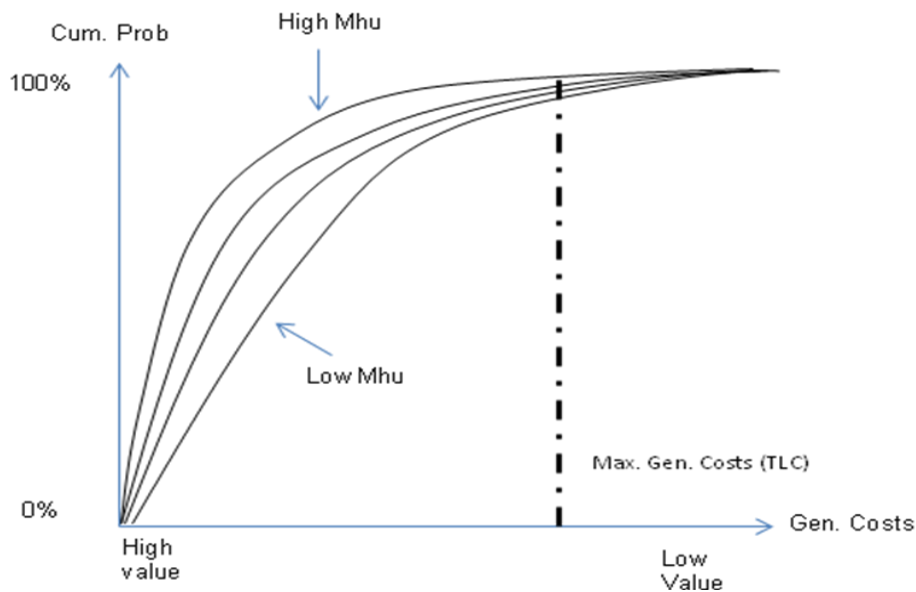
From figure 13.11 can be concluded that the influence of  $\mu$  is rather limited. In the range from 0.05 to 0.5 the value of the NPV doesn't change much. Only if the value of  $\mu_{\text{bulk}}$  is reduced to 0.01 then the NPV will be reduced with 7.5% compared to the initially assumed 0.5 value. The reason why the influence of the parameter  $\mu_{\text{bulk}}$  is limited is due to two reasons. The first reason for the limited influence is that only a part of the total transported cargo is influenced by the variation of  $\mu_{\text{bulk}}$  (transported amount of bulk cargo). The competition model for containers has an own  $\mu$  - value which is not affected by a change in the value of  $\mu$  for bulk cargo.

The second reason is that due to the addition of the TLC criteria (TLC for bulk cargo must at least be 30% lower than the nearest competitor) the maximum allowable generalized costs is limited. If figure 13.2 is recalled it shows that the extra criteria automatically implies that the calculated market share will be large.

Figure 13.11: Influence value  $\mu$  on the NPV

Note: 2009 values

If the value of  $\mu_{\text{bulk}}$  is changed, than that will have an influence on the shape of the cumulative probability line. In figure 13.12 several cumulative probability functions are sketches each representing a different value of  $\mu_{\text{bulk}}$ .

Figure 13.12: Graphical overview of the influence of different values of  $\mu_{\text{bulk}}$ 

Source: own figure

Figure 13.12 shows that the lower the value of  $\mu_{\text{bulk}}$  is, the less steep the cumulative probability line will become. It can also be seen that the maximum value of generalized costs are limited due to the additional criteria of having at least a reduction of 30% on the TLC. The difference between the different lines becomes less when the generalized costs are lower. Only when there is a large difference between  $\mu_{\text{bulk}}$  values (such as 0.5 and 0.01) then there will be a difference in calculated market share. If the market share is reduced, that will lead to less cargo that can be

transported so that the revenue will be reduced and therefore also the NPV. This is what is observed in figure 13.11.

### 13.6 Enlarging the potential market

In this section a calculation will be made with the total model, in order to determine the maximum additional distance that the cargo can be transported from the small inland waterway to a destination further inland with a truck. In section 4.6 the potential market for the small barge system was determined for cargo flows to and from companies located at small inland waterways and for cargo to and from small inland waterways plus an additional part of road haulage.

In order to perform the calculations, all the already mentioned input parameters of the previous chapters are used. In table 13.7 all the different input parameters are given again.

Table 13.7: Overview of all the input parameters

Parameter	Value
$L_{\text{barge}}$	50 m
$B_{\text{barge}}$	6.8 m
Loading capacity	28 TEU or 550 tonne
Independent sailing barge	Yes
$\alpha_l$	25°
$\alpha_{st}$	25°
$V_{\text{barge}}$	7 km/h
$N_{\text{thrusters}}$	4
Max power installed	Yes
Propulsion system	Batteries
N Crew members	1 Captain
Sailing range barge	45 km
Propulsion system tug	Diesel direct
$N_{\text{propellers}}$	3
Sailing regime	Semi continuous
Selected waterways	1,2,3
$N_{\text{barges}}$ per waterway	2
$V_{\text{convoy}}$	12,5 k/m
Fin. Structure	20%equity / 80%loan
Inflation	1,80%
Profit TAX	25.5%

The last input needed to make the necessary calculations is the potential market for the small-barge system. This potential market is the market of the current day cargo flows transported from a deep sea port (in this case Antwerp) with small inland ships to the small inland waterways, plus the current day cargo flows transported to the companies located at the small inland waterways with trucks (see table 2.5 for the complete overview of the potential market).

This analysis will calculate how many additional kilometres of road transportation can be added to the small barge system, so that the small barge system is still competitive towards the competing modes. Therefore the covered distance of the competing modes is kept constant.

This analysis will be done for both the situation when the external costs (chapter 9) are not internalized and when they are internalized. The analysis will also deal with a variation in the value of the goods transported in the containers (fully loaded or empty) (the value of bulk cargo is kept constant). A third variation is to keep the additional truck transport for bulk cargo at zero kilometres, so that only additional transport for container transport is considered.

The additional costs for the small barge system will be equal to the transportation cost for the truck transport plus an additional handling cost of the cargo. Because the barges can also be used as a floating warehouse, the cargo will be stored at the barges. Therefore the containers (or tonnes of bulk cargo) can be directly transferred from the barge to the truck so that only one additional handling cost is added.

In table 13.8 the results of the calculations are shown. In the table the achieved NPV is given as function of the additional distance of road transportation. First the result of the base scenario (direct calls at companies located at the small inland waterways) is given. The second part of the table deals with the mentioned analysis.

From table 13.8 it can be concluded that, if the transported containers are loaded, they cannot be transported further inland. The allowable "road" distance is less than zero kilometres, due to the addition of the handling costs of the cargo. So only the addition of an extra handling cost will make it impossible to transport the containers further inland with trucks. If the external costs are internalized, the small barge system becomes more competitive. However, the allowable covered distance is still smaller than zero so that no additional inland transportation can be done.

Table 13.8: Results of the calculations

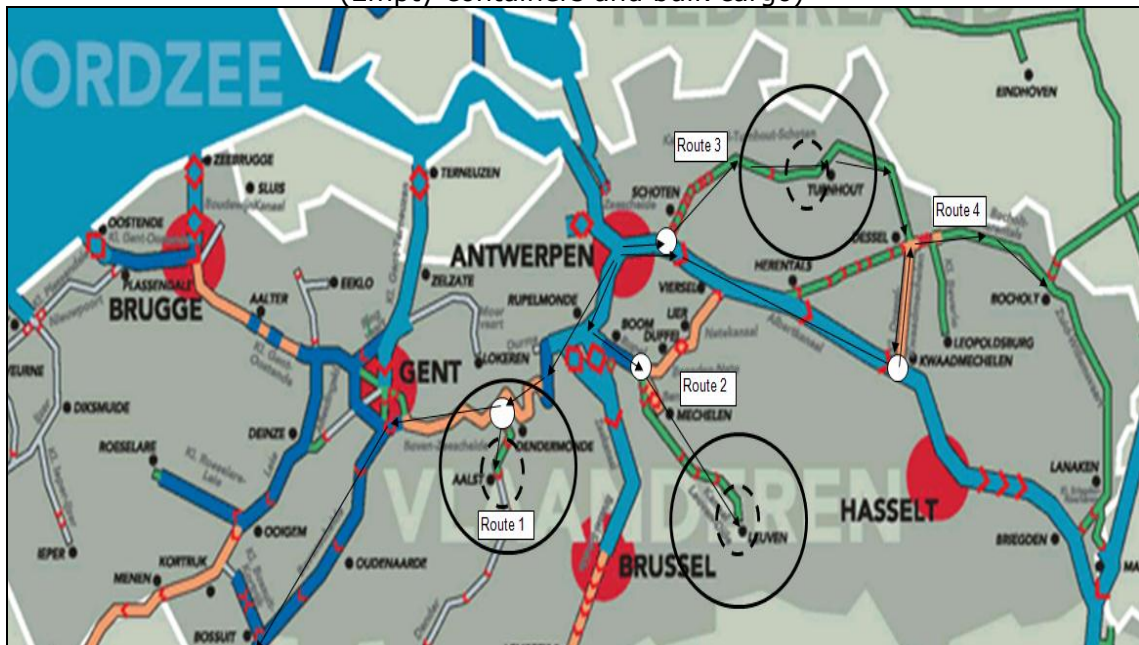
	Internalization of external costs	loaded container	Additional km	NPV
<b>no additional road km</b>	no	Yes	none	€ 1,896,971
<b>additional road km for bulk and containers</b>	no	yes	-25	€ 98,436
	Yes	yes	-10	€ 274,892
	no	no	13	€ 278,055
	no	no	3	€ 1,919,325
	Yes	no	27	€ 204,235
	Yes	no	17	€ 1,817,821
<b>additional road km only containers</b>	no	yes	-19	€ 125,719
	Yes	yes	3	€ 96,691
	no	no	18	€ 1,857,857
	Yes	no	37	€ 1,885,843

Note: 2009 values

The reason why it is possible to add road kilometres to the small barge system if the containers are empty, is the value of time (VoT), which is zero. Therefore the (in-transit) inventory costs are zero. In section 13.3 we already concluded that, if the small barge system is used, the inventory costs are larger than the inventory costs of road transportation. By eliminating those costs, it becomes possible to increase the area from which containers can be transported to and from the deep-sea port. These two potential areas are sketched in figure 13.13.

If the same analysis is done for empty containers ( $\text{VoT} \rightarrow 0$ ), it becomes possible to add further inland transportation. Now two distances are determined. The first distance is the maximum distance so that the NPV is becoming positive (so the investment decision is positive) (13 km) and a distance which will make the NPV (almost) equal to the initial NPV (3 km). If the external costs are internalized, the two previously mentioned distances increase to 27 and 17 km respectively.

Figure 13.13: Overview of the increase in potential market area  
(Empty containers and bulk cargo)



Source: Own composition based on original figure PBV

Note: dashed circle= no internalization of external costs

solid circle = internalization of external costs

From the bottom part of table 13.8 it can be concluded that, when only considering the containers to be transported with additional road transport, it is possible to add 3 km of road transportation if the external costs are internalized, even if the containers are loaded. In that case the NPV is just positive, but it is not possible to get the same NPV if the containers do not have additional road transport. If the containers are empty, the potential market area is increased in comparison with the case when also bulk cargo has to be moved further inland with a truck.

The analysis that has been done did not include the competition of another intermodal option via the larger waterways. Therefore the total of the regions indicated in figure 13.13 cannot automatically be added to the



potential market for the small barge system. This is especially true of waterways one, two and three, where the outskirts of the indicated regions will reach the outskirts of the "intermodal range" of inland terminals located along the large waterways.

### 13.7 Preliminary conclusions

This chapter has shown that by changing the transportation mode for a company the total logistics system has to be altered. If a company is willing to shift its cargo flows to the small inland waterways, more cargo has to be stored at their premises, thereby increasing the total inventory costs. The price that will be offered by the small barge system must be low enough so that the TLC for a company are lower than the TLC of the other modes. Otherwise the companies located at the small inland waterways will not shift their cargo flows. Therefore this extra criterion of smaller total logistics costs compared with the other modes is added to the total model.

The inventory costs are much dependent on the value of the transported cargo. So, if the value of the cargo is too high then the more flexible and faster mode (=road transport) will most likely be chosen.

The sensitivity analysis has showed that the influence of the value of  $\mu_{\text{bulk}}$  is limited especially for values in the range from 0.5 to 0.05. Only when the value of  $\mu_{\text{bulk}}$  becomes smaller than 0.01 then the largest variation in NPV will occur (7.5%).

From the intermodal calculations can be concluded that it is not possible to transport loaded containers further inland with a truck for the considered design. So, only direct calls at companies located directly at the small waterway can be considered. However, if the containers are empty, 3 km of road transport can be added. If the external costs are internalized, that distance increases to 17 km. If bulk cargo has a destination at a water-bound company and therefore only the containers have to be transported further inland, the potential distance that the truck can drive is increased, compared with the case when also bulk cargo has to be moved further inland with a truck.

In the next chapter the complete developed model, of chapters 5 to 13, is used to determine the most optimal design of the network and tug plus barges. In this analysis, initially, only direct deliveries to companies located at the small inland waterways will be considered. When the most optimal design is determined, again an additional analysis will be done to check whether it is possible, for that specific design, to add truck transport to the small-barge system.



# **PART III: APPLICATION**



# **14. Applying the small barge system in a real case**

## **14.1 Introduction**

To demonstrate the small-barge convoy system developed in part I of this thesis, the methodology developed in part II will be applied to one geographical area. This study will focus on a real case on the Flemish small waterway network (this chapter) and on a theoretical infrastructure analysis (chapter 15). The model, developed in part II, is used to investigate which design of network and of tug and barge design is best to use in terms of highest NPV. In order to research the best design and logistics system of the small-barge convoy, several designs and network options are calculated and analysed.

This chapter consists of 4 sections. In the first section the selection of the geographical area is given. The second section will deal with the potential demand of the selected area. The third part will consider the determination of the main features of the small-barge convoy system, such as sailing speed, number of barges deployed per waterway, etc. When the main characteristics of the concept have been determined, an overview will be given of the developed case(s), along with design of the used barges and tug. In the last section different future scenarios are given which will be used to analyse the developed business cases.

## **14.2 Selection of the geographical area**

The small-barge convoy system will be applied in a real case. It is therefore necessary to select the geographical area where the concept will be applied to. Because the concept is set up to deal with the hinterland traffic of a main hub (seaport), it has been chosen to analyse the feasibility of setting-up the small-barge convoy system in the hinterland of the seaports of Rotterdam or Antwerp. In figure 14.1 an overview of the inland waterway network in the BeNeLux can be found, where the regions are indicated with a lot of small inland waterways.

Figure 14.1 shows that the major small inland waterways are located in Belgium and the south of the Netherlands. A dense network of small inland waterways can equally be found in the northern and the mid part of the Netherlands, as well as in the region between Rotterdam and Amsterdam.

The choice has been made to do a case study based on the Flemish small inland waterway infrastructure. In the Flemish case the port of Antwerp will be used as the main port.

Figure 14.1: Overview of the selected geographical areas



Source: bureau voorlichting binnenvaart, 2009

The Flemish case study is further analysed in the next section of this chapter. There will also be an additional chapter dealing with variation of the infrastructure (chapter 15). The reason for this chapter is to analyse the effects of the infrastructure characteristics on the transportation costs and the competitiveness of the small barge concept.

### 14.3 Potential demand

The total available market of cargo flows having an origin or destination in the port of Antwerp and an origin or destination at the small waterways in Flanders is given in the figure 14.2 and table 14.1. The cargo flows are a summation of the existing cargo flows and the potential cargo flows that are now transported by road.

The cargo flows shown in table 14.1 are those cargo flows with an origin or destination at companies located directly at the small inland waterways. The calculations in chapter 13 have shown that no additional road transportation can be added to the small barge system when the containers are loaded and when two barges are used in a convoy which is sailing to three different small inland waterways (all the containers in the potential cargo flows are loaded). The potential market area can be increased if empty containers are added. But that specific cargo flow data is not available, so that only direct deliveries to companies located at the small

inland waterways are considered. In the upcoming section the main features of the small barge system will be determined. When the most promising design (barge, tug and network) has been determined, again an analysis will be made to determine whether it is possible to add cargo flows which have to be transported with an additional truck movement.

Figure 14.2: Overview of the different small waterways in Flanders



Note: original figure adapted from PBV

Table 14.1: Cargo flows from the seaport Antwerp to the different waterways

		ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4
Small Waterway	[-]	Dender	Leuven-Dijle	Dessel - Turnhout - Schoten	Bocholt - Herentals
Cargo flow containers (in)	[TEU]	2,250	7,500	8,140 <sup>49</sup>	-
Cargo flow containers (out)	[TEU]	2,720	12,600	9,950	-
Cargo flow bulk (in)	[tonne]	233,500	128,000	10,000	231,461
Cargo flow bulk (out)	[tonne]	-	-	84,000	463,248

Source: BCI (2006), FISN data (2008), cargo flows WenZ and NV de scheepvaart, (2008)

In the upcoming analysis the demand is considered to be constant. Only the supply side will be changed. The impact of varying demand (decreasing) will be further researched in chapter 16 on the implementation of the small barge convoy system. That chapter will analysed the impact of operating the small barge convoy with only half of the potential demand.

<sup>49</sup> in the cargo flows the container flows from the inland terminal in MOL are added in because these cargo flows are part of the potential market study of Waterslag, 2006

## **14.4 Determining the main features of the small barge convoy system**

When the total potential demand is known, the main features of the small barge convoy system need to be determined. These main features are:

- Convoy of independent or non-independent sailing barges
- The number of barges per waterway
- The propulsion system of the tug (diesel direct or diesel electric)
- The sailing regime on the tug
- The design speed of the tug and barge convoy
- The selected number of waterways
- The number of extra barges in the total system
- Adding inland container terminals to the total system

In order to determine the features mentioned above, the developed model of part II is used to construct several graphs in which the influence of the analysed parameter is shown. The researched parameters are expressed in NPV of the total tug and barge system (see chapter 11). Also the calculated total logistics costs are given (see chapter 13). The TLC per TEU and tonne are an average of the different waterways. In this research the TLC per TEU should be at least 5% smaller than its nearest competitors, while the TLC per tonne should be at least 30% smaller (see chapter 13).

All the design input parameters will be same as shown in table 13.4. If some parameters are changed, this will be mentioned in the specific analysis.

In the following analysis the fuel price, interest costs, steel costs are calculated at 2009 level. In section 14.5 the influence of changing these figures will be determined via a scenario analysis.

As could be seen in chapter 6.3, several port organization options can be used for the small-barge system. For the Flemish case the multiple-barge exchange point option is used (6.3.2.3). The reason for this option is that the distance between the terminal groups is considerable. Therefore, the tug is also used to push the barges between the terminal groups in the seaport (see figure 6.11).

The demand data given in table 14.1 is aggregated at the level of the port, i.e. from the data it cannot be known to which specific destination the cargo goes in the port. Accordingly, two locations are chosen in order to perform the calculations. The first port destination is the Oosterweel-port because there are a lot of bulk terminals. The cargo data shows that a large part of the cargo flows is bulk cargo. The second port-area chosen is the Wilmarsdonk-port. If the data are more disaggregated in the port-region that could be used in the developed model (see figure 6.12).

### **14.4.1 Independent or non-independent sailing barges**

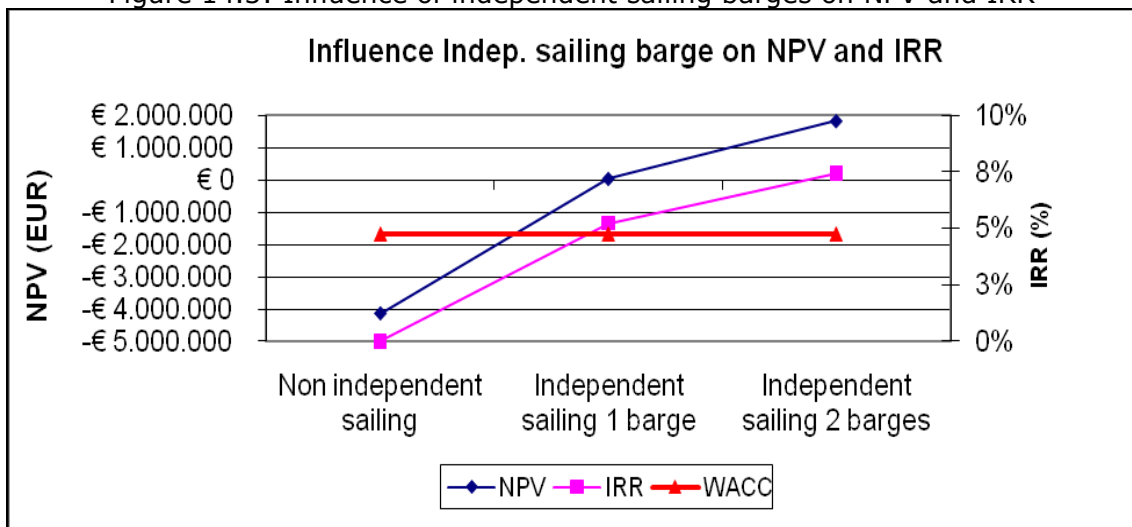
In this section the NPV (enterprise perspective; see also chapter 11) and the total logistics costs per TEU and tonne are calculated for three cases in

which barges will be pushed on routes numbers one, two and three (see figure 14.2). Also the TLC of the competing modes are presented.

In the first case, the tug will push single barges to the small inland waterways, from where the tug will also push the barges on those waterways. In the second case the tug will push a single barge at the large waterway which can sail independently on the small inland waterways. In the third case the tug will push two barges to each waterway. If the barges can sail independently on the small inland waterways, the tug and barge convoy can increase in size (number of barges), but, if the tug also has to push the barge on the small waterways, the tug and barge convoy is limited to one barge, due to the fairway and lock dimension restriction on those waterways. In the analysed cases the tug is designed with a diesel direct propulsion system that can sail at a speed of 3.5 m/s. On the tug there will be a semi-continuous sailing regime. In the preformed analysis it is assumed that the barge can be operated with a single captain (see table 13.4). The implications of the situation when it is not possible to operate the barge with one captain will be further analysed in the next part of this chapter (scenario analysis).

In figure 14.3 the results are given from the preformed NPV and IRR calculations.

Figure 14.3: Influence of independent sailing barges on NPV and IRR



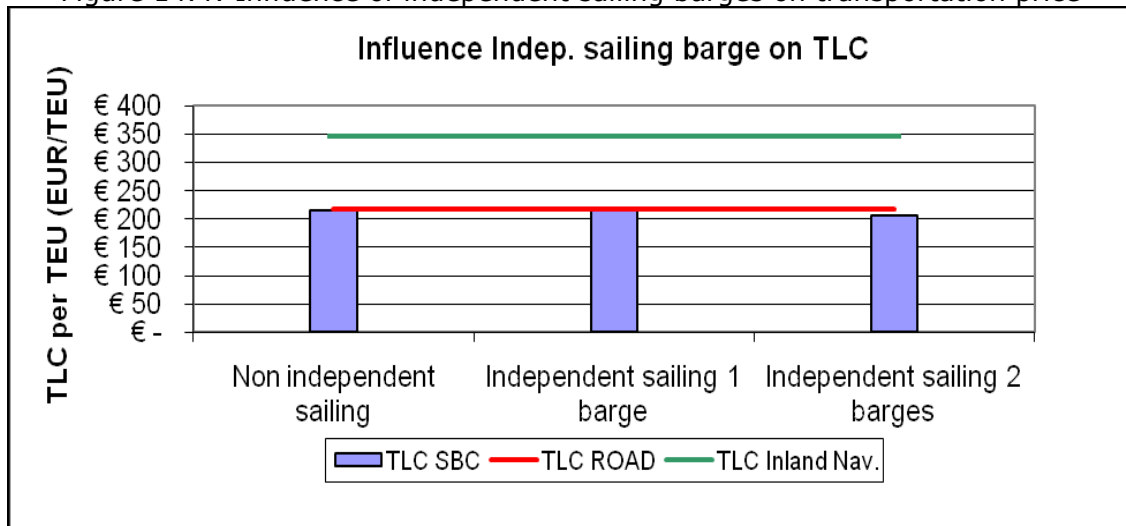
Note: 2009 values

Figure 14.3 indicates that, if the barges cannot sail independently on the small inland waterways, the NPV increases from €-4,100,000<sup>50</sup> to €1,800,000 if the barge can sail independently (2 per waterway). If only one barge is used, the NPV is just positive.

In figures 14.4 and 14.5 the total logistics costs (TLC) per TEU and tonne are given. Those figures could lead to the conclusion that the TLC per TEU and tonne will be reduced if the barges can sail independently.

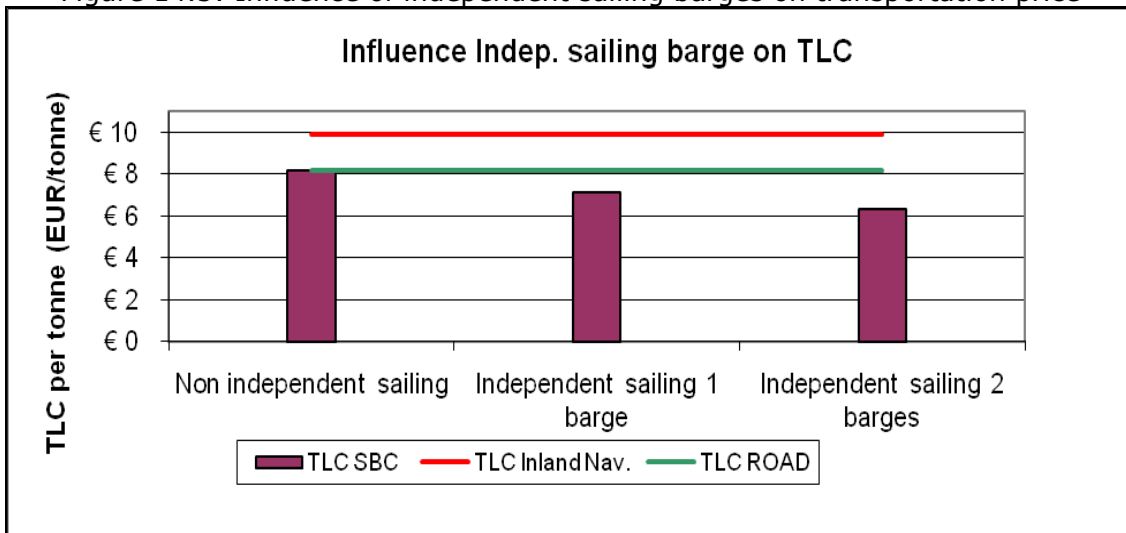
<sup>50</sup> Discounting factor  $r = \text{WACC} = 4.8\%$  see chapter 11

Figure 14.4: Influence of independent sailing barges on transportation price



Note: 2009 values

Figure 14.5: Influence of independent sailing barges on transportation price



Note: 2009 values

This is due to the fact that the time needed to perform a transportation task increases if the tug has to push the barges on the small inland waterways. This increase is caused by the necessity of un-coupling before and re-coupling the barge after every lock passed by the convoy on the small waterway. The reason is that the lock dimensions are too small to accommodate a barge including a tug. As a result of the increased transportation time, the transportation costs, and also the transportation price, will increase. This will result in an increase in TLC compared to the independent sailing barges. In order to implement a new system the TLC cannot be larger than that TLC of the competing modes. Section 13.4 determined that the TLC per TEU should be at least 5% smaller and per tonne the difference should be at least 30%. These differences cannot be achieved for the non-independent sailing option. This indicates that no suitable business case can be made if the tug must also push the barge on the small inland waterway. Also for the single independent sailing option the required difference in TLC cannot be done either (the difference in TLC per TEU cannot be obtained). A positive investment can be made if at least 2 independently sailing barges are used in one convoy.



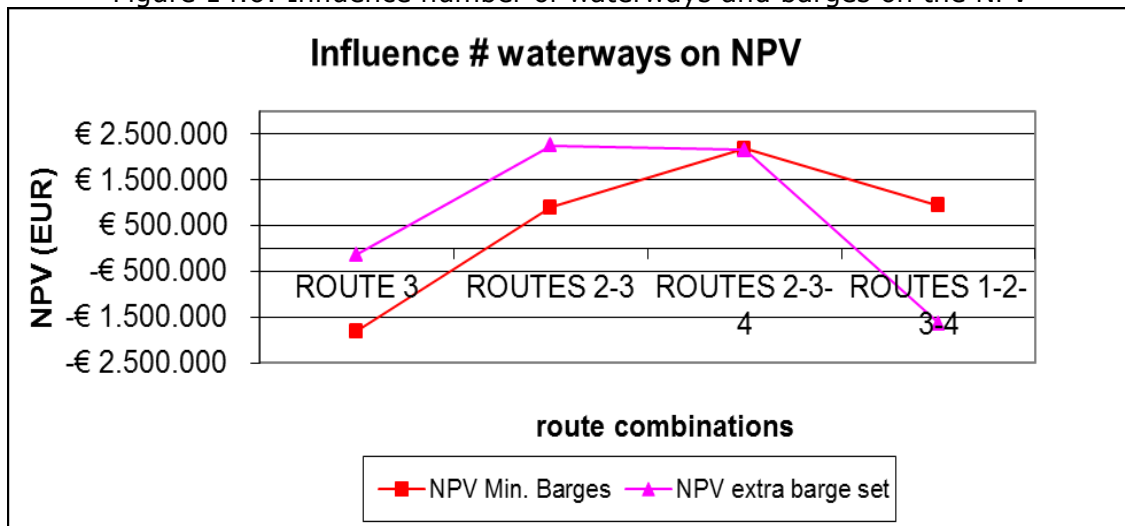
It is therefore concluded that a non-independently sailing barge system cannot be used, so that the used barges must be capable of sailing independently. From figures 14.4 and 14.5 it can also be concluded that the TLC, and also the transportation price, is reduced if the size of the barge convoy increases. The competitiveness of the small barge convoy is increased if the size of the barge train is increased.

#### 14.4.2 Determining the network and number of barge sets

In this section of chapter 14 the influence of adding more waterways to the total small barge system will be analysed. The network combinations are varied from a single route (route 3), up to combinations of two (routes 2-3), three (routes 2-3-4) and four routes. In addition, the influence of the number of barge sets in the system is analysed. In this analysis, the tug is designed with a diesel direct system and the tug will sail with a semi-continuous sailing regime. On all the waterways, a barge convoy of two barges is being pushed by the tug.

In figure 14.6 the NPV of minimum number of barge sets and extra barge sets as a function of the number of selected routes are given (see chapter 6.4).

Figure 14.6: Influence number of waterways and barges on the NPV



Note: 2009 values

From figure 14.6 it can be concluded that by adding more routes to the total barge system the NPV will increase. If only one waterway is used, no suitable business case can be made ( $NPV < 0$ ). If only one route is used (route 3), the time to push the barges from the seaport to the small waterway is smaller (1 day) than the time needed to sail and handle the barges on the small waterway (3 days). Therefore the tug will be used once every three days. If an extra waterway is added (Routes 2-3), more barges are pushed and the tug will be used twice every three days. If three routes are used, the tug will be in use every day. The NPV will further increase in this case because the tug will be used all days.

If 4 routes are used, the NPV will decrease again. The decrease in NPV, when combining four routes, is due to the increase in transportation costs. This increase is caused by the reduced economies of density of the tug and

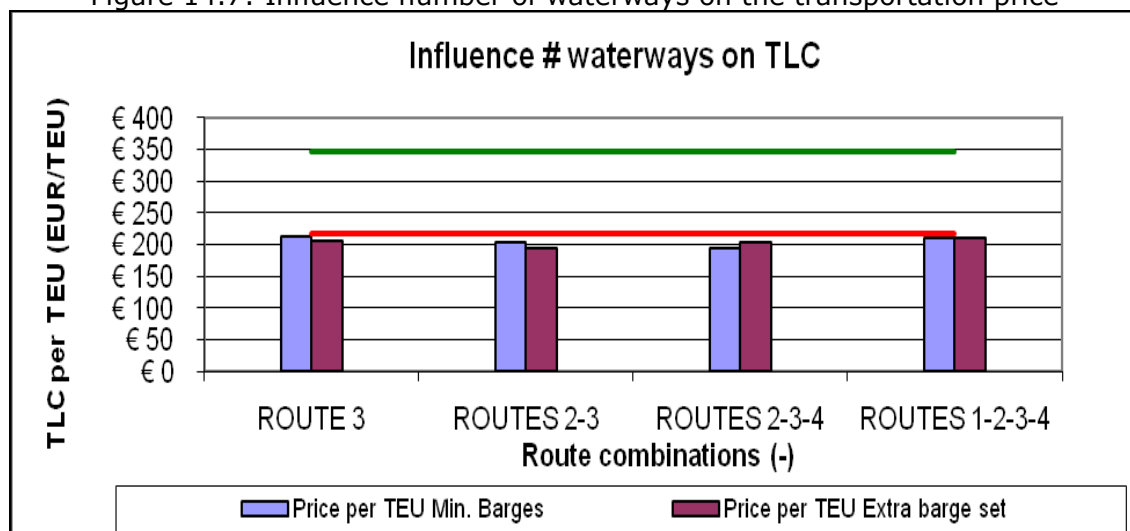
barge system. The time needed to push all the barges from all the waterways is larger (4 days) than the time needed that the barges are on the small waterways (3 days). So the fixed costs are increased (due to more barges) while there is not an increase in transported cargo.

If only a logit model was used in the competition model, the increase in transportation costs (and also the price) could be accepted due to a reduction in the number of departures per year per waterway. The amount of cargo that will be transported per waterways is reduced so that a smaller percentage of the total available demand is needed and a higher price can be accepted. For these kinds of design the TLC approach has to be added (see chapter 13.2).

Figure 14.6 shows that by adding an extra barge set to the small barge system the NPV will increase because more trips per year can be made. The time needed when a barge set on the small waterway has to return to the seaport is reduced if more barge sets are used. If more barge sets are added to the system when the tug is sailing to three different waterways, the NPV will be almost the same if no extra barges are added. The extra costs of having more barges are only partly compensated for by a small increase in departures per year (from 83 to 87 per waterway). If extra sets are added when the tug is pushing barges to 4 different waterways, the NPV will decrease again to a level below zero (no investment possible). This decrease is also due to the fact that even more barges are added to a system that will not benefit from extra capacity. In figure 14.7 and 14.8, the TLC are given per TEU and tonne for the small barge system and its competitors.

If the TLC is analysed, it can be concluded that by adding more waterways the TLC are reduced until there are three routes in the system. When the fourth route is added, the TLC will increase again to the level of the TLC of road transportation, owing to the decrease in trips that can be made and therefore to the increase in transportation costs. The increase in costs is due to the increase in the number of barges so that the fixed costs are increased. Chapter 8.3 has already shown that the total transportation costs are very much dependent on the fixed costs.

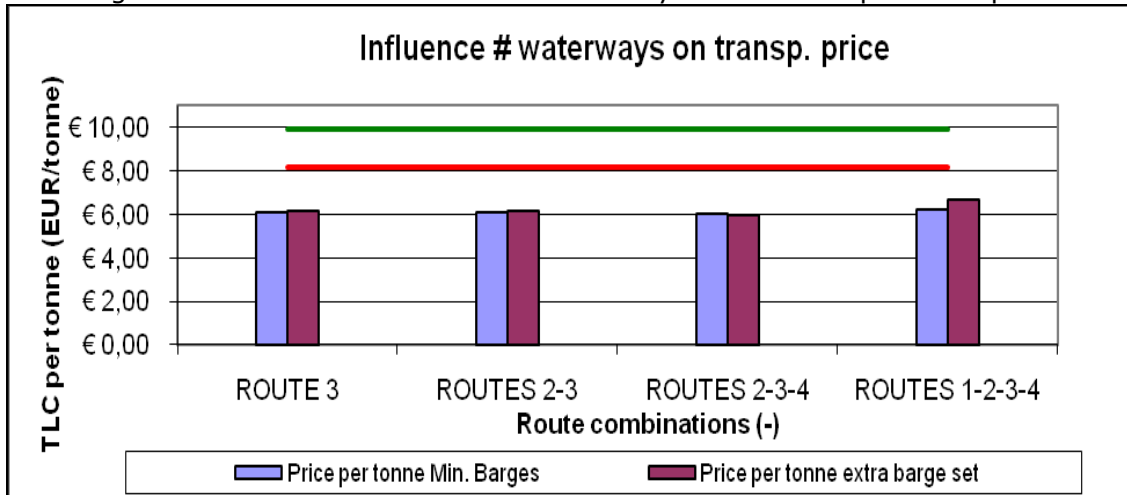
Figure 14.7: Influence number of waterways on the transportation price



Note: 2009 values

In all situations, for the transportation of bulk, the TLC are lower than the TLC of the main competitors (figure 14.8). Therefore it can be concluded that transporting bulk cargo has a higher potential than transporting containers. This is due to the higher costs of keeping containers in stock (in-transit and at the company). These stock costs are related to the value of the products (see chapters 8 and 13).

Figure 14.8: Influence number of waterways on the transportation price



Note: 2009 values

In order to determine the network and number of barge sets, it can be concluded that adding extra waterways is profitable until the time needed to push the barges from the entrance of the small waterway to the seaport becomes larger than the total time needed by the barges to spend on the small waterway. In this case a combination of 3 routes is the best option.

Regarding the extra barge sets it can be concluded that adding extra barges sets is profitable if the time needed before a barge on a small waterway is available, is reduced to a time that is equal to the time needed to push the barges from the entrance of the small waterways to the seaport.

#### 14.4.3 Determining the propulsion system, sailing regime, sailing speed and the number of barges per waterway

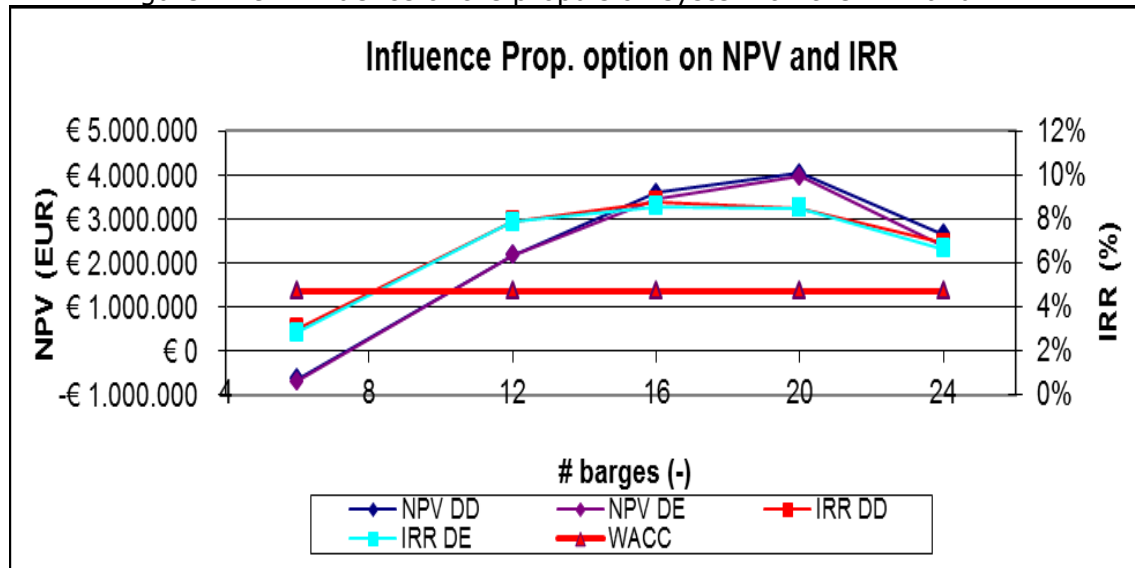
In this section the propulsion system, the sailing regime, the sailing speed and the number of barges per waterway will be determined. All the parameters analysed are made function of the number of barges that are deployed on the selected waterways. The selected waterways are kept constant and are routes numbers two, three and four (see figure 14.2). In table 14.2 an overview is given of the number of deployed barges per waterway. In the analysis of the selected parameters only the total number of used barges is given in the graphs.

Table 14.2: Overview of the number of deployed barges per waterway

	Route 2	Route 3	Route 4	total barges
	[-]	[-]	[-]	[-]
Option 1	1	1	1	6
Option 2	2	2	2	12
Option 3	4	2	2	16
Option 4	4	4	2	20
Option 5	4	4	4	24

In the preformed analyses the barges are sailing independently on the small inland waterways and they are equipped with batteries. In chapter 8, fig 8.4 shows that the transportation costs do not differ much between the different barge propulsion systems. The speed of the tug and barge convoy is set at 3.5 m/s and a semi-continuous sailing regime is used. The influence of the number of barges per waterway and opting for a diesel direct or a diesel electric system is given in figure 14.9.

Figure 14.9: Influence of the propulsion system on the NPV and IRR

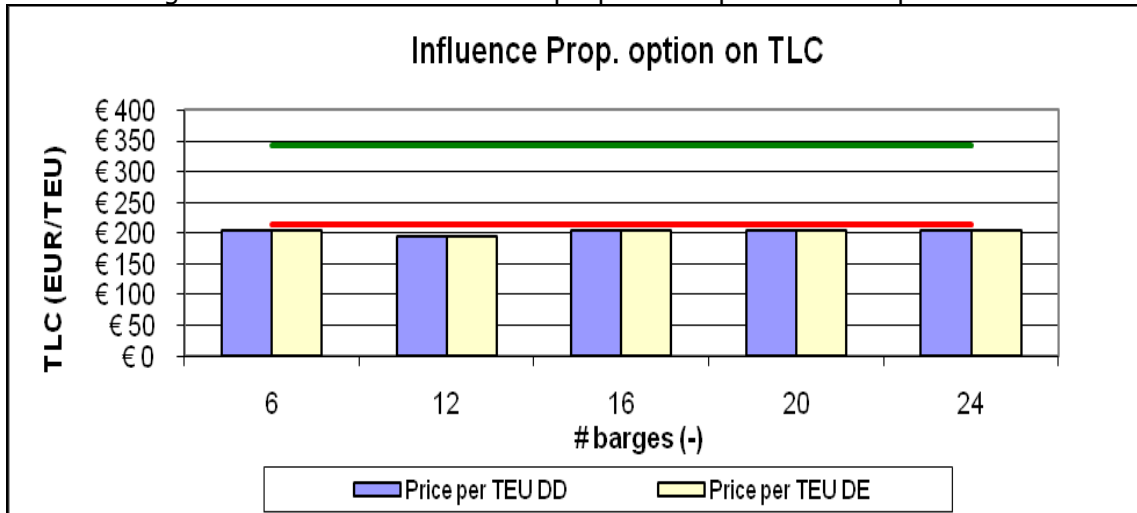


Note: 2009 values

From figure 14.9 it can be concluded that an optimum value of NPV is achieved when 20 barges are deployed. In terms of IRR 12 barges is the most optimal option. There is an optimum because adding more barges to the total tug and barge system means more cargo capacity and thus generation of more revenue. Only if too many barges are added, not all the barges can be fully loaded, due to insufficient demand. Therefore the revenue will not grow while the costs do. Therefore the NPV and IRR will decrease if too many barges are used in the network.

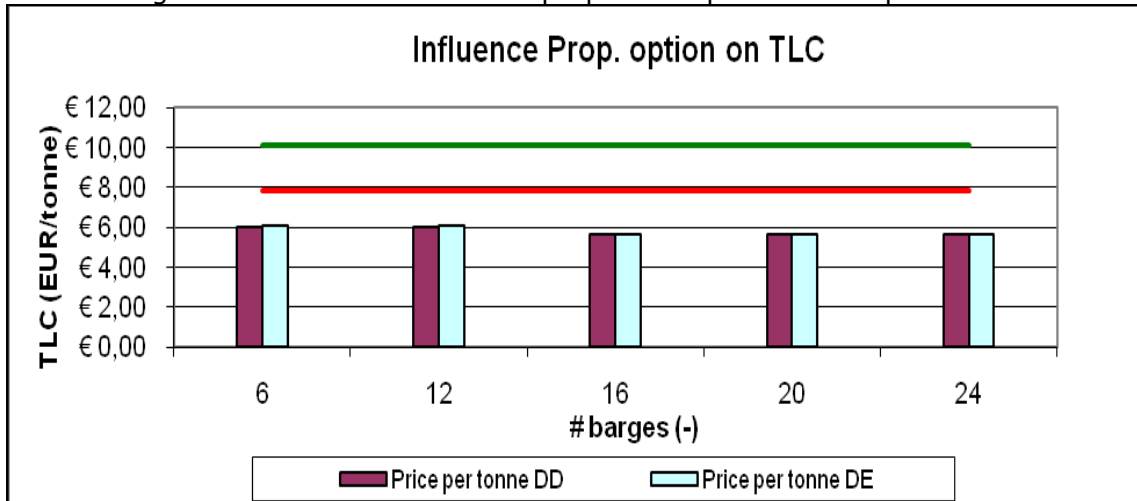
In figure 14.10 and 14.11 the TLC per TEU and tonne are given as a function of the number of deployed barges. In the same figure the TLC of the competing modes are also added.

Figure 14.10: Influence of the propulsion option on TLC per TEU



Note: 2009 values

Figure 14.11: Influence of the propulsion option on TLC per tonne

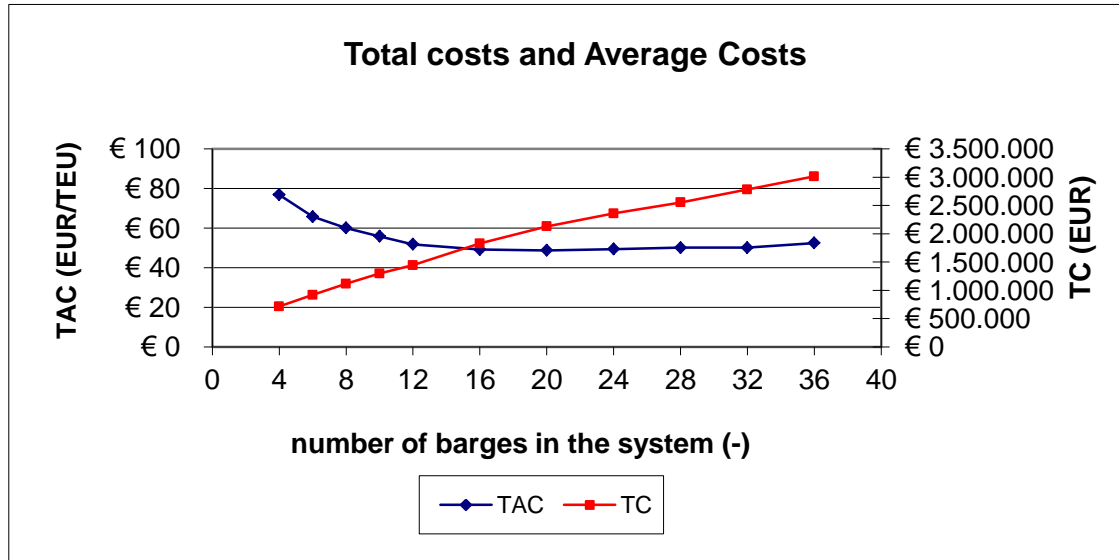


Note: 2009 values

Figures 14.10 and 14.11 show that the TLC per TEU and tonne will decrease if the number of barges deployed on the waterways increase. The reduction will be very small if more than 16 barges are used in the small barge convoy system. The figures also show that the TLC per TEU of the barge convoy are 5% smaller than the TLC per TEU of road transport. The TLC per tonne are much smaller for the barge convoy than for the competing modes (<30%). This large difference is mostly due to the value of the transported cargo and therefore also to the costs related to the transportation time (in-transit-carrying costs) and inventory costs (see also chapter 13).

In figure 14.12 an overview is given of the average total costs per TEU and tonne as function of the number of barges added in the tug and barge convoy.

Figure 14.12: Total costs and total average costs as function of the number of barges



Note: 2009 values

The figure shows that the total average costs (TAC) decrease until there are 24 barges in the total system (4 barges per waterway). If more barges are added, then the TAC are almost constant. In the same figure also the total costs are shown, which will not grow exponentially but will increase with a power smaller than one. This can be seen in relation 14.1.

$$TC = a \cdot N_{\text{Barges}}^{\pi} \quad (14.1)$$

TC = total costs [EUR]  
 A = constant = 282,611 [EUR]  
 $N_{\text{Barges}}$  = number of barges [-]  
 $\pi$  = constant = 0.6638 [-]

Figure 14.9 was already concluded that the most optimal configuration of the small barge system is achieved when 20 barges are deployed. The 20-barge option is in the region that the TAC are still (slightly) decreasing. This is an indication that the demand line will intersect the marginal costs line at a position where the TAC is still decreasing.

In figure 14.13 a schematic overview of the demand, the long-run marginal costs (LRMC) and the total average costs (TAC) lines of the small barge convoy system are given. In this figure the LRMC-line of the small barge concept will intersect the TAC in its minimum. The figure shows that the TAC will decrease with the increasing size of the deployed convoy. This can be explained by the fact that the crew costs, for example, depend on the size of the convoy. If the barge convoy is increased from 1 barge to 2 barges, no extra crew members are needed. Therefore the crew costs are the same on the large waterway. The fuel costs per loading unit will also be reduced because by increasing the size of the barge-convoy the resistance will grow less than linearly, due to the barge train coefficient (see chapter 7.2). When more power is needed to push more barges, larger engines will be installed which will be more effective than the smaller engines (see chapter 7.3).

Figure 14.13: Schematic overview of the demand- and the supply line of the SBCS

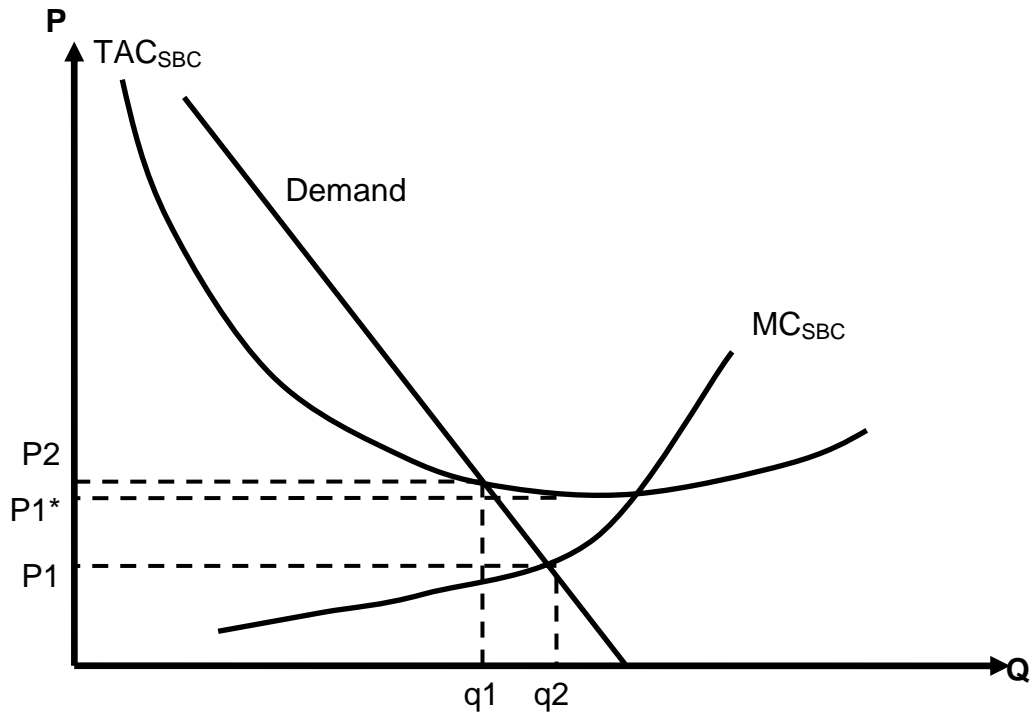


Figure 14.13 indicates that the demand on the small waterways is too small so that the demand line will have an intersection with the marginal costs line at the point where the TAC is still decreasing ( $q_2$ ). This indicates first of all that the prices cannot be determined by the LRMC because in the long run the TAC are higher than the MC ( $P1^* - P1$ ). Secondly, this indicates that not enough cargo is available to accommodate similar small-barge systems. Therefore the small barge convoy will operate in a natural monopoly. This means that no other inland shipping company can enter the same business with the same costs structure (large amount of fixed costs which relates to the amount of barges in the small-barge convoy system). Traditional small ships and trucks with different costs structures can enter the market. Therefore this small barge convoy system is quite similar to the railway operators, large electricity plants, water plants, etc. The reason for this behaviour is the large impact of the fixed costs on the total costs. The better the assets are utilized, the lower the average costs will be.

From figure 14.9 it can also be concluded that the difference between the diesel electrical option and the diesel direct propulsion option is very small. In the first two options (6 and 12 barges) the difference is negligibly small. When more barges are added, the NPV of the diesel direct option is a little bit higher than the NPV of the diesel electric option. Even if a propulsions system is designed for two specific sailing conditions (pushing 2 or 4 barges, see section 7.3), that more complex and expensive option will not result into a higher NPV.

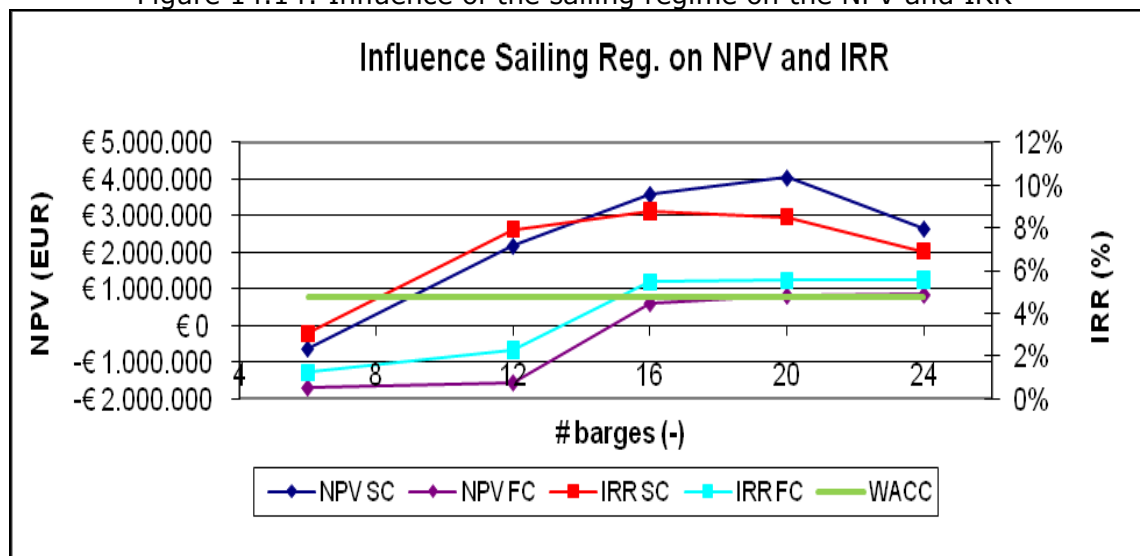
The result can be explained by the relatively small power requirements between the two design conditions. If a diesel-electrical option is installed, the generator-set installed for the second condition (4 barges) is small, which will lead to a higher specific fuel consumption of the small gen-set (small engines consume more fuel per produced kW than larger ones). A diesel electrical propulsion system also has an additional loss of 10%

because mechanical energy has to be transformed into electrical energy, which again has to be transformed into mechanical energy.

Graphs 14.10 and 14.11 show that the difference between the TLC for the diesel direct and the diesel electric option is very small. It can be therefore concluded that it does not matter which propulsion option is chosen in terms of NPV and TLC. Consequently, the choice of a propulsion system has to be based on other aspects such as the most reliable and easiest to install option. In those terms the diesel direct system is more in favour than the diesel electrical system. The diesel electrical system will have more components such as electric engines, switch boards and converts. This will make that option more complex, while the extra complexity will not lead to extra NPV compared to the more robust diesel direct system. Therefore the diesel direct system will be chosen to be installed on the tug.

The next parameter to be analysed is the sailing regime on the tug and barge convoy. In this analysis the same route combinations as in the previous analysis are used. Only, now is the sailing regime varied instead of the propulsion system. The now fixed propulsion system is the diesel direct option. Figure 14.14 shows that there is a large difference between the semi (SC) and full-continuous (FC) sailing regime.

Figure 14.14: Influence of the sailing regime on the NPV and IRR



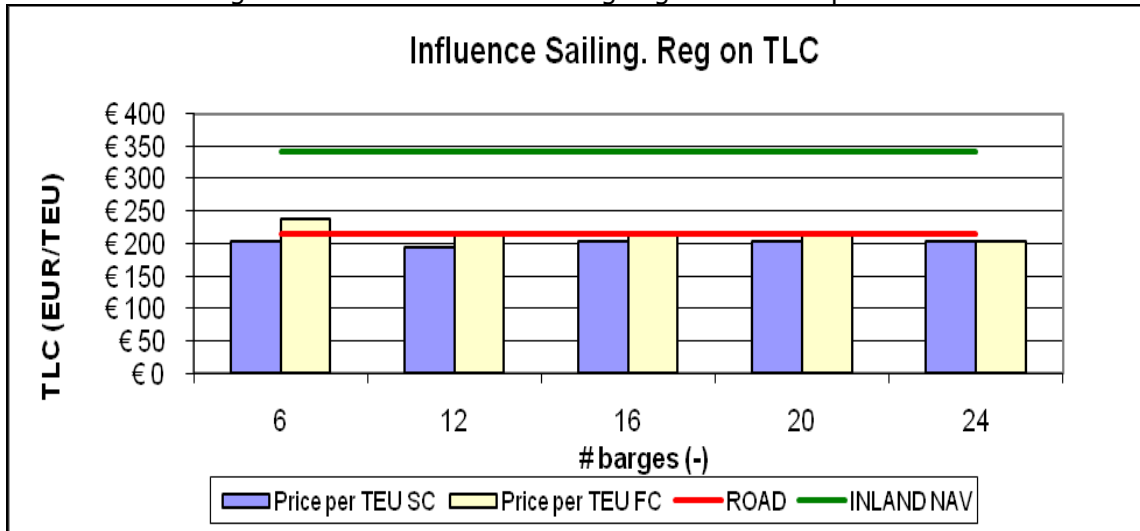
Note: 2009 values

The semi-continuous option has a much higher NPV and IRR than the full continuous option. In a FC option the tug will be in use for 24 hours per day (including 24 hours per day crew-costs on the tug), while there are not enough barges to move in the extra time. Therefore the extra costs are not compensated for by extra revenue. The NPV will increase for the full continuous options if the barge train size increases from 6 to 26 barges. The NPV of the full continuous option is increasing with increasing barge train size. If the barges are operated 24 hours per day, the transportation time is reduced resulting in a decrease of the in-transit-inventory costs. This will have large impact.

The same conclusion can be made based on the figures 14.15 and 14.16, where the TLC is given for the SC and FC sailing regime.

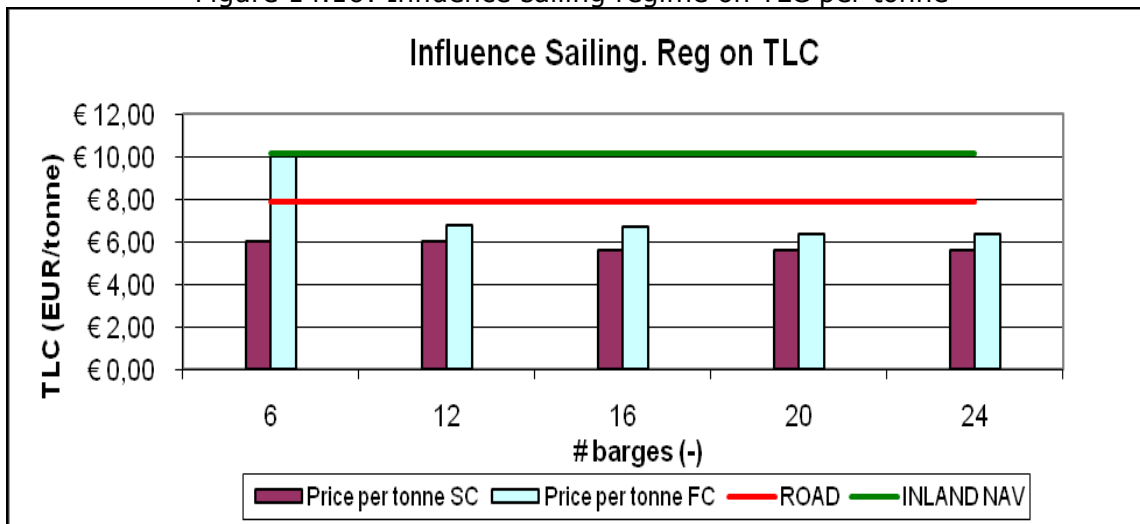


Figure 14.15: Influence sailing regime on TLC per TEU



Note: 2009 values

Figure 14.16: Influence sailing regime on TLC per tonne



Note: 2009 values

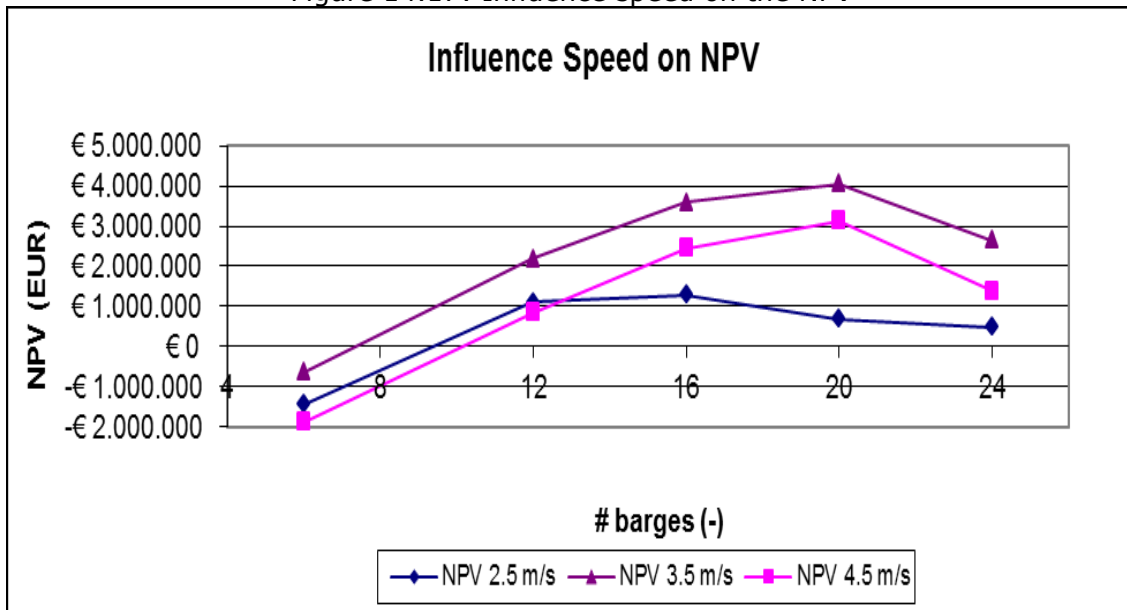
The TLC per TEU decreases to the level of SC sailing regime if the FC sailing regime is used when the number of barges in the network is increased. This is because, when the available operating time of the barge is increased, the total transportation time is decreased (from 1.3 days in the SC to 0.74 days in FC). This decrease in transportation time will also decrease the in-transit-inventory costs. This decrease in inventory costs is the largest for the commodity type with the largest value (loaded containers) instead of the commodity type bulk. The increase in the transportation price will be countered by decreasing the in-transit-inventory costs for container transport and not for bulk transport. As a result, the TLC per tonne for the FC sailing regime is much higher than the TLC when the SC sailing regime is used, which decreases the competitiveness.

Based on the higher NPV of the SC sailing regime and the lower TLC per TEU and tonne cargo, it can be concluded that a semi-continuous sailing regime has to be chosen instead of the full continuous sailing regime.

The third parameter to be analysed is the speed of the tug and barge convoy. In this analysis the same route combinations are used as in the previous analysis; only the speed is varied instead of the propulsion system or sailing regime. The sailing regime is now determined at semi-continuous. In figure 14.17 the influence different design speeds are given. The speeds are varied from 2.5 m/s (9 km/h), 3.5 m/s (12.6 km/h) to 4.5 m/s (16.2 km/h).

Graph 14.17 shows that the NPV for the 2.5 m/s and 4.5 m/s option is lower than the 3.5 m/s option for all the barge combinations. The line of the 4.5 m/s option has the same pattern as the 3.5 m/s line with an increasing NPV when the number of barges pushed is increased until there are 20 barges in the total system. The maximum value of the 2.5m/s is reached when there are 16 barges deployed. The 4.5 m/s design has a higher NPV than the 2.5 m/s design when the barge train is increased ( $N_{\text{barges}} > 12$ ). This is because the higher speed will decrease the transportation time so that more trips per year can be made if at least one barge train has four barges. If four barges are coupled in one convoy, the time needed to couple and decouple them will be consume quite a lot of time, so that less time is available to sail. By increasing the speed this can be compensated for in comparison with the 2.5 m/s design. Over the total range of barge train size the 3.5 m/s design still has the highest values, so that increasing the speed to 4.5 m/s is not useful.

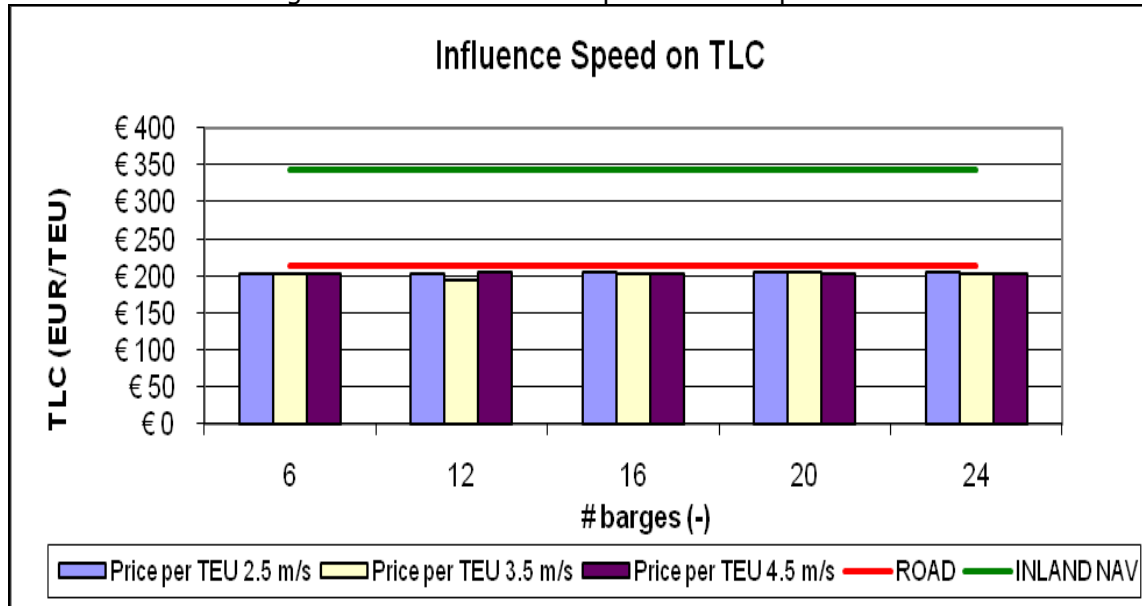
Figure 14.17: Influence speed on the NPV



Note: 2009 values

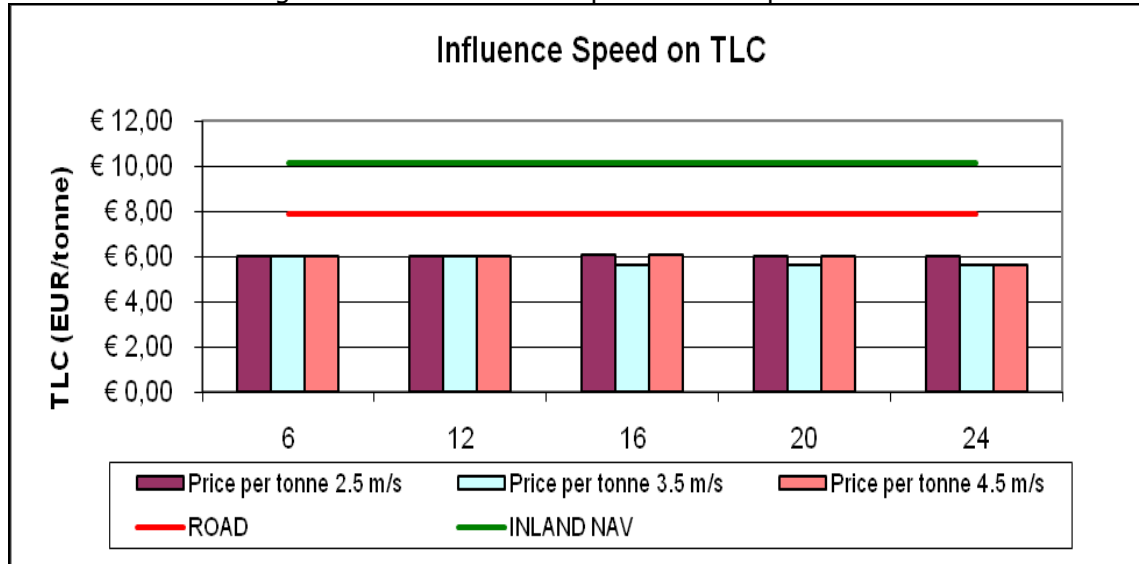
In figures 14.18 and 14.19 the TLC for the three different sailing speeds are given. Those figures show that the 3.5 m/s option will have the lowest TLC up to the moment that 20 barges are in the system.

Figure 14.18: Influence speed on TLC per TEU



Note: 2009 values

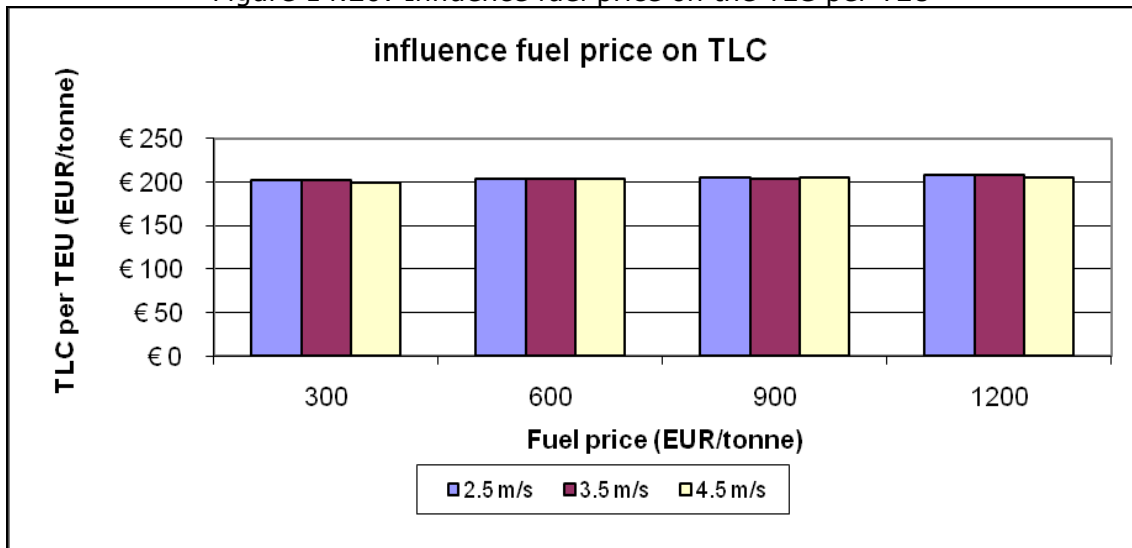
Figure 14.19: Influence speed on TLC per tonne



Note: 2009 values

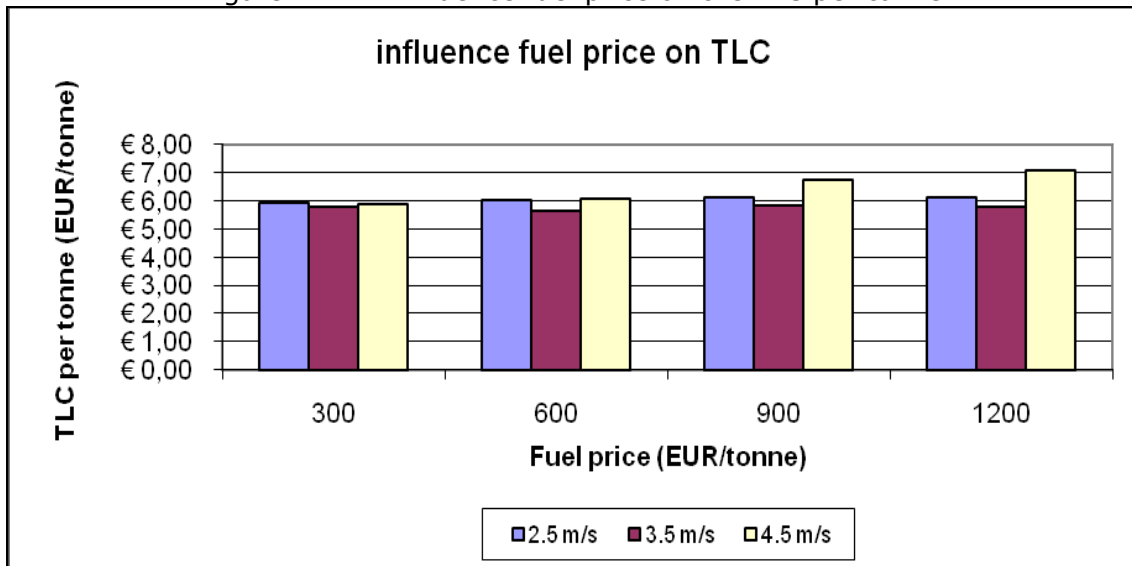
One of the most important parameters that will influence the transportation costs if the speed is changed is the fuel price. In the previous analysis the fuel cost was taken as the current fuel price of €600 per tonne (2009 value). But the tug and barge convoy will be operated for at least 20 years. Therefore, in order to determine the speed of the convoy, the expected fuel price must also be taken into account. In order to perform these calculations, option 4 (20 barges) is analysed further with the variation in the fuel price from €300 per tonne to €1200 per tonne. The results can be found in figures 14.20 and 14.21, where the TLC as function of the fuel price is shown. In these calculations the TLC will be determined, so that for all the calculations the NPV is the same as in the base scenario, in which the fuel costs were equal to 600 EUR per tonne.

Figure 14.20: Influence fuel price on the TLC per TEU



Note: 2009 values

Figure 14.21: Influence fuel price on the TLC per tonne



Note: 2009 values

From figures 14.20 and 14.21 it can be concluded that by increasing fuel price the TLC per TEU are increased slightly, but that by increasing the fuel price the option of sailing 3.5 m/s will result in the lowest TLC per tonne. For the TLC per TEU the same conclusion can be drawn, except, if the fuel costs halved (300 EUR/tonne), then the speed of the barge convoy should be increased to 4.5 m/s (19 km/h). Another conclusion is that the TLC is not very dependent on the fuel costs. This is due to the costs structure of the small barge system (see figure 8.4). The majority of the total logistics costs are determined by the fixed costs, crew costs and the container handling costs (see chapter 10), causing changes in the fuel price not to affect the total logistics costs much.

It is consequently concluded that the speed of the tug and barge convoy should be 3.5 m/s (12.6 km/h). This speed will have the highest NPV for all the analysed tug and barge configurations and it will lead to the lowest TLC (also for high fuel prices), turning it into the most competitive option.

If the number of barges is considered that are deployed on the selected waterways, the optimum condition is when 20 barges are deployed (maximum value of NPV), while when 12 barges are deployed, the IRR has the highest value. The reason for this difference in maximum IRR and maximum NPV is the reduced filling rate of the barges when the number of barges in the total network is increased. The reduction in filling rate is caused by the limited amount of cargo that can be transported.

Because for all the analysed barge combinations the IRR is larger than the minimum required WACC, all options can be accepted. Now the selected barge convoy configuration will be determined by the highest level of NPV, which is option 4 (20 barges option) (see also chapter 11).

The optimum number of barges is the same for all the analysed parameters. Therefore a change in sailing regime, speed of the convoy or propulsion system does not affect the optimum composition of barge convoy on the selected waterways.

#### 14.4.4 Influence of adding additional truck transport to the small barge system

In this section the influence of adding additional truck transport to the most optimal design of the network and tug and barge design will be analysed. The influence of three different parameters is determined on the allowable kilometres that can be added to the small barge system. The parameters are the internalization of the external costs, all bulk cargo having an origin or destination at a water-bound company (no additional road kilometres) and the effect of loaded or empty containers. In table 14.3 the results of the calculations are given. The analysis will be same as has been done in chapter 13 (sensitivity analysis competition model).

Table 14.3: Influence of adding truck transport

	int. Ext	loaded container	Additional km	NPV
<b>no additional road km</b>	No	Yes	Non	€ 4,078,585
<b>additional road km for bulk and containers</b>	No	Yes	-19	€ 99,996
	Yes	Yes	-2	€ 4,214,942
	Yes	Yes	7	€ 1,941,633
	Yes	Yes	13	€ 252,354
	No	No	3	€ 106,711
	Yes	No	21	€ 4,217,480
<b>additional road km only containers</b>	No	Yes	-12	€ 161,855
	Yes	Yes	17	€ 4,161,748
	No	No	2,5	€ 4,107,548
	Yes	No	30	€ 4,136,141

Note: 2009 values

From the calculations it can be concluded that it is not possible to add truck transport to the small barge system if loaded containers and bulk cargo have to be transported without internalizing the external costs (-19 km). If the external costs are internalized, 7 km can be added in order to have an NPV which is 50% of the base case when no additional road transportation is considered. If the containers are empty, 21 km of road transport can be added if the external costs are internalized.

If the bulk cargo flows all have a destination (or origin) at water-bound companies, it can be concluded that loaded containers cannot be transported further inland with a truck. If the external costs are internalized for loaded containers, 17 km of additional road transport can be added. If the containers are empty, those containers can be transported for 2.5 km even without the internalization of external costs. The best option to add truck transport to the small barge system is when the external costs are internalized, the transported containers are empty and bulk cargo will have a destination (or origin) at the small inland waterways (30 km).

#### 14.4.5 Influence of adding inland container terminals to the network

The last parameter to be analysed in this chapter is adding inland container terminals (ICT) to the total barge system. In this analysis two different designs are considered. If an ICT is added, of the barges which are pushed by the tug are left behind at the inland terminal. The barges which are used to sail between the inland and deep-sea terminals are now designed without a wheelhouse. This is not needed because these barges do not have to sail long periods. The barge-train formations are coupled and uncoupled at the ICT. In figure 14.22 the locations of the ICT are given on the selected routes.

Figure 14.22: Overview of the locations of the ICT



Note: 1) original figure adapted from PBV; 2) Rectangles are the locations of the ICT

In this analysis calculations will be made with and without the addition of ICT to the tug and barge network. In the first calculation the tug and barge convoy will sail to routes 2-3 with 6 barges on route 2 (of which 2 barges are only going to the inland terminal) and 4 barges on route 3 (on route 3 the ICT was already incorporated; see section 14.2). In the second option a 4-barge convoy is deployed on routes 2-3 (2 barges will go to an ICT) and a 2-barge convoy on route 4.

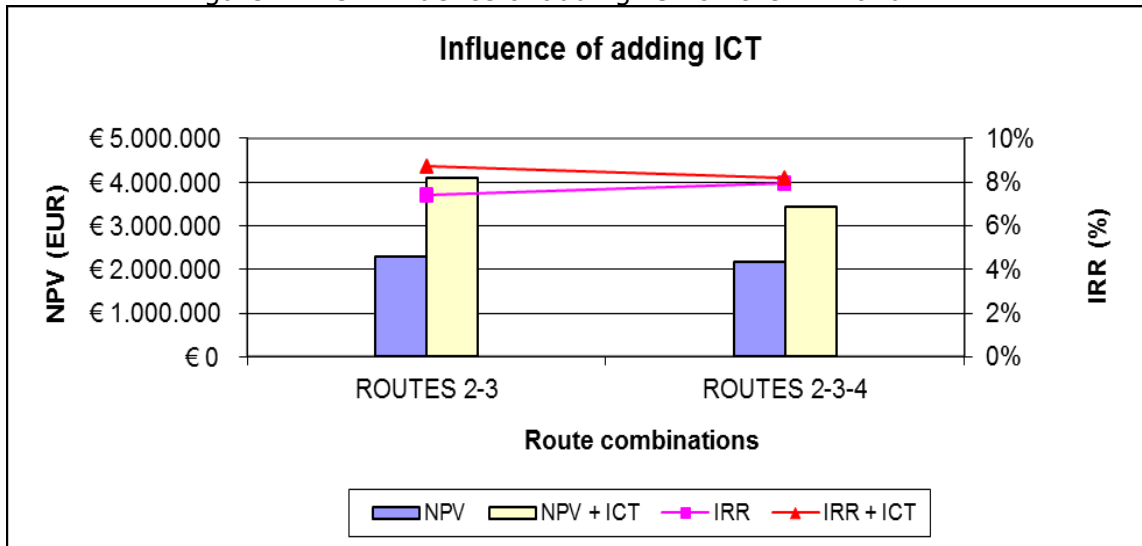
Because no detailed cargo flow information is available from the ICT added to route 2, the occupation rate of the barges sailing to the inland terminals is fixed at 70%. The criterion applied here is that the TLC for the small-barge system must be at least 10% lower than the nearest competitor (RHK inland ship).

In figure 14.23 the NPV and the IRR of the tug and barge convoy are given as a function of the two different route combinations.

From figure 14.23 it can be concluded that the NPV will increase if ICTs are added in the total tug and barge system. The increase in NPV is higher when the tug and barge system only sails to routes numbers 2 and 3. This higher increase for the route 2-3 combinations is due to the higher number of possible trips per year in the 2-3-4 option. The reason for the higher number of trips per year is that, due to the increase in barge-train size, the time needed to couple and uncouple the barge trains is increased and so is the total transportation time. Owing to this increase in transportation time, the number of trips per year is reduced, but this loss in trips is compensated for by the increase in value of transported cargo.

If only two routes are combined into the network (routes 2 and 3), the increase in time does not decrease the number of trips that can be made per year because the time that the barges need to spend on the small waterways is larger than the time needed for the tug and barge convoy to sail on the large waterway. Therefore the number of departures is determined by the "small waterway" time (see also 14.4.2). So, if only two routes are used, the concept gains by the addition of extra tonnages, while, if three routes are used, the concept "suffers" also a little bit by the addition of extra barges in the convoy.

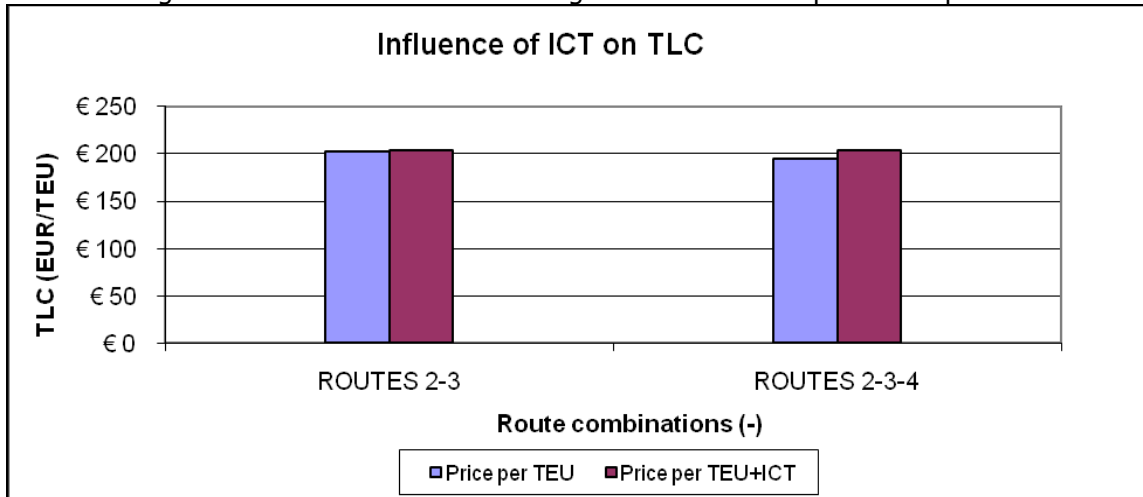
Figure 14.23: Influence of adding ICT on the NPV and IRR



Note: 2009 values

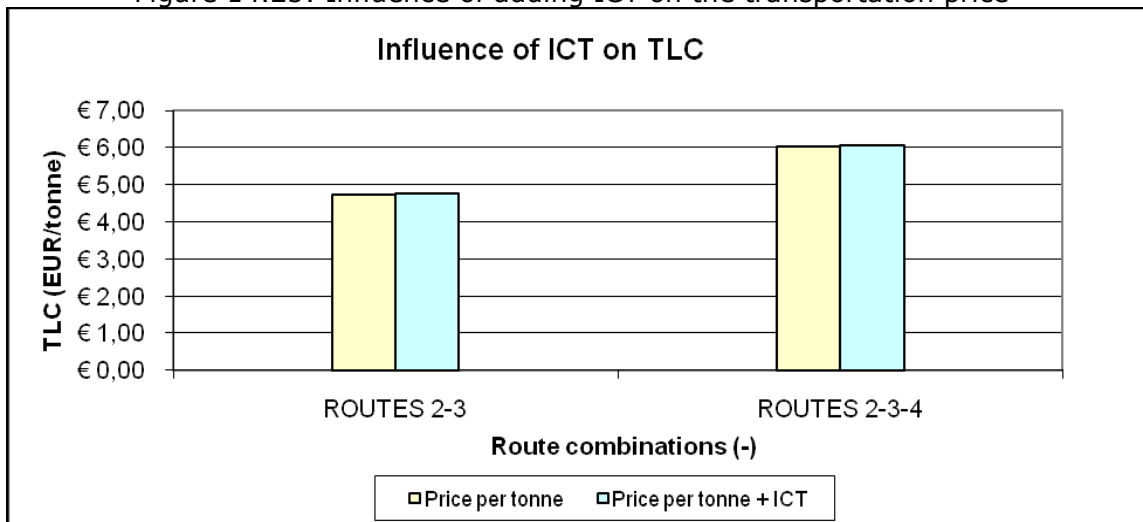
In figure 14.24 and 14.25 the TLC per TEU and tonne are presented, while in figure 14.26 the TLC per TEU are given for the cargo transported to the inland terminals with the small barge convoy system and the existing larger inland ships (RHK ship).

Figure 14.24: Influence of adding ICT on the transportation price



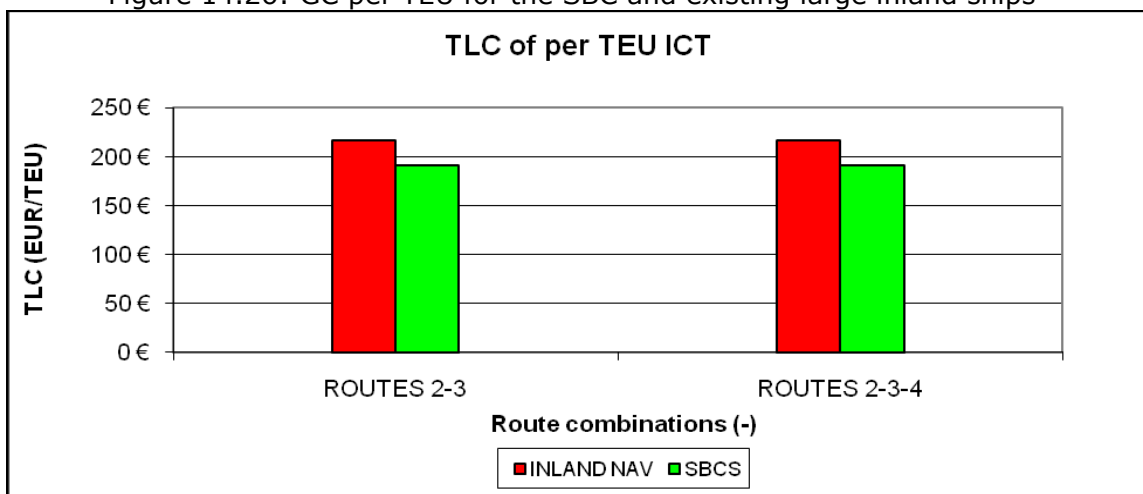
Note: 2009 values

Figure 14.25: Influence of adding ICT on the transportation price



Note: 2009 values

Figure 14.26: GC per TEU for the SBC and existing large inland ships



Note: 2009 values

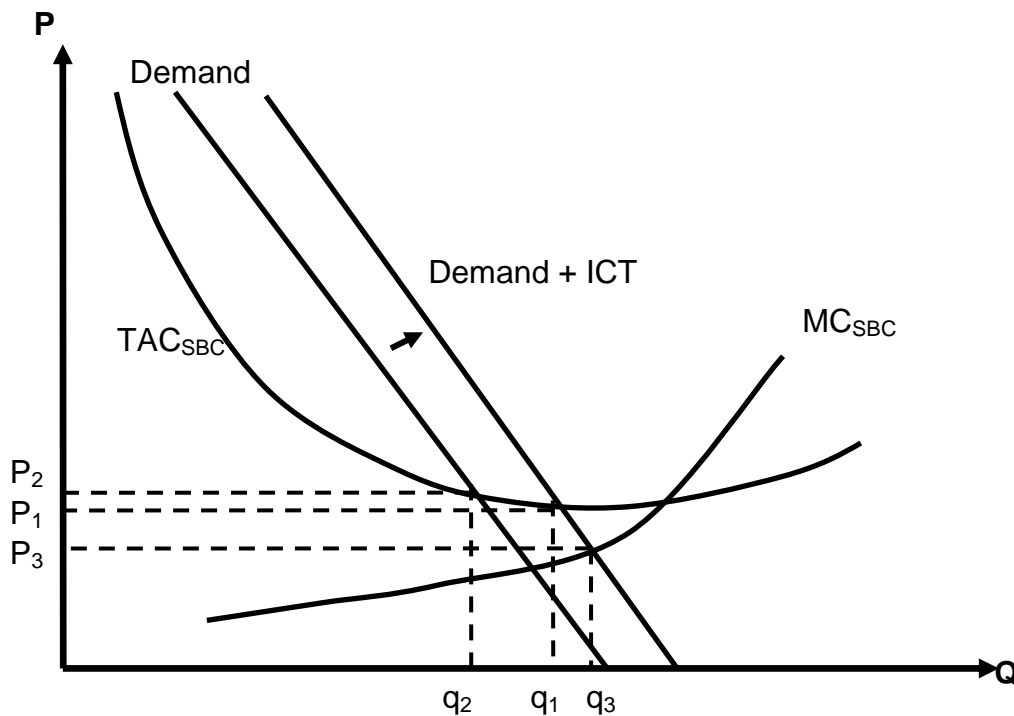
From these figures the conclusion can follow that by adding extra ICT barges to the convoy, the TLC per TEU and tonne do not change much. The



maximum allowable TLC are determined by the competitors. Although the TLC (and therefore also the transportation price per TEU or tonne) are not changed by adding the ICT to the total system, the NPV has increased. This increase is caused by a small decrease of transportation costs but mostly by the addition of extra cargo that can be transported.

In the figure 14.27 the same graph as in figure 14.8 is repeated with the difference that only in this case the demand line is shifted upwards, due to the increase in potential market by the addition of ICTs. As a result, more cargo can be transported ( $q_2$  instead of  $q_1$ ), while the total average costs will decrease ( $P_4$  instead of  $P_2$ ).

Figure 14.27: Schematic overview of the demand and supply lines



If the same transportation price is offered as in the situation where the ICT are not added (see figures 14.24 and 14.25), the profit margin will be higher due to the decrease in average costs. Therefore the increase in NPV is explained when the ICT are added to the system.

The mechanism given in figure 14.27 is the explanation for the results obtained in figures 14.23 to 14.25. From those figures it can be concluded that the TLC will be the same while the NPV increases. That increase in NPV is due to the increase in the amount of transported cargo ( $q_1$  to  $q_2$ ) and an increase in profit margin which is caused by a decrease in average costs ( $P_1$  to  $P_2$ ).

#### 14.4.6 Findings of the main features of the small barge convoy system

From the previous analysis it can be concluded that on the Flemish small waterway network, in order to have the highest level of NPV:

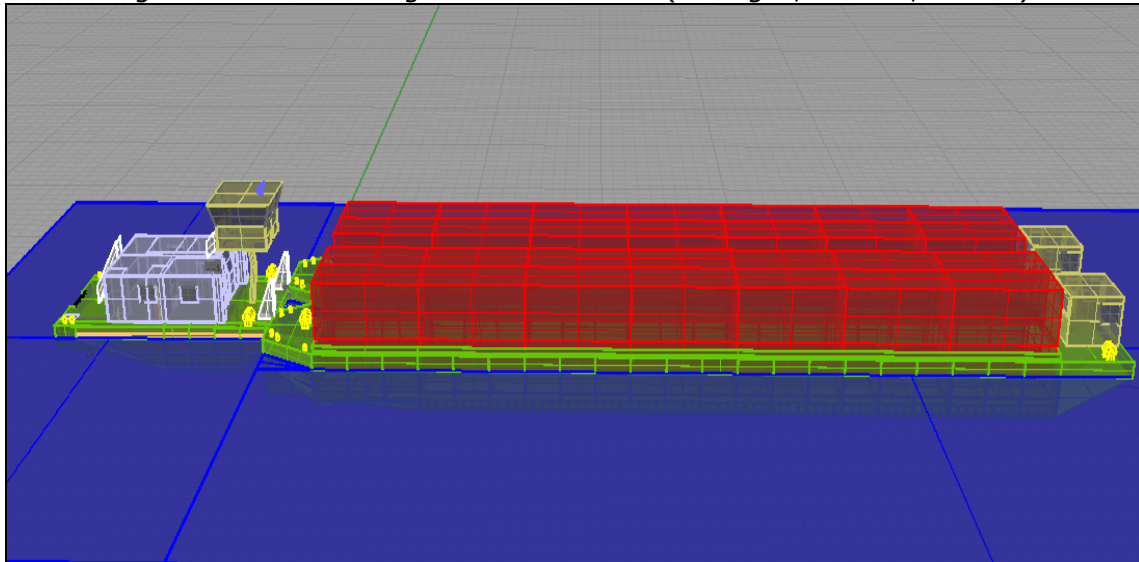
- The tug and barge convoy should sail in a semi-continuous regime
- The tug and barge convoy should have a design speed of 3.5 m/s
- Tug should be equipped with a diesel direct propulsion system
- Adding extra barges sets is useful if fewer than 2 routes are combined into the tug and barge network (routes 2 and 3)
- Additional road transport, without the internalization of the external costs, is only possible to add to the small barge system if only empty containers are transported and all the considered bulk cargo has an origin or destination at a water-bound area (2.5 km). If the external costs are internalized, it is also possible to transport loaded containers (17 km).
- Adding ICTs to the total tug and barge system is useful to increase the NPV if the tug and barge convoy has to sail to two routes

From the previous analysis two cases can be identified:

- Case I: Sailing with the tug and barge convoy to route two (4 barges), route three (4 barges) and route four (2 barges) (condition 4 table 15.1)
- Case II: Sailing with the tug and barge convoy to routes two (6 barges) and three (4 barges), while two barges are pushed to the ICTs on the selected routes

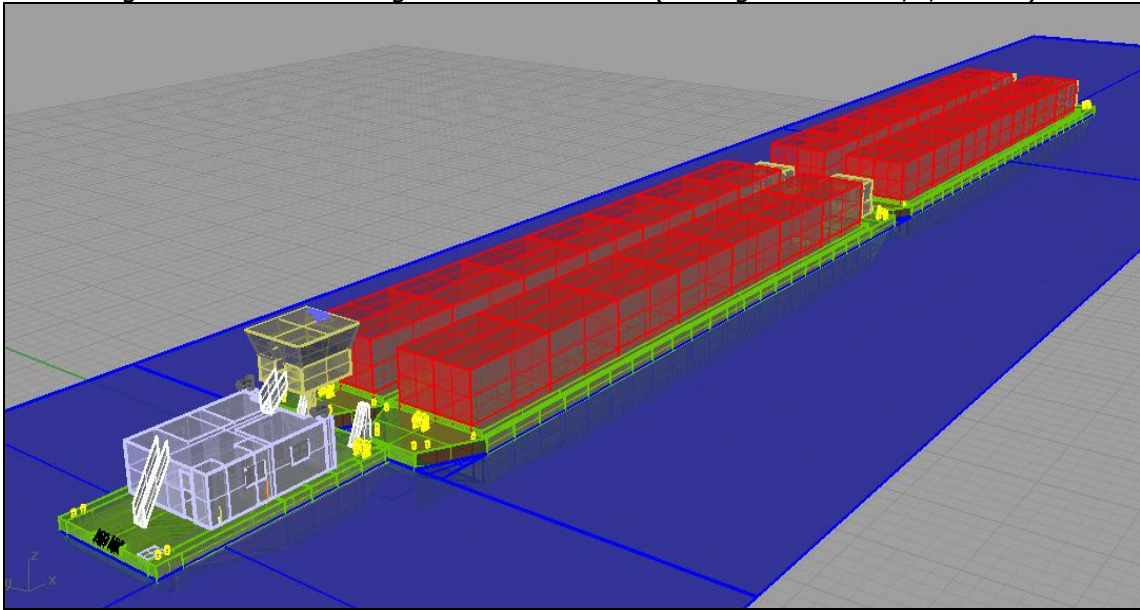
The designs of the tug and barges are given in figures 14.28 and 14.29, where a 3D-Rhino model is shown of the design of the first business case. In appendices V.1 to V.3 an overview of the design data and the general arrangements is given.

Figure 14.28: 3D design of the first case (2 barges, route 4, case I )



Source: own composition, result of the design model (see chapter 7)

Figure 14.29: 3D design of the first case (4 barges routes 2,3, case I)



Source: own composition, result of the design model (see chapter 7)

These two selected cases will be analysed in the next section of this chapter by way of a scenario analysis.

### 14.5 Dealing with future uncertainties

In order to determine whether the small barge convoy system can succeed in a competitive market, a lot of future uncertainties must be taken into account. To deal with those uncertainties, different scenarios are developed which are built up of different policy decisions and economic developments which influence the competitiveness of the small barge system.

To build up the scenarios, the different actors, who are playing a major role in the competitiveness of the concept, need to be determined first. The major actors are:

- Policy makers / government
- Investment companies
- "Normal" inland shipping companies
- Deep-sea terminals
- Inland shipping company unions

In table 14.4 an overview is given of the current role, their interest and decision power of the different actors.

Table 14.4: Overview of the different actors

Actors	Current role	interest	Power
Policy makers / government	making policy and governing the infrastructure	achieving a mode split from road towards rail and inland navigation	Large
Investment companies	investing in new ships	making money	Medium
"Normal" Inland shipping companies	transporting cargo via inland waterways	making money, keeping their own market share	Low
Deep-sea terminals	loading/unloading deep sea and inland ships	clustering cargo flows, reducing the number of calls with low number of TEU's	Large
Inland shipping company unions		fair competition	Medium

Source: own composition

The scenarios that need to be developed will be built up out of the following components:

- Infrastructure policy for road, rail and inland navigation
- Inland navigation policy
- Economic developments
- Number of small inland ships which can compete with the concept

In table 14.5 the different scenarios are presented, where the first scenario is the worst possible scenario for the small barge convoy system and the sixth is the best possible scenario. Scenario 4 is the base scenario which is used in all the previous calculations. All the monetary values are given in the base year 2009.

Table 14.5: Developed future scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
<b><u>Infrastructure development</u></b>						
Road	Enough capacity	Enough capacity	Enough capacity	Enough capacity	Congestion + 10% TT	Congestion + 10% TT
Inland waterways	Upgrade infra	Only maintenance	Only maintenance	Only maintenance	Only maintenance	Only maintenance
<b><u>Inland Nav policy</u></b>						
Int. Ext costs	no	no	no	no	no	Yes
Adjustment crew rules	no	no	no	Yes	Yes	Yes
Exceptions small ships	Yes	Yes	Yes	Yes	Yes	No
<b><u>Economic parameters</u></b>						
Fuel price	€ 900/tonne	€ 900/tonne	€ 600/tonne	€ 600/tonne	€ 600/tonne	€ 600/tonne
Inflation	1,8%	1,8%	1,8%	1,8%	3%	3%
Interest costs	10%	10%	4,6%	4,6%	4,6%	4,6%
Costs of Equity	15%	15%	10%	10%	10%	5%
<b><u>Existing small inland fleet</u></b>						
Number of ships	enough ships	dim. Ships	dim. ships	dim. ships	dim. ships	No ships

Source: own composition

The first scenario is one in which the government will make the decision to upgrade the small inland waterways to larger waterways, while the barges are dimensioned on the small waterways. Therefore the smaller barges

have to compete with larger “normal” inland ships. In this scenario the crew rules are not adjusted and it is not possible to sail with only one captain on the small waterways. The required standards for inland ships commissioned by the EU will also not be applied to the small ships. In this scenario it is also very difficult to borrow money, the interest costs will be high and the minimum IRR that the investment company will require will be high.

The last scenario (6<sup>th</sup>) is the complete opposite of the first scenario. There is no upgrade of the small waterways and due to the economic growth (and therefore the demand for transport) the roads will be congested. The crew rules are changed in favour for the small barge convoy system, the external costs are internalized and the small ships must comply with the new standards of the EU, so that no small ships are left. Due to this reduction in competition, the risk of implementing the new concept is reduced and the costs of equity will go down, as well as the interest costs of the loan.

The scenarios 2 to 5 are gradually built up of the most negative to the best possible scenario.

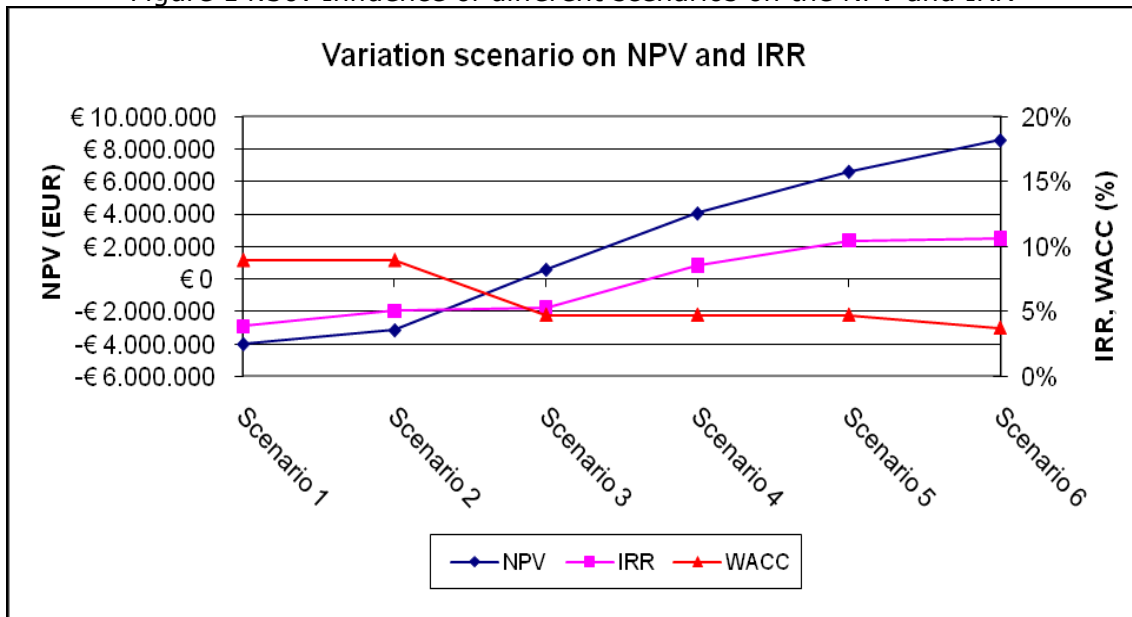
As already recognized in chapter 7, the newbuilding price of the tug and barges is very difficult to determine. Therefore also a variation of the newbuilding price will be added to the 6 developed future scenarios. The variation of newbuilding price will vary from -15%, 0% and +15% deviation from the calculated values in chapter 7. These variations will form the “third dimensions” in the scenario analysis.

### *Business Case I*

The first case where the tug will push 2 barges to route 4 and 4 barges to routes 2-3 is researched. In figure 14.30 the NPV and the IRR are shown when there is no variation in the newbuilding price of the barges and tug as a function of the different scenarios. The same graph also shows the WACC. In figure 14.31 the NPV is shown for three different newbuilding prices (15%, 0% and -15%), again as function of the 6 different scenarios. In figures 14.32 and 14.33 the TLC per TEU and tonne are given, again as a function of the different scenarios and the three different newbuilding prices. In these figures also the TLC of the competing modes is given.

From figure 14.30 it can be concluded that the NPV and IRR of the small-barge convoy system will increase with an increasing scenario number. The increase in NPV can be achieved due to the increase of the transportation prices. The transportation prices can be increased because of increasing transportation prices of the competitors (internalization of external costs) and by a decrease in costs (decrease of costs of equity, fuel price, interest costs). Figure 14.30 also may lead to the conclusion that in the first two scenarios no business case can be made because the IRR is lower than the WACC (NPV < 0). The increase in WACC is due to the increase in costs of equity (10% to 15%) and interest costs (4.6% to 10%).

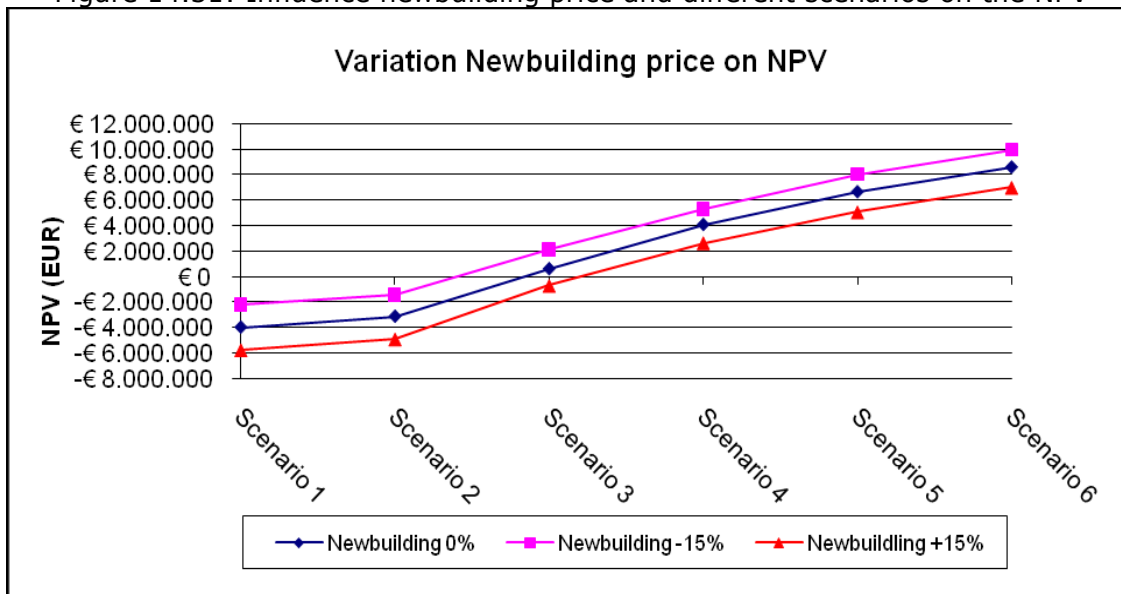
Figure 14.30: Influence of different scenarios on the NPV and IRR



Note: 2009 values

Figure 14.31 shows that the difference in NPV for the different newbuilding prices is relatively small (€1.500.000 per 15% change in newbuilding costs). All the three lines follow the same trend and a change in newbuilding price will not change the investment decision of the small-barge system ( $NPV > 0$ ,  $r = WACC$  see chapter 11). In scenario 3 an increase of 15% of the newbuilding price of the barges and tug will almost make the NPV, negative so that the investment decision will be negative.

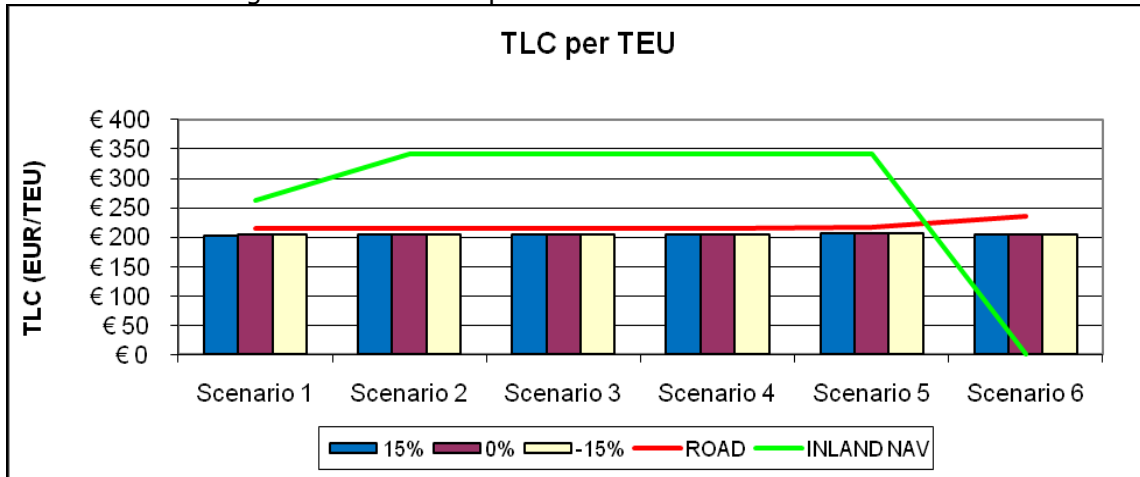
Figure 14.31: Influence newbuilding price and different scenarios on the NPV



Note: 2009 values

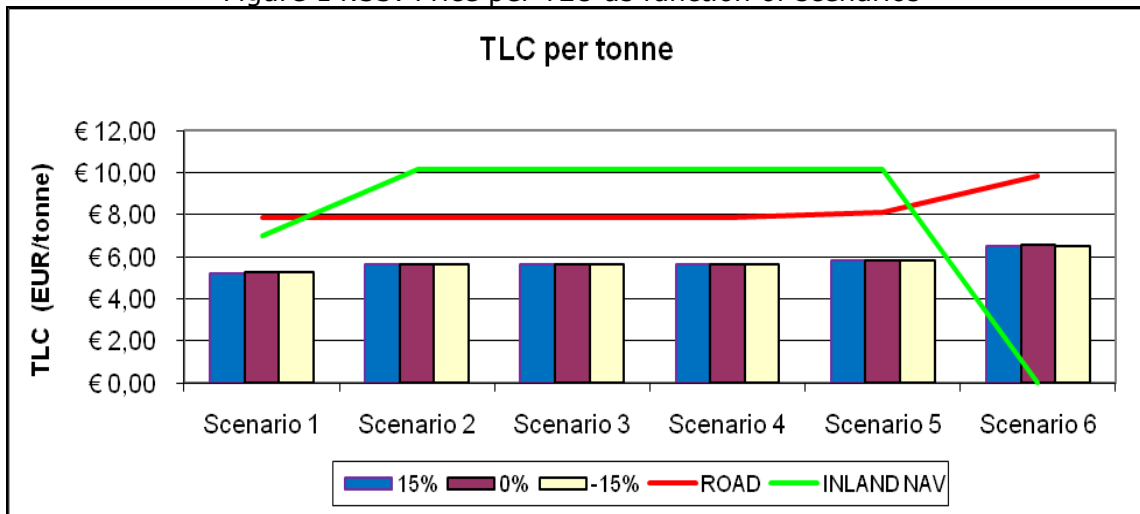
In the figures 14.32 and 14.33 the TLC per TEU and tonne are given as function of the different scenarios. In all the scenarios the TLC of the concept are to be at least 5% smaller compared to its nearest competitor for container transport and 30% smaller for bulk cargo (see also chapter 13).

Figure 14.32: Price per TEU as function of scenarios



Note: 2009 values

Figure 14.33: Price per TEU as function of scenarios



Note: 2009 values

The TLC per TEU or tonne (100% newbuilding price) will be constant in scenarios 2, 3 and 4 because the TLC of the competitors are kept constant. In scenario 1 the small inland waterways are upgraded to class IV waterways, so that bigger ships can be used. As a result, the transportation price per TEU and tonne decrease for classic inland shipping, resulting in a decrease of TLC (and also transportation price) for the small-barge system transporting bulk cargo. In scenarios 5 and 6, the transportation price for road transport is increased, due to an increase in transportation time caused by congestion. Therefore, the TLC (and transportation price) for the small barge system can increase. In scenario 6 the external costs are internalized resulting in a bigger difference in TLC between the small barge system and its competitors.

If scenario 1 is analysed, it can be concluded that it will not provide a suitable business case because the NPV is smaller than zero (or IRR < WACC). This scenario is the most unfavourable scenario for the small-barge convoy system. The small waterways are upgraded to class IV waterways and no single captain sailing on the small inland waterways is allowed. Also the fuel price of €900 per tonne fuel and an interest cost of 10% are not in favour of the concept. It can therefore be concluded that business case I

cannot survive in scenario 1. It is, surprisingly, not the upgrade of the class II canals to class IV that is devastating for the small barge convoy system but it is the increase in equity costs. In figure 14.30 it can be seen that the decrease in NPV is much larger between scenarios 2 and 3 than between scenarios 1 and 2.

Figures 14.32 and 14.33 show that the decrease in TLC of inland navigation will only lead to a situation that the TLC of the small-barge system must be lowered for bulk cargo and not for container transport. The competition of the larger ships will result in a smaller potential market for the transportation of bulk cargo.

In the second scenario the waterways are not upgraded and the competition comes from the existing small inland ships and road transportation. Figure 14.30 shows that still no business case can be made, due to the high costs of equity of 15% (given as a minimum in scenario 2) and interest costs.

In the third scenario the financing requirements are lowered. The equity costs are set at 10% and the loan can be obtained with an interest rate of 4.6%. Also the fuel price per tonne is lowered from €900 to €600. In this scenario it is possible to make a suitable business case. Because of the reduction of the financing and fuel costs, the transportation costs are reduced and therefore the profit margin is increased.

In the fourth scenario it is possible to sail with only one captain on the barges when they are sailing on the small inland waterways due to an adjustment of the manning rules on the small waterways. In this scenario the small-barge convoy system can be implemented. The transportation costs are lower so that the profit margin increases even more. As a result, the NPV and IRR will increase. It can therefore be concluded that adjusting the crew rules on the small inland waterways will affect the competitiveness and the profitability of the concept quite considerably (increase of NPV from €600,000 to €4,000,000), but, if the crew rules on the small waterways are not adjusted, still a suitable business case can be made (see scenario 3).

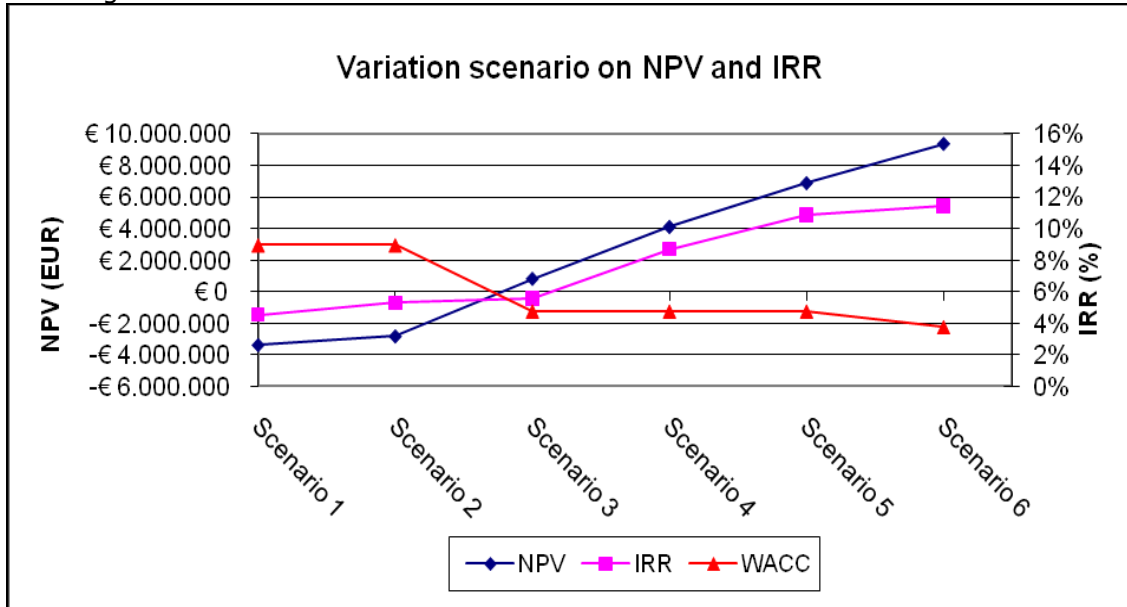
In the fifth and sixth scenario the NPV and IRR will increase even further, due to the increase in transportation price. This increase of transportation price can be explained by the extra transportation costs of the main competitor road transportation. This increase in transportation costs (and price) is due to the increase of transportation time caused by extra congestion on the road network. In the sixth scenario the external costs are internalized so that an even bigger difference in TLC between the small barge convoy system and other competitors can be obtained (15% difference for containers and 50% difference for bulk cargo). As a result, the small-barge convoy system will increase its competitiveness towards road transportation and a very good business case can be made. It can also be concluded that the failure of the contemporary road network and the internalization of the external costs are contributing positively towards the small-barge convoy system but they are not necessary to construct a business case.



*Business Case II*

When in the second case the tug will push 6 barges on route 2 and 4 barges on route 3 from the convoy to route two, 2 barges will stay behind at the inland terminal. This case is further researched via a scenario analysis in this section. In figure 14.34 the NPV and the IRR are given as a function of the different scenarios.

Figure 14.34: Influence of different scenarios on the NPV and IRR case II



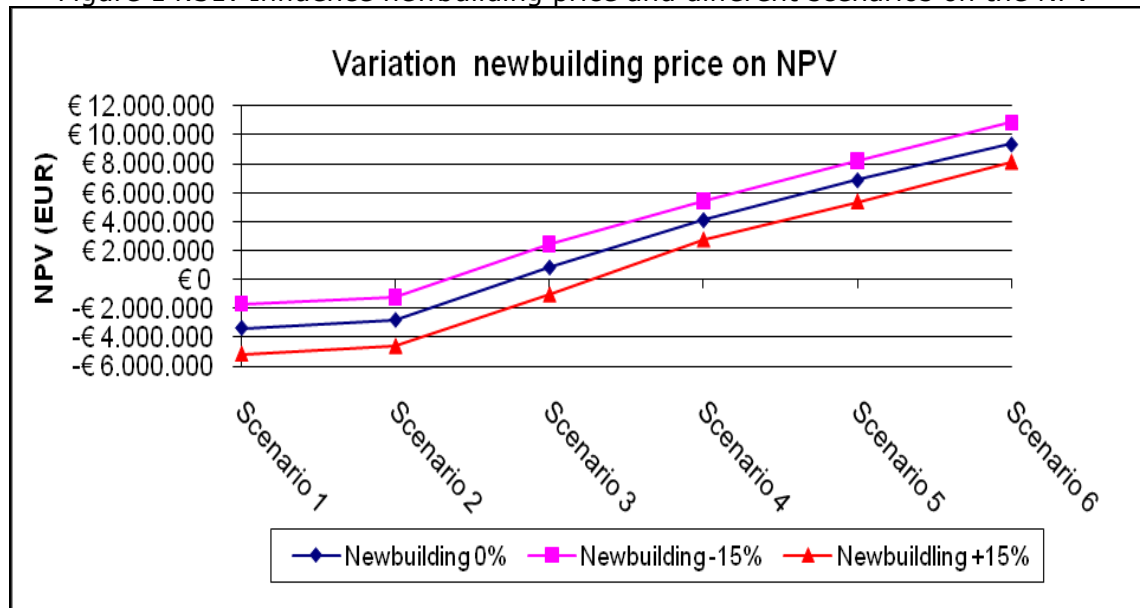
Note: 2009 values

From figure 14.34 it can be concluded that the NPV and IRR will increase with the different scenarios. If figure 14.34 is compared with figure 14.30, it can be concluded that the difference in NPV and the IRR over the different scenarios are more or less the same. In scenarios 1 and 2 it is not possible to construct suitable business cases because the IRR is lower than the WACC ( $NPV < 0$ ). Only the difference between the achieved IRR and WACC is smaller for the second case than for the first case. In the last scenario (6), the increase in NPV is larger for the second business case than in the first one.

In figure 14.35 the NPV is shown for the three different newbuilding prices (15%, 0% and -15%) as function of the 6 different scenarios.

The difference between the three lines is almost the same as in the first business case. If the newbuilding prices of the tug and barges are decreased with 15% then it is not even possible to make suitable business case in scenarios 1 and 2. If the newbuilding costs are increased then in scenario 3 it is not possible to make a suitable businesses case ( $NPV < 0$ ).

Figure 14.31: Influence newbuilding price and different scenarios on the NPV

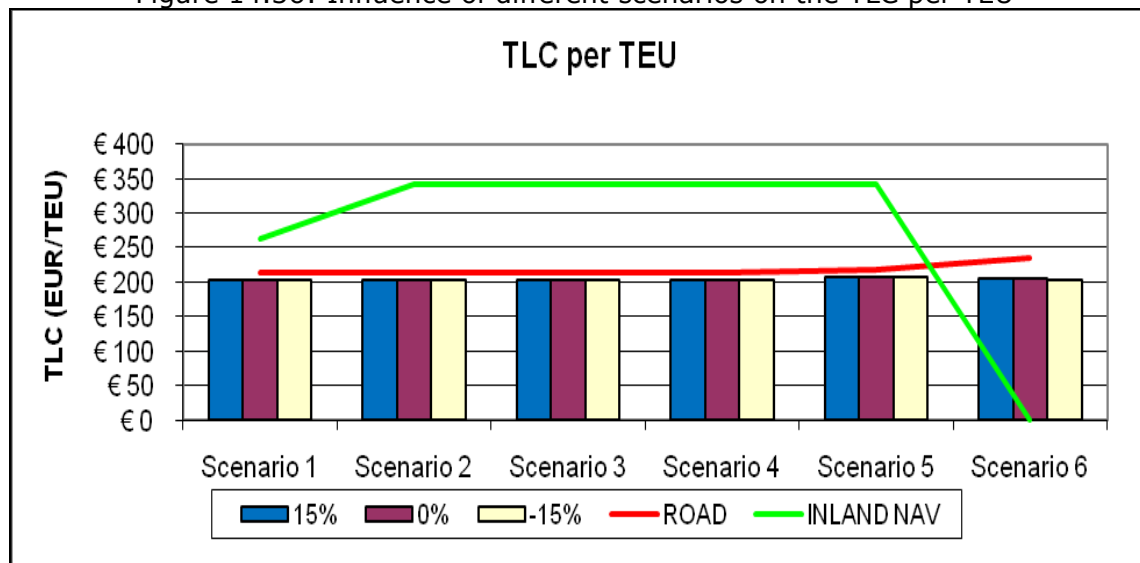


Note: 2009 values

In the figures 14.36 to 14.38 the TLC per TEU (on the small waterway and ICT) and tonne are given also as function of the different scenarios.

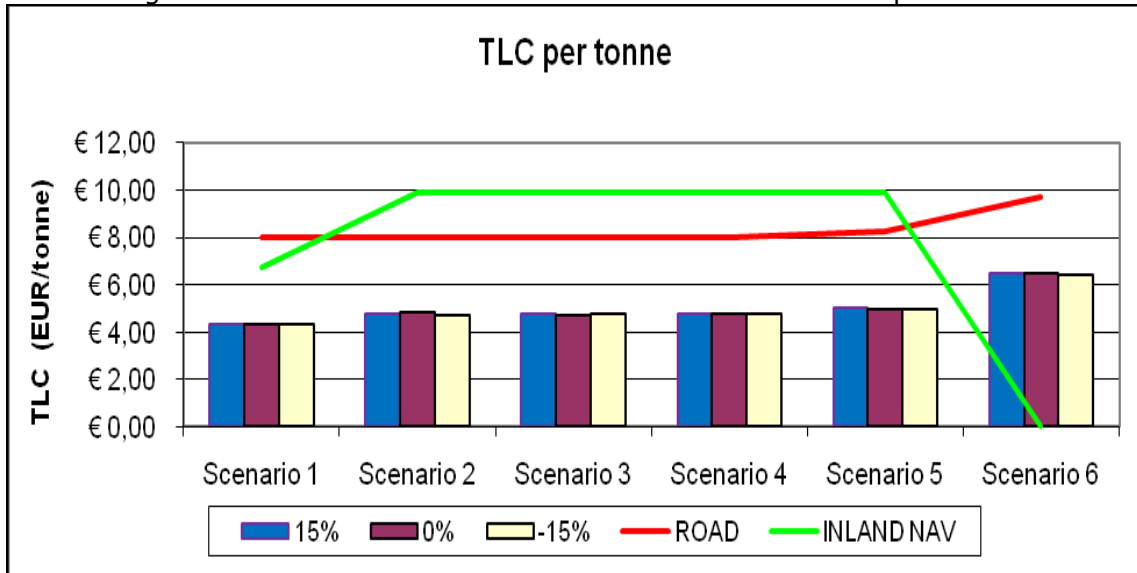
Figure 14.36 show that the TLC per TEU are at least 5% lower than the nearest competitor (road) and that the difference will even be larger in scenario 6 (15%). In figure 14.37 the same pattern can be seen. Although the TLC in the first scenario are reduced due to the upgrade of the small inland waterways (see also the first business case). Figure 14.38 shows that the TLC per TEU transported to the inland container terminals will not be affected much by the different scenarios. That is largely due to the fact that the biggest part of the TLC is determined by the handling costs of the containers.

Figure 14.36: Influence of different scenarios on the TLC per TEU



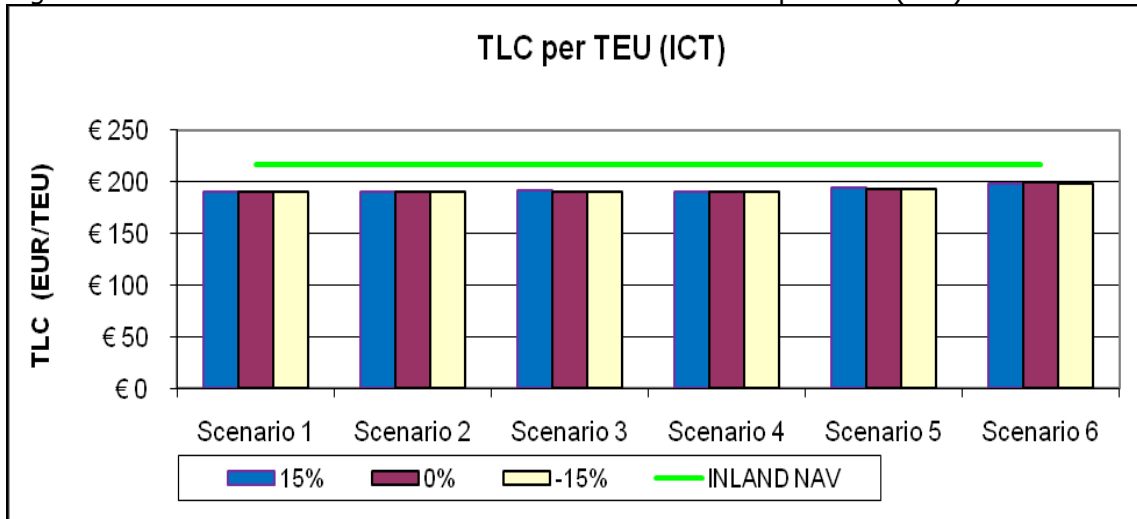
Note: 2009 values

Figure 14.37: Influence of different scenarios on the TLC per tonne



Note: 2009 values

Figure 14.38: Influence of different scenarios on the TLC per TEU (ICT)



Note: 2009 values

Scenario 1 will not provide a suitable business case due to the increase in the costs of equity to 15%. If this scenario is compared with the first case, it can be concluded that this case has a larger NPV and IRR. The reason for this is that a big part of the transported cargo is transported via the ICTs. As a result, this case is less influenced by the different scenarios.

In the second scenario the minimum level of the WACC is still not reached so that still no suitable business case can be made.

In scenario 3, 4, 5 and 6 a suitable business case can be made. As in the first case, the crew rules on the small waterways do not need to be adjusted in order to make a business case. However, if it is possible to limit the number of crew-members sailing on the barge on the small inland waterway, this will increase the NPV significantly. If the external costs are internalized, the competitiveness of the concept will increase but it is not necessary to internalize those costs to make a suitable business case.

The preformed scenario analysis can suggest the conclusion that the second case behaves in the same way as the first case when it is influenced by the different scenarios.

## 14.6 Preliminary conclusions

From the analysis in section 14.4 it can be concluded that on the Flemish small waterway network, in order to have the highest level of NPV:

- The tug and barge convoy should sail in a semi-continuous regime;
- The tug and barge convoy should have a design speed of 3.5 m/s;
- The tug should be equipped with a diesel direct propulsion system;
- Adding extra barges sets is useful if fewer than 2 routes are combined into the tug and barge network (routes 2 and 3);
- Additional road transport, without the internalization of the external costs, is only possible to add to the small barge system if only empty containers are transported and all the considered bulk cargo has an origin or destination at a water-bound area (2.5 km). If the external costs are internalized, it is also possible to transport loaded containers (17 km);
- Adding ICTs to the total tug and barge system is useful to increase the NPV if the tug and barge convoy has to sail to two routes due to the increase of demand.

Another important finding of the tug and barge convoy is that it will be affected by decreasing average costs with increasing transportation volumes. This indicates first off all that the prices cannot be determined by the LRMC because in the long run the TAC are higher than the MC, so that prices should be determined by the LRAC. Secondly, this indicates that not enough cargo is available to accommodate similar small barge systems. Therefore the small barge convoy will operate in a natural monopoly. This means that no other company can enter the same business with the same costs structure (large amount of fixed costs which relates to the amount of barges in the small-barge convoy system). Therefore some sort of regulations (licence system) must be imposed by the waterway administrators. Other ships and trucks with different costs structures can enter the market and will not be affected by this natural monopoly.

From the previous analysis two good cases can be identified:

- Case I: Sailing with the tug and barge convoy to routes two (4 barges), route three (4 barges) and route four (2 barges) (condition 4 table 15.1)
- Case II: Sailing with the tug and barge convoy to routes two (6 barges) and three (4 barges), while on route two 2 barges are pushed to the selected ICT

In order to determine whether the small-barge convoy system can succeed in a competitive market, a lot of future uncertainties have to be taken into account. To deal with those uncertainties, different scenarios were developed. The scenario analysis for the first business case can lead to the conclusion that a suitable business case in scenario 1 is impossible. It is,

surprisingly, not the upgrade of the class II canals to class IV that is devastating for the small barge convoy system but the increase in equity costs.

In the second scenario the waterways are not upgraded and the competition comes from the existing small inland ships and road transportation. Even so, still no business case can be made due to the required costs of equity of 15% (given as a minimum in scenario 2).

In the third scenario the financing requirements are lowered. By the reduction of the financing and fuel costs the transportation costs are reduced, resulting in a lower price that can be offered, which will increase the potential market.

In the fourth scenario it is possible to sail with only one captain on the barges when they are sailing on the small inland waterways due to an adjustment of the crew rules on the small waterways. The transportation costs are lower, which allows asking more competitive prices and transporting more cargo. It can therefore be concluded that adjusting the crew rules on the small inland waterways will affect the competitiveness and the profitability of the concept quite considerably, but without adjustment of the crew rules on the small waterways a suitable business case can still be made (scenario 3).

In the fifth and sixth scenario the NPV and IRR will increase even further, due to the increase in transportation price. This increase in transportation price can be accepted because of the increased transportation price of the main competitor, i.e. road haulage. In the sixth scenario the external costs are internalized into the generalized and total logistics costs, which will lead to an even bigger difference in TLC between the small barge convoy system and other competitors. As a result, the small-barge convoy system will increase its competitiveness towards road haulage and a very good business case can be made. It can also be concluded that the failure of the present-day road network and the internalization of the external costs are contributing positively towards the small barge convoy system but they are not necessary to construct a business case.

The variation of the newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for the scenarios 1, 2 and 4 to 6. Only in the third scenarios will an increase of 15% of the newbuilding price make the investment decision negative. An increase in newbuilding price will increase the transportation costs of the small barge system, so that the NPV decreases. If the newbuilding price of the tug and barges is increased and it is not allowed to sail with only one captain on the small inland waterways, no suitable business case can be made ( $NPV < 0$ ). So, except for scenario 3, in a range of 30% variation of the calculated newbuilding price, the investment decisions will not change. Only the profitability will increase if the newbuilding price is decreased (or decrease if the newbuilding price increases).

For the second business case it can be concluded that scenario 1 will not provide a suitable business case due to the increase in the costs of equity to 15%.

In the second scenario the minimum level of the WACC is still not reached, so that still no suitable business case can be made.

In scenario 3, 4, 5 and 6 a suitable business case can be made. As in the first case, the crew rules on the small waterways do not need to be adjusted in order to make a business case. However, if it is possible to limit the number of crew-members sailing on the barge on the small inland waterway, this will increase the NPV significantly. If the external costs are internalized, the competitiveness of the concept will increase but it is not necessary to internalize those costs to make a suitable business case.

The preformed scenario analysis can lead to the conclusion that the second case behaves in the same as in the first case when it is influenced by the different scenarios.

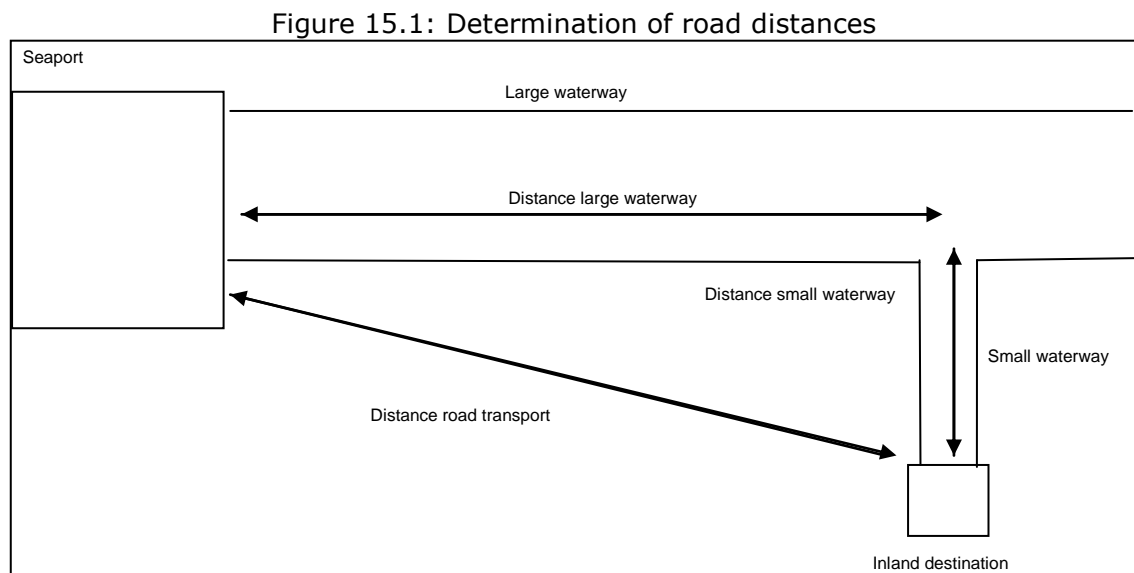
The variation of the newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for all scenarios, except scenario 3. In that scenario an increase of 15% of the newbuilding price will make the investment decision negative. As already concluded in the first business case, in a range of 30% variation of the calculated newbuilding price the investment decisions will not change (only in scenario 3); only the profitability will increase if the newbuilding price is decreased.

# 15. Infrastructure analysis

## 15.1 Introduction

This chapter deals with the influence of the infrastructure characteristics on the transportation costs (and TLC) and therefore on the competitiveness of the small barge convoy system. Will the small barge convoy system be more competitive if the sailed distance on the large waterway is increased or not?

In this chapter the distances that need to be covered on the large and small waterways are varied, all other parameters being kept constant (the same as in chapter 14). The effect of increasing the distance of the small and large waterways is determined for the competing modes. For road transportation the distance between the port and the inland destination, located at a small inland waterway will be determined with the following figure.



The distance to be covered with road transport will be calculated with the following formula:

$$D_{road} = \sqrt{D_{LW}^2 + D_{SW}^2} \quad (15.1)$$

$D_{road}$ = distance road transportation	[km]
$D_{LW}$ = distance large waterway	[km]
$D_{SW}$ = distance small waterway	[km]

The distance that needs to be covered by inland ships has to be same as for the small barge convoy system. The number of locks that needs to be passed is not varied and kept constant. The variations that will be made are shown in table 15.1.

Table 15.1: Variation analyses

Variation option	Large waterway [km]	Small waterway [km]
1	+20	0
2	+40	0
3	+60	0
4	0	+10
5	0	+20
6	0	+30

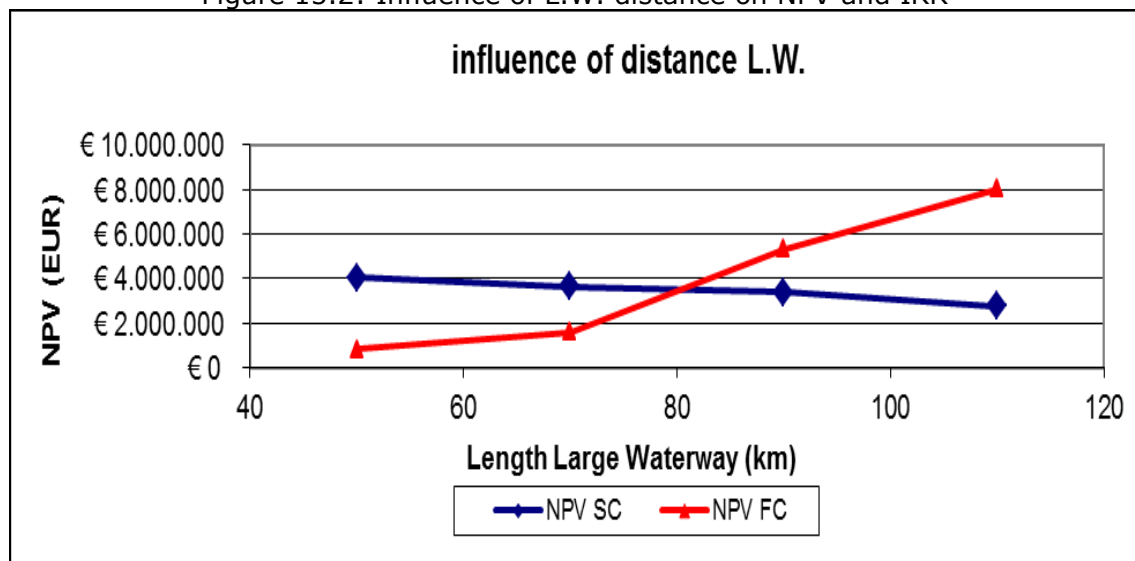
In section 2 the first 3 variations are analysed for the first business case of chapter 14 (4 barges to route 2, 4 barges to route 3 and 2 barge to route 4). In section 16.4 the variations 4, 5 and 6 are analysed. During this analysis the available market will be kept constant and will be the same as in the previous chapter.

In the analysis the transportation prices and competitiveness of the small barge system will be determined. This chapter will end with preliminary conclusions concerning the influence of the infrastructure on the small-barge system.

## 15.2 Large waterway variations

For the analysis of the variation of the distance, covered on the large waterways, the first selected business case is used. The design of the tug and barges is the same, with only one extra variation added to the analysis. Based on the analysis in chapter 14 the semi-continuous sailing regime was chosen. Now that the sailed distance on the large waterways is increased, by sailing 24 hours per day, this regime could be more effective. In figure 15.2 the results of the variation of the covered distance on the large waterways are given, where the first point of analysis starts at a large waterway distance of 50 km (base scenario).

Figure 15.2: Influence of L.W. distance on NPV and IRR



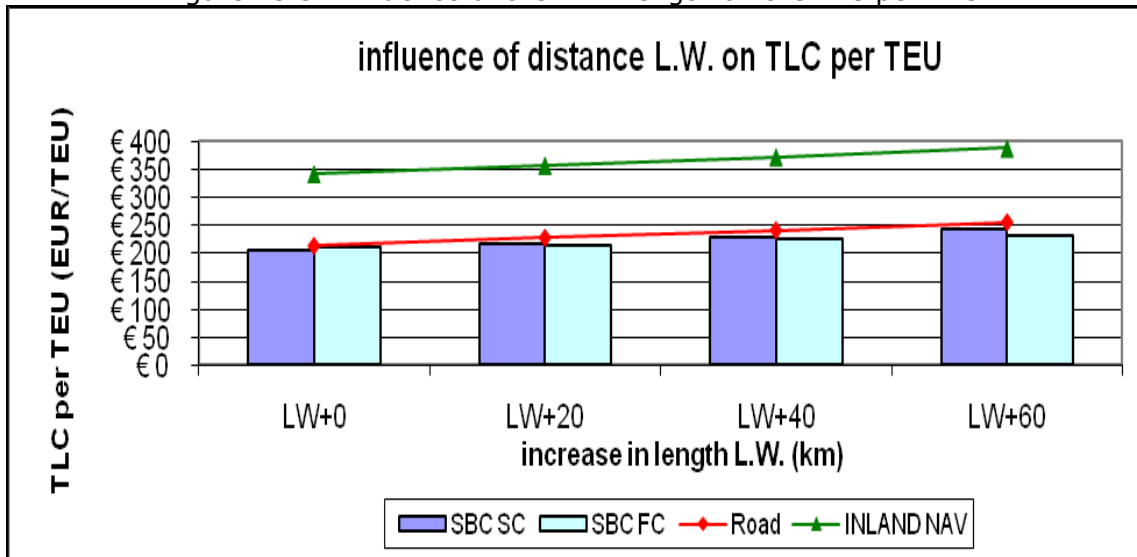
Note: 2009 values



Figure 15.2 shows that the NPV of the small-barge convoy will decrease if the distance on the large waterway is increased above 80 km. The reason for the decrease of NPV is that, due to the increase in sailed distance, the number of trips per year is reduced, implying less use of the barges and therefore an increase of the fixed costs per transported TEU or tonne. If the tug of the convoy is operated in a fully continuous regime, the NPV will increase with the increase in large waterway distance. The reason why the FC option performs better than the SC option is that, by operating the tug 24 hours per day, more trips per year can be made than in the SC option. Therefore the fixed costs per TEU or tonne decrease and therefore a more competitive price can be offered compared to the other modes.

In figures 15.3 and 15.4 the TLC per TEU and tonne (SC and FC) is given of the small barge convoy as function of the increasing distance of the large waterway. The TLC per TEU and tonne of the competing modes are given as well in these figures.

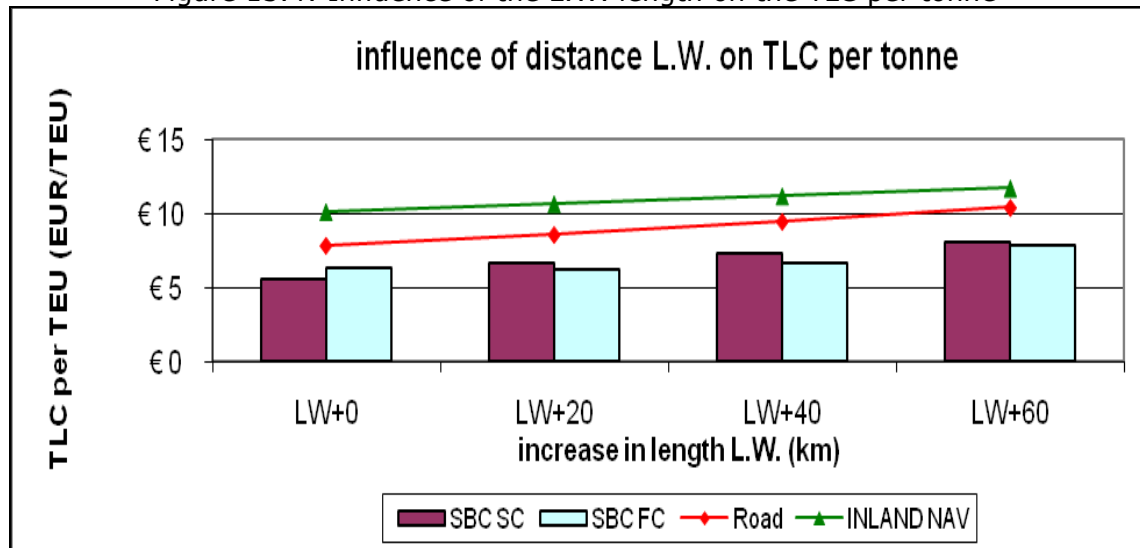
Figure 15.3: Influence of the L.W. length on the TLC per TEU



Note: 2009 values

From figures 15.3 and 15.4 it can be concluded that the TLC will increase if the sailed distance is increased. The TLC of the competing modes can also be seen to increase. The difference between the small-barge system and the nearest competitors is also larger than 5% (see chapter 13). If the small barge convoy is operated at a full continuous sailing regime, the TLC per TEU will decrease with increased sailed distance compared with the semi-continuous sailing regime. This is because the transportation time is decreased, so that also the in-transit-inventory costs are decreased. Therefore the TLC are decreased.

Figure 15.4: Influence of the L.W. length on the TLC per tonne



Note: 2009 values

Figure 15.4 shows that the TLC per tonne for the FC option are also decreased compared to the SC option, but the large waterway distance must be increased by 20 km in order for the transportation costs for the FC and SC option to be the same. The value of the transported cargo is low, so that the majority of the TLC will be determined by the handling costs and the transportation costs. The transportation costs, in the FC option, will be decreased compared with the SC option. Due to the increase in available time more trips can be made and therefore the transportation costs are decreased (fixed costs).

Besides researching the influence of the sailed distance on the large waterway on the chosen sailing regime, also the influence of the distance of the large waterway on the newly developed coupling system (chapter 7.3 and appendix H) will be researched. In chapter 8 it was already determined that the price of the new coupling system could not be determined and for that reason the analysis was based on the potential savings in transportation costs. This same strategy is also applied to this analysis in this chapter. In this analysis also the first business case is used (with a semi-continuous sailing regime).

In table 15.2 the results of the calculations are given. The transportation costs per TEU are indicated for the two different coupling times, corresponding to the old and new systems, for the different large waterway distances. Per large waterway distance the difference in transportation costs will be determined.

Table 15.2: Influence large waterway variation on the new coupling system

LW variation	[km]	+ 0		+20		+40		+ 60	
Coupling time	[h]	1/2	1/4	1/2	1/4	1/2	1/4	1/2	1/4
Fuel	[EUR/TEU]	3.92	3.92	5.57	5.57	7.23	7.23	8.89	8.89
Crew	[EUR/TEU]	14.75	13.22	15.85	14.81	16.96	15.92	18.07	17.03
RenO	[EUR/TEU]	2.77	2.77	3.23	3.23	3.68	3.68	4.13	4.13
Insurance	[EUR/TEU]	5.02	4.35	6.02	4.95	6.95	5.92	8.03	6.95
Capital Costs	[EUR/TEU]	4.85	4.21	5.82	4.78	6.71	5.72	7.76	6.71
Depreciation	[EUR/TEU]	12.55	10.88	15.06	12.38	17.37	14.81	20.08	17.37
Costs_crew_logistics	[EUR/TEU]	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Waterway costs	[EUR/TEU]	0.35	0.35	0.42	0.42	0.48	0.48	0.55	0.55
Overhead	[EUR/TEU]	1.22	1.08	1.49	1.22	1.72	1.46	1.98	1.72
total	[EUR/TEU]	46.93	42.28	54.96	48.86	62.60	56.72	70.99	64.85
Difference	[%]	9.91%		11.10%		9.39%		8.65%	

Note: 2009 values

Table 15.2 shows that the difference in transportation costs will increase initially if the covered distance on the large waterway is increased by an additional 20 km. If the covered distance on the large waterway is increased further (+40 km and + 60 km), the decrease in transportation costs becomes less. The reason is that with an increasing sailed distance the influence of the coupling time on the total number of trips per year becomes less. If the distance of the large waterway is relatively short (< 70 km), then the number of trips per year is more affected by the coupling time, especially when the tug is pushing four barges to one waterway. If more trips per year can be made, the fixed costs (capital costs, depreciation, insurance and overhead) per TEU can be reduced.

So the development and implementation costs of the new coupling system should become smaller if the sailed distance on the large waterway is increased.

### 15.3 Small waterway variations

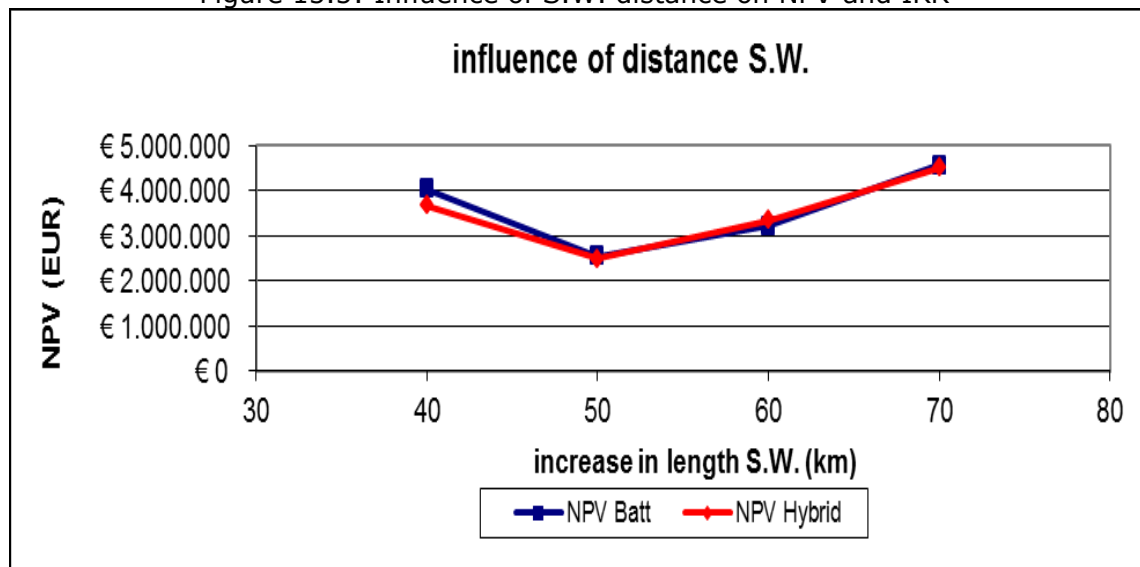
In this part of the chapter the influence of the increasing distance of the small waterway will be researched. In figure 15.5 the NPV of a battery and hybrid propelled barge is shown as function of the small waterway distance.

Figure 15.5 shows that the NPV will decline at first and, when the distance of the small waterways is increased to more than 50 km, it will increase again. The reason why this happens is due the fact that the large waterway infrastructure characteristics are kept constant in this analysis (LW distances and number of locks). If the small waterway distance is increased by 10 km (compared to the original situation) the number of departures that can be made per year is decreased because the time needed for the barges to sail on the small waterway is increased (the tug is used less on the large waterways). Therefore less cargo can be transported. The competitors only suffer from an increase in distance which will increase their variable costs, while the small-barge system also suffers from an increase in fixed costs. If the distance increases more, also the small barge

only suffers from an increase in variable costs. The increase in variable costs for the small-barge system is less than the competitors, resulting in an increase in NPV if the distance of the small waterway increases.

The same figure also indicates that changing the propulsion system of the barge will not lead to a major change in NPV if the distance of the small waterways is increased. Chapter 8 already concluded that the transportation costs of the hybrid-propelled barge and the battery-propelled barge are almost the same for the base case scenario (no variation in distance). Increasing the distance of the small waterways will make the hybrid-propelled barge slightly more favourable than the battery-propelled barge however the difference is very small.

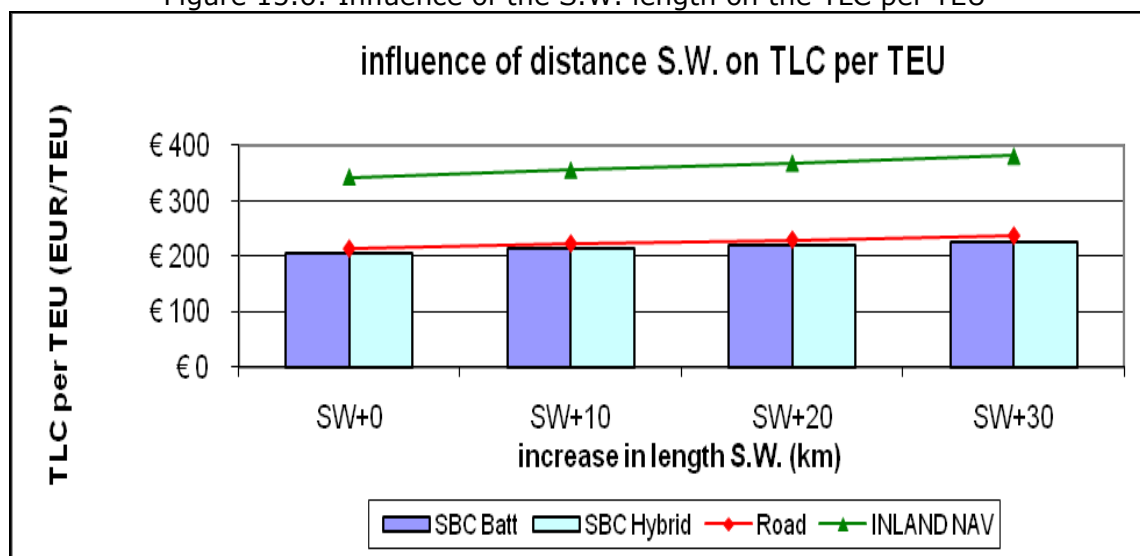
Figure 15.5: Influence of S.W. distance on NPV and IRR



Note: 2009 values

In the figures 15.6 and 15.7 the TLC per TEU and tonne are given as function of the increasing distance of the small waterway. In the same figure also the TLC of the competing modes are given.

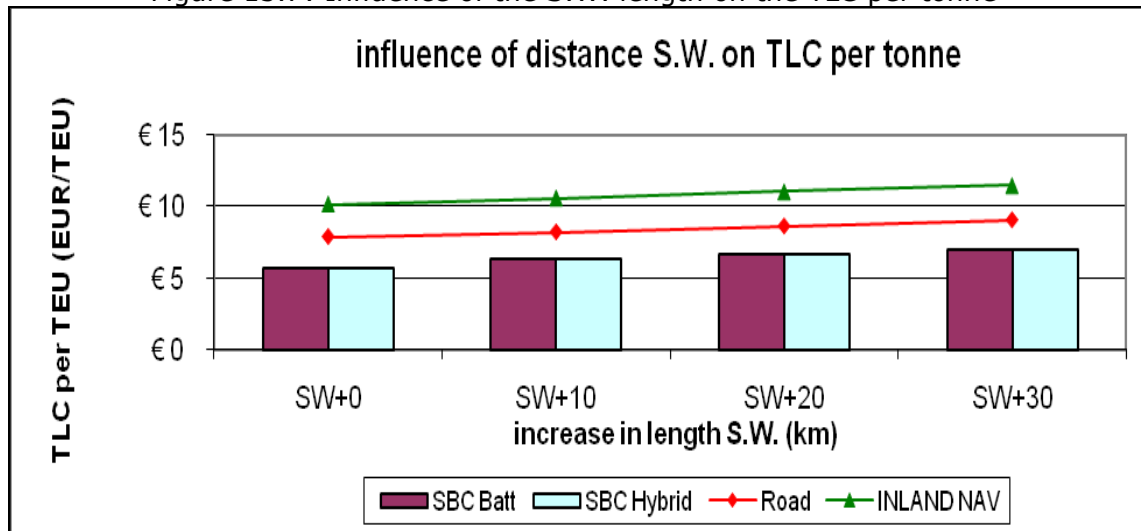
Figure 15.6: Influence of the S.W. length on the TLC per TEU



Note: 2009 values

Figure 15.6 shows that the TLC per TEU are always at least 5% smaller than the TLC of its nearest competitor. The same can be concluded from figure 15.7 where the difference between the TLC is at least 30%. In the two figures it can also be seen that the TLC of the battery-propelled barge and the hybrid-propelled barge are same.

Figure 15.7: Influence of the S.W. length on the TLC per tonne



Note: 2009 values

## 15.4 Preliminary conclusions

The results of the calculations have shown that the small-barge concept will decrease its competitiveness and decrease its NPV if the distance of the large waterway is increased in a semi-continuous sailing regime. If the sailed distance on the large waterway is larger than 80 km, a full continuous sailing option is better than a semi-continuous option. The competitiveness and the NPV of the full continuous option are then larger than the semi-continuous option. The TLC of the full continuous option will decrease, compared to the semi-continuous option, with increasing distance of the large waterway.

For the developed coupling system it can be concluded that its development and implementation costs should become smaller, than in the base case, if the sailed distance on the large waterway is increased above 70 km. The reason for this is that due to the increase in sailed distance more time is spent sailing. Therefore the influence of the coupling time on the total number of trips, that can be made per year, is reduced. As a result the amount of money saved is decreased and therefore the allowable price per coupling system is reduced.

If the distance of the small waterway is increased, the NPV will decline at first and when the distance of the small waterways is increased to more than 50 km, it will increase again. In the small waterway analysis it can also be seen that changing the propulsion of the barge from batteries to a hybrid option will not increase the NPV. Despite the lower newbuilding costs of the hybrid barge than for the battery-propelled barge, an increase in sailed distance will not make the hybrid option more competitive, due to the increase in fuel costs of the hybrid barge.



# **PART IV: IMPLEMENTATION**





# **16. Building up the small barge convoy system**

## **16.1 Introduction**

In chapter 14 two business cases were developed which could be used to re-activate the use of the small inland waterways. The developed cases were optimized if the total tug and barge system was fully working. But in order to realize this full potential, the small-barge convoy system must be implemented. In this chapter two implementation strategies will be further researched to determine which strategy will be used to implement the small-barge convoy system. This will be done in section 2 of this chapter. When the strategies are developed, they will be applied to the two developed business cases of chapter 14 in section 3. Section 4 will then discuss the implementation hurdle, whereas section 5 of this chapter will deal with the justification of the implementation subsidy. In the sixth section the required crew to man the barges and tug will be discussed. The second to last part will deal with reduced demand if the small barge system is completely operational with all the barges. This chapter will end with the conclusion.

## **16.2 Implementation strategies**

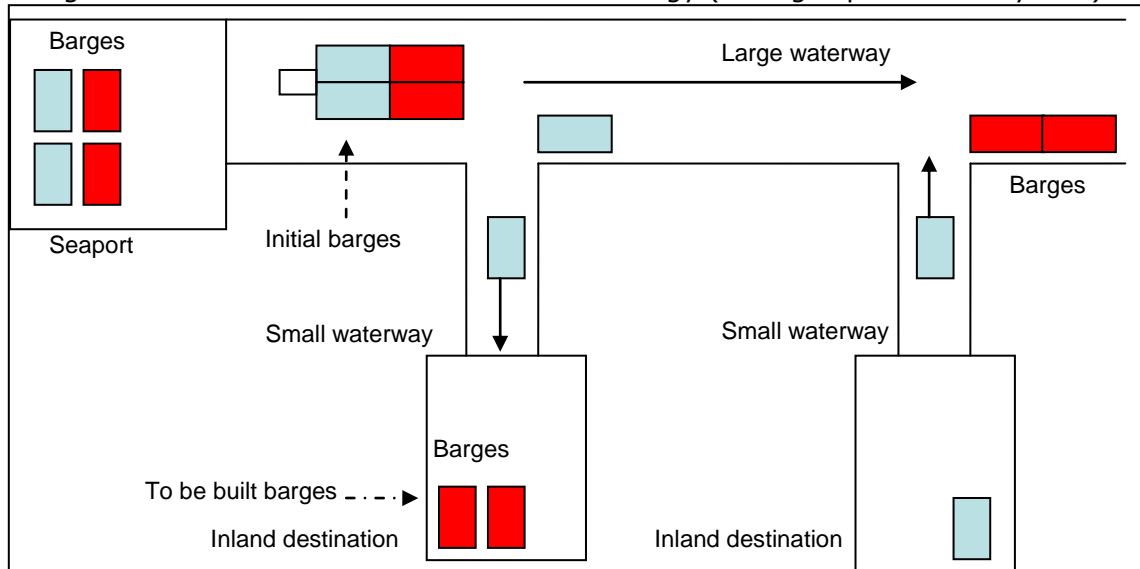
Two different implementation strategies are developed:

- Building up the small barge system from a small starting position (not all the needed barges are built in the start-up phase)
- Building up the small barge system with all the barges of which some are directly laid-up (i.e. risk of overcapacity at the start)

### **16.2.1 Strategy one**

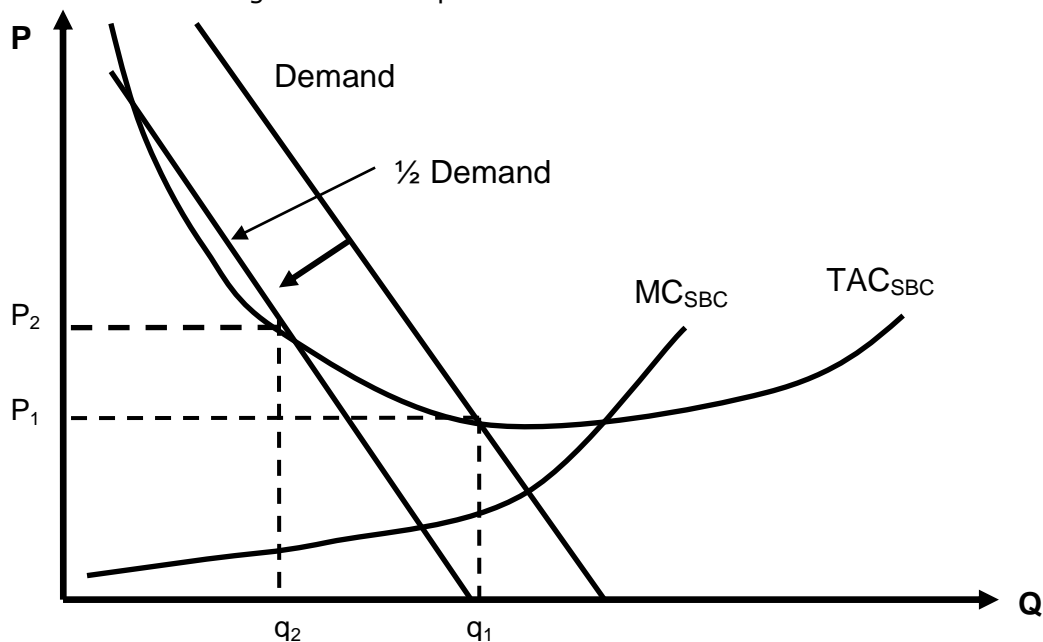
The first implementation strategy is to build up the total tug and barge system by starting from a small start position (limited capacity). The other barges are purchased later on. As could be seen in chapter 14, in the first business cases 20 barges and in the second case 16 barges are needed to set up the concept. The risks involved in building a tug plus 20/16 barges at once could be too high if not all the potential clients are willing to shift their cargo flows to the small-barge system during the start-up phase. Due to the scepticism of the new technology (electrically driven barges) or to an alternative logistic system, not all the available cargo flows might be offered to the small-barge system. Then a smaller starting position could be more desirable. In the time that only a few barges are deployed, the barge concept could prove itself and could therefore persuade the cargo owners to shift all the potential cargo flows to the new system. In figure 16.1 this implementation strategy is shown.

Figure 16.1: Overview of the start small strategy (2 barges per waterway to 4)



The drawback of this approach is that the transportation costs per TEU (or tonne) are increased if not all the barges are deployed. If more barges are added, the transportation costs and also the prices are reduced. This is illustrated in figure 16.2, where the price is increased from  $P_1$  to  $P_2$  (see also chapter 14).

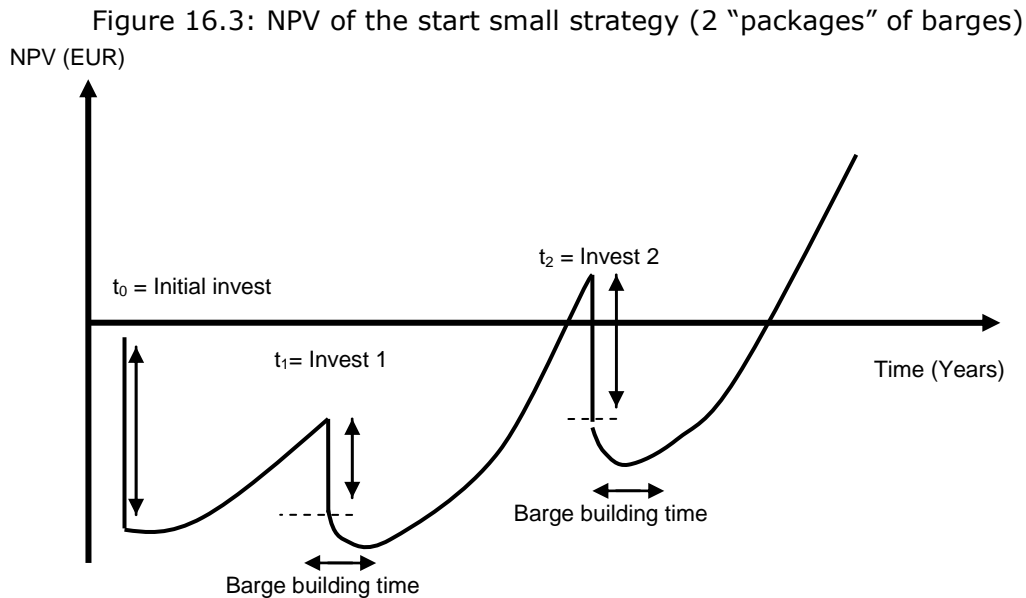
Figure 16.2: Impact of decrease of demand



In order to support the small barge system during the start-up phase, the difference in transportation price could be covered by a subsidy of the government. At the moment that all the barges are deployed, the subsidy will disappear and the concept will be completely self-supporting (see section 5).

Another drawback of this implementation strategy is that building and deploying the new barges could take too long. The time that a shipyard could start building the barges is, besides other parameters, a function of

the number of orders in the shipyard's order books. If the order books are full, it could take quite a while before the barges could be built. Moreover, the price of building the barges could change considerably because the newbuilding price is subject to the large volatility in the shipbuilding market. So barges could become more expensive (or cheaper) and therefore the transportation costs are increased (or decreased). In figure 16.3 a schematic overview is given of the NPV of the small barge system as function of the time of this implementation strategy.

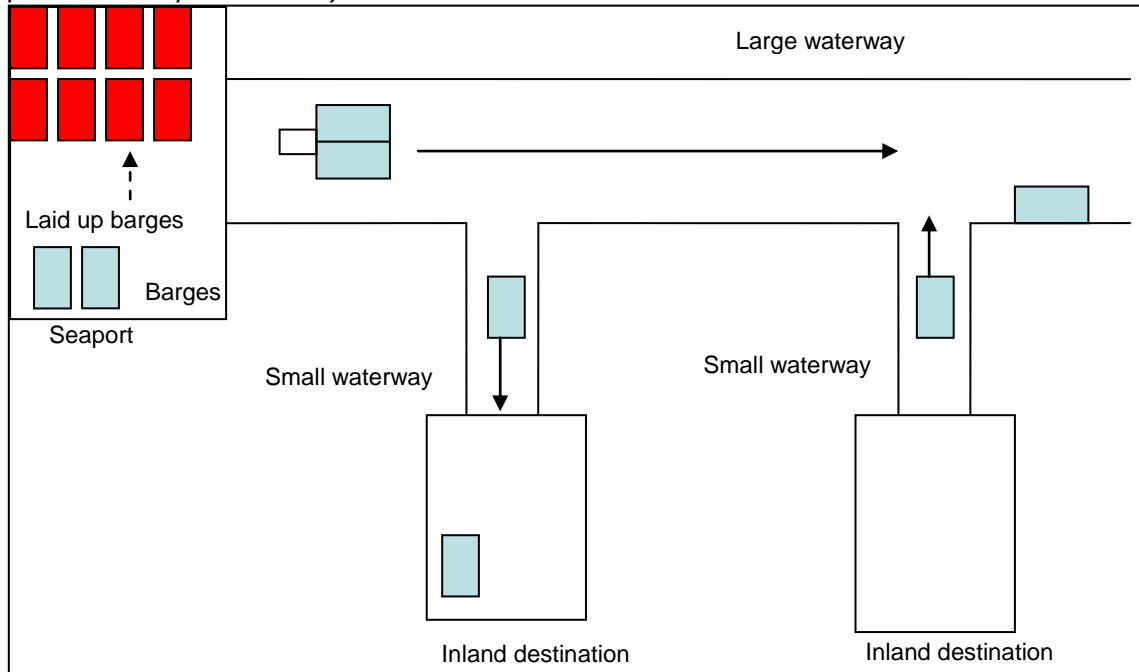


In figure 16.3 the size of investment 1 and investment 2 are very difficult to determine 2 or 3 years in advance. The figure also shows that the NPV will decrease even further after an investment is made for the extra barges. This is because one or more down payments have to be made when the barges are being built. Therefore money will go out while no extra revenue can be generated because the barges are not built yet. The building time of the barges is also a function of the volatile shipbuilding market, so that these extra costs are difficult to determine for 2 or 3 years in advance. If this strategy is applied, the building of the extra barges (invest 1 and invest 2) must also be taken into consideration during the negotiation with the shipyard via a "call option" on the extra barges.

### 16.2.2 Strategy two

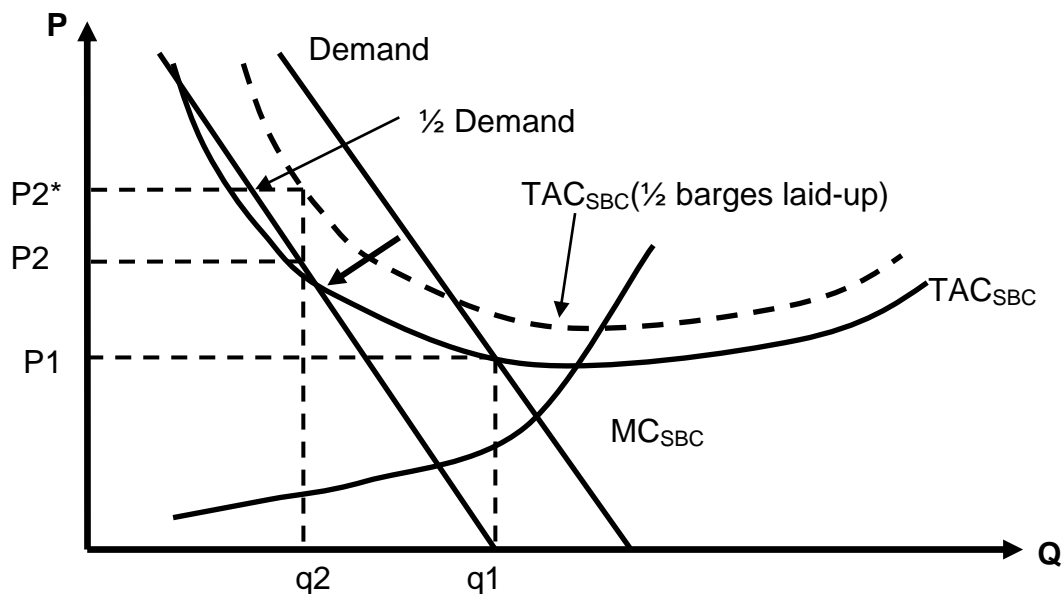
The second implementation strategy is to start with all the needed barges (sufficient capacity at the start). All the required barges plus the tug are built at once. When the building costs of the barges are low, due to empty order-books of the shipyards and/or low steel prices, the transportation costs could be reduced. The transportation costs of a tug and barge system with a large amount of barges is predominantly determined by fixed costs caused by the new building costs (interest costs, insurance and pay back loan). If, in the start-up phase, not all the barges are needed due to not enough cargo to transport (i.e. overcapacity), some barges could be laid up. In figure 16.4 a schematic overview could be seen of this implementation strategy.

Figure 16.4: Overview of the "start large" strategy (4 barges per waterway only 2 per waterways are used)



Because the demand is halved and half of the needed barges are laid-up, the transportation price per TEU (or tonne) is increased. This increase is due to the increase in TAC caused by the increase in fixed costs, which is shown in figure 16.5.

Figure 16.5: Impact of decrease of demand + ½ barges laid-up



Due to the halved demand and due to fact that half of the built barges are laid-up, the transportation price will increase not from P1 to P2 but from P1 to P2\*. If during the life-span of the small barge system the demand decreases, the supply can be adjusted by laying up barges. The total additional costs per year will then be equal to  $(P2^* - P1) \cdot q2$ .

The costs for this lay-up could also be compensated by a subsidy of the government. If all the laid-up barges are used in the system, the subsidy will be reduced (section 5).

### 16.3 Application of the implementation strategies

In this part of the chapter the two implementation strategies are applied to the two business cases of chapter 14. In this analysis a fixed, neutral, scenario is chosen (scenario 4 of chapter 14) when the calculations are made.

#### 16.3.1 Business Case I

Business case I consist of convoys of two and four barges sailing to waterways 2, 3 and 4 (see chapter 14). For the first strategy, business case I will be implemented by purchasing half of the needed barges at the initial investment and the other half of the barges after two years. It is also possible to purchase the barges in more packages but in order to make a calculation a fixed strategy is chosen. In table 16.1 the difference in transportation price is shown if not all the barges are built at once. The transportation prices, if half of the barges are deployed, are set in such a way that the NPV equals the NPV if all the barges are deployed (€4,060,000).

Table 16.1: Difference in transportation prices if ½ of the barges are deployed

Normal		ROUTE 2	ROUTE 3	ROUTE 4
TEU	[EUR/TEU]	51.84	49.27	n.a.
Tonne	[EUR/tonne]	3.85	3.82	4.15
1/2 barges deployed				
TEU	[EUR/TEU]	60.80	64.13	n.a.
Tonne	[EUR/tonne]	4.37	4.61	4.62
Difference				
TEU	[EUR/TEU]	8.95	14.85	n.a.
Tonne	[EUR/tonne]	0.52	0.80	0.47

Note: 2009 values

In table 16.2 the total transported amount of cargo is given if only half of the barges are deployed.

Table 16.2: Transported amount of cargo if ½ of the barges are deployed

transported amount		ROUTE 2	ROUTE 3	ROUTE 4
containers IN	[Cont/Year]	2,324	4,183	0
Containers OUT	[Cont/Year]	4,648	3,718	0
bulk IN	[t/Year]	41,337	4,960	41,337
bulk OUT	[t/Year]	0	16,535	41,337

The implementation cost needed per year for these cargo flows can be calculated with relation 16.1.

$$C_{\text{impl}} = [TP_{\text{TEU}} - \text{start} - TP_{\text{TEU}}] \cdot N_{\text{TEU}} + [TP_{\text{tonne}} - \text{start} - TP_{\text{tonne}}] \cdot N_{\text{tonne}} \quad (16.1)$$

$C_{\text{impl}}$  = implementation cost per year [EUR/year]  
 $TP_{\text{TEU}}$  = transportation price per TEU [EUR/TEU]

$TP_{TEU\_start}$  = transportation price per TEU in start-up phase [EUR/TEU]  
 $N_{TEU}$  = number of transported TEU per year [TEU/YEAR]  
 $TP_{tonne}$  = transportation price per tonne [EUR/tonne]  
 $TP_{tonne\_start}$  = transportation price per tonne in start-up phase [EUR/tonne]  
 $N_{tonne}$  = number of transported tonnes per year [tonne/year]

The total implementation cost of €257,550 (2009 value) per year is needed to offer a price that will result in the same NPV if all the barges are deployed. In this case a start-up phase of two years is assumed. Therefore €503,445 (2009 value) in total is needed to overcome the first two years and to build up the tug and barge system. In order to have all the monetary values in the same year, all the future costs are discounted with the WACC (see chapter 12).

For the second implementation strategy half of the barges will be laid up for a period of two years. After two years all the barges are used. In this strategy the transportation price will be increased even further because the fixed costs of the laid-up barges have to be taken into account. In table 16.3 the transportation prices are given if half of the barges are laid up.

Table 16.3: Difference in transportation prices if ½ of the barges are laid-up

Normal		ROUTE 2	ROUTE 3	ROUTE 4
TEU	[EUR/TEU]	51.84	49.27	n.a.
tonne	[EUR/tonne]	3.85	3.82	4.15
1/2 barges laid-up				
TEU	[EUR/TEU]	77.76	80.89	n.a.
tonne	[EUR/tonne]	5.06	5.26	5.58
Difference				
TEU	[EUR/TEU]	25.92	31.61	n.a.
tonne	[EUR/tonne]	1.21	1.45	1.44

Note: 2009 values

The transportation costs (and also the price) are increased quite considerably due to the increase in fixed costs caused by the laid-up barges (see figure 16.5). The amount of the transported cargo in both implementation strategies is the same. Accordingly, table 16.3 can be used again to calculate the implementation cost per year. These are €630,227 per year and €1,232,738 in a period of two years. This is an increase of almost two times compared with the first strategy.

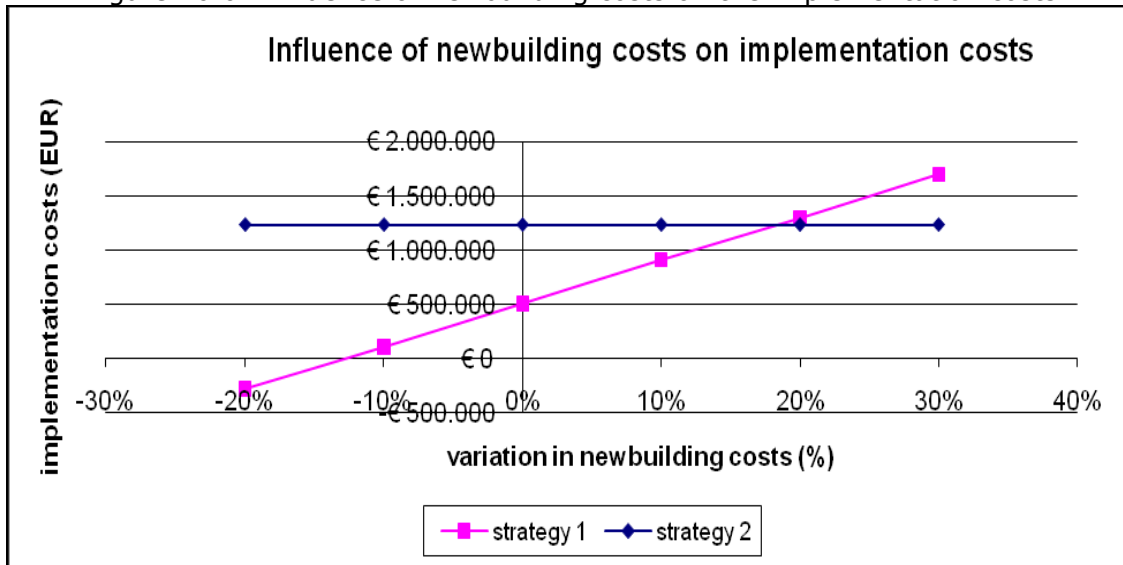
The costs related to the disadvantage of the first strategy, i.e. the unknown building time of the second part of the needed barges, will not be greater than the needed implementation cost of having all the barges built at once. Because, only if the building time of the second "package" of barges is larger than 2.8 years, will the costs of subsidising the first implementation strategy be larger than the second strategy ((€1,232,738 - €503,445)/€257,550). The time needed between the decisions made to build the extra barges and the final delivery of the barges will be very unlikely to be larger than three years.

The other disadvantage of the first strategy is the large uncertainty of the newbuilding price of the second "package" of barges. If the newbuilding prices of the barges are increased, the transportation price will be higher.

In strategy I, after 2 years, the second “package” of barges is deployed, so the transportation price is increased by the increase in newbuilding costs of the barges, which will go on for the next 18 years. In the research the depreciation of the barges (and also the cash flow calculations) is set at 20 years, so that 18 years is the rest period when all the barges are deployed.

The costs of strategy two are constant because all the barges are already available so that the volatility in the shipbuilding market does not influence the transportation costs. In strategy one the costs will consist of the implementation costs calculated at €503,445 in two years, plus the costs of the variation in newbuilding price of the second “package” of barges. In figure 16.6 the influence of the variation in newbuilding costs of the barges on the strategy costs are given.

Figure 16.6: Influence of newbuilding costs on the implementation costs



Note: 2009 values

Figure 16.6 indicates that strategy 1 is the best option until the moment that the newbuilding price of the barges is increased by more than 18% in comparison with the calculated values of chapter 7. This is due to fact that the transportation costs of the small- barge convoy system considerably depend on the fixed costs (chapter 8). A change in newbuilding costs will therefore have a large influence. But from the figure it can also be concluded that, if the barge price is decreased, strategy one will even be profitable if the barge price is decreased by more than 12%. In that case the transportation costs are lowered and more profit can be made, so that the implementation costs could even be negative (the implementation strategy will earn money).

The last aspect taken into account in the implementation analysis is the risk that the small-barge system could fail to expand to the desired optimal situation. That means that implementation costs of both strategies will have to be paid for 20 years instead of two. In that respect strategy one is a lot cheaper (€3,400,000) than strategy two when half of the barges are not used (€8,500,000). To take this aspect into account, the probability that not all planned barges will be deployed needs to be known. The risk costs of not fully implementing all the barges can then be calculated with the following relation.

$$RC_{NI} = P_{\text{not imp}} \cdot CNI \quad (16.2)$$

$RC_{ni}$  = risk costs of not implementing [EUR]

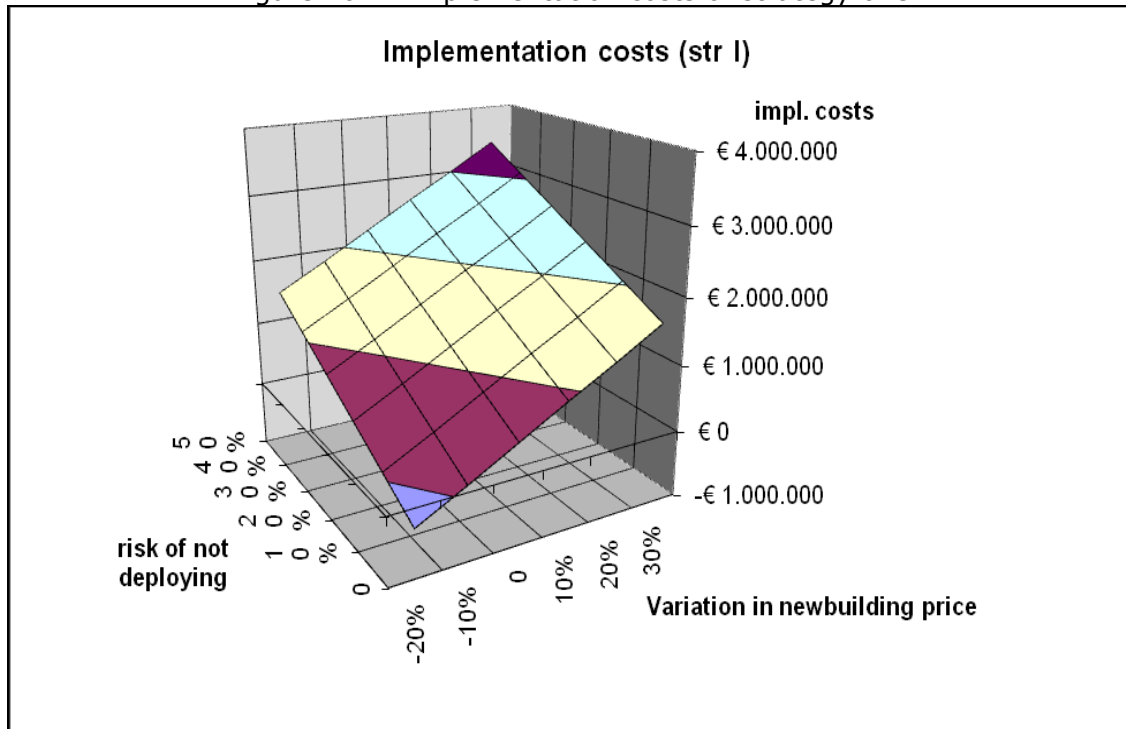
$P_{\text{not imp}}$  = probability that not all barges are implemented [%]

$CNI$  = total costs of not implementing all barges (I= 3,4 M ; II =8.5 M)[EUR]

These costs have to be added to the costs calculated and shown in figure 16.6. Now two unknowns are present: the variation in the newbuilding costs of the second “package” of barges and the risk that not all barges are implemented.

In figure 16.7 the implementation costs of strategy one is given.

Figure 16.7: Implementation costs of strategy one



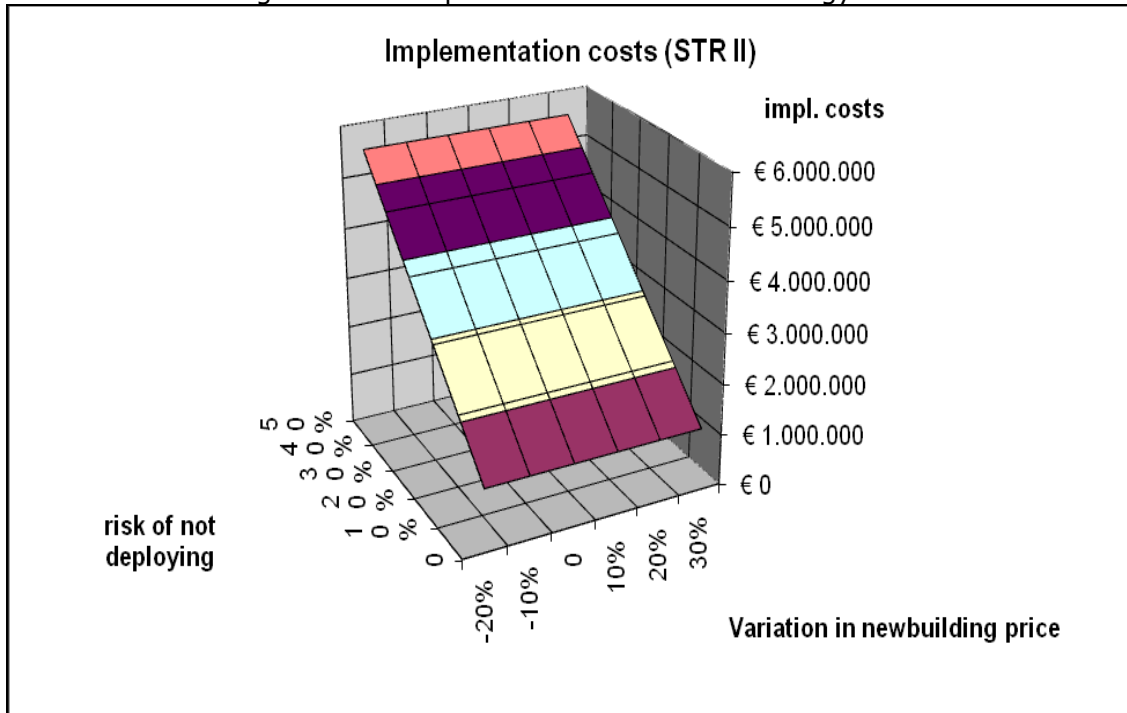
Note: 2009 values

Only probabilities up to 50% of not deploying all barges are taken into account because, if the probability is higher than 50% of not deploying all barges, then that business case should not be considered. It can be concluded that the implementation costs will increase significantly if the risk of not deploying all barges is increased.

In figure 16.8 the implementation costs of strategy 2 are given. The variation in newbuilding costs of the second “package” of barges does not influence the implementation costs of strategy 2. The influence of the increasing risk of not deploying all barges is larger for this strategy than for the first one.



Figure 16.8: Implementation costs of strategy two



Note: 2009 values

In table 16.4 an overview is given of which strategy prevails over the other in terms of implementation costs.

Table 16.4: Overview of prevailed strategies

		Variation in new building price →					
		-20%	-10%	0	10%	20%	30%
risk of not deploying	0	1	1	1	1	2	2
	10%	1	1	1	1	1	1
	20%	1	1	1	1	1	1
	30%	1	1	1	1	1	1
	40%	1	1	1	1	1	1
	50%	1	1	1	1	1	1

From table 16.4 (and figures 16.7 and 16.8) it can be concluded that strategy 2 only prevails if there is a no risk of not implementing all the barges (0%) and if the newbuilding costs of the second “package” of barges are increased by more than 10%. In all other situations strategy one is prevailed.

### 16.3.2 Business Case II

In the second business case the convoy is built up of 6 and 4 barges sailing to an inland terminal, from which 2 barges of the 6 barge convoy will not sail further than the selected inland container terminal. The first implementation strategy for business case II will be applied by purchasing 4 and 2 of the needed 6 and 4 barges at the initial investment and the other needed barges after 2 years. So only convoys of 4 and 2 barges will be used; from the 4-barge convoy two barges will sail to the destination at the small inland waterway and the other two will stay at the inland terminal.

In table 16.5 the difference in transportation price is given for the normal situation, and if not all the barges are built at once.

Table 16.5: Difference in transportation prices if 1/2 of the barges are deployed

<b>Normal</b>		ROUTE 2	ROUTE 3	ROUTE 4
<b>TEU</b>	<b>[EUR/TEU]</b>	53.44	52.6	<b>n.a.</b>
<b>tonne</b>	<b>[EUR/tonne]</b>	3.05	2.99	<b>n.a.</b>
<b>TEU ICT</b>	<b>[EUR/TEU]</b>	48.64	<b>n.a.</b>	<b>n.a.</b>
<b>1/2 barges deployed</b>				
<b>TEU</b>	<b>[EUR/TEU]</b>	60.91	68.44	<b>n.a.</b>
<b>tonne</b>	<b>[EUR/tonne]</b>	4.20	4.75	<b>n.a.</b>
<b>TEU ICT</b>	<b>[EUR/TEU]</b>	52.76	<b>n.a.</b>	<b>n.a.</b>
<b>Difference</b>				
<b>TEU</b>	<b>[EUR/TEU]</b>	7.47	16.07	<b>n.a.</b>
<b>tonne</b>	<b>[EUR/tonne]</b>	1.15	1.76	<b>n.a.</b>
<b>TEU ICT</b>	<b>[EUR/TEU]</b>	4.12	<b>n.a.</b>	<b>n.a.</b>

Note: 2009 values

Table 16.6 shows the total transported amount of cargo if only half of the barges are deployed.

Table 16.6: Transported amount of cargo if 1/2 of the barges are deployed

<b>transported amount</b>		ROUTE 2	ROUTE 3	ROUTE 4
<b>containers IN</b>	<b>[Cont/Year]</b>	1,859	4,183	<b>n.a.</b>
<b>OUT</b>	<b>[Cont/Year]</b>	4,648	3,718	<b>n.a.</b>
<b>Bulk IN</b>	<b>[t/Year]</b>	49,604	1,653	<b>n.a.</b>
<b>Bulk OUT</b>	<b>[t/Year]</b>	0	16,535	<b>n.a.</b>
<b>Cont terminal in</b>	<b>[Cont/Year]</b>	3,254	<b>n.a.</b>	<b>n.a.</b>
<b>Cont terminal out</b>	<b>[Cont/Year]</b>	3,254	<b>n.a.</b>	<b>n.a.</b>

With the increase in transportation costs and the amount of transported cargo the implementation costs per year can be calculated. These costs are €291,486 per year. The total costs during the start-up phase of two years are €569,781 (including discounting of WACC). These costs are a little bit smaller than the costs of implementing case I with strategy one.

If the second implementation strategy is used, half of the barges will be laid up for a period of 2 years. After 2 years all the barges are used. In this strategy the transportation price will be increased even further because the fixed costs of the laid-up barges have to be taken into account. In table 16.7 the transportation prices are given if half of the barges are laid up.

Table 16.7: Difference in transportation prices if ½ of the barges are deployed and ½ are laid-up

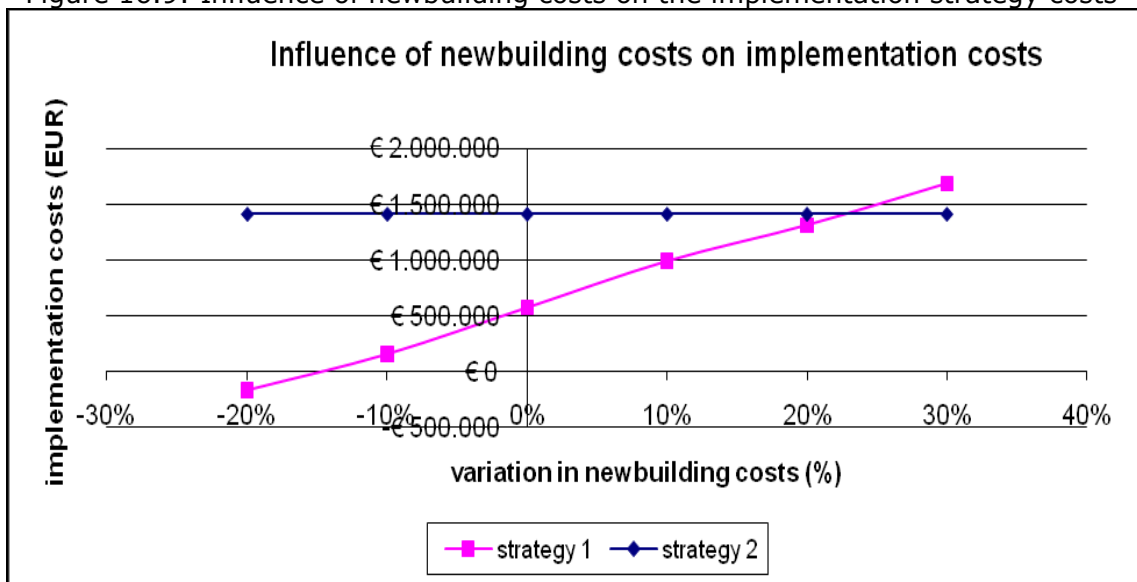
Normal		ROUTE 2	ROUTE 3	ROUTE 4
TEU	[EUR/TEU]	53.44	52.36	n.a.
tonne	[EUR/tonne]	3.05	2.99	n.a.
TEU_CT	[EUR/TEU]	48.64	n.a.	n.a.
1/2 barges laid-up				
TEU	[EUR/TEU]	82.02	88.59	n.a.
tonne	[EUR/tonne]	4.11	4,50	n.a.
TEU_CT	[EUR/TEU]	74.37	n.a.	n.a.
Difference				
TEU	[EUR/TEU]	28.59	36.22	n.a.
tonne	[EUR/tonne]	1.06	1.51	n.a.
TEU_CT	[EUR/TEU]	25.73	n.a.	n.a.

Note: 2009 values

The implementation costs of strategy two are €719,839 per year, so the total costs during the start-up phase of two year are €1,408,022. These costs are a little bit larger than the costs of implementing case I with strategy two.

In figure 16.9 the influence of the variation of the newbuilding price of the second “package” of barges is given. If the increase of the newbuilding price of the second “package” of barges is larger than 22% then strategy two will be the best implementation strategy. In all other situations strategy one is prevailed. If the newbuilding costs decrease by more than 15%, strategy one will be generating money.

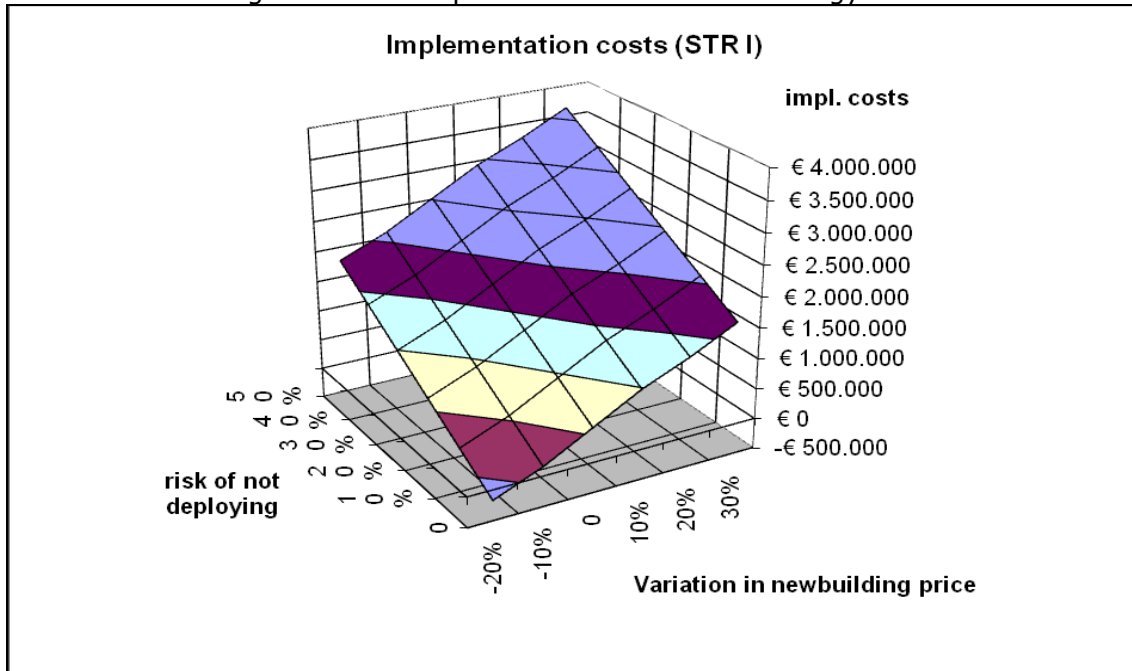
Figure 16.9: Influence of newbuilding costs on the implementation strategy costs



Note: 2009 values

In this analysis the risk costs of not implementing all barges will also be taken into account. Figure 16.10 indicates the total implementation costs of strategy one for business case two with a variation in the newbuilding price of the second “package” of barges and a variation in the risk of not deploying.

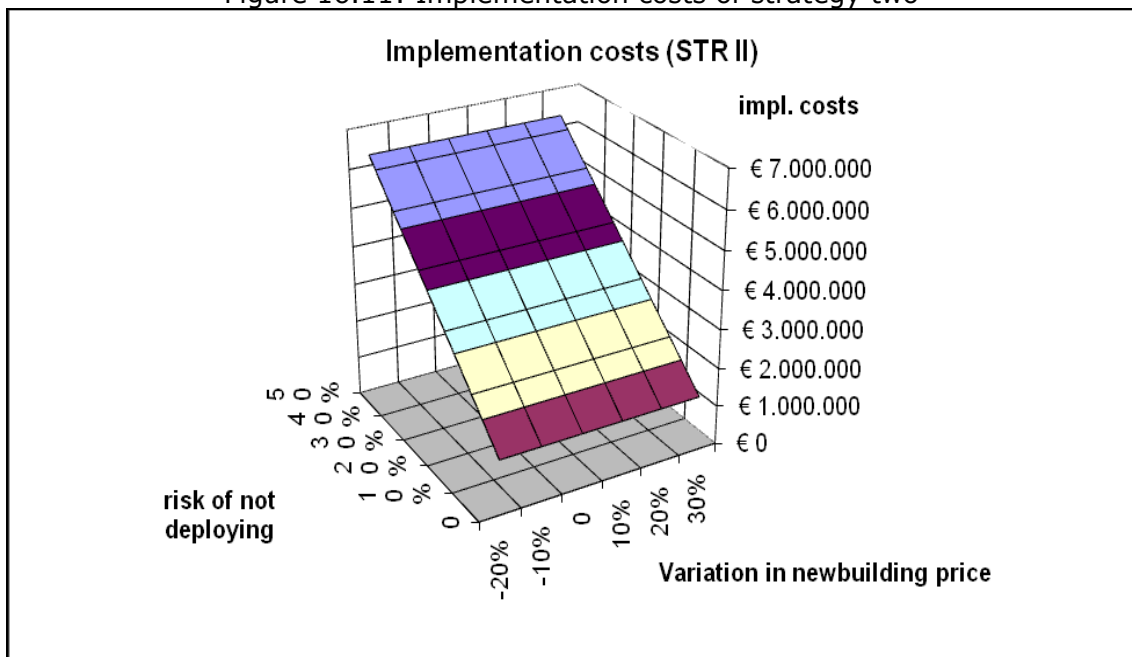
Figure 16.10: Implementation costs of strategy one



Note: 2009 values

In figure 16.11 the total implementation costs of strategy two is shown. These costs are, even as in business case I, not dependent on the variation of the newbuilding price of the second "package" of barges.

Figure 16.11: Implementation costs of strategy two



Note: 2009 values

In table 16.8 an overview is given of which implementation strategy prevails. If the risk of not deploying is less than 10% and if the variation in newbuilding costs of barges is higher than 20%, strategy 2 prevails. In all other situations strategy one prevails.

Table 16.8: Overview of prevailed strategies

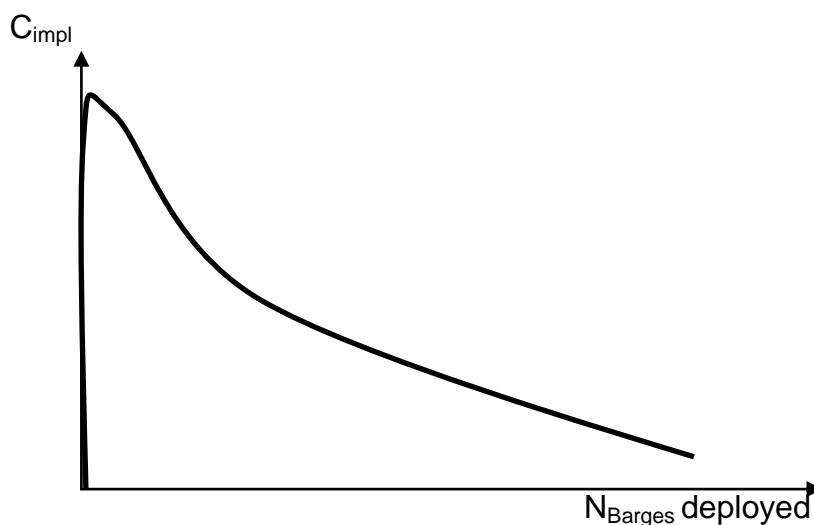
		Variation new building price →					
		-20%	-10%	0	10%	20%	30%
risk of not deploying	0	1	1	1	1	1	<b>2</b>
	10%	1	1	1	1	1	1
	20%	1	1	1	1	1	1
	30%	1	1	1	1	1	1
	40%	1	1	1	1	1	1
	50%	1	1	1	1	1	1

Table 16.8 indicates that for the second business case the same strategy prevails as for the first business case (i.e. the first one).

## 16.4 The implementation hurdle

Section 3 has shown that, in order to implement the developed small-barge system, additional money is needed to set up the system. This money is needed because, in order to make the system work, a critical amount of barges in the total system is needed (increasing scale of return). In figure 16.12 this implementation hurdle is sketched graphically.

Figure 16.12: Overview of the implementation hurdle



Note: own figure

The hurdle can be taken either be taken by adding this extra cost to the investment calculations, or with the help of government support in the way of an implementation subsidy.

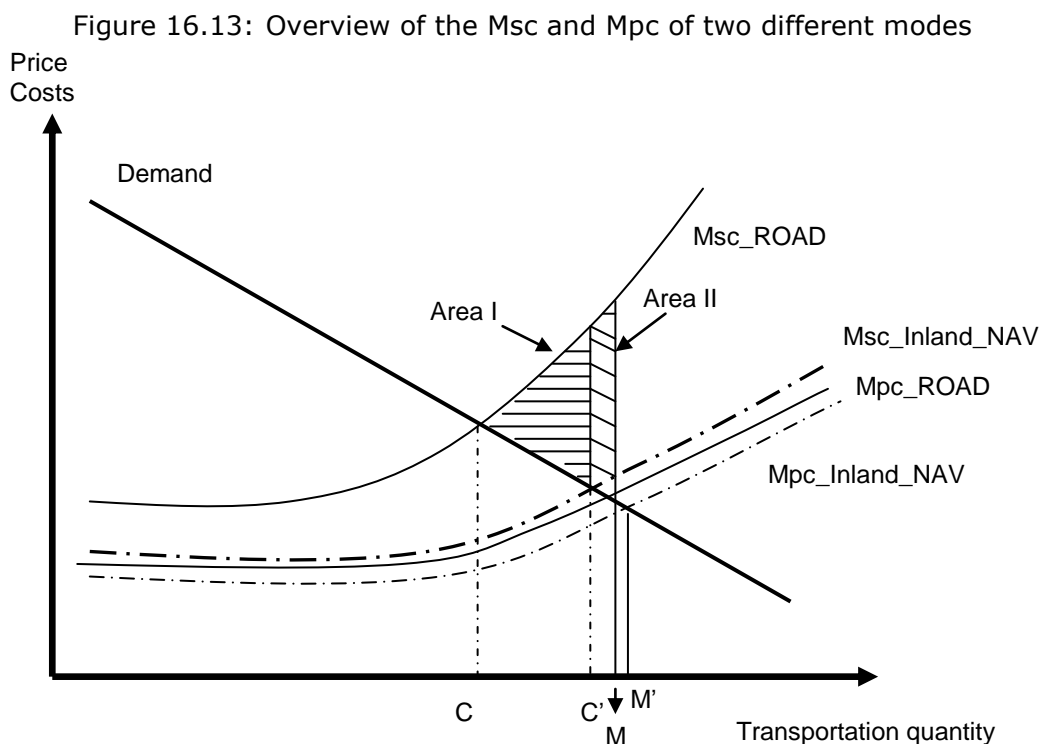
If this hurdle is taken by the small barge company itself, the NPV of the first business case will vary from €4,060,000 (no implementation costs, scenario 4) to a range of €4,340,000 to €645,000 (depending on the variation in probability of not deploying all the required barges and variation in newbuilding price of the second “package” of barges (implementation strategy 1)). For the second business case the NPV will vary from €4,100,000 to a range of €4,270,000 to €470,000. So, if the implementation cost must be taken into account by the small-barge company, the NPV will decrease significantly so that the investment

decision could become questionable (however the NPV is still positive the absolute value is reduced significantly). The reason of a potential negative investment decision is not related to the actual operation of the small-barge system, but due to the large implementation hurdle that needs to be taken to start up such a system.

It is also possible that the implementation cost can be covered by an implementation subsidy. Then the implementation cost will be covered by the government and not by the small-barge company, so that those costs will not influence the investment decision. In section 5 the justification of such an implementation subsidy will be given.

## 16.5 Justification of an implementation subsidy

The implementation subsidy for the small-barge system can be justified because the external costs can be reduced if cargo is transported with the small barges instead of by road. In figure 16.13, which could already be seen in figure 9.3, the visualization of the total external costs is given.



Note: own composition

The external costs are costs caused by the transport user for which he does not pay, causing not all the total social costs to be taken into account. The government aim is to reduce these external costs by stimulating more sustainable transportation modes. In that respect inland navigation and especially the small barge convoy system, designed for re-activating the small inland waterways, could be used so that these costs will be reduced. It can therefore be suggested that a government could support the implementation of the small barge convoy system.

A limiting factor for subsidy is that the reduction in external costs must be larger than the granted subsidy.

$$SUB \leq \Delta C_{\text{ext}} = \text{AREA}_I \quad (16.3)$$

SUB = subsidy costs

[EUR]

$\Delta C_{\text{ext}}$  = reduction of external costs

[EUR]

$\text{AREA}_I$  = area I given in figure 16.13

In table 16.9 the total external costs are given for when the first business case is not implemented and for when it is implemented.

Table 16.9: Cargo flows and external costs per year

	No SBC			SBCS implemented		
	[TEU]	[tonne]	[EUR]	[TEU]	[tonne]	[EUR]
SBCS	0	0	0	25,644	249,574	98,605
Inland Navigation	9,000	698,089	251,312	0	483,907	174,207
Road	29,190	218,620	1,019,881	12,546	183,228	593,054
Total	38,190	916,709	<b>1,271,193</b>	38,190	916,709	<b>865,866</b>

Note: 2020 projection values

From table 16.9 it can be concluded that by implementing the tug and barge system, the external costs can be reduced by €405,327 per year.

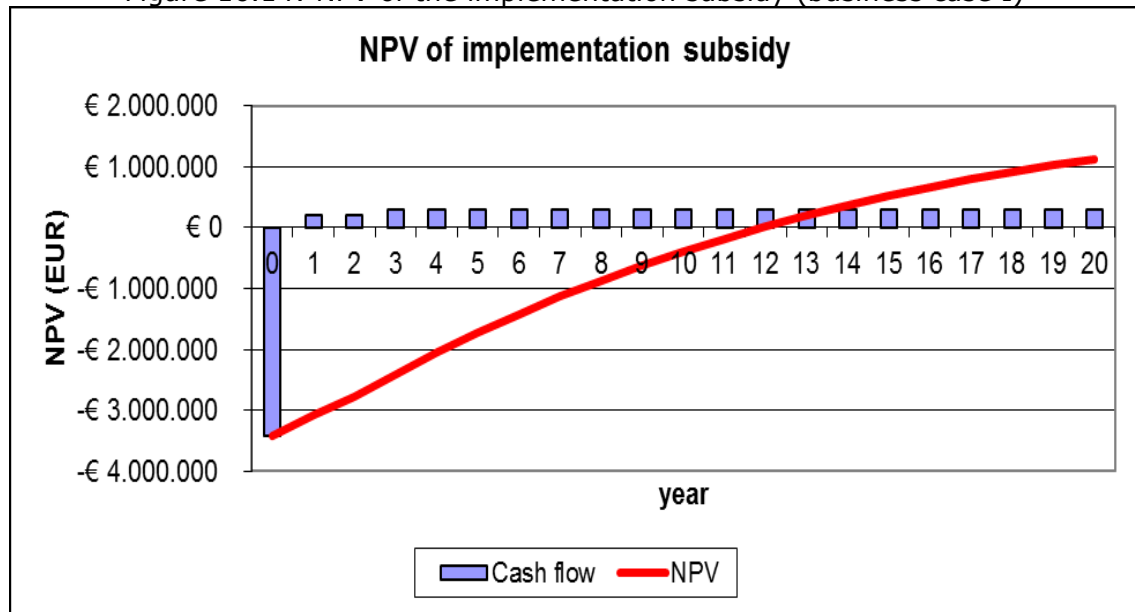
In order to determine whether the government should grant the implementation subsidy, an additional criterion will be added. The government should treat the subsidy as an investment which should aim to obtain a positive NPV. The return is the reduction in external costs and the investment is the granted subsidy.

If strategy one is applied, the biggest total implementation costs needed are €3,400,000 (including the 50% risk costs of not implementing). In all the calculations the life time of the concept was set at 20 years (based on the depreciation). In the first 2 years half of the total external costs are taken into account because only half of the barges are deployed. The other 18 years the costs reduction is also set at 50% of the additional cargo flows because there is a 50% probability that not all the barges will be implemented. Therefore 75% of the total reduction per year is considered. All the external costs savings are discounted with a factor of 4%<sup>51</sup> per year.

The NPV of the investing subsidy is given in figure 16.14. The total NPV after 20 years is €1,120,000.

<sup>51</sup> Taken from Arcadis et al. 2009

Figure 16.14: NPV of the implementation subsidy (business case I)



Note: 2009 values

Figure 16.14 indicates that even the most expensive subsidy investment will have a positive NPV, so that it can be concluded that granting the subsidy can be justified for the first developed business case.

In table 16.10 the total external costs are given if business case II is not implemented and when it is implemented. The cargo flows that are transported to and from the inland container terminals are not taken into account. These cargo flows are already transported via the inland waterways and shifting those cargo flows to the small-barge system has no added value for a government.

Table 16.10: Cargo flows and external costs per year

	No SBC			SBC implemented		
	[TEU]	[tonne]	[EUR]	[TEU]	[tonne]	[EUR]
Concept	0	0	0	14,409	67,792	101,408
Inland Navigation	9.000	11.951	4.302	0	4,813	1,733
Road	22.190	208.049	714.932	16,781	147,395	526,152
Total	31.190	220.000	<b>719.235</b>	31,190	220,000	<b>629,293</b>

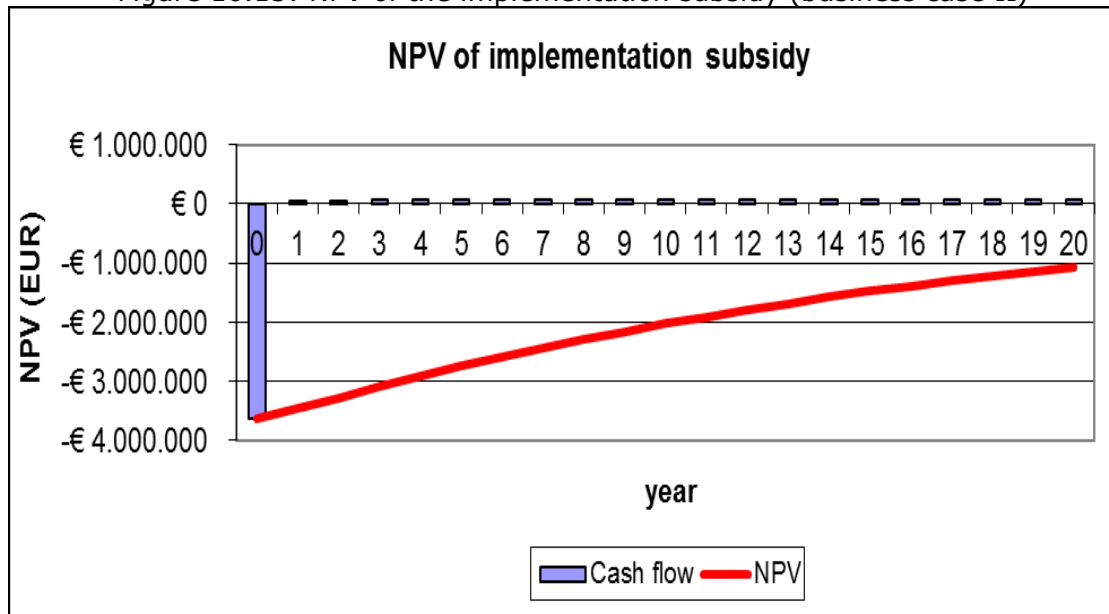
Note: 2020 projection values

The external costs reduction per year equals €89,941, which is lower than the first business case. The reason is that less cargo is shifted from the road to the inland waterways because a large part of the total transported cargo flows is transported to and from the inland container terminals which already were transported via the inland waterways.

Also for the second business case a NPV calculation will be made for the subsidy investment of the government. If implementation strategy one is applied, the largest investment is €3,600,000, while the return per year equals €89,941. In figure 16.15 the NPV of the implementation subsidy can be found. The NPV is -€1,00,000 which is almost €2,120,000 less than the first business case.



Figure 16.15: NPV of the implementation subsidy (business case II)



Note: 2009 values

From figure 16.15 it can be concluded that in the most expensive situation (50% probability of not deploying the barges and a 30% increase of newbuilding costs) an implementation subsidy cannot be justified. Only if the risk of not deploying is reduced to a maximum of 10% and if the variation in the newbuilding price is reduced to a maximum increase of 10% a subsidy can be justified.

## 16.6 Crew collection

This section of chapter 16 will deal with the crew needed on the barges and tug for the two business cases. First, an overview is given of the number of personnel and crew members. In section three the collection of the needed crewmembers is described. These crew members can either come from the inland navigation sector itself or from people coming from a totally different sector. This chapter will end with a conclusion.

### 16.6.1 Amount of personnel needed

In chapter 8 table 8.1 showed an overview of the number of crew members in a tug and barge formation. The number of crew members needed for the tug is based on that table, from which it can be concluded that three crewmembers (captain, sailor and a helmsman) are needed. But a double amount is needed because, when one tug crew is off, the other crew is needed (system sailing regime).

The number of crew members needed in the seaport is set at 2. These two men are needed to relocate the barges from the collection points (see chapter 6 on multiple barge exchange points) to the desired terminals.

The number of crew members needed on the small inland waterways is determined for the situation when that the barges can be manned by a single captain. If that is not possible, double the number is needed (see also scenario analysis of the business case in chapter 14). The small barge

crew is rotated between the different waterways. For business case II fewer small barge captains are needed because half of the barges are left behind at the inland terminals and therefore the barges have to sail less independently on the small inland waterways.

The number of personnel needed at the main office to deal with administration, planning and managing the business is set at 3. One personnel member is needed for the administration and one for the planning. The other member will be the director of the business who is controlling and managing it. In table 16.11 an overview is given of the total needed personnel / crew members.

Table 16.11: Overview of the needed amount of personnel

	B.CASE I	B.CASE II
	[-]	[-]
Tug crew	3x2	3x2
Port crew	2	2
Small waterway Crew	6	4
Office	3	3

### 16.6.2 Crew collection

The people needed for the tug and barge system can be divided into three different crew groups:

- Tug crew
- Barge crew in the seaports
- Barge crew on small waterways

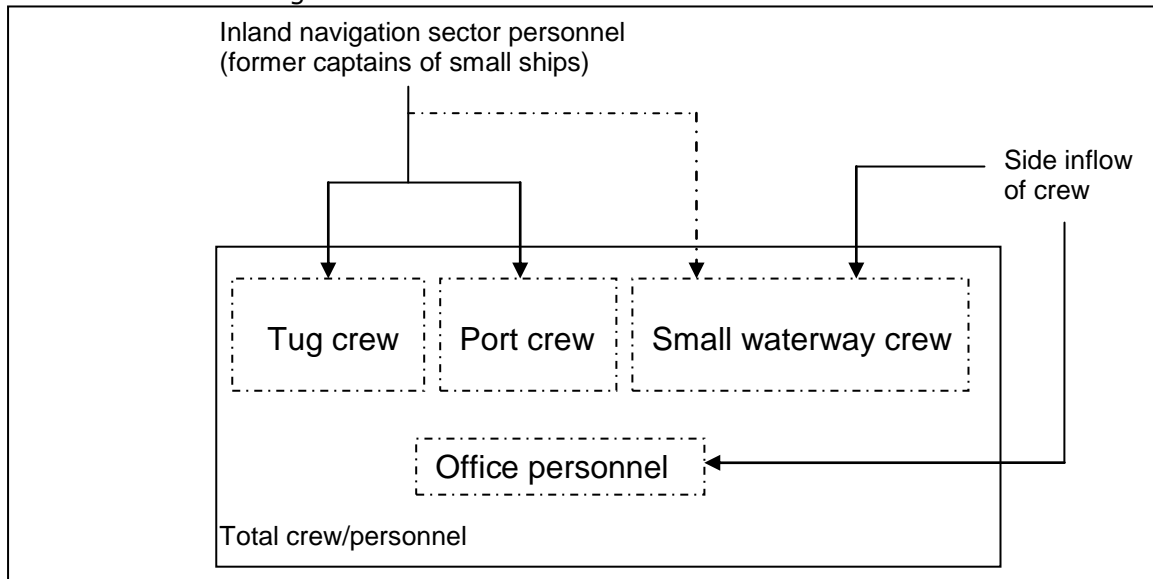
For the tug a crew is needed that will operate the tug and barge convoy on the large waterways. That crew will consist of people from the sector itself, which should be a licensed captain with qualified crew members. These crew members will operate the tug in a week-on week-off sailing regime. As to the crew needed for moving the barges in a seaport, also official qualified inland navigation crew is needed. The barges have to sail in an environment where a lot of other ships (small and large) are sailing, which requires a skilled crew.

For the crew of the barges on the small inland waterways original inland navigation captains could also be used. But for the small waterways, in addition new groups of people can be thought of:

- old small ship-owners still wanting to sail but not to own a vessel
- people from another sector (truck-drivers, train-operators for example) willing to sail but not to own a vessel

In figure 16.16 a schematic overview is given of the crew and personnel collection.

Figure 16.16: Overview of the crew collection



Source: own composition

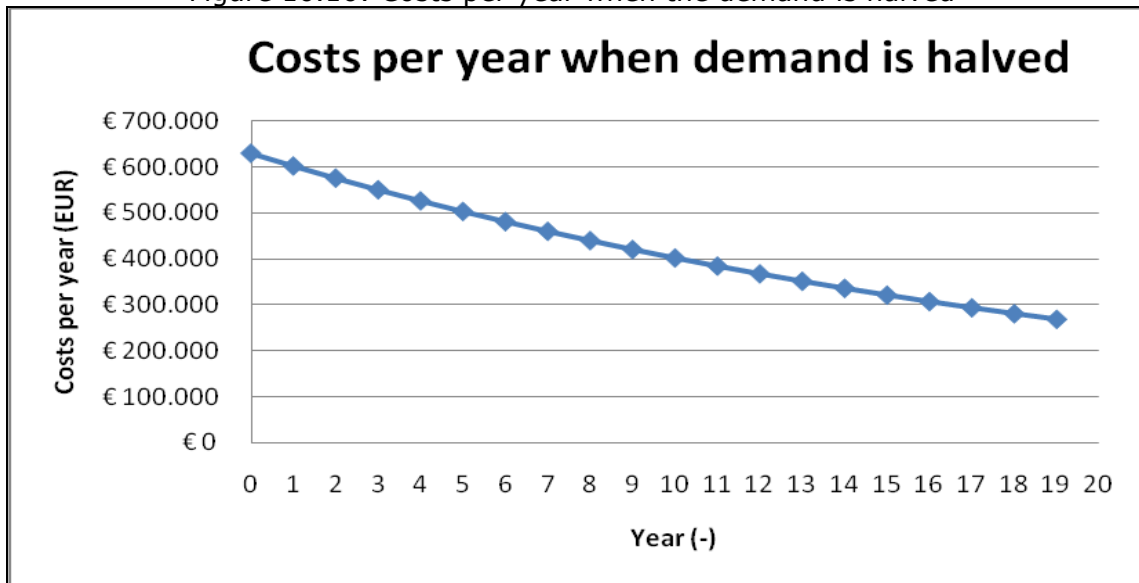
The first group can be used immediately because they have all the necessary papers and licences to operate the barges. For the second group there is a problem. They should be trained to operate the barge on the small waterways. Normally there are large entry barriers to becoming a captain on an inland ship, so that a lot of time and effort is needed to become one (see chapter 3). To overcome that problem a new kind of certificate should be introduced stating that the new captain can only sail with a barge on small waterways. Then a separate training and exam should be followed to prove to the shipping inspection that the new captains can operate the barges safely on the small inland waterways.

It could be expected that the existing captains of the inland fleet are opposed to these measures because the new captains are allowed to sail with less experience, which could be interpreted as unfair competition. But because the new captains are only operating the barges at small waterways which are less used (see chapter 3), the unfair competition with existing captains on small waterways is negligible. Therefore the new barge captains are not allowed to sail on other waterways (CEMT >III).

### 16.7 Influence of the reduction of demand

The last section of this chapter will deal with the influence of reduced demand on the small inland waterway network when the complete barge system is up and running. In this situation the barge system is set-up and has taken the implementation hurdle. So if in this case demand is reduced the barges have to be laid up. In the analysis it is assumed that demand is halved and that 10 of the 20 barges have to be laid up. In the previous sections was already calculated that laying up half of the barges will costs €630,227 per year (16.2.2). These costs per year are depreciated with the same discounting factor as has been used in chapter 14 ( $r = \text{WACC} = 4.6\%$ ) in order to compare the different costs. In figure 16.16 the costs per year are given if half of the barges are laid up.

Figure 16.16: Costs per year when the demand is halved



Note: 2009 values

In this analysis the barge system is completely built up, therefore the first two years are already in the past. Therefore only costs from year 2 and onwards will be used in the analysis. So if, for example, in years 3 and 4 the demand is halved, it will cost €1,077,149 (2009 values).

In order to take these potential setbacks into account these costs must be added to the initial NPV and the costs of building up the small barge system. This is illustrated in formula 16.4.

$$NPV_{\text{total}} = NPV_{\text{Initial}} + NPV_{\text{building\_up}} + NPV_{1/2\_demand} \quad (16.4)$$

$NPV_{\text{total}}$  = Total NPV of the investment (2009 value) [EUR]

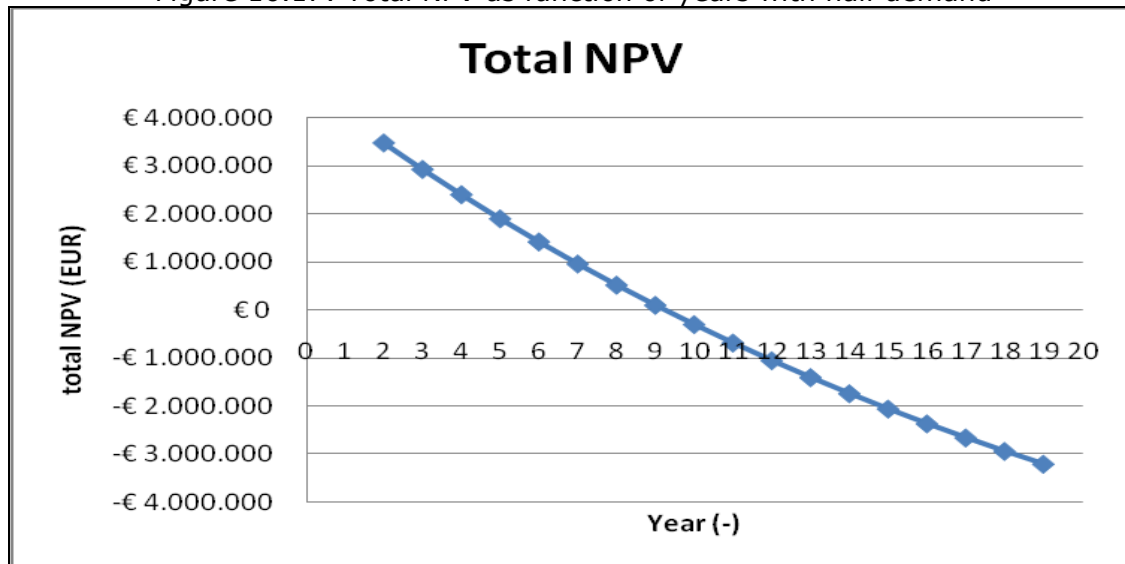
$NPV_{\text{Initial}}$  = NPV of the initial investment (2009 value) [EUR]

$NPV_{\text{Building\_up}}$  = NPV of building up the system (2009 value) [EUR]

$NPV_{1/2\_demand}$  = NPV of having only half of the demand (2009 value) [EUR]

If the costs of building up the small barge system, are tackled by an implementation subsidy, than the  $NPV_{\text{building\_up}}$  can be set at zero Euros (see section 16.5). In figure 16.17 the total NPV is given as function of years when only half of demand available for the first business case.

Figure 16.17: Total NPV as function of years with half demand

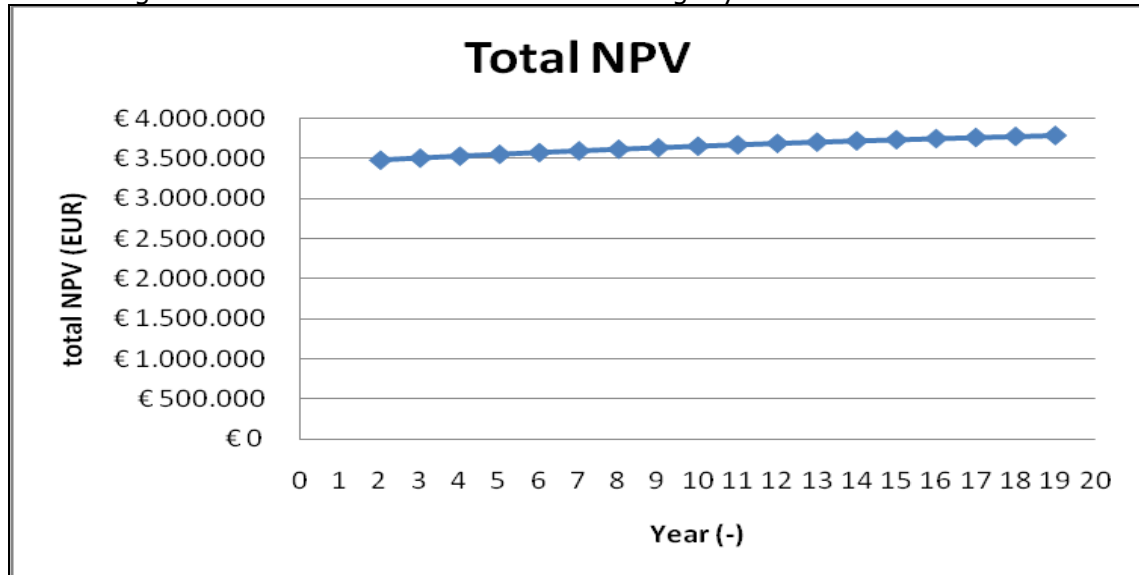


Note: 2009 values

From figure 16.7 can be concluded that if from year 2 (the year when the total system has been built up) the demand is halved, it will take up to year 9 before the  $NPV_{total}$  becomes negative. In total life span of the small barge system the  $NPV_{total}$  will be reduced to from €4,060,000 to -€3,200,000.

If only in one specific year the demand is halved, the  $NPV_{total}$  will not be changed much compared to the  $NPV_{initial}$ . This is illustrated in figure 16.18.

Figure 16.18: Total NPV as function of single years with half demand



Note: 2009 values

So if the demand is reduced temporary the small barge system can deal with that (small reduction of  $NPV_{total}$ ). But if the reduction of demand, after the total implementation, is permanent than the  $NPV_{total}$  will reduce significantly to a value below zero which will make the system unprofitable.

## 16.8 Preliminary Conclusion

The two implementation strategies are applied to both business cases and it can be concluded that strategy one, i.e. building up capacity, prevails in almost all of the considered cases. Only if the newbuilding costs of the barges are expected to increase by more than 10% and the risk of not implementing all the barges is less than 10%, strategy two is the best option. Therefore the first implementation strategy should be used to build up the small barge system.

If the implementation cost has to be covered by the small barge company, the investment decision will be very much influenced by the variation in implementation cost (due to the chosen strategy of building up capacity). If the implementation cost is covered by an implementation subsidy, with the reduction in external costs as a return, it will have a positive NPV. Therefore the implementation subsidy can be justified for the first business case.

For the second business case the implementation subsidy cannot be justified in all considered conditions. The reason for the difference with the first business case is that in the second business case also containers to inland container terminals are transported. These cargo flows are already transported with inland navigation and shifting the cargo from one ship to the other will not cause a significant reduction in emissions. It is also not in the interest of a government to shift cargo flows from one ship to the other, but to shift cargo flows towards transportation modes that will have the lowest external costs (from road to the inland waterways). Therefore only a part of the transported cargo flows will contribute to the reduction of external costs.

With respect to the number of crew members needed on the tug and barges and the personnel on the office it is concluded that the largest number of people needed are the crew members who are sailing on the barges on the small inland waterways. Great difficulty could be expected if all those small barge captains must have all the required licences and sailing experience before they can start sailing the barges. Therefore it is advisable to attract former captains of small inland ships to the small barge company. If not enough former captains are available then, another solution could be obtained by giving the small barge captains a limited sailing permit, only valid at the small inland waterways so that side inflow of new people can be used to man the small barges.

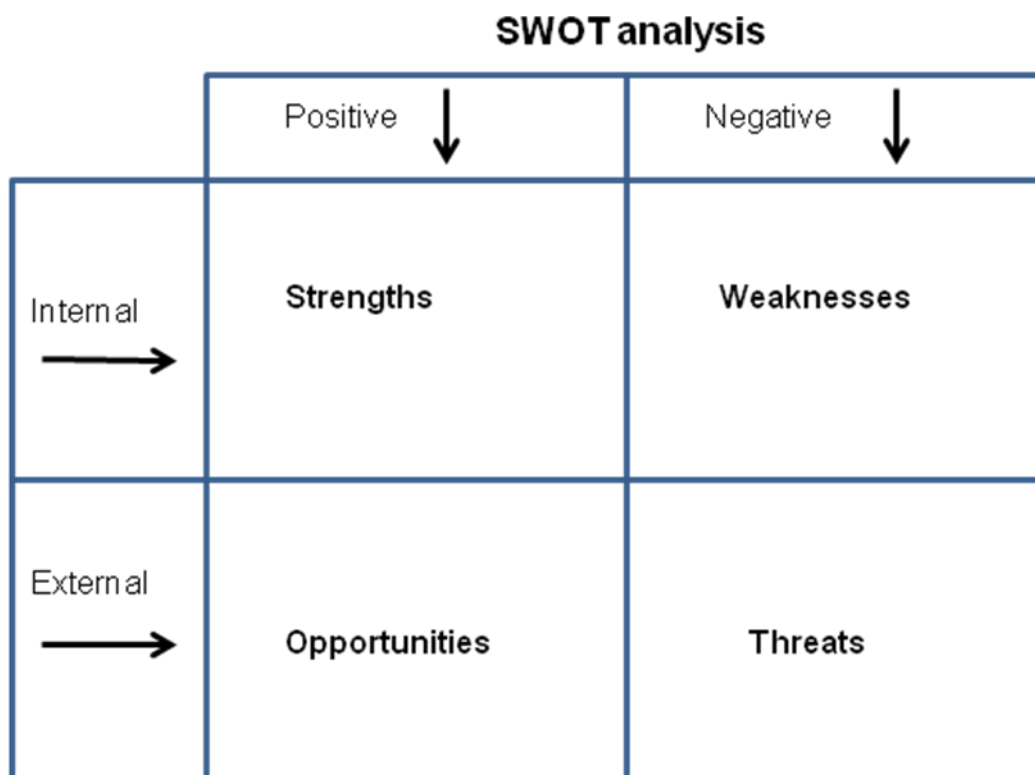
When the total small barge system is built up and if the demand is reduced temporarily the small barge system can deal with that. But if the reduction of demand is permanent, then the  $NPV_{total}$  will reduce significantly to a value below zero, which will make the system unprofitable.

## 17. SWOT analysis

### 17.1 Introduction

In this chapter a Strength, Weakness, Opportunities and Threats (SWOT) analysis of the developed small barge system will be made. A SWOT analysis is a business economics model that will incorporate the internal strength and weaknesses and the external opportunities and threats. Based on this analysis the strategy of the small barge system will be determined. The SOWT analysis was developed in the 1960s by the Stanford Research Institute (SRI). In figure 17.1 the SWOT matrix is given.

Figure 17.1: SWOT analysis matrix



Source: Stanford Research Institute

As figure 17.1 indicates there are four main research items rearranged in internal and external factors and positive and negative factors. Strengths are the positive factors which are only related to the internal aspects of the small barge system. While opportunities are also positive factors but they only relate to external factors.

The next section of this chapter will deal with the strengths of the small barge system. The third part will give the weaknesses of the system. When the internal factors are determined the external factors will be determined. The fourth section will deal with the opportunities while the fifth part deals with the threats. In section 17.6 the complete SWOT table will be presented and the strategy of the small barge system will be determined. This chapter will end with some conclusions.

## 17.2 Strengths of the small barge system

The strength of the small barge system will be determined by the following factors.

- **New system tackles all existing problems of small inland ships**  
All the problems concerning the operation of the small inland ships are tackled in the new small barge system. The main problem of the small inland fleet is their poor profitability due to competition of other modes of transportation and other inland ships. As a result, all the newbuild ships increase in size to achieve economies of scale of the inland fleet. Another result of the poor profitability is that banks / investing companies are not willing to invest in new small ships. The poor profitability of the small inland ships will make that no new ship-owner are available to operate a small ship. There is also a social problem with small inland ships. There are not of people willing to live at a small inland ship due to the small living space on that ship.

Because the poor profitability problem is solved in the SBCS, due to the economies of scale during when sailing in the tug and barge convoy, and due to the fact that the new small barges are designed without a living space the SBCS has a good potential to survive.

- **Make use of small waterways (accessibility of inland navigation)**  
The small barge convoy system could be used in dealing with the in chapter 3 mentioned problems of increasing congestion on the road network and growing awareness of environmental care, and the diminished supply on the small inland waterways. The adjustment of the inland waterway infrastructure is too costly and will take too long to materialize. Therefore the small barge system is a better solution.
- **Flexible with regards to network design**  
The design of the network of the small barge system is flexible. This means that the number of waterways, the selected waterways and the number of barges per waterway can be changed. So if demand on one waterway is reduced the barges can be relocated to another waterway (chapter 6). It is also possible to use the barges to transport cargo from inland terminals to a deep sea port (chapter 14).
- **Reliable system with cargo handling and sailing split**  
The small barge system has the main advantage that the sailing part of a trip and the cargo handling part are split. The most expensive part of the total system, the tug and the crew, will be sailing as much as possible because the tug does not have to wait in the port to load and unload the barges. It only has to spend time in the port to couple and uncouple the barges (chapter 4). Another advantage is that on each small waterway one extra day (and in the port 2 days) is added in the total logistics. This means that delays of 24 hours on the small waterways can be handled within the system. This will make that the system is reliable (chapter 6).



- **Latest technology on new ships**  
The tug and the barges will be newly built. This means that the latest technologies in propulsion technology can be incorporated. An example is that all the barges are designed with a double bottom which can become compulsory in the future for all inland ships (chapter 7).
- **Small effect of fuel price on total costs**  
The total costs of the small barge system are for more than 50% determined by fixed costs. The total costs are for less than 10% determined by fuel costs. This means that large variations of the fuel price will not have a large impact on the costs (see chapter 8). This means that with increasing fuel prices the total costs of the small barge system will not increase much, which will lead to a competitive advantage towards its competitors.
- **Low external costs compared to road transport**  
External costs are caused by accidents, noise, climate change, infrastructure and congestion. The external costs, or costs for society are the lowest for inland navigation (see section 16.5).
- **No competition of other small barge systems**  
In chapter 14 we concluded that, on the Flemish small inland waterways, the small barge system will create the environment of a natural monopoly. This means that the first one who starts up the small barge system will be in the advantage to other small barge systems. This means that no competition of other small barge system is expected.

### 17.3 Weaknesses of the small barge system

In this section the weaknesses of the small barge system will be presented.

- **Increased complexity within the logistics of the small barge company**  
In chapter 6 the network of the small barge system was dealt with. In the network are the movements of the tug and barge convoy and the barges uncoupled. This means that three different crews are needed (small barges, tug and port crew) and therefore more planning is needed to streamline the operations. This aspect is taken into account by the additional overhead costs of € 150,000.
- **Low flexibility in operation**  
When the small barge system is operated the barges will be relocated at fixed times. This means that, if a client wants to transport more cargo than was originally ordered, the small barge system cannot deal with that (chapter 6).
- **High fixed costs (vulnerable to permanent reduction of demand)**  
In chapter 8 was already concluded that more than 50% of the costs are related to fixed costs. This means that when demand decreases, and supply has to be adjusted accordingly, the total costs will not be reduced much. This was also concluded from chapter 16 where was shown that laying up barges is more expensive than operating the system with only a limited amount of barges.

- **Large implementation hurdle**

Chapter 16 has shown that, in order to start up the small barge system, a large implementation hurdle has to be taken. If the costs related to start up the system have to be completely taken by the investor of the system the NPV reduces significantly (almost to zero Euros in the worst situation).

- **Dependent on limited amount of clients**

All the cargo flows with an origin or destination at the small inland waterways are accumulated from 24 different companies (see also table 13.4). If only the cargo flows needed in the developed business case (routes 2-3-4) are considered than 18 companies will account for all the cargo flows. On route 4 only two companies will determine the total cargo flows. This makes the small barge system, on route 4, largely dependent on those companies. If one company will relocate its activities or if it will not use the small barge system the small barge company will suffer. If the reduction of demand is temporally then the system can bare this. But if the reduction is permanent then the small barge system will suffer and will be unprofitable (see section 16.6).

## **17.4 Opportunities of the small barge system**

In this section of chapter 17 the opportunities of the small barge system will be presented.

- **New markets (pallets)**

In chapter 2 also the possibility of adding palletized cargo flows to the small barge system was addressed. With the developed concept it is possible to add one or more dedicated "pallet barges" to the total system. The classic inland navigation cargo flows (bulk and containers) can serve as backbone. These new cargo flows can become of great importance in the future if more cargo will be shipped with containers and pallets.

- **Zero emission shipping on small inland waterways (marketing)**

The barges are designed with a battery pack installed in its double bottom which is recharged by the main engines of the tug (chapter 7). This means that on the small inland waterways (where the barges will sail) there are no emissions. This could be used in the marketing of the small barge system.

- **Repositioning of empty containers**

In chapter 14 (14.4.4) showed that, if the containers are empty, additional road transportation can be added to the small barge system. This means that the potential market can be increased from only water bound companies to "inland" destination up to 2.5 to 3 km from the waterway.

## **17.5 Threats to the small barge system**

The first threats to the small barge system will come from the competition of road transportation and classic small inland ships. These threats will be based on two separate moves: an offensive one and a defensive one.

- **Offensive moves of the competition**

Bargemen of small inland ships will most likely not undertake offensive actions to counteract the implementation of the small-barge system. The reason is that the differences in prices per TEU and tonne are too large, so that the small inland ships will not survive a price war. The reaction for the bargemen of the small inland ships will therefore be a defensive one.

The road transporting companies will reduce their tariffs for the transportation of loaded containers. Due to the shorter transportation time (higher speed), the main advantages of road transportation will be exploited. A small tariff reduction is enough to maintain their competitive advantage. For empty containers the competitive advantage of a shorter transportation time will be reduced and therefore it will be very difficult to compete with the small-barge convoy.

- **Defensive moves of the competition**

The bargemen of the small inland ships will be very vulnerable to the implementation of the small-barge convoy system. The small waterways are the natural environment of the small inland ships in the inland shipping sector. Extra competition will therefore be very hard for them. The bargemen could also see the implementation as a provocation. The small inland shipping sector is having a tough time (see chapter 3). As a result, government research and money is invested in keeping the small inland waterway operational (see chapter 3), where that research and money is used to develop an additional competitor. It is therefore most likely that the bargemen will react in a defensive way, willing to maintain their entry barriers of sailing with two crewmembers on small inland waterways as well as the required 3-year inland navigation experience to become a captain. In addition, if the small-barge system is implemented, the captains of the small inland ships could start actions and even strikes<sup>52</sup>.

The road transporting companies will be less vulnerable than the bargemen of small inland ships because of the implementation of the small-barge convoy system. Their potential market is much larger than the potential market of the small inland waterways because trucks are not limited to the geographical restrictions of the small inland ships. If the road transporting companies lose their cargo flows to and from the small inland waterways, that loss will be marginal. They will not see the implementation of the small barge convoy system as a provocation but just as an additional competitor.

- **Insufficient amount of personnel**

The largest number of people needed for the small barge system are the crew members, who are sailing on the barges on the small inland waterways. Great difficulty could be expected if all those small barge captains must have all the required licences and sailing experience before they can start sailing the barges. Therefore it is advisable to attract former captains of small inland ships to the small barge company. If not enough former captains are available than, another

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<sup>52</sup> 1970s inland shipping strikes

solution could be obtained by giving the small barge captains a limited sailing permit, only valid at the small inland waterways so that side inflow of new people can be used to man the small barges.

- **Regulation of small barge systems on the small inland waterway network**

Due to the fact that the small barge system will operate in a natural monopoly environment it can be expected that operation of the small barge company will be monitored by the government.

## 17.6 Small barge system strategy

In order to determine what the strategy of the small barge system must be first the total SWOT will be given. In table 17.1 the total SWOT matrix is given with all the previously mentioned items.

Table 17.1: SWOT analysis of the small barge system

<b>Strengths</b>	<b>Weaknesses</b>
<ul style="list-style-type: none"> <li>- New system tackles all existing problems of small inland ships</li> <li>- Make use of small waterways (increase of accessibility of inland navigation)</li> <li>- Flexible with regards to network design</li> <li>- Reliable system with cargo handling and sailing split</li> <li>- Latest technology on new ships</li> <li>- Small effect of fuel price on total costs</li> <li>- Low external costs compared to road transport</li> <li>- No competition of other small barge systems</li> </ul>	<ul style="list-style-type: none"> <li>- Increased complexity within the logistics of the small barge company</li> <li>- Low flexibility in operation</li> <li>- High fixed costs (vulnerable to permanent reduction of demand)</li> <li>- Large implementation hurdle</li> <li>- Dependent on limited amount of clients</li> </ul>
<b>Opportunities</b>	<b>Threats</b>
<ul style="list-style-type: none"> <li>- New markets (pallets)</li> <li>- Zero emission shipping on small inland waterways (marketing)</li> <li>- Repositioning of empty containers</li> </ul>	<ul style="list-style-type: none"> <li>- The road transporting companies will reduce their tariffs</li> <li>- The bargemen wanting to maintain their entry barriers</li> <li>- Insufficient amount of personnel</li> <li>- Regulation of small barge systems on the small inland waterway network</li> </ul>

In order to overcome the weaknesses of the small barge system the following strategies are determined:

- 1) One of the main weaknesses of the small barge system is the large starting up cost. Therefore the system will be built up from a small starting position. Also the implementation costs could be covered by a subsidy (chapter 16).

- 2) Another weakness of the system is that, for cargo flows to and from the small inland waterways, it is dependent on only a few companies. If one of the initial clients stops using the small barge system the network can be redesigned and a new route can be added to the network. Another option is to bind the clients to the small barge company by leasing out (or selling of) some of the barges. Another advantage is that a large part of the fixed costs can be reduced if some of the barges can be leased out.

In order to deal with the threats to the small barge system the following strategies are determined:

- 1) Based on the identified threats to the system, it can be concluded that the two main competitors of the small barge system will react differently to the implementation of the system. The road transporting companies will focus their "battle" on the cargo flows of loaded containers. For cargo flows of empty containers and bulk cargo it will be difficult to compete on price with the small- barge system. Therefore the small barge system must focus on bulk cargo and empty containers during the start-up phase of the system. When the small barge concept is implemented, loaded containers could be considered.
- 2) The bargemen of the small inland ships will, most likely, react on a very emotional basis and therefore in a very defensive way by recalling and defending the existing entry barriers and current manning rules for the inland navigation sector. Therefore, during the implementation of the small-barge system, the sector must be involved. A way to get the bargemen of the small inland ships involved is that they could become the crew members needed in the small barge system (see chapter 16). It is also important to stress to the sector that only an adjustment of the crew-rules on the small waterways is proposed. All the other manning-rules are respected and no unfair competition will occur.
- 3) The threat of insufficient amount of personnel can be tackled if more side-inflow of personnel can be achieved, especially for captains who will be sailing with the barges on the small waterways. Also former captains of small inland fleet can be used (section 16.6).

## **17.7 Preliminary conclusions**

The SWOT analysis has showed that there are a lot of strong points and opportunities for the small barge system. Therefore the small barge system must focus on those strong points. But it is even more important to deal with weaknesses and threats. One strategy, to deal with the weaknesses of the large implementation hurdle, is to build up the system from a small starting position and that the implementation costs could be covered by a subsidy (chapter 16). Another strategy that can be used to deal with large amount of fixed costs is to involve the potential clients by leasing out the barges for long periods (2 or more years) or even sell the barges. This will make the small barge system also less vulnerable to the limited number of companies and it will reduce the fixed costs.

In order to deal with the threat of the competition of road transport on the container market, it could be a good strategy, at the start of the small barge system, to focus on the transportation of empty containers. Another threat will come from the current ship owner of the small inland fleet. The current day inland shipping sector could want to maintain the current entry barriers. It is therefore important to get the current inland sector involved in the small barge company. Also former captains could be used to operate the small barges or to work on the tug. This would also tackle the problem of insufficient amount of personnel. Another way to solve that problem is to aim at side inflow (section 16.6).

# **PART V: MAJOR CONCLUSIONS**





## **18. Conclusions and recommendations**

In this final chapter of the thesis the main findings and recommendations for further research are given. This chapter is divided into three parts. Section 18.1 will deal with a brief summary of the study. Section 18.2 will elaborate on the observations and the main conclusions of the study. In section 18.3 recommendations for further research are given.

### **18.1 Brief summary of the study**

Inland shipping in North Western Europe is well known transportation mode that can make use of a large and dense inland waterway network. However in the last 45 years no new small inland ships have been built. As a result the small inland fleet is diminishing, and only in Flanders 4,000,000 tonnes of cargo (WenZ, de Scheepvaart, 2009) transported to and from companies located at the small inland waterways, by small inland ships, risk being shifted to road transportation. Those tonnages are then added to the already heavily congested road network. These extra tonnages and the potential further increase in cargo flows will lead to more investments in expanding the existing road capacity while the available infrastructure of the small waterways will not be used at all. This small waterway capacity is very much needed to deal with a part of the total tonnages that have to be transported from the seaports of Rotterdam and Antwerp to their respective hinterlands.

Another consequence of the diminishing of the small inland fleet is that the diversity in the total inland fleet will disappear. The new ships that are being built are increasing in size and therefore the available sailing area of these ships is reduced because the large ships can only sail on a limited number of inland waterways.

The first objective of this thesis is to gain insight into the existing problems concerning the diminishing small inland fleet and, as a result of that, a reduction of the use of the small inland waterways. The second objective is to develop a new inland navigation concept that could be used to reactivate the use of the small inland waterway network. The third objective is to determine the optimal design for the concept developed (network and ship design). The fourth objective is to research the possibility of implementing, in an economically viable way, the small barge convoy system via suitable business cases.

The four main objectives are now reformulated into five main research questions:

- 1) What are the existing and expected problems concerning the use of small inland ships?
- 2) What type of solution could be developed to reactivate the use of the small inland waterway network?
- 3) How does the proposed solution work? What is the optimal design of the proposed solution?

4) Is it possible to construct a suitable business case for the developed solution?

5) How could the developed solution be implemented and how will the other modes react to the introduction of the proposed solution?

The main research will be divided into five main research areas each with their own research goals:

A) Problem definition

This part of the research deals with the existing and expected problems concerning the use of small inland ships on small inland waterways. The existing problems are researched along with the reason behind the lack of new small inland ships via a literature study. Also the effect of losing the small inland waterways on the external costs will be taken into account.

B) Providing a potential solution

Based on the results of the research of the problem definition an innovative inland navigation concept will be proposed to provide a solution for the problems mentioned.

C) Modelling of the proposed solution

The methodology as developed in this study is an integrated modelling approach of 4 sub-models which will all be used to research the developed small barge convoy system. The 4 sub-models used into the main model are:

1) Network design

In this part of the research the several network design options, limited to the developed small barge system, are analysed, e.g.: what is the number of barges to be pushed, to which waterways and at which speed?

2) Tug and barge design

The barges and tug that are used do not exist yet. Therefore new designs should be made. The designs will be based on the main design parameters, such as: required speed, cargo carrying capacity, number of barges push by the tug, type of propulsion system (diesel direct, diesel electric). The barges and tug will be designed to comply within the rules of the shipping inspection ("scheepvaartinspectie") and the rules of the Germanische Lloyds.

3) Generalized cost calculation of the small barge system

Based on the chosen network and the designs made for the developed concept, the transportation and total logistics costs will be determined.

4) Price setting / Competition research

Besides the (generalized) costs of the small barge convoy system, also the (generalized) costs of the competitive modes must be taken

into account. Based on the generalized costs of the developed concept and the competitors it can be determined if the small barge convoy system can offer a competitive price.

#### D) Applications of the small barge convoy system

When the design of the network, tug & barge convoy, transportation costs and prices of the new concept are known, a concrete business case will be made to see if it is possible to invest in the small barge convoy system. In order to determine if the small barge convoy system can be implemented, a minimum value of the internal rate of the return (IRR) must be achieved.

#### E) Implementation research

In this part of the thesis, the start-up phase of the small barge convoy system will be researched. What are the start-up costs, how many barges should one start with? Also an overview of the strength and weaknesses of the small barge system will be researched via a SWOT analysis. Based on this analysis several strategies will be developed in order to deal with the weaknesses and threats of the system.

## **18.2 Observations and conclusions**

In the elaboration on the research five main research questions were defined to be investigated: The existing and expected problems concerning the use of small inland ships, the development of a new type of inland navigation system to reactivate the use of the small inland waterway network, network and tug & barge design, application of the small barge convoy system and implementation research. This section of the chapter describes the specific research questions formulated for these issues, summarizes the main research results regarding each question and provides the major conclusions.

### **18.2.1 The existing and expected problems concerning the use of the small inland ships**

The supply on the small inland waterway network is diminishing mainly due to too server competition from road transportation. This has resulted in five main observations:

- No new small inland ships are being built
- Technical decline and withdrawal of the existing small inland fleet
- Limited to no inflow of new young captains for the small inland fleet
- Reduction of the available captains
- Insufficient maintenance of the small inland waterway infrastructure

A consequence of the diminishing small inland fleet is the inevitable disappearance of diversity in the total inland fleet. The new ships that are being built are increasing in size and therefore the available sailing area of these ships is reduced because the large ships can only sail on a limited number of inland waterways. There is consequently a serious risk of being left with only large inland ships, while more than 50% of the inland waterway network can only be reached with smaller (<600 tonne) ships.

Due to an increasing number of large ships (and also their respective capacity), an overcapacity in the large inland shipping segment will occur. Because of this, in combination with a reduced sailing area, heavy competition between those ships is expected.

With respect to the small inland waterway infrastructure, the diminishing small inland fleet in Flanders will lead to a shift of 4,000,000 tonnes of cargo, from the waterways to the road. Those tonnages are added to the already heavily congested roads. These extra tonnages and the further increase in cargo flows will lead to more investments in expanding the road capacity, while the available infrastructure of the small waterways will not be used at all. This capacity is very much needed to deal with a large part of the total tonnages to be transported. As the waterways are cheaper to maintain than roads and as they are already present, therefore no new infrastructure investments are needed to deal with a large part of the total transported tonnages. The maintenance costs of the existing waterways will hardly be influenced due to a potential increase of ships sailing on those waterways so that no large increase in maintenance costs of the small waterways is expected.

The reason why almost no small inland ships are used to transport containers from a deep-sea port to destinations in its hinterland (except dedicated transport from a container terminal a hinterland destination) is due to the small call sizes at the deep-sea terminals. Therefore these ship will not get priority at the deep sea terminals so that those ships will experience a large waiting time in the port. These large port residence costs will decrease the number of trips that can be made per year and the costs per TEU are increased (decrease in the economy of density). The deep-sea terminals will act as a barrier to using small inland ships for container transportation.

Due to a growing awareness of environmental care and carbon footprint, the EU member states want to stimulate the use of the modes producing the lowest amount of emissions per preformed tonne\*km. These emissions in transport could be diminished by the reactivation of the small inland waterway network providing transport of part of the cargo flows.

### **18.2.2 The development of a new type of inland navigation system**

In order to deal with the previously mentioned problems of increasing congestion on the road network and growing awareness of environmental care, and the diminished supply on the small inland waterways there are two main solutions. One is to adjustment of the inland waterway infrastructure however that is too costly and will take too long to implement. Therefore the adjustment of the inland navigation system is a better solution. This new inland navigation system is the small barge convoy system, which comprises out a barge train of small barges which can sail independently on small inland waterways. With this concept it is possible to combine different small waterways into one large network that can be served by the small barge system. Also due to the modular character of the concept potential clients could be bind to the concept by leasing out some of the barges and the small barge system can be built up

gradually. This small barge convoy system could be used in dealing with the mentioned problems.

### 18.2.3 Network and tug & barge design in a real case

From the preformed analysis on the Flemish small inland waterway network can be concluded, With respect to the network design of the small barge system on the Flemish waterway network, the following conclusions can be drawn:

- The most optimal network configuration consist out of a network where routes 2-3-4 are combined (see figure 14.2)
- Adding extra barges sets is useful if only routes 2 and 3 are sailed to. If more routes are combined the extra barge sets will not increase the profitability of the tug and barge convoy
- Adding inland container terminals (ICTs) to the total tug and barge system is useful to increase the NPV but it will also increase the TLC if the tug has to sail to more than two routes. So ICTs can be added if only 2 routes are combined

With respect to the design of the barge can be concluded that:

- The main dimensions of the barge will be made as large as possible to still pass the locks on the small inland waterways
- With regards to the hull form the barge:
  - o If possible the lowest value of  $\alpha_I$  (bow of the barge) (25 degrees) is advised because that will lead to the lowest resistance at the highest speeds
  - o The best choice for  $\alpha_{st}$  (stern of the barge) is then 25 degrees. This will decrease the resistance of the barge in the operational speed of the barge on the small waterways. If one opts to install a generator set in the aft of the barge then  $\alpha_{st}$  cannot be chosen freely but it must be altered in order to create enough space to allocate the generator set ( $\alpha_{st} < 10^\circ$ )
- The barge will be equipped with 4 thrusters in the aft of the barge and one in the bow
- The differences in transportation costs between the battery-propelled barge, the generator-set barge and the hybrid barge are small. If the fuel price will increase then the transportation costs of the battery barge will be marginal smaller. Therefore the choice will be made to propel the barges with battery pack in the double bottom of the barge. However if that solution is too technical challenging then the other alternatives could also provide suitable options

With respect to the tug, as used the Flemish small inland waterway network, the following conclusions can be drawn:

- The tug and barge convoy should sail in a semi continuous regime

- The tug and barge convoy should have a design speed of 3.5 m/s
- The tug should be equipped with a diesel direct propulsion system
- The tug will be equipped with 3 propellers

With respect to the competition research can be concluded that the inventory costs are much dependent on the value of the transported cargo (high VoT). So if the value of the cargo is too high then the more flexible and faster mode (=road transport) will most likely be chosen and the small barge convoy cannot compete for that type of cargo.

It can also be concluded that it is not possible to combine additional road transport with the small barge system for loaded containers. So only direct calls at companies located directly at the small waterway can be considered for loaded containers. However if the containers are empty a small distance of road transport can be added to the small barge transport (<2.5 km). If the external costs are internalized then that distance increased (<17 km). If bulk cargo have a destination at a water bound company and therefore only the containers have to be transported further inland than the potential distance that the truck can drive is increased compared to the case were also bulk cargo has to be moved further inland with a truck.

#### **18.2.4 Business case development**

In the development of the business cases, it was the aim to maximize the NPV of the initial investment. In order to do that, cargo flows need to be shifted from the road towards the small-barge system. It could be seen that, by changing the transportation mode, the total logistics system of potential clients has to be altered. If a company is willing to shift its cargo flows to the small-barge system, more cargo has to be stored at their premises, increasing the total inventory costs. The price that will be offered by the small-barge system must be low enough so that the TLC for a company are lower; otherwise the company will not shift its cargo flows. The inventory costs are much dependent on the value of the transported cargo. So, if the value of the cargo is too high, the more flexible and faster mode (=road transport) will most likely be chosen. This is especially the case for loaded containers. It is best to focus on low-value products such as bulk (sand, iron ore, etc.) and empty containers.

Another important finding of the tug and barge convoy was discovered, during the developed of suitable business cases, is that it will be affected by decreasing average costs if the transportation volumes increases. This indicates first of all that the prices cannot be determined by the LRMC because in the long run the TAC are higher than the MC, so that prices should be determined by the LRAC. Secondly, this indicates that not enough cargo is available to accommodate similar small barge systems (with the same costs structure). Therefore the small-barge convoy will operate in a natural monopoly. This means that no other company can enter the same business that has the same costs structure (large amount of fixed costs which relates to the amount of barges in the small-barge convoy system). Therefore some sort of regulations (licence system) must be imposed by

the waterway administrators. Other ships and trucks, which have different costs structures, can enter the market and will not be affected by this natural monopoly.

From the preformed network and design analysis two good cases can be identified:

- Case I: Sailing with the tug and barge convoy to routes two (4 barges), route 3 (4 barges) and route 4 (2 barges) (condition 4 table 14.1).
- Case II: Sailing with the tug and barge convoy to routes two (6 barges) and three (4 barges), while on route two 2 barges are pushed to the selected ICT.

In order to determine whether the small barge convoy system can succeed in a competitive market, a lot of future uncertainties have to be taken into account. To deal with those uncertainties, different scenarios were developed. For the two developed business cases a scenario analysis was performed in order to take the uncertain (exogenous) effects into account.

#### *Business Case I*

From the scenario analysis for the first business case it can be concluded that it is impossible to make a suitable business case in scenario 1. It is, surprisingly, not the upgrade of the class II canals to class IV that is devastating for the small- barge convoy system, but the increase in equity costs.

In the second scenario the waterways are not upgraded, so that the competition comes from the existing small inland ships and road transportation. Even so, still no business case can be made, due to the required costs of equity of 15% (given as a minimum in scenario 2).

In the third scenario the financing requirements are lowered. By the reduction of the financing and fuel costs the transportation costs are reduced, so that a lower price can be offered which will increase the potential market.

In the fourth scenario it is possible to sail with only one captain on the barges when sailing on the small inland waterways, due to an adjustment of the crew rules on the small waterways. The transportation costs are lower, a more competitive price can be asked and more cargo can be transported. It can therefore be concluded that adjusting the crew rules on the small inland waterways will affect the competitiveness and the profitability of the concept quite considerably, but if the crew rules on the small waterways are not adjusted, then still a suitable business case can be made (scenario 3).

In the fifth and sixth scenario the NPV and IRR will increase even further, due to the increase in transportation price. This increase of transportation price can be accepted thanks to the increased transportation price of the main competitor, i.e. road haulage. In the sixth scenario the external costs are internalized into the generalized and total logistics costs which will lead to an even bigger difference in TLC between the small-barge convoy system

and other competitors. As a result, the small-barge convoy system will increase its competitiveness towards road haulage and a very good business case can be made. It can also be concluded that the failure of the present-day road network and the internalization of the external costs are contributing positively towards the small-barge convoy system but they are not necessary to construct a business case.

The variation of the newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for the scenarios 1, 2 and 4 to 6. Only in the third scenario will an increase of 15% of the newbuilding price make the investment decision negative. An increase in newbuilding price will increase the transportation costs of the small barge system so that the NPV decreases. So, if the newbuilding price of the tug and barges is increased and it is not allowed to sail with only one captain on the small inland waterways, it is not possible to make a suitable business case ( $NPV < 0$ ). In conclusion, except for scenario 3, in a range of 30% variation of the calculated newbuilding price, the investment decisions will not change. The profitability will increase if the newbuilding price is decreased (or decrease if the newbuilding price increases).

### *Business Case II*

For the second business case it can be concluded that scenario 1 will not provide a suitable business case, due to the increase in the costs of equity to 15%.

In the second scenario the minimum level of the WACC is still not reached, so that still no suitable business case can be made.

In scenarios 3, 4, 5 and 6 a suitable business case can be made. As in the first case, the crew rules on the small waterways do not need to be adjusted in order to make a business case. However, if it is possible to limit the number of crew-members sailing on the barge on the small inland waterway, this will increase the NPV significantly. If the external costs are internalized, the competitiveness of the concept will increase, but it is not necessary to internalize those costs to make a suitable business case.

From the preformed scenario analysis can be concluded that the second case behaves the same as the first case when it is influenced by the different scenarios.

The variation of the newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for all scenarios, except scenario 3. In that scenario an increase of 15% of the newbuilding price will make the investment decision negative. Thus, as already concluded in the first business case, in a range of 30% variation of the calculated newbuilding price the investment decisions will not change (only in scenario 3); the profitability will only increase if the newbuilding price is decreased.

The results of the infrastructure calculations in chapter 15 have shown that the small-barge concept will decrease its competitiveness and decrease its NPV if the distance of the large waterway is increased with a semi-continuous sailing regime. If the sailed distance on the large waterway is



larger than 80 km, a full continuous sailing option is better than a semi-continuous option. The competitiveness and the NPV of the full continuous option are then larger than the semi-continuous option. The TLC of the full continuous option will decrease, compared to the semi-continuous option, with increasing distance of the large waterway.

For the developed coupling system it can be concluded that its development and implementation costs should become smaller, than in the base case, if the sailed distance on the large waterway is increased above 70 km. The reason for this is that due to the increase in sailed distance more time is spent sailing. Therefore the influence of the coupling time on the total number of trips, that can be made per year, is reduced. As a result the amount of money saved is decreased and therefore the allowable price per coupling system is reduced.

If the distance of the small waterway is increased, the NPV will decline at first and, when the distance of the small waterways is increased to more than 50 km, it will increase again. In the small waterway analysis a change in the propulsion of the barge from batteries to a hybrid option will not increase the NPV. Despite the lower newbuilding costs of the hybrid barge than for the batter-propelled barge, an increase in sailed distance will not make the hybrid option more competitive due to the increase in fuel costs of the hybrid barge.

### **18.2.5 Implementation research**

The two implementation strategies are applied to both business cases and it can be concluded that strategy one, building up capacity, is prevailed in almost all of the considered cases. Only if one expects that the newbuilding costs of the barges will increase with more than 10% and the risk of not implementing all the barges is less than 10% then strategy two is the best option. Therefore the first implementation strategy should be used to build up the small barge system.

If the implementation cost has to be covered by the small barge company then the investment decision will be very much influenced by the variation in implementation cost (due to the chosen strategy of building up capacity). If the implementation cost will be covered by an implementation subsidy, with the reduction in external costs as a return, it will have a positive NPV. Therefore the implementation subsidy can be justified for the first business case.

For the second business case the implementation subsidy cannot justified in all considered conditions. The reason for the difference with the first business case is due to the fact that in the second business case also containers to inland container terminals are transported. These cargo flows are already transported with inland navigation and shifting the cargo from one ship to the other will not cause a significant reduction in emissions. It is also not in the interest of a government to shift cargo flows from one ship to the other but to shift cargo flows towards transportation modes that will have to lowest external costs (from road to the inland waterways). Therefore only a part of the transported cargo flows will contribute in the reduction of external costs.

With respect to the number of crew members needed on the tug and barges and the personnel on the office it is concluded that the largest number of people needed are the crew members who are sailing on the barges on the small inland waterways. Great difficulty could be expected if all those small barge captains must have all the required licences and sailing experience before they can start sailing the barges. Therefore it is advisable to attract former captains of small inland ships to the small barge company. If not enough former captains are available than, another solution could be obtained by giving the small barge captains a limited sailing permit, only valid at the small inland waterways so that side inflow of new people can be used to man the small barges.

When the total small barge system is built up and if the demand is reduced temporary the small barge system can deal with that. But if the reduction of demand is permanent, than the  $NPV_{total}$  will reduce significantly to a value below zero which will make the system unprofitable.

The SWOT analysis has showed that there are a lot of strong points and opportunities for the small barge system. Therefore the small barge system must focus on those strong points. But it is even more important to deal with weaknesses and threats. One strategy, to deal with the weaknesses of the large implementation hurdle, is to build up the system from a small starting position and that the implementation costs could be covered by a subsidy (chapter 16). Another strategy that can be used to deal with large amount of fixed costs is to involve the potential clients by leasing out the barges for long periods (2 or more years) or even sell the barges. This will make the small barge system also less vulnerable to the limited number of companies and it will reduce the fixed costs.

In order to deal with the threat of the competition of road transport on the container market, it could be a good strategy, at the start of the small barge system, to focus on the transportation of empty containers. Another threat will come from the current ship owner of the small inland fleet. The current day inland shipping sector could want to maintain the current entry barriers. It is therefore important to get the current inland sector involved in the small barge company. Also former captains could be used to operate the small barges or to work on the tug. This would also tackle the problem of insufficient amount of personnel. Another way to solve that problem is to aim at side inflow (section 16.6).

## **18.3 Recommendations**

The recommendations in this thesis will be spit up into two different parts. First there are the scientific recommendations. The second set of recommendations will consist out of policy recommendations.

### **18.3.1 Scientific recommendations**

Based on the preformed research there are 5 scientific recommendations formulated.

- 1) The hull form of the barge is adapted on basis of from the resistance study (see section 7.2). Now that the research has shown that it is

possible to set up the small barge system, it is advised to optimize the hull form even further by means of a proper resistance and propulsion tests in a towing tank.

- 2) The new coupling system, developed in chapter 7 (appendix H), is worthwhile to invest in if the coupling time can be reduced from  $\frac{1}{2}$  hours to  $\frac{1}{4}$  hours per barge coupling. It is advised that more research must be done to determine if it is possible that the coupling time can be reduced with  $\frac{1}{4}$  hour.
- 3) In the scenario analysis it could be seen that the upgrade of the small inland waterway infrastructure will not cause much harm to the business case. Apparently, the small-barge convoy can also compete with inland ships of class IV. It is therefore advised to also research the possibility of adding cargo flows of companies located at larger waterways to the tug and barge network.
- 4) In all the analyses of this thesis the barges are owned by the small-barge company. Some barges can be owned, or leased by potential clients. In that situation the fixed costs of the small-barge company will be lowered and the potential clients are more bound to the small-barge company. It is therefore advised that more research should be done on how different barge ownership structures would influence the small-barge company.
- 5) The fifth recommendation is that the potential market for palletized cargo flows to and from the small inland waterways must be researched. If there are palletized cargo flows available, these can be added to the small-barge system if the system is up and running. If more barges are added to the system, the average costs are slightly decreased (TAC will decrease only marginally after there are 20 barges in one system) and that will also contribute to a reduction in transportation costs.

### **18.3.2 Policy recommendations**

Based on preformed research 6 policy recommendations have been formulated.

- 1) The first recommendation is to allow single captain operation of the small barges and classic small inland ships on the small inland waterways. This will decrease the transportation costs for the small-barge system, so that its profitability and/or competitiveness will increase. This will make the system more attractive for investment companies and banks. If they see that a good business case can be made, they will invest in the new system without the financial help of the government.
- 2) Besides the complete standstill in newbuildings of small inland ships, there are also great difficulties in manning the available inland ships. Most of the young starting captains will start with a large ship instead of a small one. Attracting new crew-members from outside the inland navigation sector seems necessary to man the barges of the small-

barge system. In order to attract new people, the entry-barriers to becoming a captain must be reduced. It is therefore advised to grant sailing permits to small-barge captains after only 6 to 12 months of training. This sailing permit is only valid for the small inland waterway network and if the barges are empty or loaded with non-dangerous cargo.

- 3) The third recommendation is to acknowledge the fact that the old way of operating an inland ship (living and working at the ship and operating the ship by a family) is not going to work anymore in the future. The policy for the small inland ships must be focused on professionalizing that segment of the inland shipping market. That can be done by stimulating and/or creating inland shipping companies which operate several (big and small) ships. The developed small-barge system is such an example where one central office will run the company. By de-fragmenting the small inland shipping sector also the market power will increase, so that their influence in the total logistic chain will increase.
- 4) The fourth recommendation is that, in order to implement new inland navigation systems, a start-up subsidy or a loan guaranty can be granted. This subsidy will only cover the implementation of the system and not the actual operation. It is advised not to grant subsidies to inland navigation systems that cannot compete on their own without the help of government subsidies.
- 5) The fifth recommendation is that due to the natural monopoly where the small barge system will operate in the government must monitor the system via a licence system to prevent potential abuse of this position towards other potential companies who want to start the same sort of business. It is not possible (with the current market) to operate more than one small barge systems in the Flemish waterway network.
- 6) The last recommendation concerns the maintenance of the small inland waterway network. It is advised to provide a waterway depth that belongs to class of the waterway ( $h=2.5\text{m}$  for class II waterways). Under maintained waterways will result in a reduced depth of the waterway and therefore also in a reduction of the draft and extra shallow water resistance of the ships sailing on that waterway. If, due to budget restrictions, it is not possible to maintain the small waterways, then alternative solutions could be supported such as the developed small-barge system in which the barges are designed for the current day depth of the waterways (see also policy recommendation four).

### **18.3.3 Implementation recommendations**

Based on preformed research also 3 implementation recommendations have been formulated.

- 1) This research has shown that the small-barge system will operate in a natural monopoly (compared to similar systems), which is similar

to operating a train network. Train operators also have the experience to deal with the transportation of different cargo types in one block train (cars, bulk cargo, containers, liquid bulk, etc.). It is therefore advised that one or two persons from a train operator will advise or join the management of the small-barge system.

- 2) The research has also shown that empty containers are perfectly suitable for transport with the small-barge system (especially when additional road transport is needed). For loaded containers and for not water-bound companies, "normal" truck transport is a better choice. It is therefore advised that the small-barge system must seek cooperation with a truck transport. The trucking company will deal with the transportation of the loaded containers (high time pressure) and the small-barge system will deal with the transportation of the empty containers.
- 3) As already mentioned in this thesis, it is advised that the small barge system must be operated as one professional company (policy recommendation 3). There is also an on-going trend of integrating several fragmented logistical companies into a single company (Shipping companies owning container terminals and even trucks to deal with the hinterland transport). It is therefore advised that the small barge company must also be integrated into a logistics company such as a large shipping company.

# Literature list

## Part I

Acradis et.al, 2009; Maatschappelijke Kosten-batenanalyse voor de vervanging van drie 600 ton-sluizen door een of meer sluizen van min. 1350 ton. (in Dutch)

Bruggeman h., 2001, 175 jaar het kanaal, een gegraven kanaal lopend van Maastricht naar 's-Hertogenbosch (in Dutch)

Buck Consultants International, 2006: WATERSLAG: onderzoek naar de vrachtpotentie en inventaris van de waterweginfrastructuur in Vlaanderen en Zuid-Nederland, (In Dutch)

Buck Consultants International, 2008; Een goede toekomst voor het kleine schip *Visie en actieplan* (in Dutch)

Bureau voorlichting binnenvaart,2009;  
<http://www.bureauvoorlichtingbinnenvaart.nl/>

CBS, 2010;  
<http://www.cbs.nl/en-GB/menu/themas/dossiers/conjunctuur/publicaties/artikelen/archief/2010/2010-3031-wm.htm> (visited June 2010)

CE Delft, 2004; J.M.W. (Jos) Dings, H.P. (Huib) van Essen (CE), B.H. (Bart) Boon (CE), F. (Frank) Bruinsma (VU), J. (Jan) Rouwendal (VU), M. (Mark) Koetse (VU) *Onderhoud en beheer van infrastructuur voor goederenvervoer*

De binnenvaart, 2010; <http://www.debinnenvaart.nl/>, website visited in 2010

De Nocker, Broeckx,2004; Kengetallen externe kosten goederentransport VITO (in Dutch)

Dullaert W., Meersman H., Moglia F., van de Voorde E.,1998; Regulation and deregulation in inland navigation 8th WCTR proceedings p321- p334

Dutch Inland Shipping Information Agency (BVB),2009; The future of freight transport and inland shipping in Europe 2010-2011

ECB, 2010; European Central Bank "Euro area (changing composition) - HICP - Overall index, Annual rate of change, Eurostat, Neither seasonally or working day adjusted (visited 2010)

European Commission,2008; M. Maibach, C. Schreyer, D. Sutter (INFRAS), H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten (CE Delft), C. Doll (Fraunhofer Gesellschaft – ISI), B. Pawlowska, M. Bak (University of Gdansk), *Handbook on estimation of external costs in the transport sector, Internalization Measures and Policies for All external Cost of Transport (IMPACT), Version 1.1, Delft, CE, 2008, pp. 264-*

FOD economie, 2008; Vervoer binnenscheepvaart, 2006

FOMV,2010a; Federerale overdienst mobiliteit en vervoer  
<http://www.mobilit.fgov.be/nl/index.htm> visited in 2010

FOMV, 2010b; Federale Overheidsdienst Mobiliteit en Vervoer, personal contact

- GTS schepen, 2010,; <http://www.gtsschepen.nl/>, website visited in 2010
- Infrastructuur masterplan, 2010; infrastructuur masterplan voor de Vlaamse waterwegen, horizon 2014
- ITB, 2010, INSTITUUT VOOR HET TRANSPORT LANGS DE BINNENWATEREN vzw in cooperation with FEDERALE OVERHEIDSDIENST MOBILITEIT EN VERVOER Vervoer te Land- Binnenvaart, MARKTOBSERVATIE: BINNENVAARTVLOOT TOEBEHOREND AAN IN BELGIE GEVESTIGDE EIGENAARS 2009
- Jansen B., Verver G.J., 2008, Distrievaart – Troubled past of a future network (report made for the master course “shipping management” TU Delft)
- Konings, R., 2003; Network design for intermodal barge transport, in: *Transportation Research Record: Journal of the Transportation Research Board*, no. 1820, pp. 17 – 25.
- Konings, R., 2004; Development of container barge transport on small waterways: from increasing scale to increasing scope, in: *Transportation Research Record: Journal of the Transportation Research Board*, no. 1871, pp. 24 – 32.
- Konings, R., 2007; Opportunities to improve container barge handling in the port of Rotterdam from a transport network perspective, in: *Journal of Transport Geography*, 15 (6), pp. 443 – 454.
- Meersman, Van de Voorde, Vanelslander, Verbergh, 2009, Indicatorenboek 2008, Duurzaam goederenvervoer Vlaanderen (in Dutch)
- Meersman, Van de Voorde, Vanelslander, Verbergh, 2010, Indicatorenboek 2009, Duurzaam goederenvervoer Vlaanderen (in Dutch)
- MIRT, 2011; Infrastructure investment program Netherlands [http://mirt2011.mirtprojectenboek.nl/mirt\\_2011/project\\_en\\_programmabladen/?projectregion=Brabant](http://mirt2011.mirtprojectenboek.nl/mirt_2011/project_en_programmabladen/?projectregion=Brabant) (visited in 2011)
- NEA, 2003; onderzoek kosten per uur in de binnenvaart (In Dutch)
- NV de Scheepvaart, 2007, 2008, 2009; Traffic figures <http://www.descheepvaart.be/publicaties.aspx>
- Pausenberger L., 2009; Alternatieve financiering van grote infrastructuurwerken (Master thesis) (in Dutch)
- PBV, 2009a; unloading and loading figures Flanders <http://www.binnenvaart.be/nl/downloads/documents/ladingenenlossingen.pdf>
- PBV, 2009b; Container flows in Flanders, [http://www.binnenvaart.be/nl/downloads/documents/containervervoerTEU\\_000.pdf](http://www.binnenvaart.be/nl/downloads/documents/containervervoerTEU_000.pdf)
- PBV, 2010; [http://www.binnenvaart.be/nl/waterwegen/kaart\\_containers.html](http://www.binnenvaart.be/nl/waterwegen/kaart_containers.html) visited in August 2010
- Port of Antwerp, 2009; <http://www.portofantwerp.com/annualreport/2009/nl/active.php?id=2>
- Port of Rotterdam, 2009; <http://www.portofrotterdam.com/nl/actueel/pers-en-nieuwsberichten/pages/binnenvaartverchttterug.aspx>
- Rhinecontainer, 2009; [www. Rhinecontainer.nl](http://www.rhinecontainer.nl) visited in 2009

## Literature list

Schuttevaer, 2010 <http://www.schuttevaer.nl/nieuws/actueel/nid13168-nederlandse-alleenvaarder-moet-zijn-schip-laten-keuren-in-belgi.html> visited in januari 2011 (in Dutch)

Stopford, 1997, Maritime economics 3th edition

Technum NV, Resource Analysis, , Ecory, KU Leuven ,2002; Studie naar de ontwikkelingsmogelijkheden van de kleine waterwegen in Vlaanderen inzake Scheepvaart (studie into the navigation possibilities of small waterways in Flanders, Commissie of Vlaams overlegplatform van waterwegbeheerders), Antwerpen

Verbeke, Macharis, Cornillie, 2007, DE DERDE GOLF BINNEN DE BINNENVAART: PALLETVERVOER SUCCESVOL GETEST IN DE PRAKTIJK (in Dutch)

Verkeer en Waterstaat, 2004; Alleenvaartregeling Jaarbericht Inspectie pp. 33

Verkeer en Waterstaat,2007; Benutting binnenvaart en vaarwegen Beleidsdoorlichting van de begrotingsartikelen 34.02 en 35.04 (onderdeel binnenvaart) (in Dutch)

Wiegmans B., 2005; Evaluation of Potentially Successful Barge Innovations

Wiegmans B. and Konings R.,2007; Strategies and innovations to improve the performance of barge transport

WenZ, 2007, 2008, 2009, Traffic figures  
<http://www.wenz.be/Scheepvaart/Statistieken.html>

## Part II

Beelen, M., Meersman, H., Onghena, E., van de Voorde, E., Vanelslander T., 2007; Optimalisering openingstijden zeehaventerminals, Antwerpen: Universiteit Antwerpen 85p. (onderzoekspaper/ steunpunt Goederenstromen)

Beelen, Markianidou, Pauwels, Vanelslander, Van Hassel; 2009; AN ECONOMIC FEASIBILITY STUDY FOR THE UPGRADE OF SMALL INLAND WATERWAYS; ETC 2009 conference proceedings

Blauwens,G; De Baere, P; Van de Voorde, E, 2008; Transport Economics third edition, Uitgeverij De Boeck nv, Antwerp

Blauwens, G., Janssens, S., Vernimmen, B. and Witlox, F.,2001; Modale keuze in het goederenvervoer op basis van een vergelijking van de totale logistieke kostprijs: twee concrete gevalstudies (in Dutch)

Blauwens, G., Vandale N., van de Voorde E., Vernimmen, B. and Witlox, F., 2006; Towards a modal shift in freight transport? A Business logistics analyses of some policy measures; transport reviews Vol.26,No.2 239-251

Bolt E.,2003; Schatting energiegebruik binnenvaartschepen Versie 3, (in Dutch)

Burgers J.,2005; "ThyssenKrupp Veerhaven" TU Delft (Master thesis)

CCNR, 2009; centrale commissie voor de Rijnvaart Europese Binnenvaart marktobservaties 2009 p.41 (in Dutch)

CBRB,2003; Basisdokument Containerbinnenvaart (in Dutch)



- CE Delft, 2008; M. Maibach, C. Schreyer, D. Sutter (INFRAS), H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten (CE Delft), C. Doll (Fraunhofer Gesellschaft – ISI), B. Pawlowska, M. Bak (University of Gdansk), Handbook on estimation of external costs in the transport sector Internalisation Measures and Policies for All external Cost of Transport (IMPACT), Version 1.1
- CE&VU, 2004; “de prijs van een reis. De maatschappelijke kosten van het verkeer”, bewerking Ecorys (in Dutch)
- Dekker S., 2005; PhD report: Port Investment Towards an Integrated Planning of Port Capacity,
- Den Boer, *et.al.*, 2008; STREAM Studie naar Transport Emissies van Alle Modaliteiten Delft, CE, (in Dutch)
- Deloitte, 2009; KMO Kompas 2009: een financieel portret van een aantal belangrijke sectoren (in Dutch)
- De scheepvaart, 2010, inland waterway costs  
<http://www.descheepvaart.be/Rubriek/Beroepsvaart/Scheepvaartreglementering.aspx>
- Dijkstra, ir. W.J., 2001; Emissiefactoren fijn stof van de scheepvaart Rapport Delft (in Dutch)
- Dutch Inland Shipping Information Agency *et.al.*, 2009; The power of inland navigation: the future of freight transport and inland shipping in Europe 2010-2011
- Ecorys, 2009; Verkeer- en vervoersprognoses binnenvaart Scheldegebied Situatie 2007 en prognoses 2020/2040 (In Dutch)
- E.U., 2006; RICHTLIJN VAN HET EUROPEES PARLEMENT EN DE RAAD van 12 december 2006 tot vaststelling van de technische voorschriften voor binnenschepen en tot intrekking van Richtlijn 82/714/EEG van de Raad (in Dutch)
- European Commission, 2009; Terminal handling charges during and after the liner conference era, Luxembourg, publication office of the European Union
- European Commission, 2010; INLAND NAVIGATION IN EUROPE, Market observation, 2009/2
- Germanische Lloyds, 2006; Rules for Classification and Construction Ship Technology, Inland Navigation Vessels Hull Design and Construction
- Gerrits W., 2007; Dynamic Port Planning under Competition “Development of a tool for strategic investment planning” Delft (master thesis)
- Hengst S. 1997; Inleiding in constructieleer maritieme techniek (TU delft lecture notes) (in Dutch)
- Higgins R., 2007; Analyses of financial management, eight edition, international edition, The McGraw-Hill Companies, Inc., New York
- Holtrop, Mennen, van Terwisga, 1990; Een empirisch model voor de weerstandspredictie van bakken, Projectnummer: 89 B.3.23.1 MARIN report (In Dutch)

## Literature list

- Itlb, 2010; OVERZICHT VAN DE KOSTEN- EN KOSTPRIJSEVOLUTIE VOOR HET BEROEPSGOEDERENVERVOER OVER DE WEG (in Dutch)  
<http://www.itlb.be/uploads/Evol%20December%2012-31%20NL%20actu.pdf>
- Kantoor binnenvaart, 2010;  
[http://www.kantoorbinnenvaart.org/files/LOONTABEL\\_2010-jan\].pdf](http://www.kantoorbinnenvaart.org/files/LOONTABEL_2010-jan].pdf)
- Konings R., 2005; Hub-and-spoke networks in container-on-barge transport
- Konings, R., Y. Bontekoning and C. Maat, 2006; De concurrentiekracht van intermodal vervoer in ruimtelijk perspectief: intermodal op welke schaal?, in: M. Despontin & C. Macharis (eds), *Mobiliteit en (groot)stedenbeleid, 27ste Vlaams Wetenschappelijk Economisch Congres*, Brussel, pp 181 – 205. Copyright © VUBPRESS.
- Klein Woud H., Stapersma, 2002; D. Design of propulsion and electric power generation systems, published by IMarEST Lodon
- Kuiper G., 2002; Resistance and Propulsion I Lecture notes TU Delft
- Leijsen, Korteweg and Derriks, 2009; Welvaartseffecten van het internaliseren van externe kosten, Kennisinstituut voor Mobiliteitsbeleid maart 2009 (in Dutch)
- Lipczynski, Wilson and Goddard, 2005; Industrial organization, competition, strategy, policy 2<sup>nd</sup> edition, Pearson Education limited, England
- MacKenzie P.M., Forrester M.A., 2007, Sailboat propeller drag in journal of ocean engineering 35 (2008) PP. 28–40
- Hopman, Nienhuis, 2009, the future of ships and shipbuilding – a look into the crystal ball in Future challenges for the port and shipping sector, Meersman, Van de Voorde, and Vanelslander P.27 – P.52
- NEA, 2003; onderzoek kosten per uur in de binnenvaart (In Dutch)
- NEA, 2010, Kostenontwikkeling binnenvaart 2009 en raming 2010 (In Dutch)
- Schip en werf de zee, 2000; Het NEOKEMP concept P.22-26 (in Dutch)
- Raad voor de transportveiligheid, 2004; De stabiliteitsrisico's van binnenschepen en drijvende werktuigen (in Dutch)
- RAND, 2004; Main Survey into the Value of Time in Freight Transport by Road
- RAND, 2005; Reliability Ratio's voor het Goederenvervoer (in Dutch)
- Rijkswaterstaat Dienst Zeeland, 2006; Scheepvaart in Zeeland 2005 (in Dutch)
- Rothengatter, W 1994; Do external benefits compensate for external costs of transport? Transportation research A vol. 28A No.4, pp321-328
- Schilperoord, Drs. H.A. 2004; "Binnenvaart voortdurend duurzaam" Final Report 9P1060 (Royal Haskoning, 2004) (in Dutch)
- Schuttevaer, 2007, <http://www.schuttevaer.nl/nieuws/actueel/nid7893-alleenvaart-belgi235-wassen-neus.html> visited in januari 2010 (in Dutch)

Schuttevaer, 2010 <http://www.schuttevaer.nl/nieuws/actueel/nid13168-nederlandse-alleenvaarder-moet-zijn-schip-laten-keuren-in-belgi.html> visited in januari 2010 (in Dutch)

staalprijzen, 2010; [www.staalprijzen.nl](http://www.staalprijzen.nl) visited in 2010

Standaardmethodiek MKBA MOW, 2006 op basis van MIRA 2005 (in Dutch)

Steel weight estimation according to H.J. Westers [1962, 1978]

Thill C. et. al.;2005; State of the art existing hull- and propulsor concepts

UK steel, 2008, Analysis of steel price developments – spring 2008  
<http://tr.trfastenings.com/downloads/newsdownloads/pricerises/uksteelreasonsforincreasesspring08.pdf>

Van Dorsser J.C.M., 2004; Economische Haalbaarheid van Palletvaart, master thesis (in Dutch)

Van Dorsser J.C.M., 2005; Economische Haalbaarheid van het AMSBarge project, master thesis (in Dutch)

van Terwisga, 1989; Weerstand en voortstuwing van bakken, een literatuurstudie  
Projectnummer: 88 B 3.23.1 MARIN report (In Dutch)

Verbergh, E., 2009; The external costs of CO<sub>2</sub>- Emissions in the hinterland freight transport: The Belgium case

Vernimmen, B. and Witlox, F., 2001; Using an inventory theory approach for modal choice: a case study.

Watson, D.G.M., 1998; Practical Ship Design, Elsevier Science Ltd, Oxford, UK

### **PART III**

Bittlingmayer G., 1982; Decreasing average costs and competition: A new look at the Addyston Pipe Case, *Journal of Law and Economics*, Vol 25, no.2, pp.201-229

Macharis, C. and A. Verbeke, 2001; Het intermodale transportsysteem vergeleken met het unimodale wegvervoer, *Tijdschrift voor Economie en Management*, vol. XLVI, 1, pp. 39 – 63. (in Dutch)

SCHOEMAKER P., 1993; Multiple scenario development: its conceptual and behavioural foundation in strategic management journal Vol. 14, 193-213

## List of abbreviations

BEP = Barge exchange point

BTC = Barge train coefficient

BTF = barge train formation

CHC = Cargo handling costs

CHC<sub>road</sub> = Cargo handling costs road transportation

CHC<sub>IS</sub> = Cargo handling costs inland shipping

D<sub>total</sub> = Total demand

DD = Diesel direct propulsions system

DE = Diesel electrical propulsions system

EXT = External costs

EXT<sub>road</sub> = External costs road transportation

EXT<sub>IS</sub> = External costs inland shipping

FLEX = Flexibility costs

FLEX<sub>road</sub> = Flexibility costs road transportation

FLEX<sub>IS</sub> = Flexibility costs inland shipping

GC = Generalized costs

GC<sub>is</sub> = Generalized costs inland shipping

GC<sub>road</sub> = Generalized costs road transportation

FC = Full continuous sailing regime

Index = Inflation index

INVENT<sub>i</sub> = Inventory costs mode i

IRR(i) = Internal of rate of return of design option I

ITI = In transit inventory costs

ITI<sub>is</sub> = In transit inventory costs inland shipping

ITI<sub>road</sub> = In transit inventory costs road transportation

LRMC = Long run marginal costs

MBEP = Multiple barge exchange points

MC = Marginal costs

NPV<sub>total</sub> = Total NPV of the investment

NPV<sub>Initial</sub> = NPV of the initial investment

NPV<sub>Building\_up</sub> = NPV of building up the system

NPV<sub>1/2\_damand</sub> = NPV of having only half of the demand

OC = Overhead costs

PM = Profit margin

REL = Reliability costs

REL<sub>in</sub> = Reliability costs for inland navigation

REL<sub>road</sub> = Reliability costs for road transportation

REL<sub>dwell</sub> = Reliability costs due to dwell time

REL<sub>hinter</sub> = Reliability costs hinterland

REST = Rest costs which will consists of the reliability and flexibility costs

SBCS = Small barge convoy system  
SC = Semi continuous sailing regime  
SUB = Implementation subsidy  
SWBM = Still water bending moment

TAC = Total average costs  
TAX = Tax rate  
TC = Total transportation costs  
TC<sub>IS</sub> = Transportation costs inland shipping  
TC<sub>road</sub> = Transportation costs road transportation  
TEU = Twenty foot equivalent  
TLC<sub>i</sub> = Total logistical costs of mode i  
TP = Transportation price

VAR( $t_{\text{dwell}}$ ) = Variance in dwell time  
VoT = Value of time

WACC = Weighted average costs of capital

## Summary of the thesis

Inland shipping in North Western Europe is well known transportation mode which can make use of large and dense inland waterway network. However in the last 45 years no new small inland ships have been built. As a result the small inland fleet is diminishing, and only in Flanders 4,000,000 tonnes of cargo (WenZ, de Scheepvaart, 2009) transported to and from companies located at the small inland waterways, by small inland ships, risk being shifted to road transportation. Those tonnages are added to the already heavily congested road network. These extra tonnages and the potential further increase in cargo flows will lead to more investments in expanding the existing road capacity, while the available infrastructure of the small waterways will not be used at all while the small waterway capacity is very much needed to deal with a part of the total tonnages that have to be transported.

In this dissertation the previously mentioned problems will be further research and a potential solution will be proposed. In the thesis four main objectives formulated are formulated. The first objective of this thesis is to gain insight into the existing problems concerning the diminishing small inland fleet and, as a result of that, a reduction of the use of the small inland waterways. The second objective is to develop a new inland navigation concept that could be used to reactivate the use of the small inland waterway network. The third objective is to determine the optimal design for the concept developed (network and ship design). The fourth objective is to research the possibility of implementing, in an economically viable way, the small barge convoy system via suitable business cases.

The four main objectives have been reformulated into five main research questions:

- 1) What are the existing and expected problems concerning the use of small inland ships?
- 2) What type of solution could be developed to reactivate the use of the small inland waterway network?
- 3) How does the proposed solution work? What is the optimal design of the proposed solution?
- 4) Is it possible to construct a suitable business case for the developed solution?
- 5) How could the developed solution be implemented and how will the other modes react to the introduction of the proposed solution?

In chapter 2, a general introduction of the inland waterway system in Northwest Europe is given. Also the used definitions for small waterways and small ships and the market and transported tonnages via the small inland waterways in Flanders are described.

In chapter 3, showed that the supply on the small inland waterway network is diminishing mainly due to too server competition from road transportation. This has resulted in five main observations:

- No new small inland ships are being built
- Technical decline and withdrawal of the existing small inland fleet
- Limited to no inflow of new young captains for the small inland fleet
- Reduction of the available captains
- Insufficient maintenance of the small inland waterway infrastructure

A consequence of the diminishing small inland fleet is that the diversity in the total inland fleet will disappear. The new ships that are being built are increasing in size and therefore the available sailing area of these ships is reduced because the large ships can only sail on a limited number of inland waterways. Therefore there is a large risk that there will be only large inland ships, while more than 50% of the inland waterway network can only be reached with smaller (<650 tonne) ships. Due to an increasing number of large ships (and also their respective capacity) an overcapacity in the large inland shipping segment will occur. Combined with a reduced sailing area, a heavy competition between those ships is expected.

Due to a growing awareness of environmental care and carbon footprint, the EU member states want to stimulate the use of the modes producing the lowest amount of emissions per preformed tonne\*km. These emissions in transport could be diminished by the reactivation of the small inland waterway network providing transport of part of the cargo flows.

In order to deal with the previously mentioned problems of increasing congestion on the road network and growing awareness of environmental care, and the diminished supply on the small inland waterways there are two main solutions developed in chapter 4. The first solution is to upgrade the inland waterway infrastructure. This has been found too costly and it will also take too much time to implement. Therefore the adjustment of the inland navigation system is a better solution. This new inland navigation system is the small barge convoy system, which comprises out a barge train of small barges which can sail independently on small inland waterways. With this concept it is possible to combine different small waterways into one large network that can be served by the small barge system. Also due to the modular character of the concept potential clients could be bind to the concept by leasing out some of the barges and the small barge system can be built up gradually. This small barge convoy system could be used in dealing with the mentioned problems.

In chapters 5 to 13 a methodology was developed to research the developed small- barge concept. In the developed methodology a network design, tug and barge design, transportation costs and competition models were combined into a single model. The main goal of the total model is to determine the profitability, expressed in the Net Present Value (NPV), of the investment in a specific ship and network design.

In chapters 14 to 15 the developed methodology is demonstrated with a case study on the Flemish small waterway network. On the basis of the preformed analysis, with respect to the network design of the small barge

system on the Flemish waterway network, the following conclusions can be drawn:

- The most optimal network configuration consists of a network where routes 2-3-4 are combined (see figure 14.2)
- Adding extra barges sets is useful if only routes 2 and 3 are sailed to. If more routes are combined, the extra barge sets will not increase the profitability of the tug and barge convoy
- Adding inland container terminals (ICTs) to the total tug and barge system is useful to increase the NPV, but it will also increase the TLC if the tug has to sail to more than two routes. So ICTs can be added if only 2 routes are combined

For the design of the barges it can be concluded:

- The hull form of the barge will be made as large as possible to allow passing the locks on the small inland waterways
- With regard to the hull form the barge:
  - o If possible, the lowest value of  $\alpha_I$  (bow of the barge) (25 degrees) is advised because that will lead to the lowest resistance at the highest speeds
  - o The best choice for  $\alpha_{st}$  (aft ship of the barge) is then 25 degrees. This will decrease the resistance of the barge in the operational speed of the barge on the small waterways. If a generator set in the aft of the barge is chosen,  $\alpha_{st}$  cannot be chosen freely, but it must be altered in order to create enough space to allocate the generator set ( $\alpha_{st} < 10^\circ$ )
- The barge will be equipped with 4 thrusters in the aft of the barge and one in the bow
- The differences in transportation costs between the battery-propelled barge, the generator-set barge and the hybrid barge are small. If the fuel price increases, the transportation costs of the battery barge will be marginally smaller. Therefore the choice will be made to propel the barges with a battery pack in the double bottom of the barge. However, if that solution is too technically challenging, the other alternatives could also provide suitable options

With respect to the design of the tug, the following conclusions can be drawn:

- The tug and barge convoy should sail in a semi-continuous regime
- The tug and barge convoy should have a design speed of 3.5 m/s
- The tug should be equipped with a diesel direct propulsion system
- The tug will be equipped with 3 propellers

As to the competition research, the inventory costs are much dependent on the value of the transported cargo (high VoT). So, if the value of the cargo is too high, the more flexible and faster mode (=road transport) will most likely be chosen and the small-barge convoy cannot compete for that type of cargo.



It can also be concluded that it is not possible to add additional road transport to the small barge system if the transported containers are loaded (intermodal option). Therefore, only direct calls at companies located directly at the small waterway can be considered for loaded containers. However, if the containers are empty, a small distance of road transport can be added to the small-barge transport ( $<2.5$  km). If the external costs are internalized, that distance increases ( $<17$  km). If bulk cargo had a destination at a water-bound company and therefore only the containers have to be transported further inland, the potential distance that the truck can drive is increased, compared with the case when also bulk cargo has to be moved further inland with a truck.

In the development of the business cases it was the aim to maximize the NPV of the initial investment. In order to do that, cargo flows need to be shifted from the road towards the small-barge system. It could be seen that, by changing the transportation mode, the total logistics system of potential clients has to be altered. If a company is willing to shift its cargo flows to the small-barge system, more cargo has to be stored at their premises, thereby adding to the total inventory costs. The price that will be offered by the small-barge system must therefore be low enough so that the TLC for a company are lower; otherwise the company will not shift its cargo flows. The inventory costs are much dependent on the value of the transported cargo. Consequently, if the value of the cargo is too high, the more flexible and faster mode (=road transport) will most likely be chosen. This is especially the case for loaded containers. It is therefore best to focus on low-value products such as bulk (sand, iron ore, etc.) and empty containers.

During the development of suitable business cases, another important finding of the tug and barge convoy was discovered, i.e. it will be affected by decreasing average costs if the transportation volumes increases. This indicates first of all that the prices cannot be determined by the LRMC because in the long run the TAC are higher than the MC, so that prices should be determined by the LRAC. Secondly, this indicates that not enough cargo is available to accommodate similar small-barge systems (with the same costs structure). Therefore the small barge convoy will operate in a natural monopoly. This means that no other company can enter the same business that has the same costs structure (large amount of fixed costs which relates to the amount of barges in the small-barge convoy system). Therefore some sort of regulations (licence system) must be imposed by the waterway administrators. Other ships and trucks with different costs structures can enter the market and will not be affected by this natural monopoly.

From the preformed network and design analysis two good business cases can be identified:

- Case I: Sailing with the tug and barge convoy to routes two (4 barges), route three (4 barges) and route four (2 barges) (condition 4 table 15.1)

- Case II: Sailing with the tug and barge convoy to routes two (6 barges) and three (4 barges) while on route two 2 barges are pushed to the selected ICT

In order to determine whether the small-barge convoy system can succeed in a competitive market, a lot of future uncertainties have to be taken into account. To deal with those uncertainties, different scenarios were developed. For the two developed business cases a scenario analysis was performed in order to take the uncertain (exogenous) effects into account.

### *Business Case I*

From the scenario analysis for the first business case can be concluded that it is impossible to make a suitable business case in scenario 1. It is not the upgrade of the class II canals to class IV that is devastating for the small-barge convoy system, but the increase in equity costs.

In the second scenario the waterways are not upgraded. Therefore the competition comes from the existing small inland ships and road transportation. Even so, still no business case can be made due to the required costs of equity of 15% (given as a minimum in scenario 2).

In the third scenario the financing requirements are lowered. By the reduction of the financing and fuel costs the transportation costs are reduced, allowing a lower price that can be offered, which will increase the potential market.

In the fourth scenario it is possible to sail with only one captain on the barges when they are sailing on the small inland waterways owing to an adjustment of the crew rules on the small waterways. The transportation costs are lower, making room for more competitive prices and more cargo. It can therefore be concluded that adjusting the crew rules on the small inland waterways will affect the competitiveness and the profitability of the concept quite considerably but, if the crew rules on the small waterways are not adjusted, still a suitable business case can be made (scenario 3).

In the fifth and sixth scenario the NPV and IRR will increase even further, due to the increase in transportation price. This increase of transportation price can be accepted because of the increased transportation price of the main competitor, road haulage. In the sixth scenario the external costs are internalized into the generalized and total logistics costs which will lead to an even bigger difference in TLC between the small-barge convoy system and other competitors. As a result, the small-barge convoy system will increase its competitiveness towards road haulage and a very good business case can be made. It can also be concluded that the failure of the present-day road network and the internalization of the external costs are contributing positively towards the small-barge convoy system, but they are not necessary to construct a business case.

In the model a estimation has been made of the newbuilding prices of the barges and tug. These prices can vary quite considerable over time, which makes it very difficult to determine these prices. Therefore the influence of a varying newbuilding price has been researched. The variation of the

newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for the scenarios 1, 2 and 4 to 6. Only in the third scenario will an increase of 15% of the newbuilding price make the investment decision negative. An increase in newbuilding price will increase the transportation costs of the small barge system so that the NPV decreases. So, if the newbuilding price of the tug and barges is increased and it is not allowed to sail with only one captain on the small inland waterways, it is not possible to make a suitable business case ( $NPV < 0$ ). In conclusion,, except for scenario 3, in a range of 30% variation of the calculated newbuilding price, the investment decisions will not change. The profitability will increase if the newbuilding price is decreased (or decrease if the newbuilding price increases).

### *Business Case II*

For the second business case it can be concluded that scenario 1 will not provide a suitable business case due to the increase in the costs of equity to 15%.

In the second scenario the NPV is still negative, so that still no suitable business case can be made.

In scenario 3, 4, 5 and 6 a suitable business case can be made. As in the first case the crew rules on the small waterways do not need to be adjusted in order to make a business case. However, if it is possible to limit the number of crew-members sailing on the barge on the small inland waterway, this will increase the NPV significantly. If the external costs are internalized, the competitiveness of the concept will increase but it is not necessary to internalize those costs to make a suitable business case.

From the preformed scenario analysis can be concluded that the second case behaves in the same way as in the first case when it is influenced by the different scenarios.

The variation of the newbuilding price from -15% to 15% of the tug and barges will not change the investment decision for all scenarios, except scenario 3. In that scenario an increase of 15% of the newbuilding price will make the investment decision negative. As already concluded in the first business case, in a range of 30% variation of the calculated newbuilding price, the investment decisions will not change (only in scenario 3); only the profitability will increase if the newbuilding price is decreased.

In chapter 15 the influence of different infrastructure characteristics on the profitability of the small barge system are research. The results of the infrastructure calculations have shown that the small-barge concept will decrease its competitiveness and decrease its NPV if the distance of the large waterway is increased with a semi-continuous sailing regime. If the sailed distance on the large waterway is larger than 80 km, a full continuous sailing option is better than a semi-continuous option. The competitiveness and the NPV of the full continuous option are then larger than the semi-continuous option. The TLC of the full continuous option will decrease, compared with the semi- continuous option, with increasing distance of the large waterway.

If the distance of the small waterway is increased, the NPV will decline at first and when the distance of the small waterways is increased to more than 50 km, it will increase again. In the small waterway analysis shows that changing the propulsion of the barge from batteries to a hybrid option will not increase the NPV. Despite the lower newbuilding costs of the hybrid barge than for the battery-propelled barge, an increase in sailed distance will not make the hybrid option more competitive due to the increase in fuel costs of the hybrid barge.

In chapter 16 two implementation strategies are applied to both business cases and it can be concluded that strategy one, i.e. building up capacity, prevails in almost all of the considered cases. Only if one expects that the newbuilding costs of the barges will increase by more than 10% and if the risk of not implementing all the barges is less than 10%, is strategy two the best option. Therefore the first implementation strategy should be used to build up the small barge system.

If the implementation cost has to be covered by the small barge company then the investment decision will be very much influenced by the variation in implementation cost (due to the chosen strategy of building up capacity). If the implementation cost will be covered by an implementation subsidy, with the reduction in external costs as a return, it will have a positive NPV. Therefore the implementation subsidy can be justified for the first business case.

For the second business case the implementation subsidy cannot be justified in all considered conditions. The reason for the difference with the first business case is due to the fact that in the second business case also containers to inland container terminals are transported. These cargo flows are already transported with inland navigation and shifting the cargo from one ship to the other will not cause a significant reduction in emissions. It is also not in the interest of a government to shift cargo flows from one ship to the other but to shift cargo flows towards transportation modes that will have the lowest external costs (from road to the inland waterways). Therefore only a part of the transported cargo flows will contribute in the reduction of external costs.

With respect to the number of crew members needed on the tug and barges and the personnel on the office it is concluded that the largest number of people needed are the crew members who are sailing on the barges on the small inland waterways. Great difficulty could be expected if all those small barge captains must have all the required licences and sailing experience before they can start sailing the barges. Therefore it is advisable to attract former captains of small inland ships to the small barge company. If not enough former captains are available then, another solution could be obtained by giving the small barge captains a limited sailing permit, only valid at the small inland waterways so that side inflow of new people can be used to man the small barges.

When the total small barge system is built up and if the demand is reduced temporarily the small barge system can deal with that. But if the reduction of demand is permanent, then the  $NPV_{total}$  will reduce significantly to a value below zero which will make the system unprofitable.

In chapter 17 the SWOT analysis has showed that there are a lot of strong points and opportunities for the small barge system. Therefore the small barge system must focus on those strong points. But it is even more important to deal with weaknesses and threats. One strategy, to deal with the weaknesses of the large implementation hurdle, is to build up the system from a small starting position and that the implementation costs could be covered by a subsidy (chapter 16). Another strategy that can be used to deal with large amount of fixed costs is to involve the potential clients by leasing out the barges for long periods (2 or more years) or even sell the barges. This will make the small barge system also less vulnerable to the limited number of companies and it will reduce the fixed costs.

In order to deal with the threat of the competition of road transport on the container market, it could be a good strategy, at the start of the small barge system, to focus on the transportation of empty containers. Another threat will come from the current ship owner of the small inland fleet. The current day inland shipping sector could want to maintain the current entry barriers. It is therefore important to get the current inland sector involved in the small barge company. Also former captains could be used to operate the small barges or to work on the tug. This would also tackle the problem of insufficient amount of personnel. Another way to solve that problem is to aim at side inflow (section 16.6).

## Samenvatting van de thesis

De binnenvaartvaart in noord west Europa is een welgekende transportmodus die gebruik kan maken van een groot en zeer fijnmazig netwerk. In de laatste 45 jaar echter, is er een trend te ontdekken dat er geen kleine binnenvaartschepen meer gebouwd worden. Een gevolg hiervan is dat de kleine binnenvaartvloot aan het verdwijnen is en dat de alleen al in Vlaanderen, 4.000.000 ton vracht van de kleine binnenvaart naar de weg verschuift dreigt te worden. Deze vracht wordt dan toegevoegd aan het al hevig (over) belaste wegennet. Deze extra toegevoegde tonnage en potentiële toekomstige groei van vraag naar transport zullen leiden tot extra investeringen in het uitbreiden van het huidige wegennetwerk, terwijl de huidige kleine waterwegeninfrastructuur niet gebruikt wordt. Deze infrastructuur kan perfect gebruikt worden om een deel van de totale goederenstromen te vervoeren.

Een andere consequentie van het verminderen van de kleine binnenvaartvloot is dat de diversiteit in de totale binnenvaartvloot verdwijnt. De nieuwe schepen die gebouwd worden nemen toe in laadcapaciteit en, als gevolg daarvan, hebben deze nieuwe schepen maar een beperkt vaargebied.

In deze dissertatie worden deze bovengenoemde problemen verder onderzocht en wordt er een mogelijke oplossing ontwikkeld om de kleine binnenvaartwegen te reactiveren. Daarom zijn er een aantal doelen gesteld. Het eerste doel van deze thesis is om inzicht te verkrijgen in de huidige problematiek van de vermindering van de kleine binnenvaartvloot en, als gevolg daarvan, het afnemen van het gebruik van de kleine vaarwegen. Het tweede doel is om een nieuw binnenvaartconcept te ontwikkelen om de kleine binnenvaartwegen te reactiveren. Het derde doel is om het optimale ontwerp van het ontwikkelde concept te bepalen (netwerk en scheepsontwerp). Het vierde doel is om te onderzoeken of het mogelijk is om het concept, op een economische haalbare manier, te implementeren is via haalbare business cases.

Deze vier grote doelen werden geherformuleerd in vijf hoofdonderzoeksvragen:

- 1) Wat zijn de huidige en verwachte problemen aangaande het gebruik van kleine binnenvaartschepen?
- 2) Wat voor een oplossing kan ontwikkeld worden om het gebruik van de kleine binnenvaartwegen te reactiveren?
- 3) Hoe werkt het ontwikkelde concept, en wat is het optimale ontwerp van de voorgestelde oplossing?
- 4) Is het mogelijk om haalbare business cases te maken voor het ontwikkelde concept?
- 5) Hoe kan het ontwikkelde concept geïmplementeerd worden en hoe zullen de andere transport modi reageren op de introductie van het concept?

In hoofdstuk 2 was een algemene introductie van het binnenvaartsysteem in noord west Europa gegeven. In dat hoofdstuk zijn de gebruikte definities voor kleine vaarwegen en kleine schepen gegeven. Ook is er een overzicht gegeven van de huidige transportstromen via de kleine binnenvaartwegen in Vlaanderen.

In hoofdstuk 3 is aangetoond dat het aanbod van kleine schepen op kleine binnenvaartwegen afneemt door te grote concurrentie van wegtransport. Dit heeft geresulteerd in 5 belangrijke observaties:

- Geen nieuwe kleine schepen worden er toegevoegd aan de bestaande binnenvaartvloot
- Technische afname en vermindering van de bestaande kleine binnenvaartvloot
- Zeer beperkte instroom van nieuwe jonge binnenvaartschippers voor kleine schepen
- Afname van de beschikbare kapiteins op kleine schepen
- Onvoldoende onderhoud aan de kleine binnenvaartwegen

Een consequentie van het afnemen van het aantal kleine schepen is dat de diversiteit in de totale binnenvaartvloot verdwijnt. De nieuwe schepen die gebouwd worden, worden steeds groter waardoor het te bevaren gebied kleiner wordt doordat deze grote schepen niet door alle sluizen kunnen varen. Er is dus een groot risico dat er in de toekomst alleen nog maar grote schepen overblijven terwijl 50% van het waterwegennetwerk in Nederland en België alleen bevaren kan worden door kleine schepen (<650 ton). Door de grote toename van het aantal grote schepen is er ook een risico dat er een overcapaciteit in het segment van de grote binnenschepen ontstaat. Als dan ook nog het beperkte vaargebied van deze schepen in ogenschouw wordt genomen wordt er een zeer grote concurrentie tussen deze type schepen verwacht.

Door een toenemende bewustwording van milieubescherming en CO<sub>2</sub>-uitstoot willen de EU lidstaten transport modi, die minder emissies per tonkm produceren, stimuleren. Het reactiveren van de kleine binnenvaartwegen kan perfect bijdragen aan het behalen van deze doelstellingen.

Om een antwoord te bieden op de voorgenoemde problemen omtrent toenemende congestie op het wegennetwerk, de toenemende aandacht voor het verminderen van uitstoot en het verdwijnen van kleine binnenvaartschepen is een nieuw binnenvaartconcept ontwikkeld in hoofdstuk 4. De eerste denkpiste die gevolgd werd is die van het opwaarderen van de kleine binnenvaartwegen. Deze infrastructuuraanpassing is te kostbaar bevonden alsook dat de implementatie te lang zal duren. Daarom is er besloten om niet de infrastructuur aan te passen maar om het binnenvaartschip, en zelfs het hele binnenvaartconcept, aan te passen. Het nieuwe binnenvaartconcept is het kleine bakkenconcept. Dit kleine bakken concept bestaat uit een duwvaartkonvooi dat bestaat uit kleine, onafhankelijk varende, duwbakjes die instaat zijn om zelfstandig op kleine waterwegen te varen. De bakken worden op grote vaarwegen samengevoegd en door een duwboot voortgeduwd van een zeehaven tot het punt waar de kleine waterweg

begint. Met dit concept is het mogelijk om met een systeem verschillende (kleine) waterwegen met elkaar te combineren in een netwerk.

Omdat het concept bestaat uit meerdere kleine bakjes is het mogelijk om het totale systeem modulair op te bouwen. Een bijkomend voordeel van dit modulair karakter is dat potentiële klanten aan het concept gebonden kunnen worden door, bijvoorbeeld, bakjes aan hun te leasen.

In hoofdstukken 5 tot 13 is de methodologie ontwikkeld om het kleine bakken concept te onderzoeken. In de methodologie zijn een netwerkmodel, een duwbak en duwboot ontwerpmodel, een transportkostenmodel en een competitie model geïntegreerd in een totaal model. Het doel van dit model is om de invloed van verschillende (ontwerp)parameters op de Netto Contante Waarde (NCW) van het totale bakken concept te bepalen. Op basis van verschillende parameter analyses is het mogelijk om het meeste optimale ontwerp (zowel van de bakken, duwboot en het netwerk) te bepalen.

In hoofdstukken 14 en 15 is de ontwikkelde methodologie toegepast op een gevalstudie van het Vlaamse kleine binnenvaartnetwerk. Aangaande het ontwerp van het netwerk voor het kleine bakken systeem op de Vlaamse waterwegen kan het volgende geconcludeerd worden:

- Het meest optimale netwerkconfiguratie is een netwerk waarin routes 2, 3 en 4 zijn gecombineerd (zie figuur 14.2)
- Het toevoegen van extra bakkensets is alleen nuttig als er in een netwerk gevaren wordt bestaande uit routes 2 en 3. Als er meer routes zijn gecombineerd dan zal het toevoegen van extra bakkensets niet leiden tot een hogere NCW.
- Het toevoegen van inland container terminals (ICTs) aan het bakken concept is nuttig om de NCW te vergroten. Maar als er meer dan 2 verschillende waterwegen gecombineerd worden zullen ook de totale logistieke kosten per container (TEU) en ton vracht toenemen. Daarom is het toevoegen van ICTs alleen nuttig als er in een netwerk van 2 verschillende waterwegen gevaren wordt.

Voor het ontwerp van de bak zijn de volgende zaken te concluderen:

- De lengte van de bak moet zo groot mogelijk worden zolang de bak nog door de sluizen op de kleine waterwegen kan.
- Betreffende de rompvorm van de bak:
  - o Als het mogelijk is, zou een zo klein mogelijke waarde voor  $\alpha_1$  (vorm boeg van de bak) (25 graden) geadviseerd omdat dit leidt tot de laagste weerstand op hoge snelheden (snelheid konvooi op grote vaarwegen).
  - o De beste keuze voor  $\alpha_{st}$  (vorm achterschip) is 25 graden. Dit leidt tot een afname van de weerstand van de bak wanneer die onafhankelijk vaart op een kleine waterweg. Als er gekozen wordt voor een generatorset in het achterschip van de bak dan is het niet mogelijk om  $\alpha_{st}$  vrij te kiezen. Daarom moet, in dat geval, de



waarden aangepast worden om genoeg ruimte te creëren voor de generator set ( $\alpha_{st} < 10^\circ$ )

- De bak zal uitgerust worden met 4 thrusters die in het achterschip van de bak geplaatst zullen worden. Ook wordt er boegschroef toegevoegd om de manoeuvreerbaarheid van de bak te vergroten.
- Het verschil in transportkosten tussen een batterij, een generator set of een hybride aangedreven bak zijn klein. Als de brandstofprijs toeneemt, nemen de transportkosten van de batterij aangedreven bak het minst toe. Daarom is de keuze gemaakt om de bakken uit te rusten met een batterij aandrijving, die geplaatst wordt in de dubbele bodem van de bak. Als het echter, na verder onderzoek, blijkt dat die oplossing te moeilijk te realiseren is dan zijn de andere opties ook goede alternatieven omdat het verschil in transportkosten niet groot is.

Op basis van de uitgevoerde analyse kan, voor het ontwerp van de duwboot, geconcludeerd worden dat:

- Het duwbakkenkonvooi moet in een semi continue dienstregeling varen
- Het duwbakkenkonvooi heeft een optimale ontwerpsnelheid van 3.5 m/s
- De duwboot moet uitgerust worden met een diesel directe voorstuwinginstallatie
- De duwboot moet uitgerust worden met 3 schroeven

Het concurrentieonderzoek heeft aangetoond dat de voorraadkosten (zowel tijdens het varen als bij het ontvangende bedrijf zelf) erg afhangen van de waarde van de vervoerde vracht. Als de waarde van de vervoerde vracht te groot wordt zal de sneller en meer flexibelere transport modi (=wegtransport) gekozen worden. Voor het kleine bakkenconcept is het te moeilijk om voor die vracht de concurrentie aan te gaan.

Er kan ook geconcludeerd worden dat het niet mogelijk is om extra wegtransport toe te voegen aan het bakkenconcept als de containers geladen zijn (intermodale optie). Alleen directe afleveringen van geladen containers aan bedrijven gevestigd aan de (kleine) waterweg kunnen meegenomen worden. Echter, als de containers leeg zijn kan een klein stuk wegvervoer toegevoegd worden aan het vervoer met de kleine bakken (2.5 km). Als de externe kosten geïnternaliseerd zullen worden dan is het mogelijk om een grote stuk wegtransport toe te voegen (17 km).

Tijdens de ontwikkeling van de business cases was het doel was gesteld om de NCW van de initiële investering te maximaliseren. Om dat te doen, moeten de ladingsstromen van de weg naar het kleine-bakkensysteem worden verplaatst. Men zou kunnen zien dat, door de vervoerswijze te veranderen, het totale logistiekstelsel van potentiële klanten veranderd moet worden. Als een bedrijf bereid is om zijn ladingsstromen aan kleine bakkensysteem aan te bieden, moet meer lading op hen terrein worden opgeslagen, waardoor de totale inventariskosten zullen toenemen. De prijs die door het kleine-bakkensysteem kan aanbieden moet dusdanig zijn, zodat Totale Logistiek Kosten (TLK) voor een potentiële klant laag genoeg is t.o.v. concurrerende modi; anders zal het bedrijf zijn ladingsstromen niet verplaatsen. De inventariskosten zijn erg afhankelijk van de waarde van de vervoerde lading. Derhalve als de waarde van de lading te hoog is, zal de

flexibelere en snellere wijze (vervoer = wegtransport) het waarschijnlijkst gekozen worden. Dit is vooral het geval voor geladen containers. Het moet daarom het best geconcentreerd moeten worden op laagwaardige producten zoals bulk (zand, ijzererts, enz.) en lege containers.

Tijdens de ontwikkeling van geschikte business cases werd er een belangrijk aspect van het bakkenkonvooi ontdekt. Deze ontdekking is dat de gemiddelde kosten dalen als de vervoersvolumes stijgen. Dit wijst erop dat de prijzen niet door lange termijn marginale kosten kunnen worden bepaald omdat uiteindelijk de gemiddelde kosten hoger zijn dan de marginale kosten, zodat de prijzen door lange termijn gemiddelde kosten zouden moeten worden bepaald. Ten tweede, wijst dit erop dat niet genoeg lading beschikbaar is om gelijkaardige kleine-bakkensysteem (met dezelfde kostenstructuur) te laten overleven op hetzelfde netwerk. Daarom zal het kleine-bakkensysteem in een natuurlijk monopolie werken. Dit betekent dat geen ander kleine bakkenbedrijf dezelfde markt kan bedienen die dezelfde kostenstructuur heeft (hoge vaste kosten die gerelateerd zijn aan de hoeveelheid bakken in het klein-bakkenkonvooi). Daarom moet een soort regulering (vergunningensysteem) door de waterwegbeheerders worden opgelegd. Andere, normale, schepen en vrachtwagens met verschillende kostenstructuren kunnen wel concurreren in dezelfde markt en zullen niet door dit natuurlijke monopolie beïnvloed worden.

Van de uitgevoerde netwerk en ontwerpanalyse kunnen er twee goede business cases worden geïdentificeerd:

- Case I: Varen met het duwboot en bakkenkonvooi naar routes: twee (4 bakken), drie (4 bakken) en route vier (2 bakken) (optie 4 tabel 15.1)
- Case II: Varen met het duwboot en bakkenkonvooi naar routes: twee (6 bakken) en drie (4 bakken) terwijl op route twee 2 bakken aan geselecteerd ICT worden geduwd

Om te bepalen of het systeem van het klein-bakkenkonvooi in een concurrerende markt kan slagen moet er heel wat toekomstige onzekerheden in acht worden genomen. Om die onzekerheden te behandelen, werden de verschillende scenario's ontwikkeld. De twee ontwikkelde business cases werden aan een scenarioanalyse onderworpen om met de onzekere (exogene) gevolgen rekening te houden.

### *Business Case I*

Van de scenarioanalyse voor de eerste business case kan worden besloten dat het onmogelijk is om een geschikt case te maken in scenario 1. Het is niet de opwaardering van klasse II kanalen naar klasse IV die voor het kleine bakkensysteem funest is, maar de verhoging van kosten voor eigenvermogen.

In het tweede scenario worden de waterwegen niet opgewaardeerd. Daarom komt de concurrentie uit de bestaande kleine binnenvaartschepen

en het wegvervoer. Maar toch kan er geen business case gemaakt worden wegens de vereiste kosten van eigenvermogen van 15% (gegeven als minimum in scenario 2).

In het derde scenario worden de financieringsbehoeften verminderd. Door de vermindering van financiering (kosten rente en eigenvermogen) en de brandstofkosten worden de vervoerskosten gedrukt, zodat een lagere prijs kan worden aangeboden, waardoor de potentiële markt zal vergroten. In dit scenario is het mogelijk om een business case te maken.

In het vierde scenario is het mogelijk om met slechts één kapitein op de bakken te varen wanneer zij op de kleine binnenwateren varen. De vervoerskosten zijn lager, waardoor er ruimte komt voor meer concurrerende prijzen en meer lading. Men kan daarom besluiten dat het aanpassen van de bemanningsregels op de kleine binnenwateren aanzienlijk het concurrentievermogen en de rentabiliteit van het concept zal verbeteren. Maar als de bemanningsregels op de kleine waterwegen niet worden aangepast, is het nog steeds mogelijk om een geschikte business case te maken (scenario 3).

In het vijfde en zesde scenario zullen NPV en IRR nog verder stijgen, wegens de verhoging van vervoersprijs. Deze verhoging van vervoersprijs kan geaccepteerd worden door de verhoogde vervoersprijs van de belangrijkste concurrent: wegvervoer. In het zesde scenario worden de externe kosten geïnternaliseerd in de gegeneraliseerde en totale logistiekkosten die zullen leiden tot een nog groter verschil in TLK tussen het systeem van het klein-bakkenkonvooi en andere concurrenten. Dientengevolge, zal het klein-bakkenkonvooi zijn concurrentievermogen naar wegvervoer verhogen en is mogelijk om een zeer goede business case te maken. Men kan ook besluiten dat de mislukking van het huidige wegennet en het internaliseren van de externe kosten positief zijn voor het klein-bakkenkonvooi, maar dat ze niet noodzakelijk zijn om een business case te construeren.

In het model is een schatting gemaakt van de nieuwbouwprijzen van de bakken en duwboot. Deze prijzen kunnen vrij aanzienlijk in de tijd variëren waardoor het zeer moeilijk wordt om deze prijzen te bepalen. Daarom is de invloed van variërende nieuwbouwprijzen onderzocht. De variatie van de nieuwbouwprijs van -15% tot 15% van de duwboot en bakken zal niet het investeringsbesluit voor scenario's 1, 2 en 4 tot 6 beïnvloeden. Slechts in het derde scenario zal een verhoging van 15% van de nieuwbouwprijs het investeringsbesluit negatief doen beïnvloeden. Een verhoging van de nieuwbouwprijs zal de vervoerskosten van het kleine bakkensysteem verhogen zodat NCW vermindert. Als de nieuwbouwprijs van de duwboot en de bakken verhoogd wordt en het toegestaan is om met slechts één kapitein op de kleine binnenwateren te varen, is het niet mogelijk om een geschikte business case te maken ( $NCW < 0$ ). Samenvattend, behalve in scenario 3, in een range van 30% van de berekende nieuwbouwprijs, zullen de investeringsbesluiten niet de veranderen. De rentabiliteit zal stijgen als de nieuwbouwprijs verminderd (of dalen als de nieuwbouwprijs stijgt).

## *Business Case II*

Voor de tweede business case kan men besluiten dat in scenario 1 er geen geschikt case gemaakt kan worden. Dit is toe te schrijven aan de verhoging van de kosten van het eigenvermogen van 15%.

In het tweede scenario wordt het minimum niveau van de gewogen gemiddelde kosten van kapitaal en eigenvermogen nog niet bereikt, zodat ook hier geen geschikt case gemaakt kan worden.

In scenario's 3, 4, 5 en 6 kunnen er geschikte business cases worden gemaakt. Zoals in de eerste business case, is het niet nodig om de bemanningsregels op de kleine waterwegen aan te passen om een business case te maken. Nochtans, als het mogelijk is om het aantal bemanningsleden te beperken die op de bak op het kleine binnenwater varen, zal dit de NCW beduidend verhogen. Als de externe kosten worden geïnternaliseerd, zal het concurrentievermogen van het concept stijgen maar het is niet noodzakelijk om ze te internaliseren om een geschikte case te maken.

Van de scenarioanalyse kan men concluderen dat de tweede business case zich op dezelfde manier gedraagt als de eerste business case wanneer het door de verschillende scenario's wordt beïnvloed.

De variatie van de nieuwbouwprijs van -15% tot 15% van de duwboot en bakken zal het investeringsbesluit voor alle scenario's, behalve in scenario 3, doen beïnvloeden. In dat scenario zal een verhoging van 15% van de nieuwbouwprijs het investeringsbesluit negatief doen worden. Zoals reeds besloten in het eerste business case, zullen de investeringsbesluiten niet veranderen door een variatie van 30% van de berekende nieuwbouwprijs, (slechts in scenario 3). De rentabiliteit zal stijgen als de nieuwbouwprijs verminderd.

In hoofdstuk 15 zijn infrastructuurberekeningen gemaakt om de invloed van de infrastructuur op de rentabiliteit van het bakkenconcept te onderzoeken. De resultaten van de berekeningen hebben aangetoond dat het kleinbakkenconcept zijn concurrentievermogen en zijn NCW zal verminderen, als de afstand van de grote waterweg groeit en als er gevaren wordt in een semi-continu regime. Als de gevaren afstand op de grote waterweg groter is dan 80 km, is het vol continu varen een beter optie dan een de semi-continue optie. Het concurrentievermogen en NCW van de vol continue optie zijn groter dan de semi-continue optie. De TLK van de vol continue optie zal verminderen, in vergelijking met de semi continue optie, als de afstand op grote waterweg toeneemt.

Als de afstand van de kleine waterweg wordt vergroot, zal NCW eerst dalen en wanneer de afstand van de kleine waterwegen wordt verhoogd tot meer dan 50 km, zal het opnieuw stijgen. De analyse toonde ook aan dat het veranderen van de aandrijving van de bak, bij toenemende vaarafstand,

van batterijen in een hybride optie, de NCW niet zal verhogen. Ondanks de lagere nieuwbouwkosten van de hybride bak dan voor de batterij-aangedreven bak, zal een verhoging van gevaren afstand de hybride optie niet concurrerender maken wegens de verhoging van brandstofkosten van de hybride bak.

In hoofdstuk 16 werden twee implementatiestrategieën toegepast op beide business cases waaruit men kan concluderen dat strategie één, d.w.z. opbouwende capaciteit, in bijna alle onderzochte gevallen de beste optie is. Slechts als de nieuwbouwkosten van de bakken met meer dan 10% zullen stijgen en als het risico om alle bakken niet te laten bouwen minder dan 10% is, is strategie twee de beste optie. Daarom zou de eerste implementatiestrategie gebruikt moeten worden om het kleine bakkensysteem te implementeren.

Als de implementatiekosten voor het kleine bakkensysteem gedekt moeten worden door het kleine duwbakkenbedrijf dan zal het totale investeringsbesluit zeer veel beïnvloed worden door de variatie in kosten voor de implementatie (gerelateerd aan de gekozen strategie om capaciteit op te bouwen). Deze implementatiekosten zouden ook door een subsidie gedekt kunnen worden waardoor de initiële business case niet beïnvloed wordt. Als de implementatiesubsidie beschouwd wordt als een investering door de overheid, met de vermindering van externe kosten als terugkeer, zal het een positieve NCW hebben. Daarom kan de implementatiesubsidie voor de eerste business case worden gerechtvaardigd.

Voor de tweede business case kan ook de implementatiesubsidie in niet alle verschillende scenario's worden gerechtvaardigd. De reden voor het verschil met de eerste business case is toe te schrijven aan het feit dat in de tweede business case ook de containers naar binnenlandse containerterminals worden vervoerd. Deze ladingsstromen worden reeds vervoerd met binnenschepen en het verplaatsen van de lading van één schip naar andere zal geen significante vermindering van emissies veroorzaken. Het is ook niet in het belang van een overheid om ladingsstromen te verplaatsen van één schip naar een andere. Het heeft meer een belang bij het verschuiven van goederenstromen naar vervoerswijzen die de laagste externe kosten zullen hebben (van weg aan de binnenwateren). Daarom slechts zal een deel van de vervoerde ladingsstromen in de vermindering van externe kosten bijdragen.

Met betrekking tot het aantal bemanningsleden dat nodig is op het duwschip en de bakken en het personeel dat nodig is op het bureau kan geconcludeerd worden dat het grootste aantal mensen dat nodig zijn, de bemanningsleden zijn voor de bakken op de kleine binnenwateren. Grote moeilijkheden zou kunnen worden verwacht als al die kleine bakkapiteins alle vereiste vergunningen en de vaarervaring moeten hebben alvorens zij kunnen beginnen met het varen op de bakken. Daarom is het raadzaam om vroegere kapiteins van kleine binnenvaartschepen aan te trekken voor het kleine bakkenbedrijf. Als niet genoeg vroegere kapiteins beschikbaar zijn,

zou een andere oplossing kunnen worden verkregen door de kleine bakkapiteins een beperkte vaarvergunning, te geven die allen geldig is op de kleine binnenwateren, zodat van de zijinstroom van nieuwe mensen gebruikt gemaakt kan worden om de kleine bakken te bemannen.

Wanneer het totale kleine bakkensysteem wordt opgebouwd, en als de vraag naar transport tijdelijk verminderd kan het kleine bakkensysteem dat overleven. Maar als de vermindering van de vraag permanent is, dan zal NCW verminderen tot een waarde onder nul, zodat het systeem verliesgevend zal worden.

In hoofdstuk 17 heeft de SWOT analyse aangetoond dat er heel wat sterke punten en kansen voor het kleine bakkensysteem zijn. Daarom moet het kleine bakkensysteem zich op die sterke punten en kansen concentreren. Maar het is ook belangrijker om zwakheden en bedreigingen te behandelen. Een strategie, om het probleem van de grote implementatiehindernis te behandelen, is om het systeem van een kleine beginpositie op te bouwen, waarbij de kosten voor de implementatie door een subsidie (hoofdstuk 16) zouden kunnen worden gedekt. Een andere strategie, die kan worden gebruikt om de vaste bedrijfsuitgaven te verminderen, is de potentiële klanten te binden aan concept door de bakken te verhuren voor lange periodes (2 of meer jaren). Het is zelfs mogelijk om bakken te verkopen. Deze strategie zal het kleine bakkensysteem ook minder kwetsbaar maken voor het beperkte aantal bedrijven die gevestigd zijn aan de kleine binnenvaartwegen. Verder zal het de vaste bedrijfsuitgaven verminderen.

Om de bedreiging van de concurrentie van wegvervoer op de containermarkt te behandelen, zou het een goede strategie kunnen zijn, om bij het begin van het kleine bakkensysteem, zich op het vervoer van lege containers te concentreren.

Een andere bedreiging zal komen uit de huidige scheepseigenaar van de kleine binnenvaartvloot. De huidige binnenschippers kunnen de huidige toetredingseisen willen handhaven. Het is daarom belangrijk om de huidige binnenvaartsector bij het kleine bakkenbedrijf betrokken te krijgen. Ook zouden de vroegere kapiteins gebruikt kunnen worden om met de kleine bakken of de duwboot te varen. Dit zou ook het probleem van ontoereikende hoeveelheid personeel aanpakken. Een andere manier om dit probleem op te lossen is om naar zijinstromers te streven is (sectie 16.6).

# Appendices





## Appendix A: Barge geometry

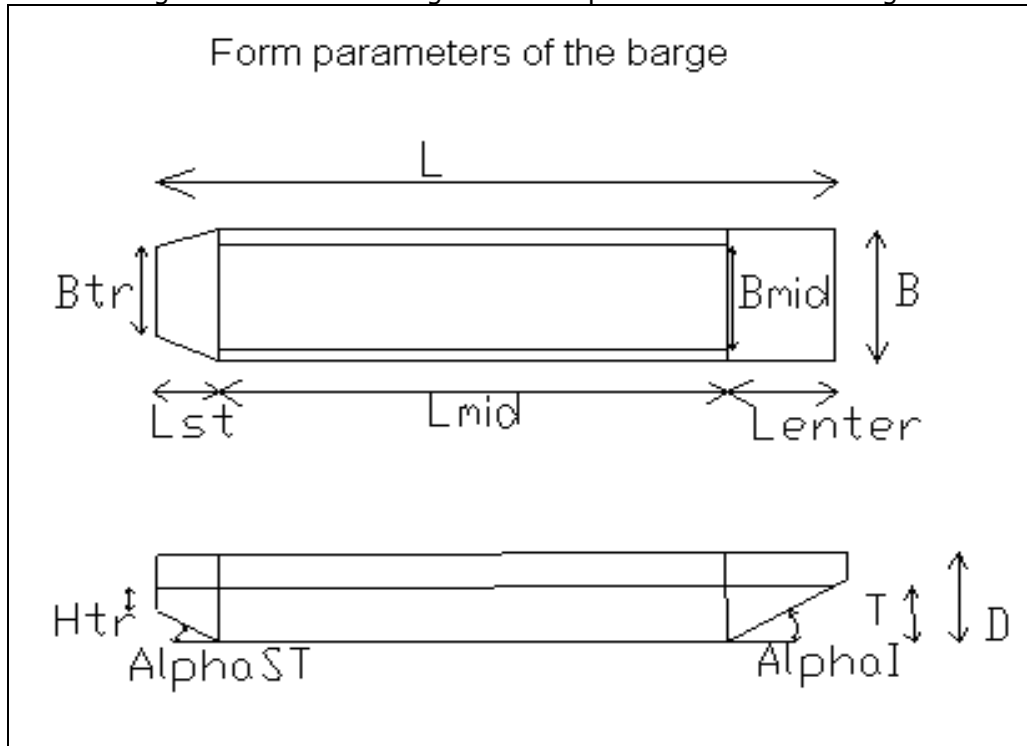
The length of the barge will be split into three different parts:  $L_{st}$ ,  $L_{enter}$  and  $L_{cargo\_space}$ .  $L_{st}$  is the length of the aft ship and  $L_{enter}$  is the length of the fore ship. These parameters will be determined indirectly by the choice of  $\alpha_{st}$  and  $\alpha_I$ . These parameters can be found in figure A.1  $L_{cargo\_space}$  will be determined by the number of containers (TEU) that are placed inside the barge.

$$L_{cargo\_space} = N_{containers} \cdot L_{container} \quad (A.1)$$

$N_{containers}$  = number of containers in the length of the cargo hold [-]

$L_{container}$  = length container [m]

Figure A.1: Local and global form parameters of the barge



Source: Holtrop *et.al.* 1990

The relation to calculate  $L_{enter}$  is given in relation A.2.

$$T = L_{enter} \cdot \tan(\alpha_I) \quad (A.2)$$

By choosing the relation A.2, the choice has been made that the bow of the barge will be at an inclined angle from the bottom plate to the point where it will reach the waterline.

The total length of the barge will be determined with the next function:

$$L_{barge} = L_{st} + L_{cargo\_space} + L_{enter} \quad (A.3)$$

The length of the barge is restricted by the maximum allowable length on the waterway that has been chosen (see chapter 6: network model). The

length of  $L_{st}$  is set at an initial value of 4 meters. If the total length of the barge is too large,  $L_{st}$  will be determined by the following relation.

$$L_{st} = L_{max} - L_{cargo\_space} - L_{enter} \quad (A.4)$$

The value of  $\alpha_{st}$  must be given as an input parameter. This parameter and the length of  $L_{st}$  along with the draft of the barge will determine the parameter  $H_{tr}$  (height of the transom of the barge).

$$H_{tr} = T - L_{st} \cdot \tan(\alpha_{ST}) \quad (A.5)$$

The beam of the barge will be determined by the maximum beam that is allowed on that waterway ( $B_{max}$ ). The beam of the cargo space of the barge will be determined by the difference of the maximum beam and the size of the side decks of the barge.

$$B_{mid} = B_{max} - 2 \cdot B_{side} \quad (A.6)$$

The size of the side deck is set at 30 cm. Now that the beam of the cargo hold is set, the number of containers that can be placed inside the barge can be determined. Therefore the beam of the barge is not fixed by the number of containers that can be placed in the cargo hold, but it is maximized to be as large as possible. The reason for that is given by the stability requirements (see section 7.2.8 of this chapter) and by the transportation costs for bulk cargo (see chapter 8: transportation costs model). If the cargo hold of barge is made as wide as possible, more bulk cargo can be transported.

Another beam component is the beam of the transom of the barge ( $B_{tr}$ ). This value is set at  $0.5 \cdot B$  when the barge is sailing independently. If the barge has to be designed as a "normal" barge, the  $B_{tr}$  is set at  $0.95 \cdot B$ .

The draft of the barge will be determined by the size and shape of the barge ( $L$ ,  $B$ ,  $\alpha_I$ ,  $\alpha_{st}$ ) and the total weight of the barge. The total weight is the weight of the payload, the steel weight and the equipment that can be placed in the barge. The depth ( $D$ ) will be determined as a function of the draft.

$$D = 1.4 \cdot T \quad (A.7)$$

The reason for adding 40% of the draft to the depth is that the free board will be high enough. This is essential because the cargo hold cannot be covered when there are containers in it. There is also a hatch coaming which increases the free board by an extra 10%. This will also lead to extra longitudinal stiffness of the barge, and when the barge is loaded with bulk material, the draft will increase and a hatch coaming will give the barge a higher free board.

## Appendix B.1: Resistance methods

### Howe

$$R_t = 0.07289 e^{\frac{1.46}{h-T}} V^2 T^{0.6 + \frac{50}{W-B}} L^{0.38} B^{1.19} \quad (B.1.1)$$

$R_t$  = resistance [lb]  
 $H$  = water depth [ft]  
 $T$  = draft [ft]  
 $V$  = speed [mph]  
 $W$  = width of waterway [ft]  
 $B$  = width of barge train [ft]  
 $L$  = length of barge train [ft]

### Bronzini

$$R_t = r_f * V^2 \quad (B.1.2)$$

$$r_f = K_f * \sum(r_i) \quad (B.1.3)$$

$$r_i = 0.0118 * B * T^{\frac{2}{5}} * (L - 70.5 * (L - \frac{L}{328})) * \sqrt{\frac{C_b}{1 - C_b}} * K_c \quad (B.1.4)$$

$$K_c = 2.42 * C_b^2 - 3.43 * C_b + 1.34 \quad (B.1.5)$$

$$K_f = \frac{(N_e * K_{fe} + n * K_f)}{(n_e + n)} \quad (B.1.6)$$

$N_e$  = number of empty barges  
 $N$  = number of full loaded barges  
 $K_{fe}$  = loading coefficient of empty barge  
 $K_f$  = loading coefficient of full barge  
 $R_t$  = resistance [lb]  
 $T$  = draft barge [ft]  
 $V$  = speed [feet per sec]  
 $B$  = width of barge [ft]  
 $L$  = length of barge [ft]

### Lattore and Ascroft

In the method of Lattore and Ascroft the resistance of a barge is calculated in the following way:

At first, the rest resistance will be calculated by determining the value of  $\frac{R_r}{\nabla}$  as a function of  $\frac{V}{\sqrt{L}}$ . The speed has been given in knots and the length

of the barge in ft. Displacement  $\nabla$  has his unit in ltonne<sup>53</sup>. The value of  $\frac{R_r}{\nabla}$

can be found in figure 7.10. The lines give an upper and under limit for the rest resistance of the barge.

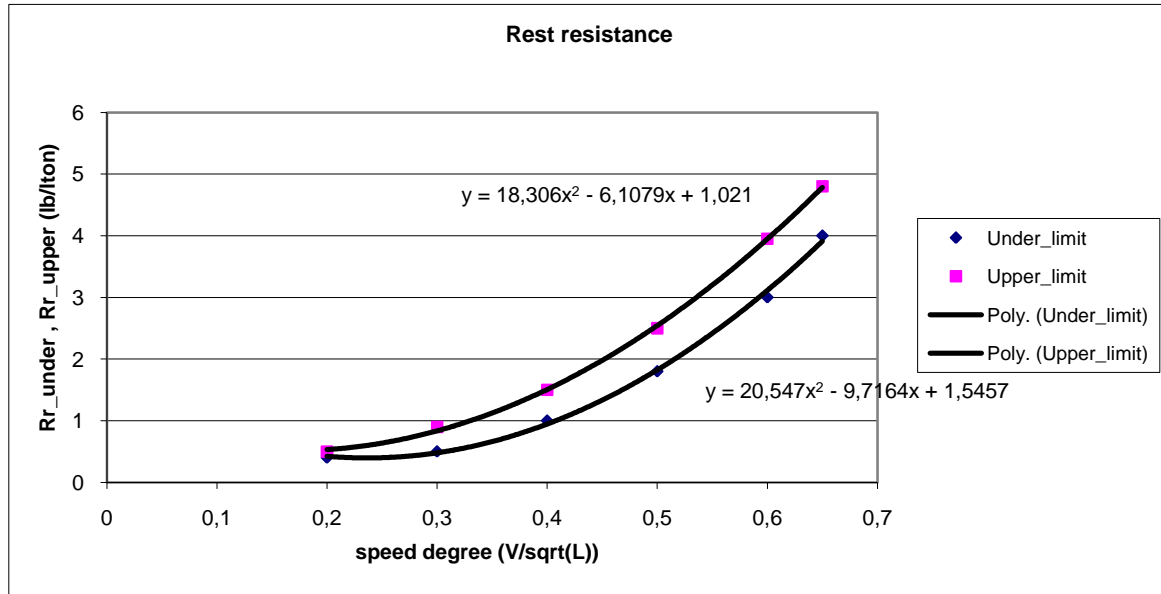
The frictional resistance is calculated with the following formula:

<sup>53</sup> Ltonne = Long tonne and is equal to 1016 kg

$$RF = f.S.v^{1,825} \quad (B.1.7)$$

where  $f$  is the Froude frictional resistance and  $S$  the wetted surface in  $ft^2$  and the speed ( $V$ ) is in knots.

Figure B.1.1: Determining rest resistance



## Appendix B.2: Resistance calculation

The resistance model of Holtrop et.al (1990) model consists of different resistance components which are:  $R_f$ ,  $R_{tr}$ ,  $R_w$ ,  $R_{vp}$  en  $R_{all}$ .

The first term is the frictional resistance and is equal to the ITTC formula:

$$R_f = \frac{\frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot 0,075}{(\log(Re)-2)^2} \quad (B.2.1)$$

$$Re = \frac{V \cdot L}{\nu} \quad (\text{reynolds number}) \quad (B.2.2)$$

$S$  = wetted surface [m<sup>2</sup>]  
 $V$  = speed of the barge [m/s]  
 $L$  = length of barge [m]  
 $\nu$  = kinematic viscosity of water [10<sup>-6</sup> m<sup>2</sup>/s]

$R_{tr}$  is the resistance of the submerged transom of the barge and can be calculated with the next formula:

$$R_{tr} = \frac{1}{2} \cdot \rho \cdot V^2 \cdot A_{tr} \cdot C_{d-tr} \quad (B.2.3)$$

$\rho$  = density of water [1000 kg/m<sup>3</sup>]  
 $A_{tr}$  = submerged transom =  $H_{tr} \cdot B_{tr}$  [m<sup>2</sup>]  
 $C_{d-tr} = 0,213 \cdot \cos(\alpha_{ST})$  [-]

$R_w$  is the wave making resistance of the barge and can be calculated with the following formula.

$$R_w = Q \cdot F_{nb}^6 \cdot \rho \cdot g \cdot B^2 \cdot T \quad (B.2.4)$$

$$g = 9,81 \text{ m/s}^2$$

$$F_{nb} = \frac{V}{\sqrt{g \cdot B}} \quad (B.2.5)$$

$$Q = 0,18367 \cdot (1 - C_p)^{-0,32144} \cdot \left(\frac{B}{L}\right)^{0,562} \cdot \left(\frac{B}{T}\right)^{0,22314} \cdot \left(\frac{L}{L_{enter}}\right)^{0,673} \quad (B.2.6)$$

$$C_p = \text{prismatic coefficient} \rightarrow C_p = \frac{\nabla}{L \cdot A_m} \quad (B.2.7)$$

$A_m$  = main frame area m<sup>2</sup>

$R_{vp}$  is the viscous pressure resistance and is calculated with the following formula:

$$R_{vp} = P \cdot \rho \cdot V^2 \cdot B \cdot T \quad (B.2.8)$$

where:

$$P = 0,11712 \cdot \left(\frac{T}{L}\right)^{0,78203} \cdot (1,05 - C_{pst})^{-1,0366} \cdot (0,02 + 0,95 \cdot \frac{H_{va}}{T_a})^{0,21336} \quad (B.2.9)$$

## Appendices

$T_a$  is the draft of the aft ship and is set equal to the draft of the ship  $T$ .  $C_{pst}$  is the prismatic coefficient of the aft ship.

$$C_{pst} = \frac{\nabla_{AFT}}{L_{st} \cdot A_m} \quad (B.2.10)$$

$H_{va}$  is a variable that will describe the pressure loss at the aft ship.

$$H_{va} = T_a - H_{tr} - R_{st} \cdot (1 - \cos(\alpha_c)) - (L_{st} - R_{st} \cdot \sin(\alpha_c)) \cdot \tan(\alpha_c) \quad (B.2.11)$$

where:

$$\alpha_c = 14 \cdot \sqrt{\frac{R_{st}}{T_a}} \cdot \frac{\pi}{180} \text{ (rad)} \quad (B.2.12)$$

$R_{st}$  is the curvature radius from the flat bottom of the barge to the inclined aft ship of the barge.

$R_{all}$  is an extra component added to the resistance of the barge due to the correlation coefficient.

$$R_{all} = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_a \quad (B.2.13)$$

in which  $C_a$  is the correlation coefficient and is set to be 0.0004.

There is another component that can be added, i.e. the appendix drag ( $R_{app}$ ). Because the barge that will be designed does not have appendices like rudders, the  $R_{app}$  is set to be 0.

The total resistance is equal to the summation of the different resistance components and is named  $R_{total\_deepwater}$  in the model. As the name predicts, this is the resistance of the barge in a waterway that can be considered infinitely deep. Because inland waterways cannot be considered infinitely deep, a correction on the resistance needs to be made to take the shallow water effect into account.

Because this resistance is a regression model, it is good to know where the boundaries are of the model. Therefore results beyond these boundaries cannot be considered reliable. The limits of the  $L/B$  and  $B/T$  ratios are:  $3 < L/B < 7.5$  and  $2.5 < B/T < 9$ . It is also important to know that the prismatic coefficient must be of the order of magnitude of 0.9.

### Appendix B.3 Shallow water correction

For the shallow water correction the method of Karpov /Basin *et.al*/ (1976) will be applied. In this method the resistance will be determined with the following formula:

$$R_{\text{ondiep}} = \frac{1}{2} \cdot \rho \cdot S \cdot ((C_f + C_a) \cdot V_1^2 + C_r \cdot V_2^2) \quad (\text{B.3.1})$$

$C_f$  = friction coefficient by speed  $V_1$

$C_a$  = Correlation correction

$C_r$  = rest resistance on DEEP water by speed  $V_2$

The wave-making and viscous pressure resistance together are the rest resistance of the barge. By recalculating these two resistance components at speed  $V_2$  the rest resistance of barge in shallow water can be determined. The frictional and the transom resistance are seen as the total frictional resistance of the barge and these two components are also recalculated with speed  $V_1$ . The correlation coefficient will be the same in deep and shallow water.

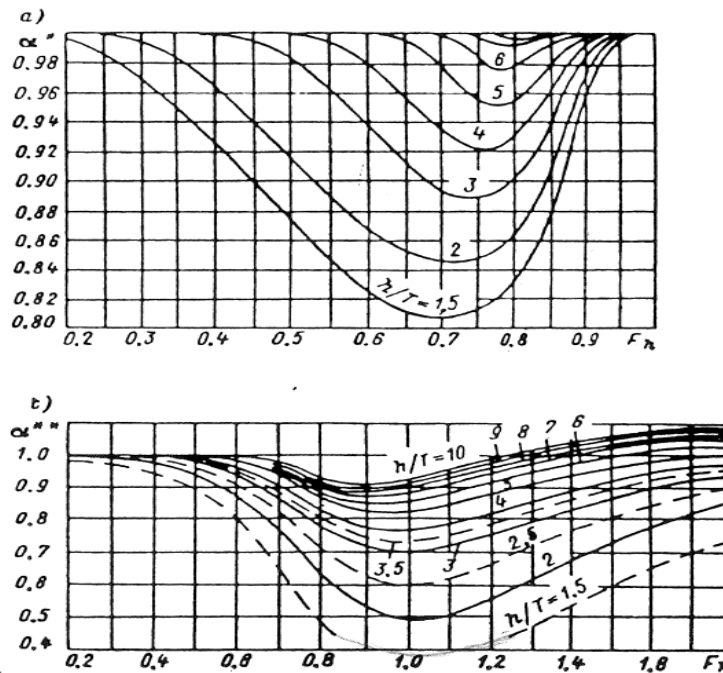
The calculations of  $V_1$  and  $V_2$  can be done with the following formulas:

$$V_1 = \frac{V}{\alpha^*} \quad (\text{B.3.2})$$

$$V_2 = \frac{V}{\alpha^{**}} \quad (\text{B.3.3})$$

where  $\alpha^*$  and  $\alpha^{**}$  are determined with the help of the lines in figure B.3.1.

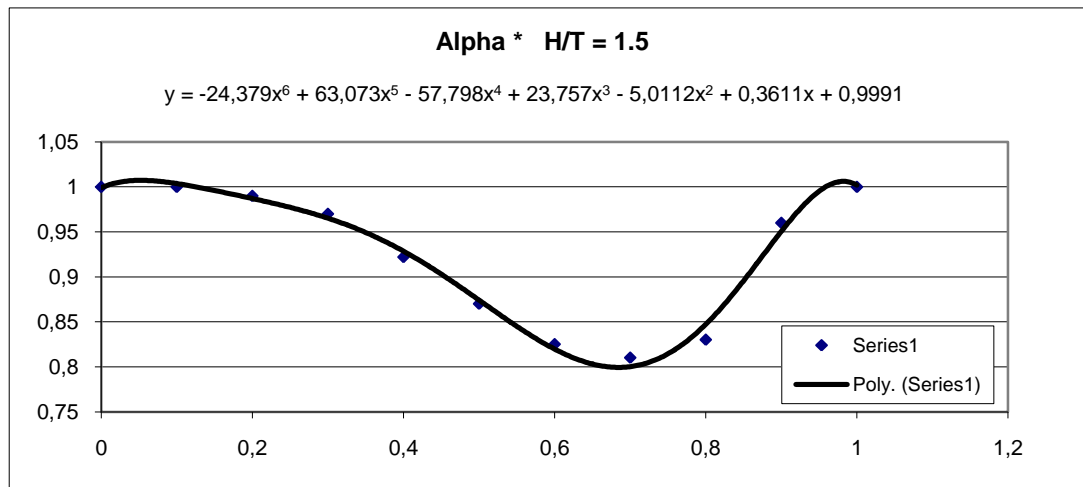
Figure B.3.1: Correction lines for the calculation of the shallow water resistance



In order to use the information in the graphs above in the model, the different  $H/T$  (water depth/barge draft) lines are estimated with a 6<sup>th</sup> power polynomial function, where  $H/T$  ratio is the ratio of the water depth of the

waterway and the draft of the ship. One of the lines to determine  $\alpha^*$  with an H/T of 1.5 is given in figure B.3.2. The other correction lines are given in appendix B.4, where the correction lines of  $\alpha^{**}$  are also given.

Figure B.3.2: Polynomial for the determination of  $\alpha^*$



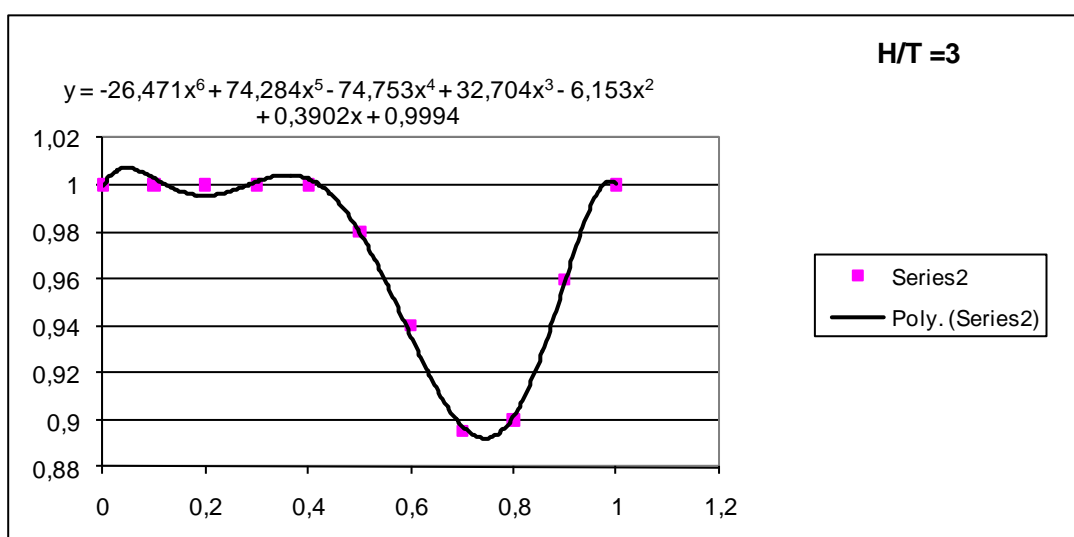
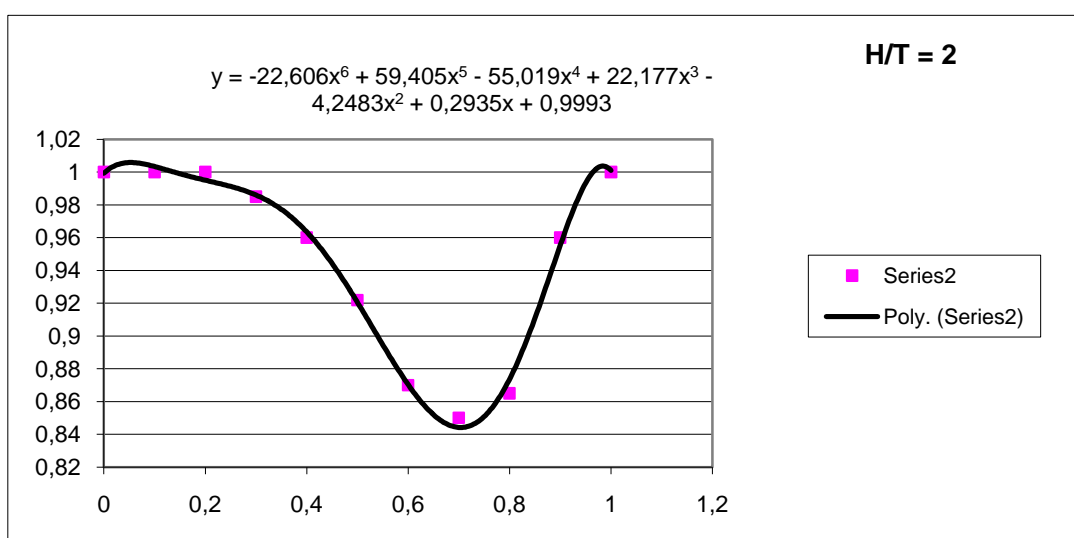
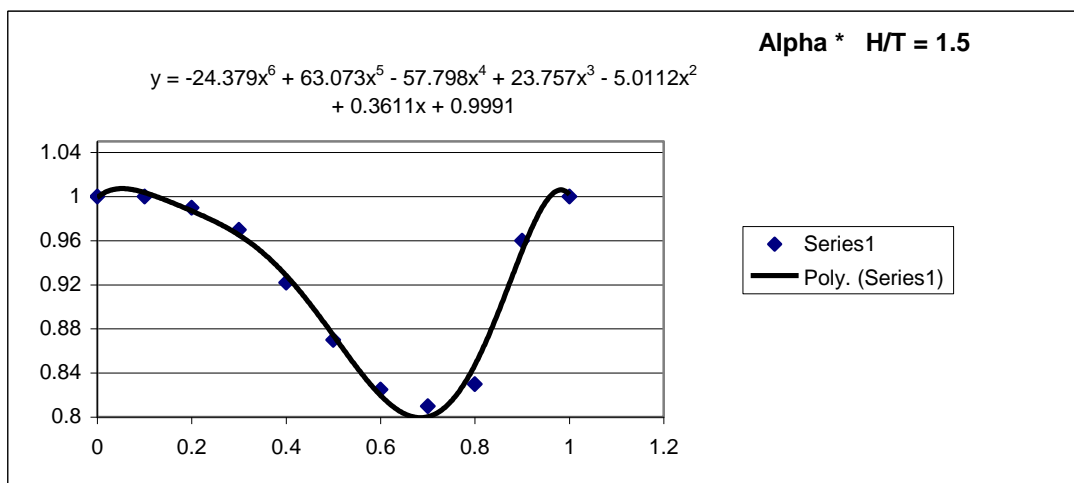
The choice has been made not to interpolate between the different lines of H/T to determine  $\alpha^*$  and  $\alpha^{**}$ . Therefore the line of H/T = 1.5 is valid from 0 to 1.75 and the line of H/T=2 is valid from 1.75 to 2.5.

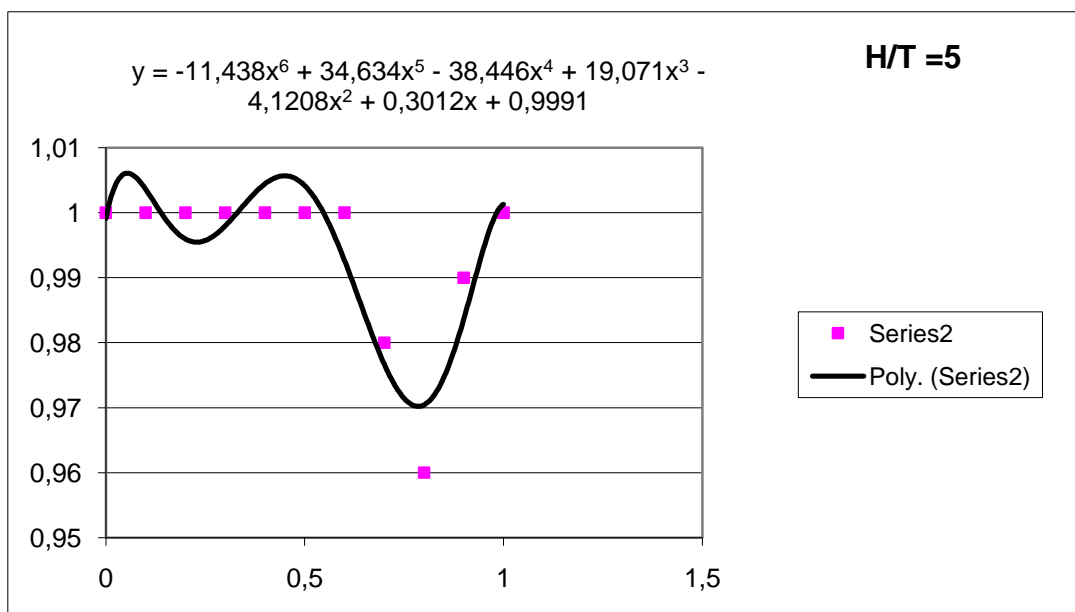
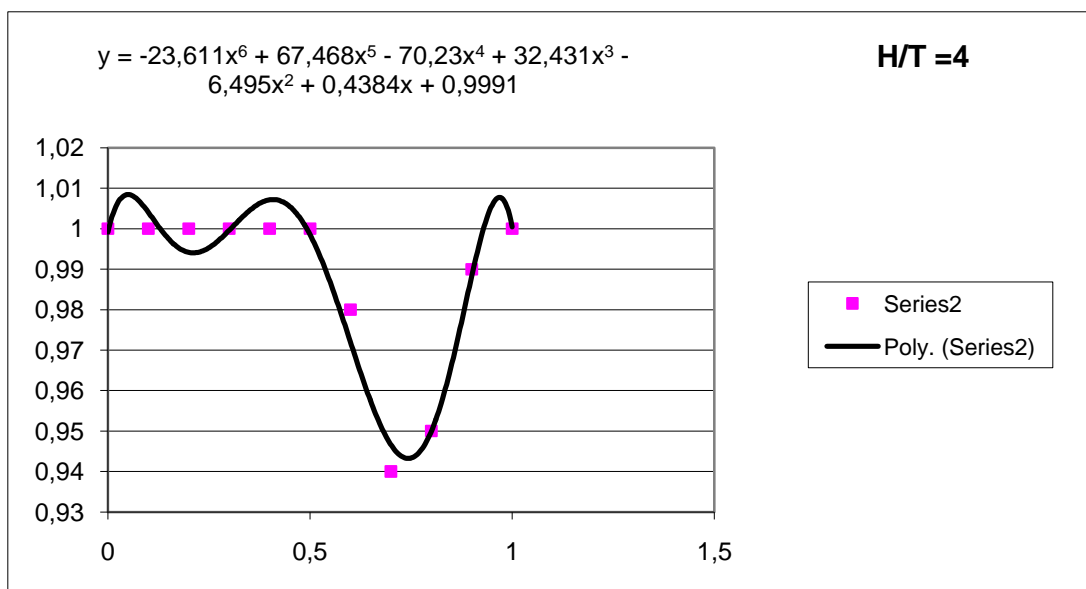
The value of X in the relation in the figure B.3.2 is  $F_{nh}$ , in which  $F_{nh}$  is the Froude depth number ( $= \frac{V}{\sqrt{g \cdot h}}$ ).

Appendix B.4 shows that for small values of  $F_{nh}$  and large values of H/T the polynome can fluctuate around 1. If  $\alpha^*$  becomes larger than one, the resistance will be underestimated. Therefore the value of  $\alpha^*$  and  $\alpha^{**}$  are restricted so that they can never be larger than one, so that  $V_1$  and  $V_2$  do not become too small and the resistance will not be underestimated.

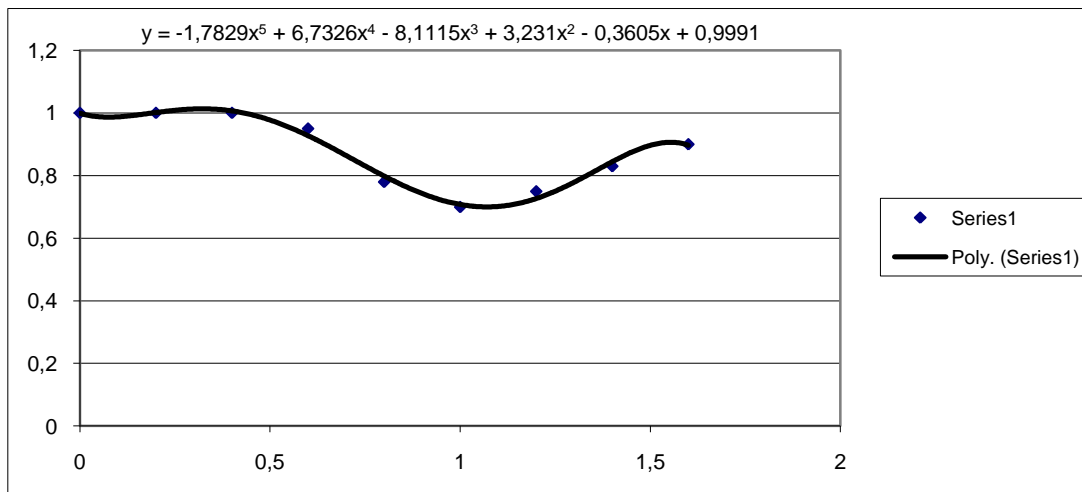
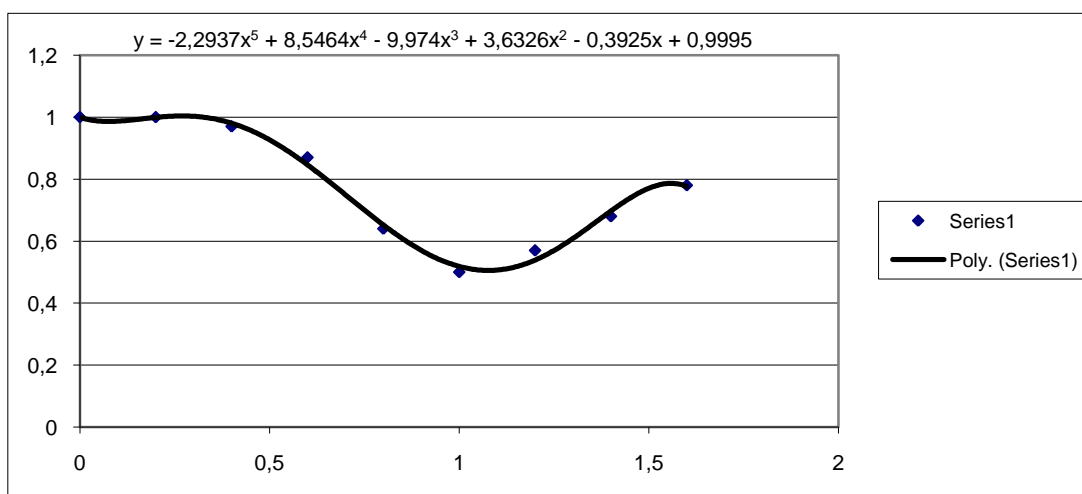
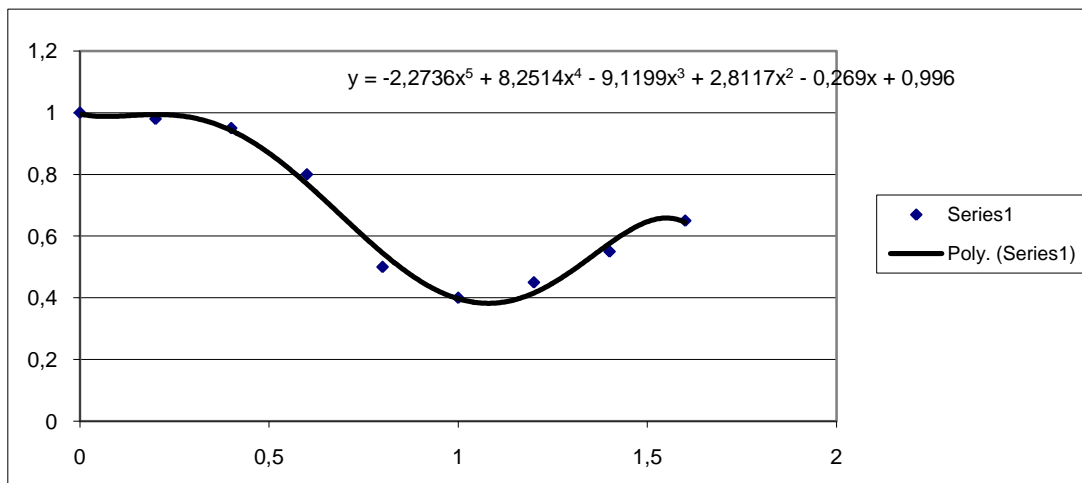


## Appendix B.4: Correction lines shallow water resistance

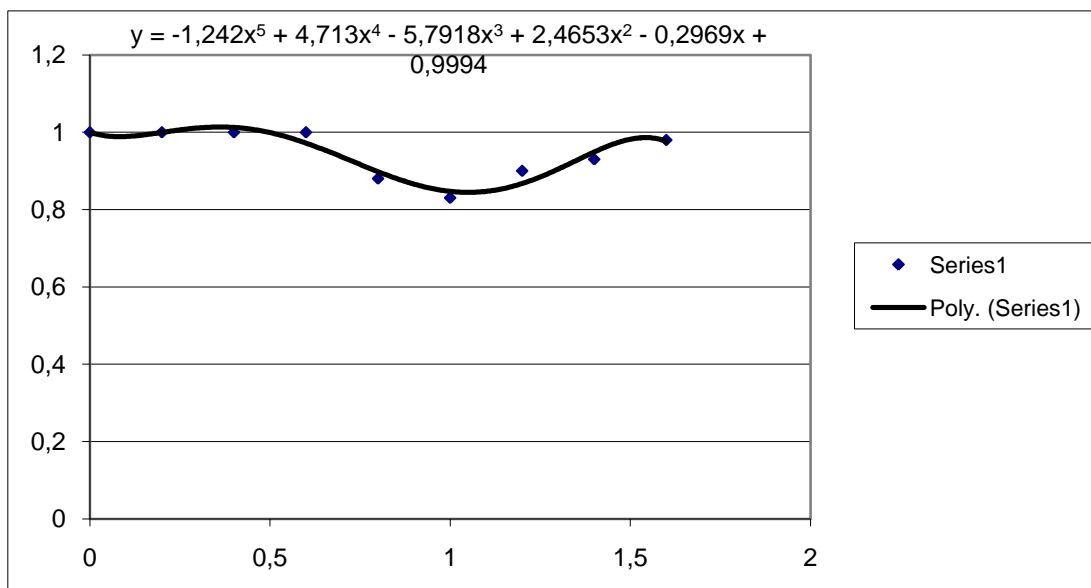
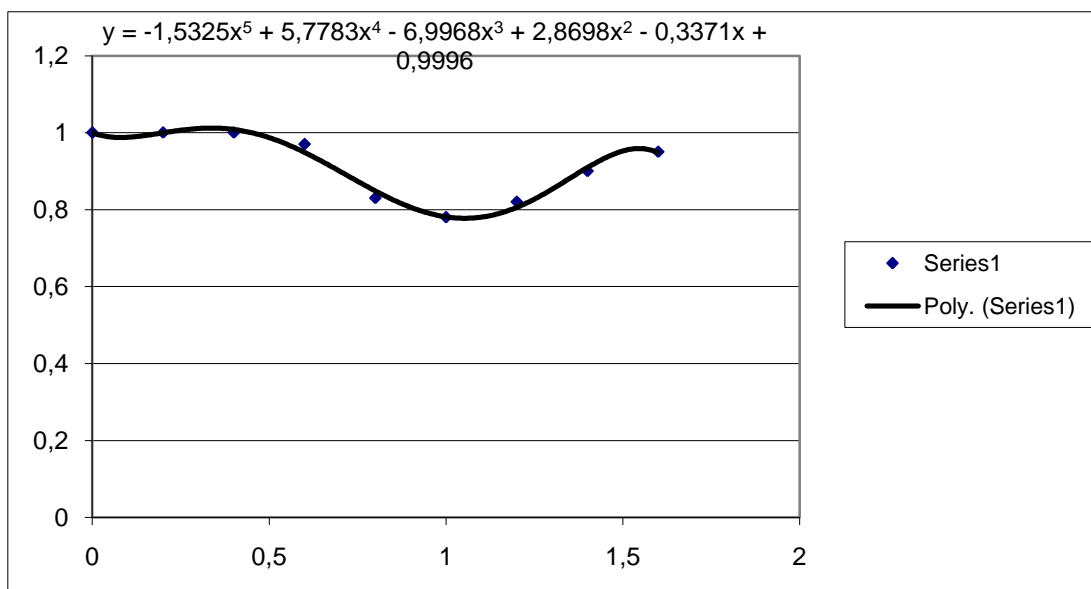




# Determination of Alpha\*\* for H/T = 1.5 , 2, 3, 4, 5

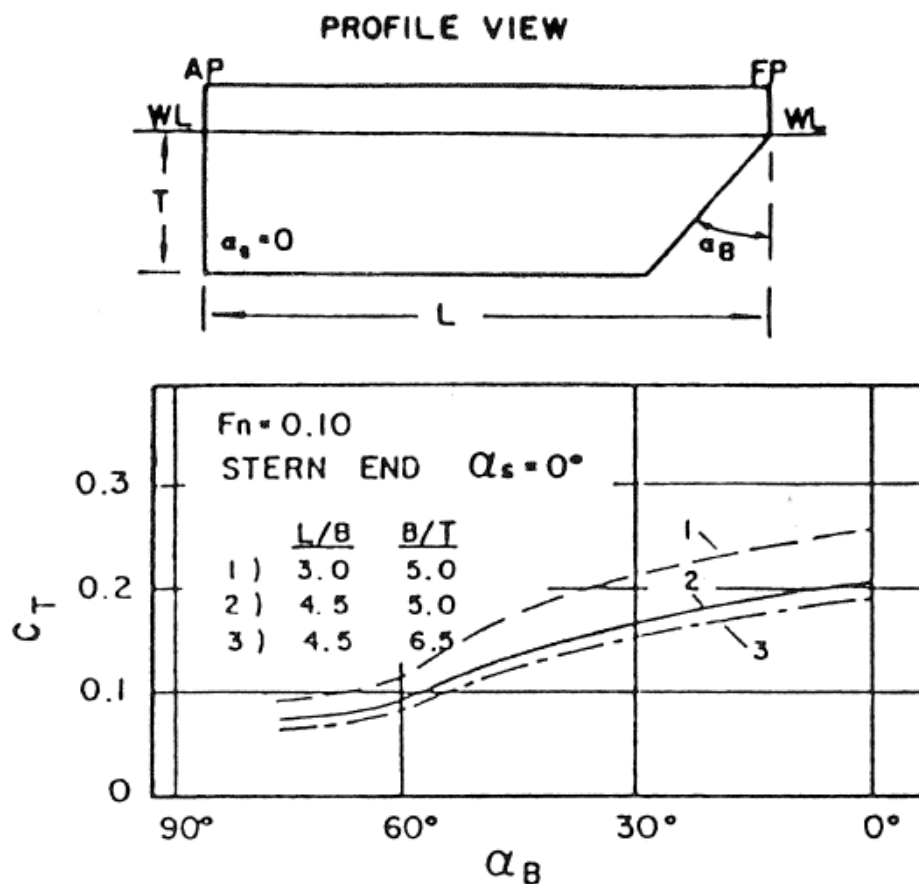


# Appendices



## Appendix B.5: influence $\alpha_I$ on barge resistance

Figure B.5.1: Resistance characteristics of a push barge



Source: van Terwisga, 1989

In this figure the angle  $\alpha(b)$  is defined the other way around from how it is used in the model.

## Appendix C.1: Construction design barge

The choice has been made to design a barge with a double bottom and side tanks so that the barge has a double hull. This will probably be obliged in the future for all inland ships. The big advantage of the double bottom is that a large part of the total longitudinal stiffness will be determined.

The next design choice is that the barge will have a transverse stiffener system instead of a longitudinal stiffener system because for ships with a length not longer than 60 meters a transverse stiffener system has a preference above the longitudinal stiffener system (Hengst, 1997). The barges that need to be designed are normally not longer than 60 meters (length is limited by the locks on the small inland water ways) so that the choice for a transverse stiffener system is the best option. The design of the double bottom is given in figure C.1.1.

Figure C.1.1: Construction of the double bottom

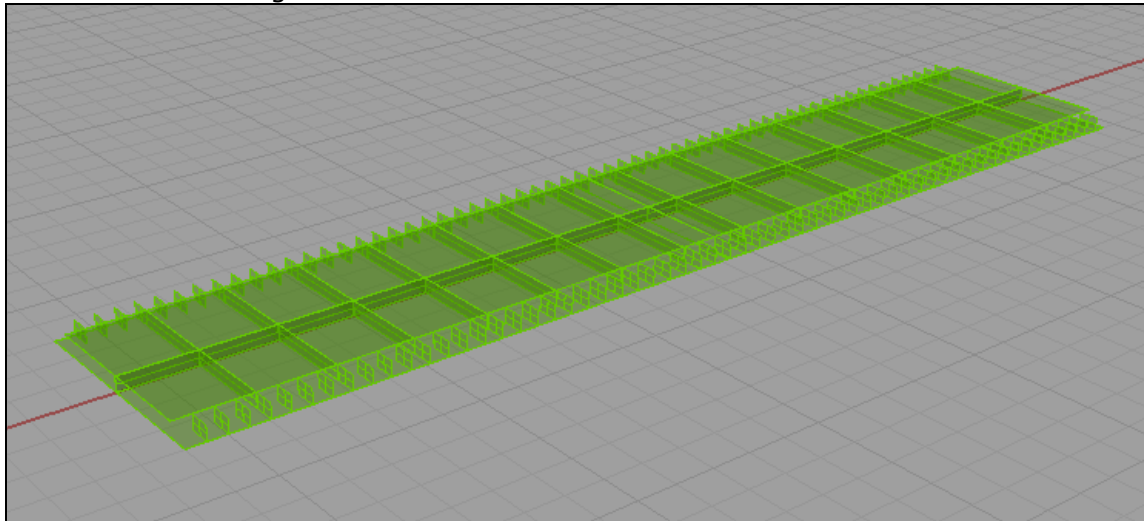
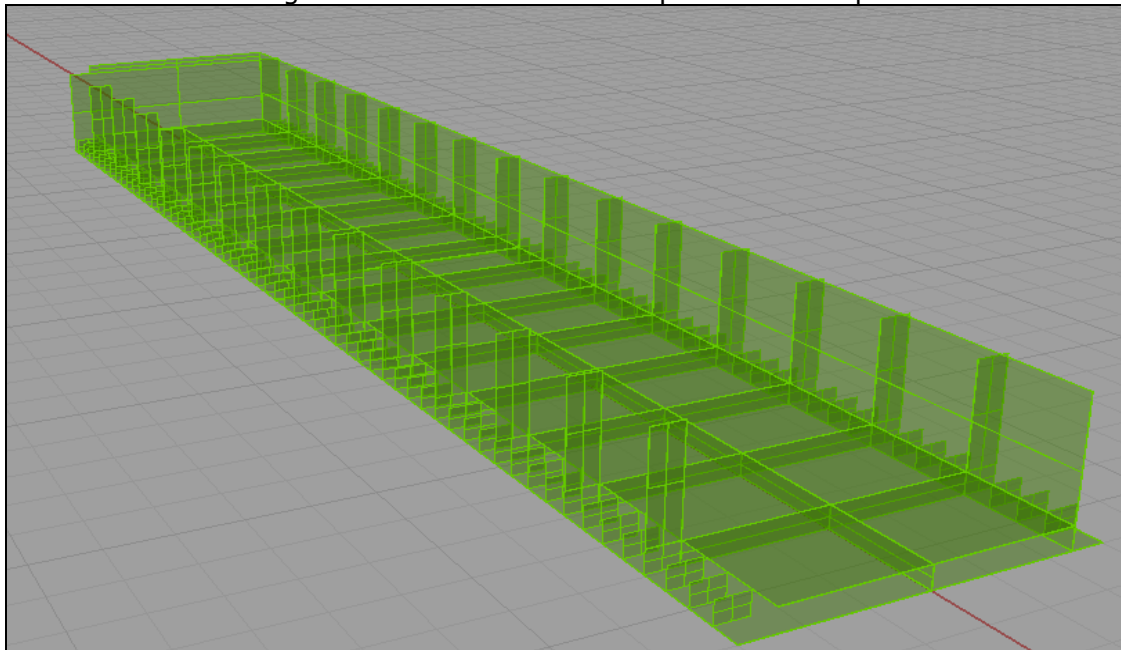


Figure C.1.1 shows that at every point where a container will start a watertight floor is placed. Between two watertight floors two non-watertight floors are placed. Between two floors three transverse stiffeners are placed. The distance between these stiffeners can be varied, but in normally it is fixed at three stiffeners between two floors. That distance is almost 50 cm and can be considered a normal value for a stiffener spacing. In the bilge plates are placed on every stiffener spacing. The transverse stiffeners on the bottom and the tank top are not drawn in Rhino but at every bilge plate there will be a stiffener at the bottom and the tank top from one side of the barge to the other side. In the centre of the double bottom a centre girder is placed, so that at every corner the containers are supported by floors and girders. The centre girder also contributes to the longitudinal stiffness of the barge and it is obligatory in the rules.

The side tanks are being built in the same way as the double bottom. On the places where in the double bottom a (watertight) floor is placed there will be also a (watertight) floor in the side tank. In figure C.1.2 the construction of the double bottom and the side tanks is given. Also the inner hull is drawn.

Figure C.1.2: Construction of parallel midship

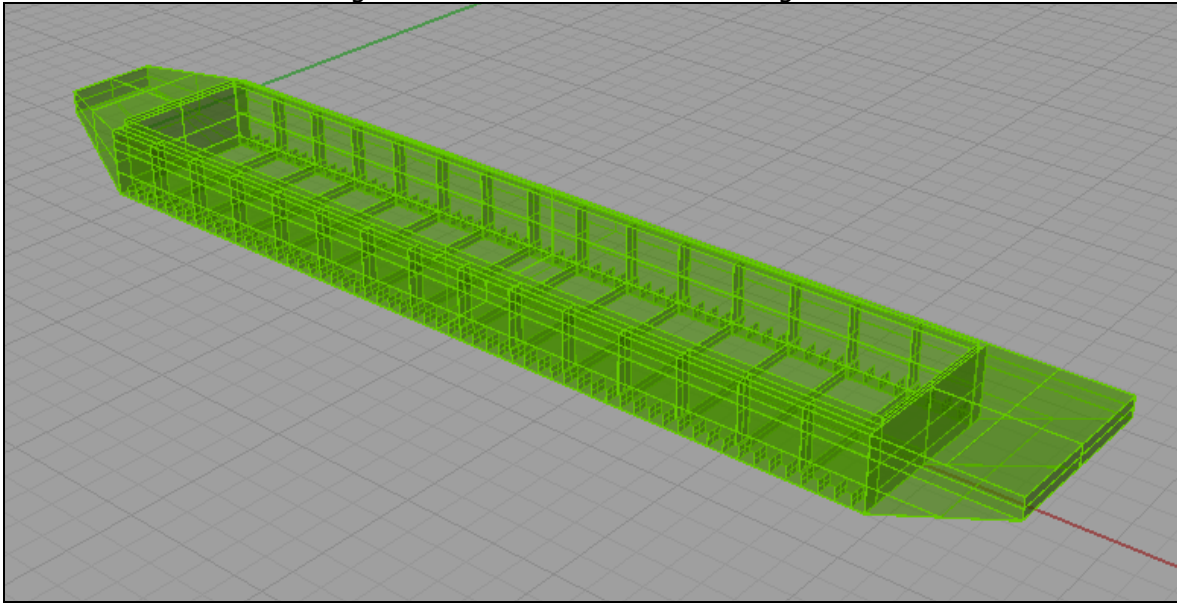


The construction weights of the fore and aft ship are determined by the average value of the construction weights of the mid ship. The weight of all the construction parts in the mid ship are added and divided by the length of the mid ship. Then you have the construction weight per unit length. The weights of the construction of the fore and aft ship are now equal to the construction per unit length multiplied by the length of the fore and aft ship and divided by two (the fore and aft ship can be considered a triangle). This is now the weight of the fore and aft ship without the weight of the shell. This approach is considered to be detailed enough for this preliminary design model.

The decks are added last to the barge model and are placed at the fore and aft ship of the barge and also the gangway will have decks. To have extra longitudinal stiffness and extra free board (see paragraph 7.3: Geometry and appendix A), the inner plating of the cargo hold is raised above the deck.

Due to the fact that barges can have a sharper aft ship, the pushing area for the tug (or other barge) is reduced. Therefore two push bars are added to the barge so that tug can push against those bars when the barges are empty (or not fully loaded). The resistance of these extra push bars is incorporated as an increase in wetted surface (S). The total barge model is shown in figure C.1.3.

Figure C.1.3: Total hull of the barge





## Appendix C.2: Scantling determination

For the scantling calculations the choice has been made to use mild steel as construction material. This is the cheapest steel that is available and because the thickness of all the construction parts is limited and cannot be reduced any more, it is not necessary to use high tensile steel.

The thickness of the bottom plating, the side plating, tank top, decks and the floors in the double bottom are all determined by the rules of the Germanischer Lloyd. Also the minimum section modulus of the transverse stiffeners in the doubled bottom and side tanks are determined with the rules. From those values the right stiffeners are selected, along with their weight per unit length. Therefore it is possible to calculate the weight of the different stiffeners. The thickness of the girders and the bilge stiffeners was not directly given. That is why the thickness of those parts is estimated to be the same as the thickness of the floors.

The thickness of the decks is also calculated with the rules and the thickness is kept the same over the entire deck. Also the thickness of the side shell and inner shell is kept constant over the depth of the barge. The thickness of the plates in the construction is increased by 2 mm according to the rules in order to deal with corrosion. The thicknesses of the plates are rounded off according to the normal way of construction rules. Values below 0.2 rounded off below and above 0.2 rounded off above.

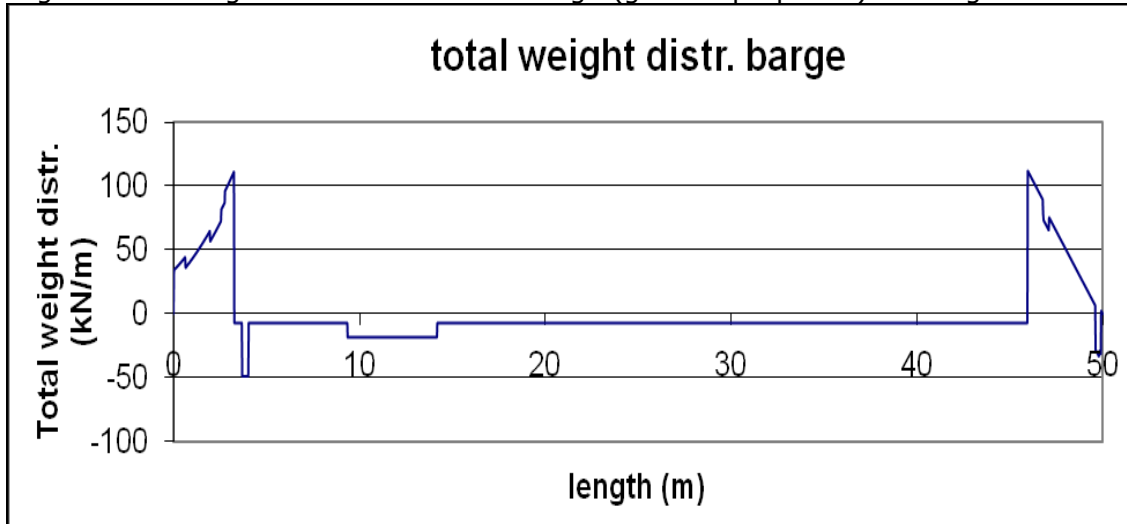
The weights of the non-watertight floors are estimated at  $2/3$  of the weight of the watertight floors.

The total construction weight is equal to the sum of all the different parts of the construction of the barge. On top of that, the weight of the anchor and couple equipment is added (that weight is estimated at one tonne). The total sum of the weights is then enlarged with 5% building margin to account for the weight of paint, welds and construction defaults.

## Appendix D: Calculation of the SWBM and stresses

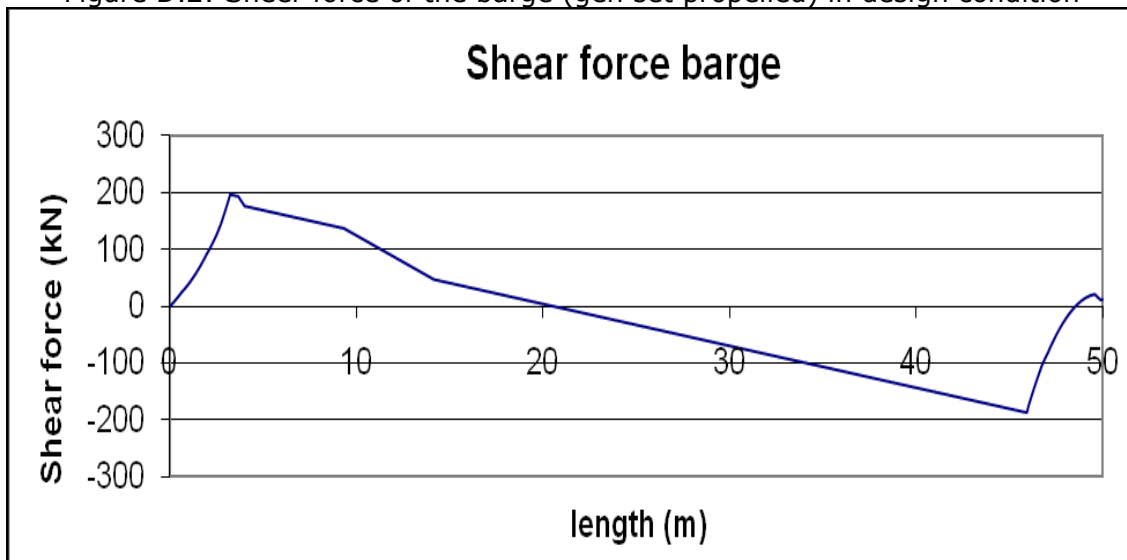
In order to calculate the still SWBM, the weight distribution of the barge needs to be determined. The weight distribution is a summation of the displacement per unit length and the weight of the barge per unit length. In order to do this, the weight and the displacement of the barge have been concretized into 2,000 parts. In figure D.1 the weight distribution of the barge is given.

Figure D.1: Weight distribution of the barge (gen set propelled) in design condition



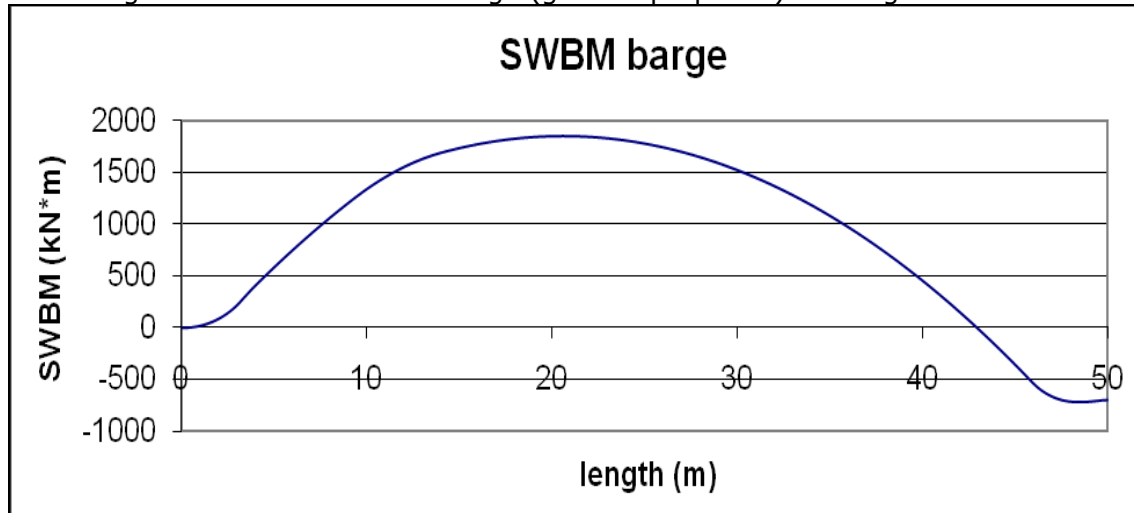
If the constructed weight distribution is integrated over the length of the barge, the shear force can be determined. For this integration the trapezium rule is used.

Figure D.2: Shear force of the barge (gen set propelled) in design condition



If the shear force line is integrated once more, the bending moment of the barge is determined. The SWBM of the barge is given in figure D.3.

Figure D.3: SWBM of the barge (gen set propelled) in design condition



In reality the moment at the end of the barge should be zero because the barge has no clamped support. In this case the moment is not completely equal to zero. That is due to the fact that the trim of the barge is not completely zero; therefore the barge is trimmed a bit backwards. But for the application of determining the SWBM this small error is accepted.

The wave bending moment is added to the still water bending moment. This Wave bending moment is calculated with the formulas taken from the Germanische Lloyds, where this formula is given for a significant wave height of 1.2 meters. (**IN**[1.2])

$$M_{\text{wave}} = 0,021 \cdot n \cdot C \cdot L^2 \cdot B \cdot (C_b + 0,7) \quad (\text{D.1})$$

$M_{\text{wave}}$  = wave bending moment [kN.m]

$n = 0,85 \cdot H_{\text{sig}} = 0,85 \cdot 1,2$  [-]

$C$  = coefficient defined as:  $C = (130 - 0,36 \cdot L) \cdot \frac{L}{1000}$  [-]

Based on the designed main frame of the barge, with the determined scantlings, the second area moment of the main frame can be determined. Based on that second area moment, the distance from the centre of gravity to the deck and the tank top, and on the total bending moment the stresses can be calculated with the following formula.

$$\sigma = \frac{M_{\text{barge}} \cdot Y_{\text{vezel}}}{10^3 \cdot I_{\text{main frame}}} \quad (\text{D.2})$$

$\sigma$  = stress at tank top or deck [N/mm<sup>2</sup>]

$M_{\text{barge}} = \text{SWBM} + M_{\text{wave}}$  [kN.m]

$Y_{\text{vezel}}$  = distance tank top or deck to centre of gravity [m]

$I_{\text{main frame}}$  = second order area moment of the main frame [m<sup>4</sup>]

The yield stress of steel is 250 MPa (=10<sup>6</sup> N/mm<sup>2</sup>). In order not to damage the construction of the barge, the maximum stress in the construction of the barge should not exceed the following value, given by the GL.

$$\sigma_{\max} = \frac{0,98.\sigma_{\text{yield}}}{1,2} \quad (\text{D.3})$$

$\sigma_{\text{Yield}}$  = yield stress of steel [MPa]

## Appendix E.1: Barge propulsion design and calculations

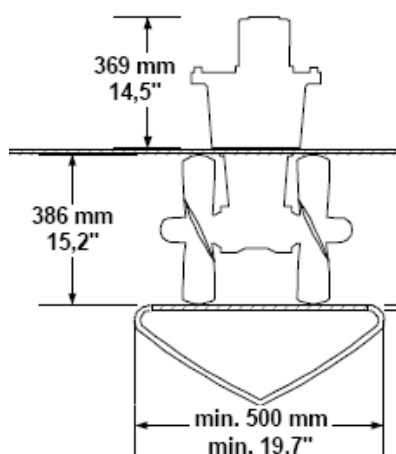
The selection for specific thrusters will be based on the power that the barge will need to have to sail at a certain speed. The water depth of the waterway, for instance, has an influence on the resistance and also on the effective power and also on the thrust that is needed. The power that needs to be installed is given in formula E.1, in which the sailing margin is set at 25% (Sailing margin is an equivalent of a sea margin).

$$P_{\text{sail\_barge}} = \frac{R_{\text{shallow\_barge}} \cdot V \cdot (1+SM)}{N_{\text{thruster}}} \quad (\text{E.1})$$

$R_{\text{shallow\_barge}}$  = shallow water resistance [kN]  
 $SM$  = sailing margin [-]  
 $N_{\text{Thruster}}$  = number of installed thrusters [-]  
 $V$  = speed of barge [m/s]

The power that the thrusters can deliver is given in the product data of side-power<sup>54</sup>. Based on the needed power and the product data the right thrusters will be selected. The size of the thrusters in the bow of the barge is set to be equal to the selected thrusters in the aft ship. In figure E.1 the thruster is given.

Figure E.1: Dimensions of the SP 550 HYD thruster



If the thrusters need to deliver more power than the power needed for the required speed, thrusters can be selected that can deliver the maximum power. This can be useful if the barge needs extra power to do some special manoeuvres (sailing in and out of locks that are located at large waterways) or to pass large ships in a deep-sea port.

Every thruster has its own dimensions and weight. If a lot of power is needed, the dimensions and weight of the thrusters will be increased. Because the thrusters are placed inside the double bottom of the barge, the height of the double bottom will be linked to the dimensions of the thrusters. If the thrusters do not fit inside the double hull, the height of the double bottom will be increased. This can be found in formula E.2.

<sup>54</sup> [www.Side-power.com](http://www.Side-power.com)

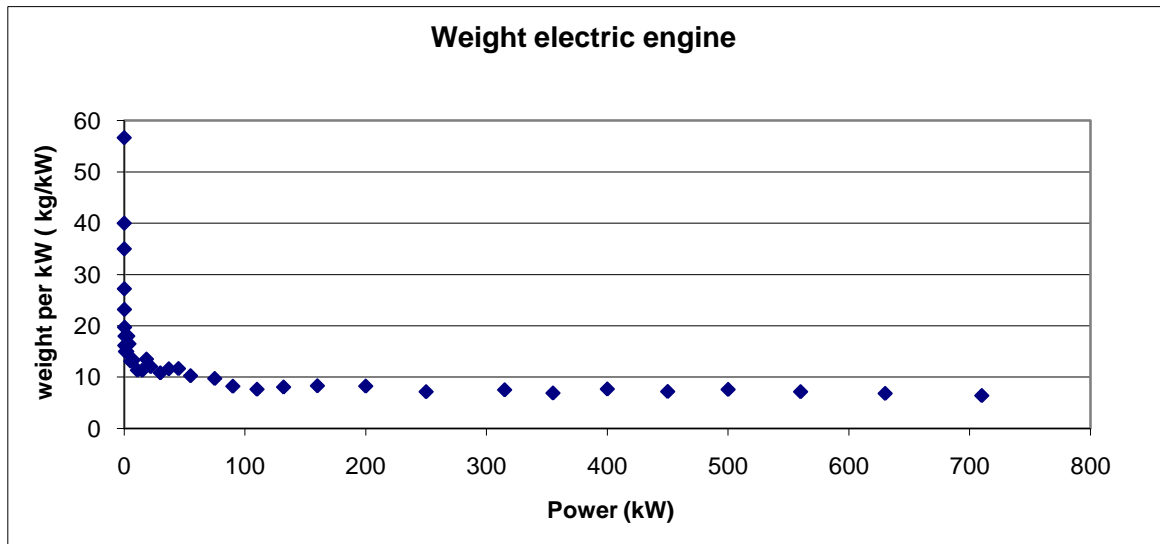
## Appendices

$$\begin{aligned}
 H_{\text{Dubbod}} &= H_{\text{thruster}} + 0,05 \quad \wedge \quad H_{\text{Thruster}} > H_{\text{dubbod\_scantlings}} \\
 H_{\text{Dubbod}} &= H_{\text{dubbod\_scantlings}} \quad \wedge \quad H_{\text{Thruster}} + 0,05 < H_{\text{dubbod\_scantlings}} \\
 H_{\text{dubbod}} &= \text{height of double bottom} & [\text{m}] \\
 H_{\text{dubbod\_scantling}} &= \text{height of the double bottom according to the rules} & [\text{m}] \\
 H_{\text{thruster}} &= \text{height of the selected thruster} & [\text{m}]
 \end{aligned}
 \tag{E.2}$$

The electric engines need to be dimensioned on the basis of the needed hydraulic power of the selected thrusters. Every thruster gets an electric engine to power the hydraulic pumps and the electric engine is also placed inside the double hull of the barge. The shape of the electric engines is assumed to cylindrical and the weight and the volume per kW are taken from product data<sup>55</sup>.

The weight of the electric engine is equal to 10 kg/kW and the relation that is being used to determine the volume of the engine is given here below.

Figure E.2: Electric engine data



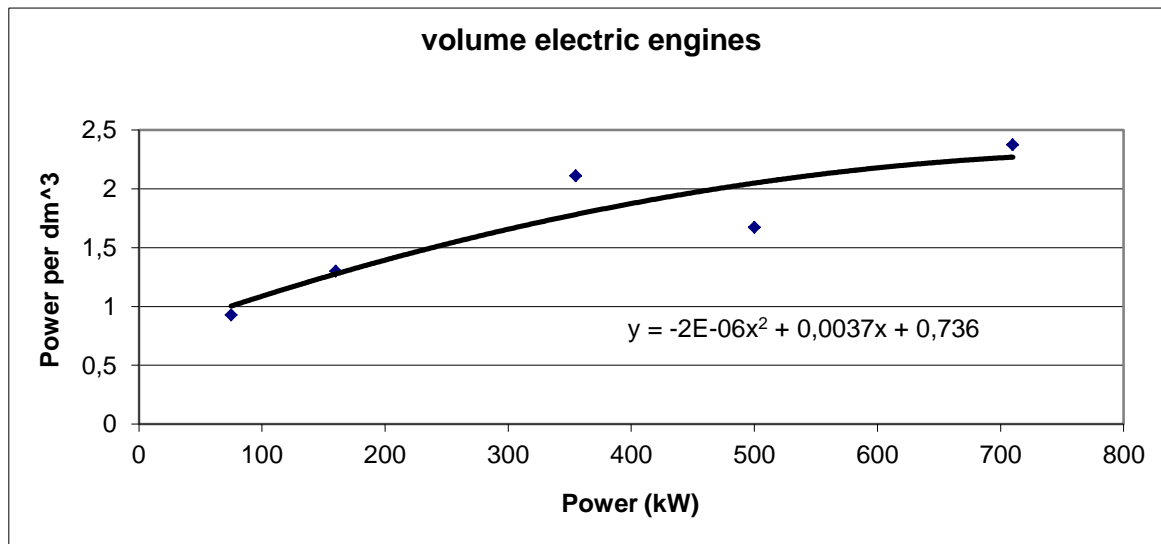
source: <http://www.kolmer.nl>

$$\begin{aligned}
 V_{\text{electric\_engine}} &= -2.10^6 \cdot P^2 + 0,0037 \cdot P + 0,736 \\
 V_{\text{electric\_engine}} &= \text{volume of the electric engine} & [\text{m}^3] \\
 P &= \text{required power electric engine} & [\text{kW}]
 \end{aligned}
 \tag{E.3}$$

In figure E.3 the total data of the electric engines is given from where relation E.13 is deducted.

<sup>55</sup> <http://www.kolmer.nl/>

Figure E.3: Electric engine data



Source: <http://www.kolmer.nl>

The diameter of the electric engine has been made dependent on the height of the double bottom. The relation is given here below.

$$D_{\text{Electro}} = H_{\text{dubbod}} - 0.10 \quad (\text{E.4})$$

The length of the electric engine is now determined with the next relation.

$$L_{\text{electro}} = \frac{P_{\text{electro}} \cdot \text{Volume}_{\text{electric\_engine}}}{\left(\frac{1}{4} \cdot \pi \cdot D_{\text{electro}}^2\right)} \quad (\text{E.5})$$

The electric engines are placed next to the thrusters in the double hull of the barge. It should be noticed that there should be enough cooling installed to cool the electric engines. The double bottom is not that high and when the electric engines have to operate for a long time, they can become very warm. On the other hand the engines are placed below the waterline, so the water outside the hull could also help to cool the engines.

The big advantage of installing thrusters is that these are capable of delivering thrust in two directions. That can be useful if the barge has to sail on a small narrow canal where there is no option to turn the barge. In that case the barge could sail in reverse to a location where it can turn. Therefore a steering installation must be placed on the aft ship, so that the captain can manoeuvre the barge from that position.

## Appendix E.2: Costs of hydraulic thrusters

Type	Price (\$)	Price (€)
<b>SP550HYD</b>	9,600	6,925
<b>SP300HYD</b>	5,000	3,607
<b>SP220HYD</b>	4,100	2,958
<b>SP100HYD</b>	3,200	2,310
EUR/ Dollar =	0.7214	(AV 2009)

Source: Hydraulic Thrusters – IMTRA Marine Products

[http://www.imtra.com/product/thrusters/side\\_power\\_hydraulic\\_thruster\\_systems/hydraulic\\_thrusters\\_2/250mm\\_hyd.htm](http://www.imtra.com/product/thrusters/side_power_hydraulic_thruster_systems/hydraulic_thrusters_2/250mm_hyd.htm)

2009 values



## Appendix F.1: Battery pack design and calculations

The amount of batteries needed depends on the speed that is required for the barge ( $V_{\text{barge}}$ ) and the time the barge has to sail at that speed ( $T_{\text{Barge}}$ ). That time will be determined with the following relation and depends on the distance that has been sailed on the small waterway ( $\text{Dist}_{\text{sw}}$ ).

$$T_{\text{barge}} = \frac{\text{Dist}_{\text{sw}}}{V_{\text{barge}}} \quad (\text{F.1})$$

On top of that one hour sailing on full power is added ( $T_{\text{Top}}$ ). That has been done, so the barge has extra power to overcome strong currents in some places and to pass large ships in port.

If the model has chosen that the barge do not have to sail independently, there are no batteries (or gen sets), electric engines and thrusters installed. If the choice has been that the barge only has to manoeuvre in and out of a lock on the small waterways,  $T_{\text{Barge}}$  will be determined at two hours. That should be enough time to sail in and out of a lock.

The total energy needed to propel the barge can be calculated with relation F.2. The total energy need is doubled, so that the barge can also sail back on the small waterway.

$$E_{\text{Barge}} = (T_{\text{Barge}} \cdot P_{\text{e}_{\text{Barge}}} + P_{\text{electric\_barge}} \cdot T_{\text{top}}) \cdot 2 \quad (\text{F.2})$$

$E_{\text{Barge}}$  = total energy needed by the barge [kWh]

$P_{\text{e}_{\text{barge}}}$  = required power to sail at the selected speed [kW]

$P_{\text{electric\_barge}}$  = required power to sail at top speed [kW]

The capacity of a battery is given in Ah (ampere hours). By multiplying the capacity by the voltage in Volts, the amount of energy that is stored in a battery is known in kWh. From that capacity only 50% can be used effectively. Batteries will not be completely empty because 30% of the capacity will be left. The batteries are also not fully loaded (up to 80%).

$$E_{\text{batt}} = 50\% \cdot \frac{12 \text{ v} \cdot 225 \text{ Ah}}{1000} \quad (\text{F.3})$$

With formulae F.2 and F.3 the amount of batteries ( $N_{\text{batt}}$ ) can be calculated:

$$N_{\text{batt}} = \frac{E_{\text{Barge}}}{E_{\text{batt}}} \quad (\text{F.4})$$

These batteries have a weight and dimensions which are taken from the product information of a battery producer. This information is given in appendix F.2.

For the allocation of the batteries the following decision has been made. The batteries are positioned with the long side in the width and with the short side in the length. The reason for that is that the batteries will fit

between the transverse stiffeners in the double bottom structure. The number of batteries that can be placed next to each other depends on the length of the batteries and the half width of the double bottom of the barge. Half of the width is used here because the centre girder will divide the double bottom in two sections. The next relation will give the number of batteries that will be placed next to each other.

$$N_{\text{batt\_wide}} = 2 \cdot \left( \frac{\frac{1}{2} B_{\text{mid}}}{L_{\text{batt}} + 0.5} \right) \quad (\text{F.5})$$

There is an extra spacing added (0.5 m per half width of the mid ship of the barge) between the batteries so that the batteries do not stand directly against each other.

The number of rows of batteries is determined with the following relation.

$$N_{\text{batt\_long}} = \frac{N_{\text{Batt}}}{N_{\text{Batt\_wide}}} \quad (\text{F.6})$$

The choice has been made to use the stiffener spacing as the spacing between the batteries, so that the batteries will fit between the stiffeners on the bottom and the tank top. The batteries are allocated around the centre of the mid ship of the barge. The reason for that is that the centre of gravity of the batteries will (almost) go inside with the centre of buoyancy of the barge; therefore the barge will be trimmed.

## Appendix F.2: Battery product data

### Battery AGM 12/225

(art.nr. 62002250)



Article number	62002250
Nominal voltage	12V
Ah capacity/C20 (capacity at 20 hours of discharge time at a surrounding temperature of 25°C)	225 Ah
Dimensions excluding poles (LxWxH)	522 x 240 x 218 mm
Dimensions including poles (LxWxH)	522 x 240 x 241 mm
Weight	64 kg
Maximal installation angle	180°
Cold starter current DIN	737A
Cold starter current SAE	1117A
Short circuit current (IEC 60896-21)	3650A
Guarantee period	2 year

### Mastervolt AGM 12/225

AGM 12/225, Battery, 225 Ah (C20), 12 V

Price: €445.38 (Including VAT at 19.6%) (2009 value)

## Appendix G: Barge stability calculations

In order to calculate the GM-value of the barge, first the centre of buoyancy needs to be determined with the following relation.

$$KB = \frac{(\text{Displ}_{\text{mid}} \cdot \frac{T}{2} + \text{Displ}_{\text{fore}} \cdot \frac{2}{3} \cdot T + \text{Displ}_{\text{aft}} \cdot \frac{2}{3} \cdot T)}{\text{Displ}_{\text{Tot}}} \quad (\text{G.1})$$

$\text{Displ}_{\text{mid}}$  = displacement of the mid part of the barge [m<sup>3</sup>]  
 $\text{Displ}_{\text{for}}$  = displacement of the for part of the barge [m<sup>3</sup>]  
 $\text{Displ}_{\text{aft}}$  = displacement of the aft part of the barge [m<sup>3</sup>]  
 $\text{Displ}_{\text{tot}}$  = displacement of the barge [m<sup>3</sup>]

The moment of inertia of the waterline can be calculated with the following relation.

$$I_t = \frac{L \cdot B^3}{12} \quad (\text{G.2})$$

The value of KB can now be determined with  $I_t$  and the displacement.

$$BM = \frac{I_t}{\nabla} \quad (\text{G.3})$$

The value of KG of the barge has been calculated with the calculated weight data of all the components that are placed in the barge including the hull and payload. The weight of the containers is set at 14 tonnes and the VcG is estimated at 40% of the height of the container. The value of GM can now be determined with:

$$GM = KB + BM - KG \quad (\text{G.4})$$

$KB$  = distance from keel to centre of buoyancy [m]  
 $BM$  = distance of centre of buoyancy to meta-centre height [m]  
 $KG$  = distance from keel to centre of gravity of total ship [m]

The values of GZ (up to 20 degrees) can be determined with the formula of Scrabanti, which is given in the next relation:

$$GZ = (GM + \frac{1}{2} \cdot BM \cdot \tan(\phi)^2) \cdot \sin(\phi) \quad (\text{G.5})$$

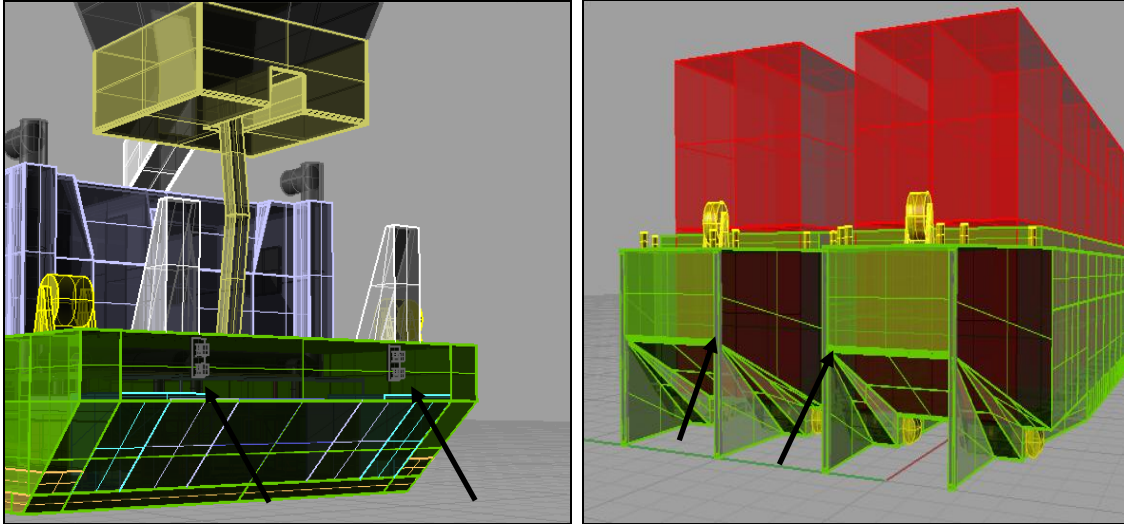
$\Phi$  = heeling angle of the barge [rad]

## Appendix H: Coupling system

In this appendix the developed coupling system between the tug and the barges is given. In figure H.1 the location of the coupling system is shown.

Figure H.1: New coupling system

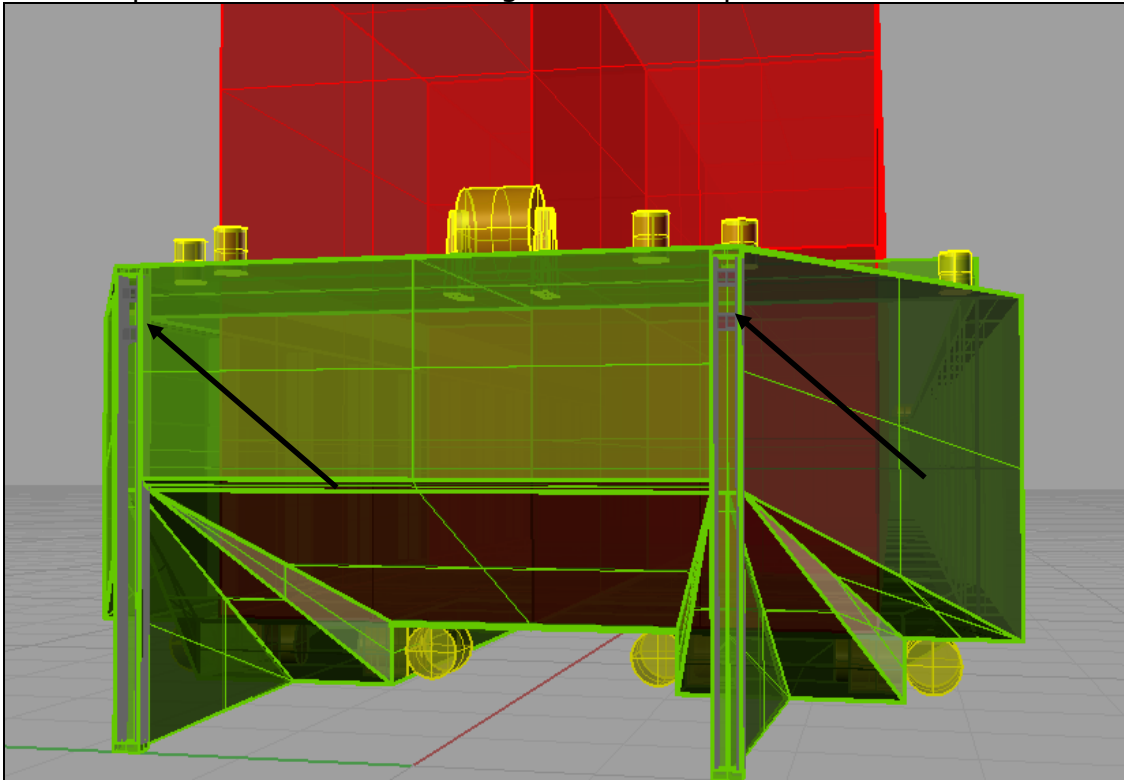
3D view



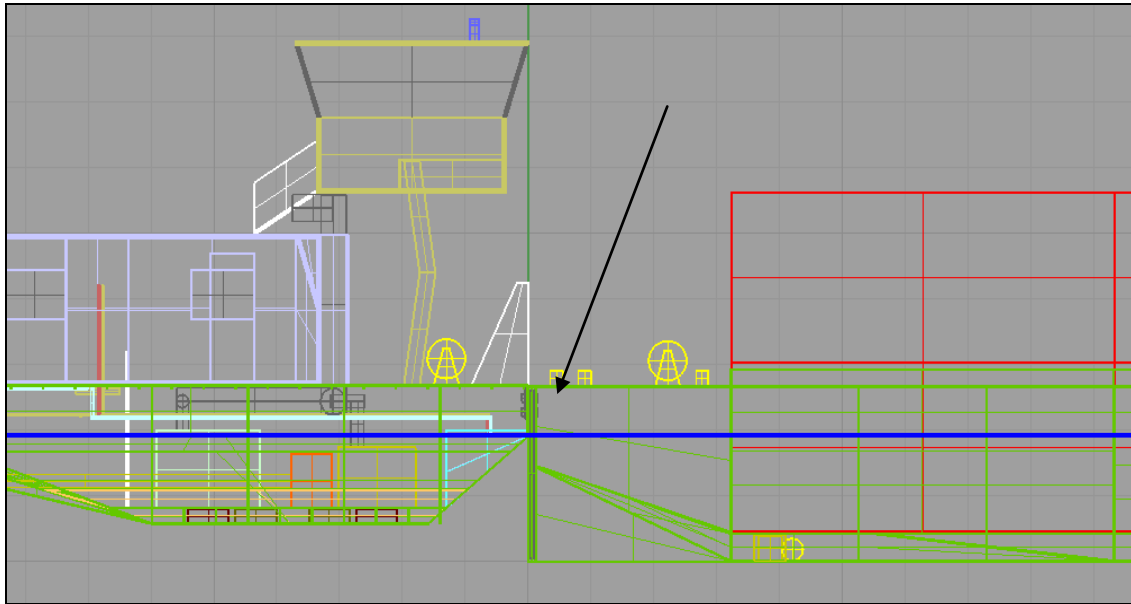
Left: connection rods

right: push rods with connecting block

3D view push rods with connecting block close-up



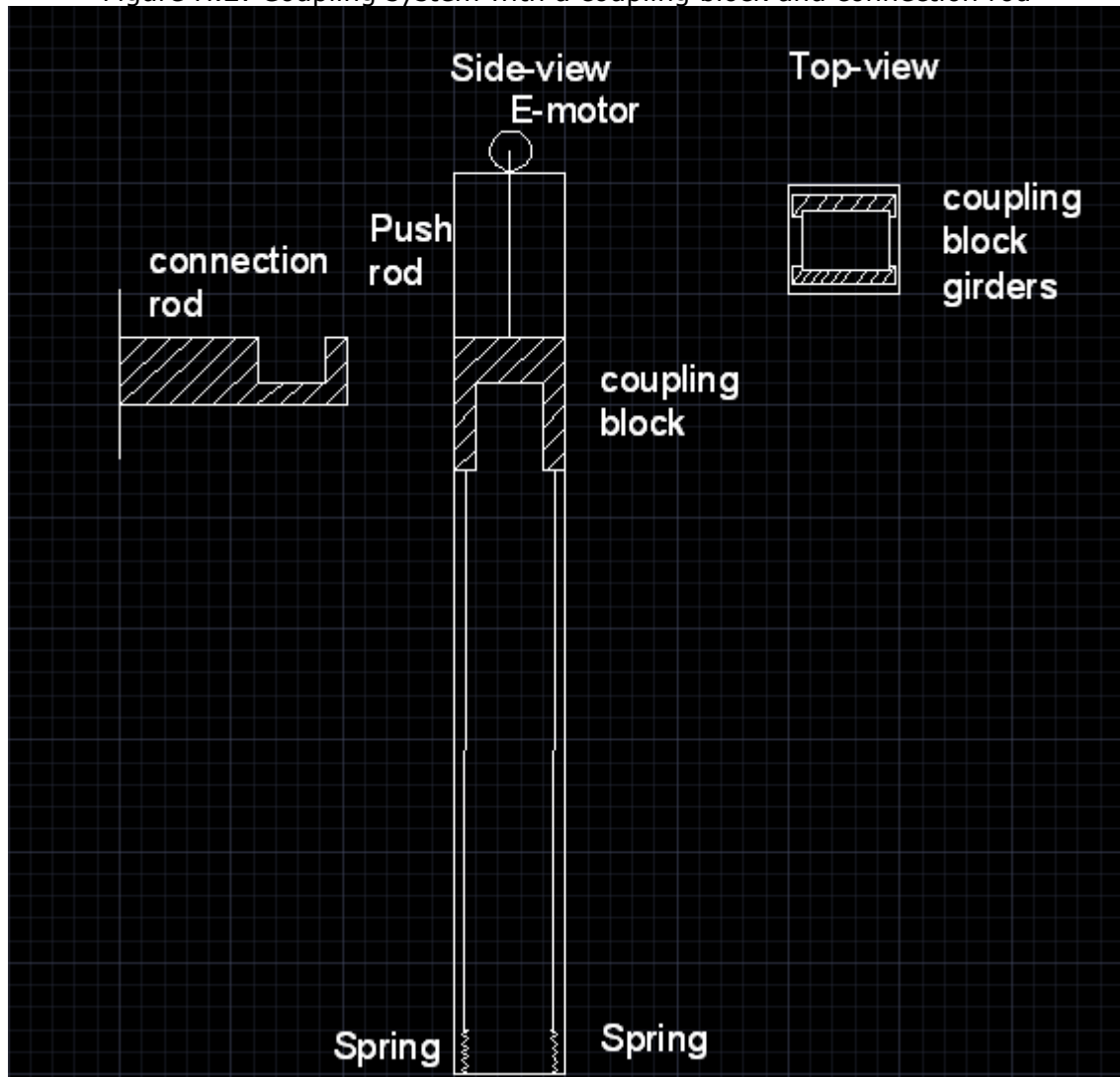
Side view



In the push-rod of the barge a coupling system is installed, which can be seen in figure H.2. The coupling block will be connected to its bottom via two cables which are connected to two springs located in the bottom part of the push-rod. The top part of the block will be connected via a cable to an electric engine. This engine will be powered by a battery and will only be used to lift the coupling block to the top part of the push-rod when a coupling has to be made. When the connection block is inside the push-rod, the coupling block will be lowered, so that the coupling block will fall over the connection block and a fixed connection will be made. The engine will stop working when the tension in the connection cable is gone. The engine can either be controlled by a person or by a computer system.

The coupling block will be alight in the push rods by a girder system. The coupling block will move inside this girder system.

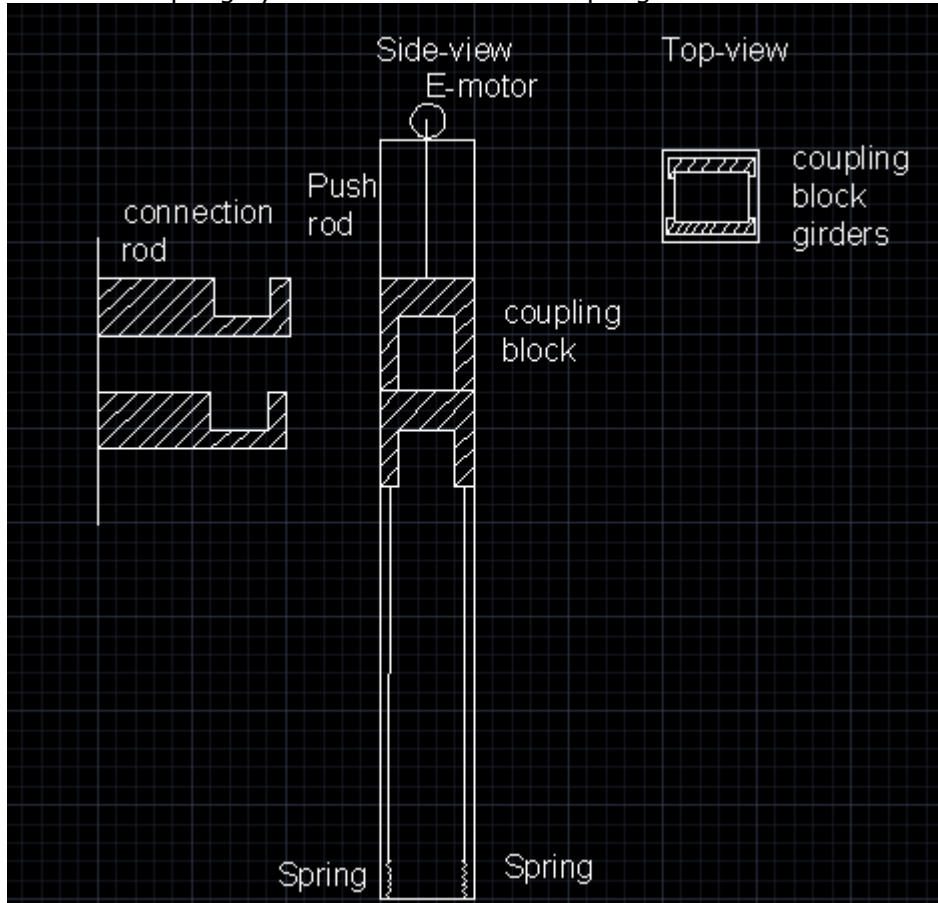
Figure H.2: Coupling system with a coupling block and connection rod



The coupling system is aligned in such a way that, if one barge is pushed, the tug and barge will have a double connection and if two barges aside have to be pushed, the one connection per barge is made. On top of this developed system also one existing hydraulic winch will be used to connect the barges which are placed next to each other.

It is also possible to double the connection rods. This can be seen in figure H.3.

Figure H.3: Coupling system with a double coupling block and connection rod



In this way a more fixed connection will be made. For this system also a sensor will be included. This sensor will be placed on the connection rods. That sensor will be used to determine the location of the connection rods relative to the coupling block. In this way the electric engine will work until the double coupling block is at the right height, so that the coupling block will be aligned with the connection rods. At that moment the tug (or other push barge) will sail into the coupling block and the electric engine will lower the coupling until the tension in the connection cable is gone. At that time the coupling block will have made a connection with the connection rods and the two units (barges or tug and barge) will be connected.

It is also possible to install the same system at the sides of the barge. In that way the barges can be coupled sideways. There are four connection points installed over the total length of the barge. It is also possible to install more than four connection points. The coupling blocks and the connection rods are installed in an asymmetrical way. In figure H.4 the sideways connection points are indicated with arrows.



Figure H.4: New coupling system (sideway connection star board)

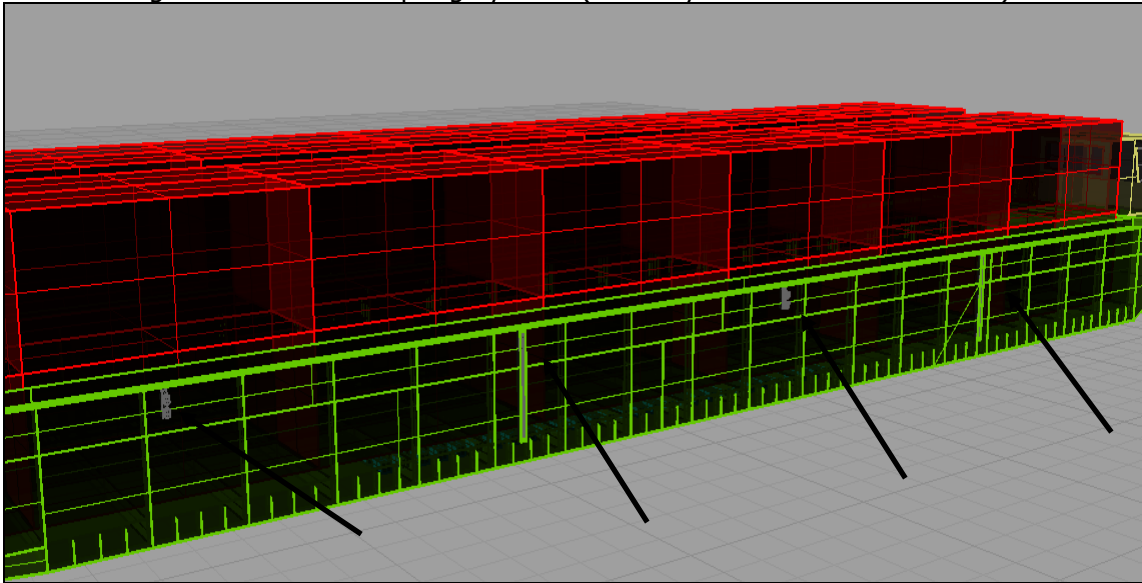
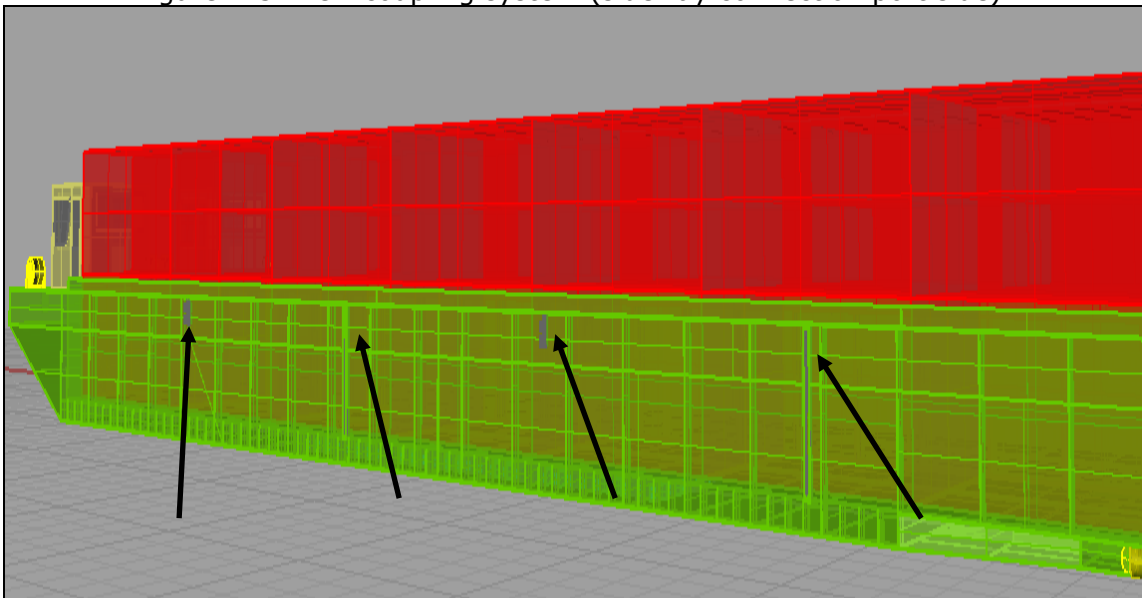


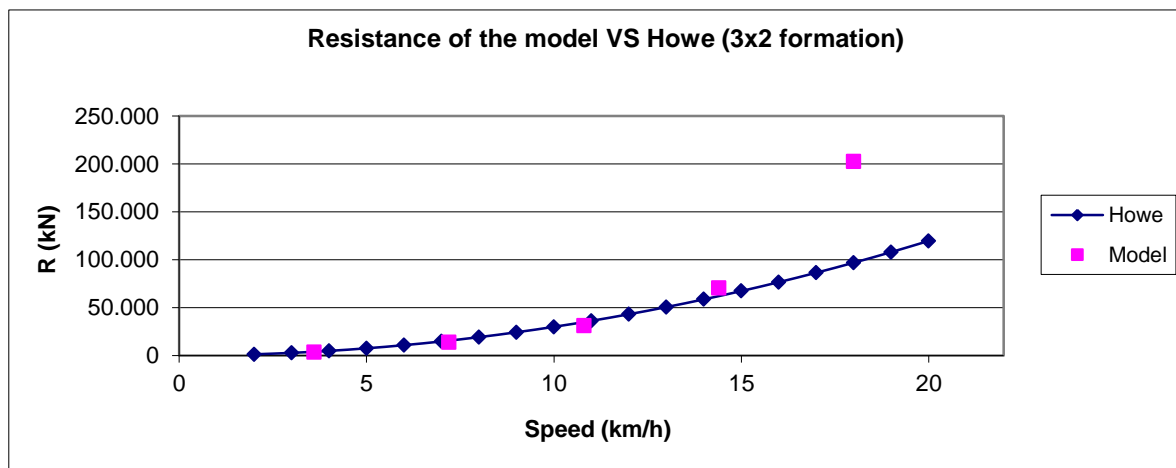
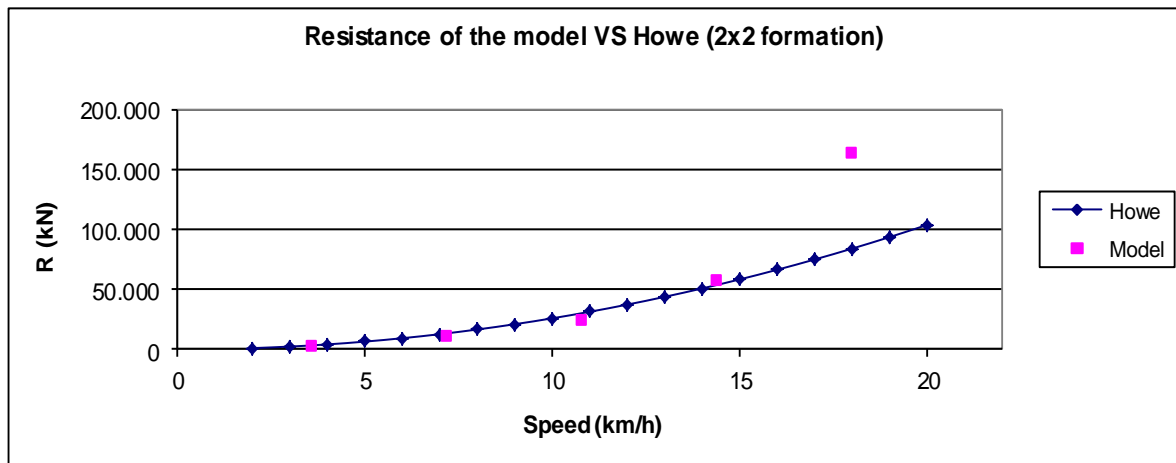
Figure H.5: New coupling system (sideway connection port side)



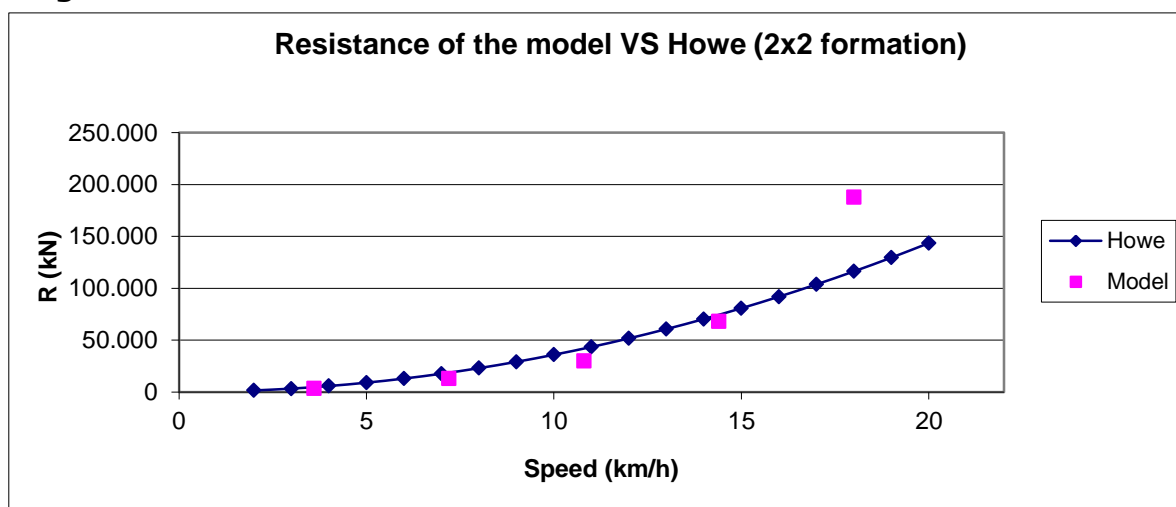
If there is a difference in draft of two barges, still a connection can be made. If the difference in draft is very large (one barge empty and the other completely loaded), only a connection at two points can be made.

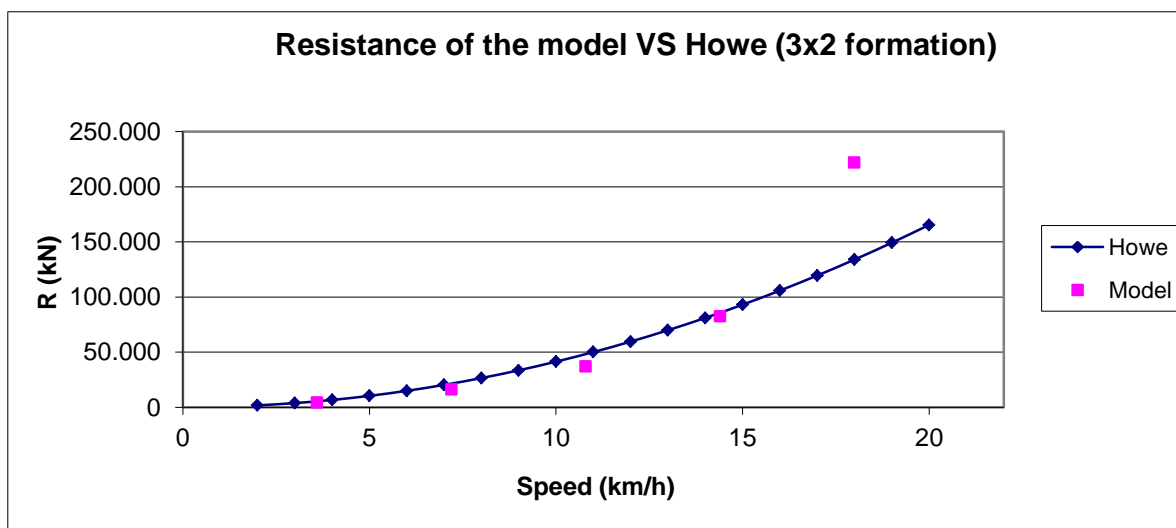
## Appendix I: Comparison barge train resistance

### Barge width of 6 meters

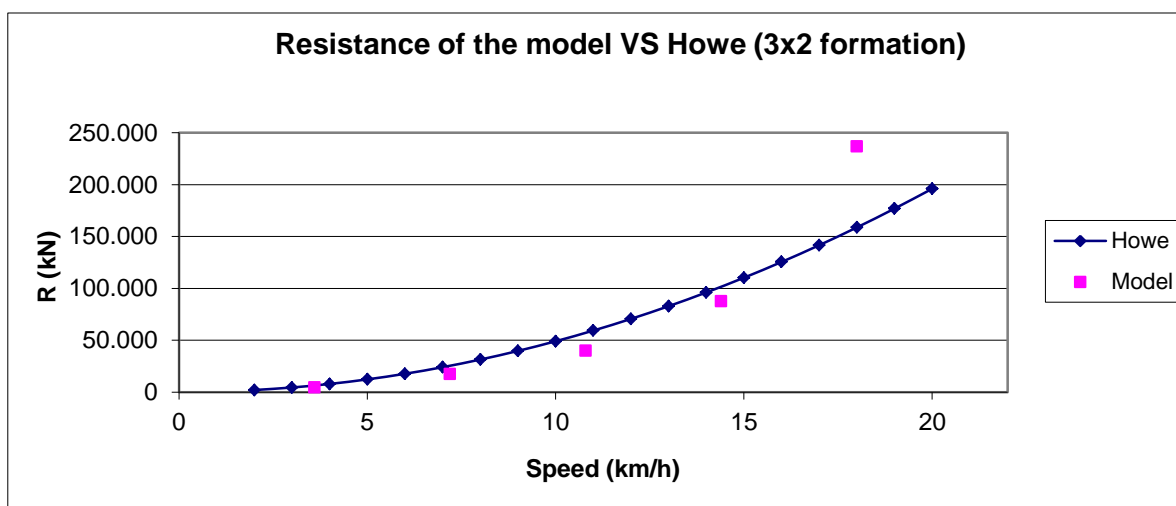
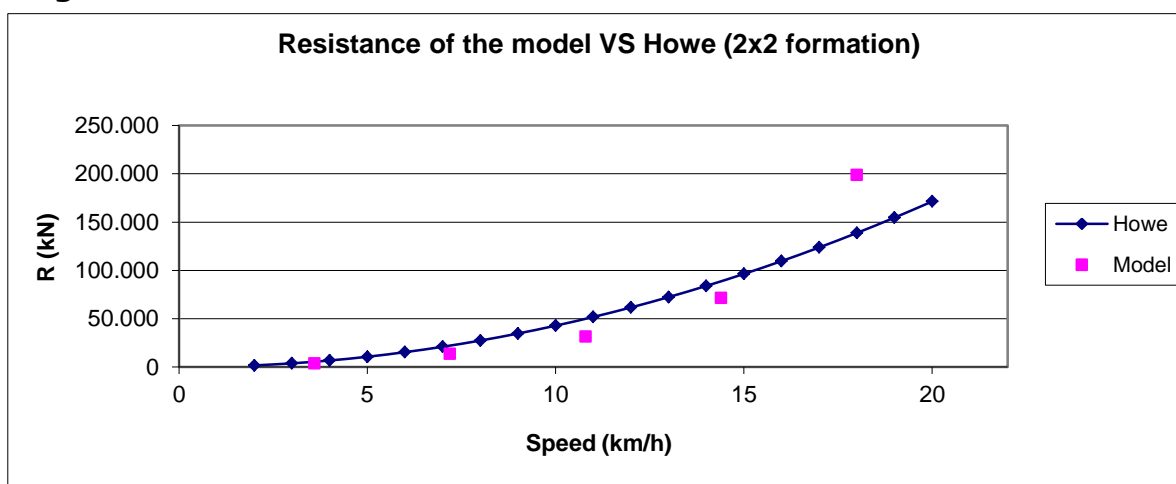


### Barge width of 7 meters





### Barge width of 8 meters



## Appendix J: Barge train formulae

For barges with a width of 6 meters the barge train coefficients are:

$$C_{\text{barge}} = 0.75 \quad ; \text{ 2 long} \quad (\text{J.1})$$

$$C_{\text{barge}} = 0.001.V^2 - 0.0046.V + 0.936 \quad ; \text{ 2 wide} \quad (\text{J.2})$$

$$C_{\text{barge}} = -0.0007.V^2 - 0.0078.V + 0.7196 \quad ; \text{ 2 long X 2 wide} \quad (\text{J.3})$$

$$C_{\text{barge}} = 10^{-4}.V^3 - 0.0042.V^2 + 0.0316.V + 0.5146 \quad ; \text{ 3 long X 2 wide} \quad (\text{J.4})$$

If the width of the barge is 7 meters, the relations are:

$$C_{\text{barge}} = 0.75 \quad ; \text{ 2 long} \quad (\text{J.5})$$

$$C_{\text{barge}} = 6.10^{-5}.V^3 - 0.0037.V^2 - 0.0319.V + 0.8829 \quad ; \text{ 2 wide} \quad (\text{J.6})$$

$$C_{\text{barge}} = 5.10^{-5}.V^3 - 0.0031.V^2 + 0.0254.V + 0.679 \quad ; \text{ 2 long X 2 wide} \quad (\text{J.7})$$

$$C_{\text{barge}} = 4.10^{-5}.V^3 - 0.0026.V^2 + 0.0201.V + 0.5904 \quad ; \text{ 3 long X 2 wide} \quad (\text{J.8})$$

If the barge has a width of 8 meters, the following relations hold:

$$C_{\text{barge}} = 0.75 \quad ; \text{ 2 long} \quad (\text{J.9})$$

$$C_{\text{barge}} = -0.0014.V^2 - 0.0115.V + 0.9118 \quad ; \text{ 2 wide} \quad (\text{J.10})$$

$$C_{\text{barge}} = -0.001.V^2 + 0.004.V + 0.7031 \quad ; \text{ 2 long X 2 wide} \quad (\text{J.11})$$

$$C_{\text{barge}} = 0.00002.V^3 - 0.0016.V^2 + 0.0145.V + 0.5734 \quad ; \text{ 3 long X 2 wide} \quad (\text{J.12})$$

The speed in these formulas needs to be given in km/h.

## Appendix K: Tug geometry

The geometry of the tug will be taken from van Terwisga (1989). In van Terwisga (1989) a literature study has been done for the hull forms of barges and tugs. In that study design relations are given for the design of a tug. These (generic) design relations are used in the design model. In figure K.1 a schematic overview is given of the tug. The tug has been divided into three parts: the bow part ( $L_{\text{enter}}$ ), the mid ship part ( $L_{\text{mid}}$ ) and the aft ship (which is also divided into three parts  $L_{\text{aft}} = L_{\text{st}} + L_{\text{aft1}} + L_{\text{aft2}}$ ).

The length of the fore ship ( $L_{\text{enter}}$ ) will be determined by the angle  $\alpha_I$  (see figure K.1) and the draft of the push ship ( $T_{\text{ps}}$ ).

$$T_{\text{PS}} = L_{\text{enter\_PS}} \cdot \tan(\alpha_{\text{I\_PS}}) \quad (\text{K.1})$$

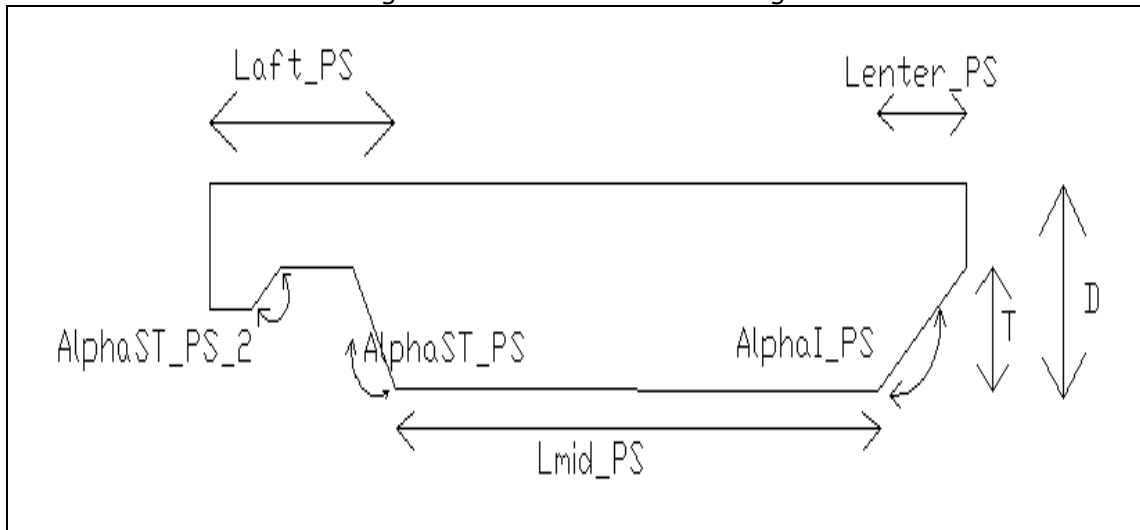
The mid ship of the tug must be given as an input variable. The length of the mid ship should be long enough, so that all the required power generation equipment can be placed inside the ship.

The length of the aft ship ( $L_{\text{st}}$ ) will be determined by the angle  $\alpha_{\text{ST}}$  (see figure K.1) and the draft of the tug.

$$L_{\text{st}} = \frac{T}{\tan(\alpha_{\text{ST}})} \quad (\text{K.2})$$

The value of  $\alpha_{\text{st}}$  has a recommended value of between 15 and 25 degrees (van Terwisga 1989). For this design model a value of 20 degrees is adapted. The lengths of  $L_{\text{aft1}}$  and  $L_{\text{aft2}}$  will be determined by the tunnel design for the propellers of the tug where these values are also taken from (van Terwisga 1989). In figure K.1 the side view of the tug is given.

Figure K.1: Side view of the tug



Source: van Terwisga, 1989

The length of  $L_{\text{aft1}}$  is set equal to the propeller diameter (van Terwisga 1989). This propeller diameter is set equal to the draft of the tug so that the propeller diameter is as large as possible in order to increase the

propeller efficiency. The length of  $L_{aft2}$  will be determined with relation K.3, which is also taken from van Terwisga (1989).

$$L_{aft2} = 1.5 \cdot D_{prop} - L_{aft1} \quad (K.3)$$

The draft of the transom will be determined by relation K.4, where the value of  $\alpha_{ST\_2}$  is set to be 12 degrees and is taken from van Terwisga (1989).

$$T_{aft} = T - \tan(\alpha_{ST\_2}) \cdot 1.5 \cdot D_{prop} \quad (K.4)$$

The beam of the tug can be an input parameter, but is also a default setting, where the beam of the tug is set being equal to the beam of the barge. The depth of the tug will be determined by the height of the double bottom and the height of the engines that are placed inside the ship. On top of that an extra margin of 50 cm is added. The margin is added to accommodate pipes and ducts that are connected to the engines. The used relation is given in formula K.5.

$$D = H_{dubbod} + H_{engine} + 0.50 \quad (K.5)$$

## Appendix L.1: Thrust and propeller calculations

The total thrust can be calculated with the following relation:

$$T_{\text{total}} = \frac{R_{\text{total}}}{(1-t)} \quad (\text{L.1.1})$$

In this relation  $t$  is the thrust deduction factor and can be calculated with the following relation, which is taken from Van Terwisga (1989).

$$t = 0.8 \cdot w \cdot (w + 0.25) \quad (\text{L.1.2})$$

In this relation  $w$  is the wake factor and can be calculated with the relation given in 7.10, which is taken from van Terwisga (1989).

$$w = 0.11 + \frac{0.16}{x} \cdot C_b^x \sqrt{\frac{\Delta^{1/3}}{D_{\text{prop}}}} \quad (\text{L.1.3})$$

$X$ = number of propellers (1 or 2)	[-]
$C_b$ = block coefficient	[-]
$\Delta$ = displacement	[m <sup>3</sup> ]
$D_{\text{prop}}$ = propeller diameter	[m]

If there are more than two propellers installed,  $x$  will be 2 in relation L.1.3 (van Terwisga 1989).

In the model the number of the installed propellers can be varied from one to four. The thrust that one propeller needs to deliver can be calculated with:

$$T_{\text{prop}} = \frac{T_{\text{total}}}{N_{\text{propellers}}} \quad (\text{L.1.4})$$

$N_{\text{propellers}}$  = number of propellers [-]

From the calculated thrust per propeller, the  $A_e A_0$  of the propeller can be determined. The choice has been made to use the Wageningen B-series propellers. The value of  $A_e A_0$  can be calculated with the next relation:

$$\frac{A_e}{A_0} = \frac{(1.3 + 0.3Z) \cdot T_{\text{prop}}}{((100 + \rho \cdot g \cdot \frac{T}{2} - 1.72) \cdot D_{\text{prop}}^2)} + 0.2 \quad (\text{L.1.5})$$

$Z$  = number of propeller blades (from 3 to 5) [-]

The value of  $A_e/A_0$  is restricted between 0.3 and 1.2. This restriction is taken from Kuiper (2002). From the calculated value of  $A_e A_0$ , the number of propeller blades and a given pitch/diameter ratio (PD) the  $K_t$ ,  $K_q$  lines can be determined. These lines can be described with a 3th power line which is given in the next relations:

## Appendices

$$KT_{\text{Prop}} = KT_0 + KT_1.J + KT_2.J^2 + KT_3 . J^3 \quad (\text{L.1.6})$$

$$KQ_{\text{Prop}} = KQ_0 + KQ_1.J + KQ_2.J^2 + KQ_3.J^3 \quad (\text{L.1.7})$$

The parameters,  $KT_0$ ,  $KT_1$ , etc will be determined from the calculations given in appendix J.2.

When  $KT_{\text{Prop}}$  and  $KQ_{\text{Prop}}$  are known, also the open water efficiency is known with the next relation:

$$\eta_0 = \frac{J \cdot K_t}{K_q \cdot 2 \cdot \pi} \quad (\text{L.1.8})$$

The weight of a single propeller can be calculated with the following relation:

$$\text{Weight}_{\text{Prop}} = \frac{A_E}{A_O} \cdot \frac{1}{4} \cdot \pi \cdot D_{\text{prop}}^2 \cdot t_{\text{Prop}} \cdot \rho_{\text{CuNiAL}} \quad (\text{L.1.9})$$

$\rho_{\text{CuNiAL}}$  = density of the propeller material (= 7650 kg/m<sup>3</sup>) [kg/m<sup>3</sup>]

$T_{\text{prop}}$  = thickness of the propeller (=15 cm) [m]

The dimensions from the ducts are taken from appendix L.3. The weight calculation of the ducts has been performed with the dimensions given in the product data.

The weight of the propeller shaft is determined from the length and the thickness of the shaft. It has been estimated that the thickness is 20 cm and that the prop shaft is made from steel. For the weight calculations of the propellers, ducts and propeller shafts a lot of estimations are made. The main purpose of the model is to give insight into the costs of different designs and not to give a complete design. Therefore no more detailed weight calculation will be made.



**Appendix L.2: Wageningen B-series data**

AeA0		0.359346	Z	4	PD	1			
KT = Σ Cstuv * J^s * (P/D)^t * (Ae/Ao)^u * Z^v						J^0	J^1	J^2	J^3
Cstuv	S	t	u	V		0.380	-0.152	-0.213	0.041
0.008805	0	0	0	0	0	0.008805	0.000000	0.000000	0.000000
-0.204554	1	0	0	0	0	0.000000	-0.204554	0.000000	0.000000
0.166351	0	1	0	0	0	0.166351	0.000000	0.000000	0.000000
0.158114	0	2	0	0	0	0.158114	0.000000	0.000000	0.000000
-0.147581	2	0	1	0	0	0.000000	0.000000	-0.053033	0.000000
-0.481497	1	1	1	0	0	0.000000	-0.173024	0.000000	0.000000
0.415437	0	2	1	0	0	0.149286	0.000000	0.000000	0.000000
0.0144043	0	0	0	1	1	0.057617	0.000000	0.000000	0.000000
-0.0530054	2	0	0	1	1	0.000000	0.000000	-0.212022	0.000000
0.0143481	0	1	0	1	1	0.057392	0.000000	0.000000	0.000000
0.0606826	1	1	0	1	1	0.000000	0.242730	0.000000	0.000000
-0.0125894	0	0	1	1	1	-0.018096	0.000000	0.000000	0.000000
0.0109689	1	0	1	1	1	0.000000	0.015767	0.000000	0.000000
-0.133698	0	3	0	0	0	-0.133698	0.000000	0.000000	0.000000
0.0063841	0	6	0	0	0	0.006384	0.000000	0.000000	0.000000
-0.0013272	2	6	0	0	0	0.000000	0.000000	-0.001327	0.000000
0.168496	3	0	1	0	0	0.000000	0.000000	0.000000	0.060548
-0.0507214	0	0	2	0	0	-0.006550	0.000000	0.000000	0.000000
0.0854559	2	0	2	0	0	0.000000	0.000000	0.011035	0.000000
-0.0504475	3	0	2	0	0	0.000000	0.000000	0.000000	-0.006514
0.010465	1	6	2	0	0	0.000000	0.001351	0.000000	0.000000
-0.0064827	2	6	2	0	0	0.000000	0.000000	-0.000837	0.000000
-0.0084173	0	3	0	1	1	-0.033669	0.000000	0.000000	0.000000
0.0168424	1	3	0	1	1	0.000000	0.067370	0.000000	0.000000
-0.001023	3	3	0	1	1	0.000000	0.000000	0.000000	-0.004092
-0.0317791	0	3	1	1	1	-0.045679	0.000000	0.000000	0.000000
0.018604	1	0	2	1	1	0.000000	0.009609	0.000000	0.000000
-0.004108	0	2	2	1	1	-0.002122	0.000000	0.000000	0.000000
-0.0006068	0	0	0	2	2	-0.009710	0.000000	0.000000	0.000000
-0.0049819	1	0	0	2	2	0.000000	-0.079710	0.000000	0.000000
0.0025983	2	0	0	2	2	0.000000	0.000000	0.041573	0.000000
-0.0005605	3	0	0	2	2	0.000000	0.000000	0.000000	-0.008968
-0.0016365	1	2	0	2	2	0.000000	-0.026184	0.000000	0.000000
-0.0003288	1	6	0	2	2	0.000000	-0.005261	0.000000	0.000000
0.0001165	2	6	0	2	2	0.000000	0.000000	0.001864	0.000000
0.0006909	0	0	1	2	2	0.003972	0.000000	0.000000	0.000000
0.0042175	0	3	1	2	2	0.024249	0.000000	0.000000	0.000000
5.652E-05	3	6	1	2	2	0.000000	0.000000	0.000000	0.000325
-0.0014656	0	3	2	2	2	-0.003028	0.000000	0.000000	0.000000

KQ = Σ Cstuv * J^s * (P/D)^t * (Ae/Ao)^u * Z^v								
					J <sup>0</sup>	J <sup>1</sup>	J <sup>2</sup>	J <sup>3</sup>
					0.380	-0.152	-0.213	0.041
Cstuv	s	t	u	V	0.051 -0.019 -0.006 -0.013			
0.0037937	0	0	0	0	0.003794	0.000000	0.000000	0.000000
0.0088652	2	0	0	0	0.000000	0.000000	0.008865	0.000000
-0.032241	1	1	0	0	0.000000	-0.032241	0.000000	0.000000
0.0034478	0	2	0	0	0.003448	0.000000	0.000000	0.000000

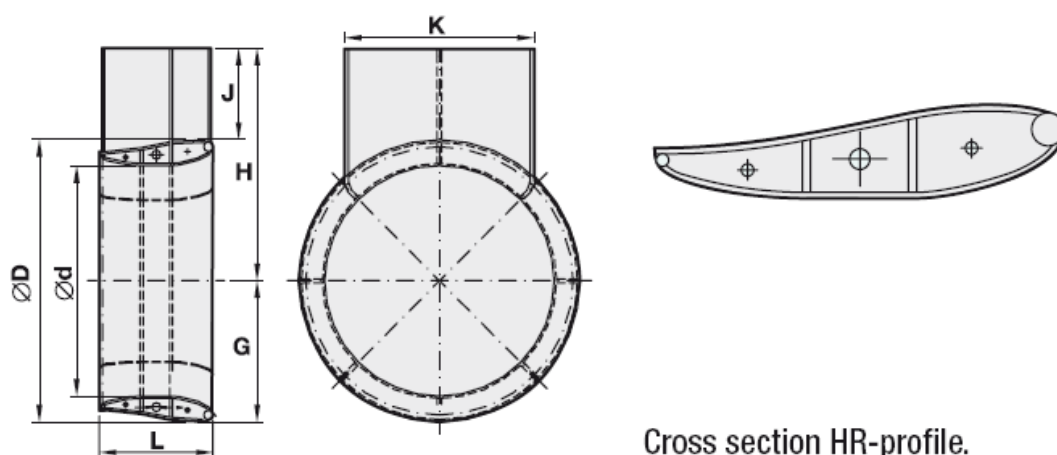
# Appendices

-0.0408811	0	1	1	0
-0.108009	1	1	1	0
-0.0885381	2	1	1	0
0.188561	0	2	1	0
-0.0037809	1	0	0	1
0.005137	0	1	0	1
0.0209449	1	1	0	1
0.0047432	2	1	0	1
-0.0072341	2	0	1	1
0.0043839	1	1	1	1
-0.0269403	0	2	1	1
0.0558082	3	0	1	0
0.0161886	0	3	1	0
0.0031809	1	3	1	0
0.015896	0	0	2	0
0.0471729	1	0	2	0
0.0196283	3	0	2	0
-0.0502782	0	1	2	0
-0.030055	3	1	2	0
0.0417122	2	2	2	0
-0.0397722	0	3	2	0
-0.0035002	0	6	2	0
-0.0106854	3	0	0	1
0.001109	3	3	0	1
-0.0003139	0	6	0	1
0.0035985	3	0	1	1
-0.0014212	0	6	1	1
-0.0038364	1	0	2	1
0.0126803	0	2	2	1
-0.0031828	2	3	2	1
0.0033427	0	6	2	1
-0.0018349	1	1	0	2
0.0001125	3	2	0	2
-2.972E-05	3	6	0	2
0.0002696	1	0	1	2
0.0008327	2	0	1	2
0.0015533	0	2	1	2
0.0003027	0	6	1	2
-0.0001843	0	0	2	2
-0.0004254	0	3	2	2
8.692E-05	3	3	2	2
-0.0004659	0	6	2	2
5.542E-05	1	6	2	2

-0.014690	0.000000	0.000000	0.000000
0.000000	-0.038813	0.000000	0.000000
0.000000	0.000000	-0.031816	0.000000
0.067759	0.000000	0.000000	0.000000
0.000000	-0.015123	0.000000	0.000000
0.020548	0.000000	0.000000	0.000000
0.000000	0.083780	0.000000	0.000000
0.000000	0.000000	0.018973	0.000000
0.000000	0.000000	-0.010398	0.000000
0.000000	0.006301	0.000000	0.000000
-0.038724	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.020054
0.005817	0.000000	0.000000	0.000000
0.000000	0.001143	0.000000	0.000000
0.002053	0.000000	0.000000	0.000000
0.000000	0.006091	0.000000	0.000000
0.000000	0.000000	0.000000	0.002535
-0.006492	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	-0.003881
0.000000	0.000000	0.005386	0.000000
-0.005136	0.000000	0.000000	0.000000
-0.000452	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	-0.042742
0.000000	0.000000	0.000000	0.004436
-0.001256	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.005172
-0.002043	0.000000	0.000000	0.000000
0.000000	-0.001982	0.000000	0.000000
0.006550	0.000000	0.000000	0.000000
0.000000	0.000000	-0.001644	0.000000
0.001727	0.000000	0.000000	0.000000
0.000000	-0.029359	0.000000	0.000000
0.000000	0.000000	0.000000	0.001799
0.000000	0.000000	0.000000	-0.000476
0.000000	0.001550	0.000000	0.000000
0.000000	0.000000	0.004787	0.000000
0.008931	0.000000	0.000000	0.000000
0.001740	0.000000	0.000000	0.000000
-0.000381	0.000000	0.000000	0.000000
-0.000879	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000180
-0.000963	0.000000	0.000000	0.000000
0.000000	0.000115	0.000000	0.000000
<b>0.051</b>	<b>-0.019</b>	<b>-0.006</b>	<b>-0.013</b>

### Appendix L.3: Nozzle data

Nozzle	Ød	ØD	G	H	J	K	L
HR 1000	1010	1238	619*	1019*	400*	840*	500
HR 1050	1060	1300	650*	1050*	400*	900*	525
HR 1100	1110	1360	680*	1080*	400*	970*	550
HR 1150	1160	1422	711*	1111*	400*	960*	575
HR 1200	1210	1483	742*	1142*	400*	1200*	600
HR 1250	1260	1545	772*	1172*	400*	1012*	625
HR 1300	1310	1606	803*	1203*	400*	1064*	650
HR 1350	1360	1667	834*	1234*	400*	1104*	675
HR 1400	1410	1730	865*	1265*	400*	1144*	700
HR 1450	1460	1790	895*	1295*	400*	1186*	725
HR 1500	1510	1852	926*	1326*	400*	1226*	750
HR 1550	1560	1913	957*	1357*	400*	1264*	775
HR 1600	1610	1974	987*	1387*	400*	1306*	800
HR 1650	1660	2032	1016*	1416*	400*	1344*	825
HR 1700	1710	2098	1049*	1449*	400*	1380*	850
HR 1750	1760	2158	1079*	1479*	400*	1420*	875
HR 1800	1810	2220	1110*	1510*	400*	1680*	900
HR 1850	1860	2282	1141*	1541*	400*	1502*	925
HR 1900	1910	2342	1171*	1571*	400*	1542*	950
HR 1950	1960	2404	1202*	1602*	400*	1582*	975
HR 2000	2010	2465	1233*	1633*	400*	1620*	1000



Source: [www.wartsila.com](http://www.wartsila.com)

## Appendix M: Rudder calculations

The total propeller area will be calculated with the following formula taken from Germinsche Lloyds<sup>56</sup>:

$$A_r = \frac{(1+50.C_b^2.(\frac{L}{B})^{-2}).L.T}{100} \quad (M.1)$$

L = length of the total convoy [m]  
 B = beam of the total convoy [m]  
 T = draft of the tug [m]  
 C<sub>b</sub> = block coefficient of the convoy [-]

The height of the rudders is set to be equal to propeller diameter.

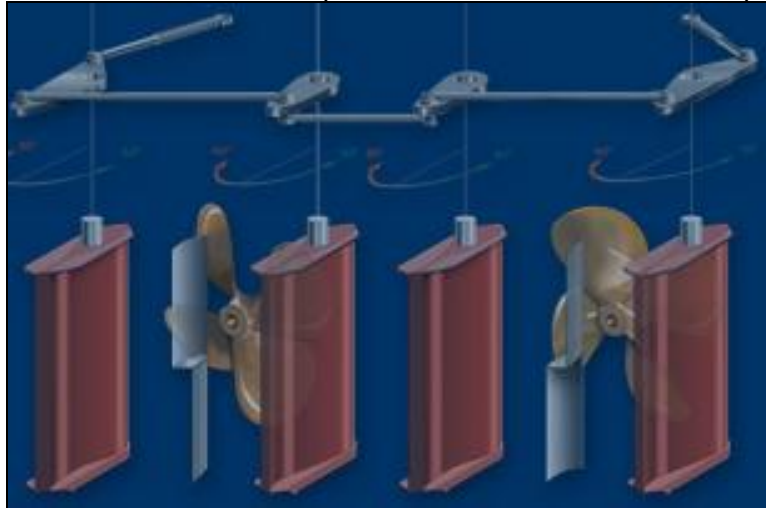
In order to determine the weight of the rudders, it is assumed that the rudders will be made from steel and the thickness of the rudders is equal to 5 cm. The weight of the rudders can then be calculated with the following relation:

$$\text{Weight}_{\text{rudders}} = N_{\text{Rudders}} \cdot L_{\text{rud}} \cdot H_{\text{rud}} \cdot t_{\text{rud}} \cdot \rho_{\text{steel}} \quad (M.2)$$

N<sub>rudder</sub> = number of rudders [-]  
 L<sub>rud</sub> = length of the rudder [m]  
 H<sub>rud</sub> = height of the rudder [m]  
 t<sub>rud</sub> = thickness of the rudder [m]  
 ρ<sub>steel</sub> = density of steel [kg/m<sup>3</sup>]

In figure M.1 the double rudder system of Van de Velde marin systems is shown.

Figure M.1: Double rudder system of Van der Velde Marin systems



<sup>56</sup> This relation is valid for container ships but is here applied for inland ships

## Appendix N.1: Determining working point propellers

In order to determine the working if the propeller, first the Kt-line of the tug (plus barges) must be determined with relation N.1.

$$K_t(\text{Tug}) = \frac{T_{\text{Prop}}}{\rho \cdot V_a^2 \cdot D_{\text{prop}}^2} \cdot J^2 \quad (\text{N.1.1})$$

$$V_a = V_s \cdot (1-w) \quad (\text{N.1.2})$$

The intersection of the KT-Prop-line and the KT-Tug-line will give the value of the advanced ratio (J). (Recall equation L.1.6 for the Kt propeller line)

$$\rightarrow KT_0 + KT_1 \cdot J + KT_2 \cdot J^2 + KT_3 \cdot J^3 = \frac{T_{\text{Prop}}}{\rho \cdot V_a^2 \cdot D_{\text{prop}}^2} \cdot J^2 \quad (\text{N.1.3})$$

This equation will be solved in the tug design model for J. When J is known, then also the KQ- and the  $\eta_0$ -value are known. (See equations L.1.7 and L.1.8) From the advanced ratio also the RPM of the propeller can be determined in the working point.

$$n = \frac{V_a}{J \cdot D_{\text{prop}}} \quad (\text{N.1.4})$$

n = propeller RPM [1/s]

## **Appendix N.2: Calculating propulsion efficiency and installed power**

The total propulsion efficiency can be calculated with relation N.2.1.

$$\eta_d = \eta_0 \cdot \eta_R \cdot \eta_H \cdot \eta_{\text{shaft}} \quad (\text{N.2.1})$$

$$\text{In which } \eta_R = 1, \eta_H = \frac{1-t}{1-w}, \eta_{\text{shaft}} = 0.97 \quad (\text{N.2.2})$$

The required installed power can be calculated with relation N.2.3.

$$P_b = \frac{R(V_s) \cdot V_s}{\eta_d} \quad (\text{N.2.3})$$

$R(V_s)$  = resistance of the tug plus barges as function of the required speed [N]

## Appendix 0: Gen-set data

Caterpillar					Dimensions			
Engine Name	Type	Engine Power	RPM	BSFC	Weight	L	B	H
[-]	[-]	[kW]	[rpm]	[g/kWh]	[kg]	[m]	[m]	[m]
MARINE C4.4	60Hz	42	1800	306.7	776	1.658	0.700	1.187
Marine 3304B	60hZ	69	1800	357.6	1225	2.400	0.979	1.273
MARINE C4.4	60 HZ	76	1500	306.7	776	1.658	0.700	1.187
MARINE C9 LEHM4965-00	60hZ	175	1800	293.3	1753	2.106	0.996	1.169
MARINE 3406C	50Hz	215	1500	216.8	3791	2.902	0.996	1.472
MARINE C18	50Hz	275	1500	199.5	3791	3.040	1.151	1.470
MARINE C18	50Hz	350	1500	192.8	3791	3.040	1.151	1.470
MARINE C18	50Hz	400	1500	195.8	3950	3.040	1.151	1.470
MARINE C18	50Hz	450	1500	200.7	4510	3.040	1.151	1.470
MARINE 3508B	50Hz	630	1500	198.5	5216	2.105	1.703	1.834
MARINE 3508B	60Hz	715	1500	208.5	5216	2.105	1.703	1.834
MARINE 3512B	50Hz	880	1500	205.8	8029	2.640	1.703	2.073
MARINE 3516B	50Hz	1180	1500	203.7	8029	3.180	1.785	2.052

Source: Caterpillar product data

## Appendix P: Diesel engine data

### Diesel Engine DATA Caterpillar

						Dimensions			
	Engine Name	Type	Engine Power	RPM	BSFC	Weight	L	B	H
			[kW]	[rpm]	[g/kWh]	[kg]	[m]	[m]	[m]
1	3056	C-Rating	93	2,600	202.0	595	1.068	0.779	0.801
2	3056	C-Rating	153	2,500	275.0	595	1.068	0.779	0.801
3	C7	C rating	235	1,800	216.4	799	1.224	0.942	0.933
4	C12	A-Rating	253	1,500	200.0	1,177	1.573	1.056	1.008
5	C18	A-Rating	339	1,400	198.1	1,673	1.560	1.089	1.247
6	C18	B-Rating	357	1,500	197.6	1,673	1.560	1.089	1.247
7	C18	C-Rating	530	1,600	209.3	1,718	1.560	1.089	1.247
8	C18	D-Rating	651	1,800	207.3	1,718	1.558	1.057	1.172
9	C18	E_Rating	747	1,800	212.7	1,718	1.558	1.057	1.172
10	3508B	C-HP	820	1,735	206.6	4,619	2.157	1.703	1.806
11	3512	A-RATING	900	1,200	204.9	6,532	2.645	1.703	2.052
12	3516	A-Rating	1,195	1,200	201.2	8,029	3.180	1.703	2.052
13	3512	D-Rating	1,305	1,800	225.9	6,532	2.645	1.703	2.052
14	3516	C-rating	1,491	1,800	201.2	8,028	3.690	1.703	2.052
15	3526B	B-Rating	1,566	1,600	203.1	7,795	3.187	1.703	2.052

Source: Caterpillar product data



## Appendix Q: Gearbox data

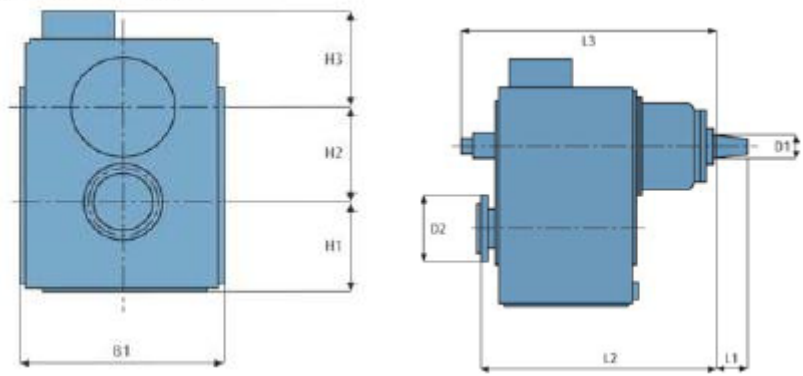
Reduction gear Reintjes

1. Single input, single output

Gear box	Type	P/N (Nm)	i	Weight (kg)	Dimensions		
					B	H	L
					[mm]	[mm]	[mm]
NR							
Reintjes 1	WAF144	0.17	3.950	460	640	810	635
Reintjes 2	WAF244	0.21	5.950	460	640	810	635
Reintjes 3	WAF274	0.25	7.409	730	830	1,165	670
Reintjes 4	WAF364	0.30	6.048	810	750	1,140	745
Reintjes 5	WAF464	0.40	5.905	940	800	1,285	745
Reintjes 6	WAF542	0.55	3.955	1,040	840	1,230	820
Reintjes 7	WAF665	0.70	5.905	1,800	1,160	1,500	980
Reintjes 8	WAF743	0.88	3.950	1,800	1,160	1,440	1,040
Reintjes 9	WAF843	1.15	3.905	2,450	1,300	1,555	1,110

Source: Reintjes product data

Types VLJ 430 - 2230:



## Appendix R: Fuel, lubrication and dirty oil tanks

### Fuel tanks

The fuel consumption of a single trip can be calculated with the following formula.

$$\text{Fuel}_{\text{con\_trip}} = \frac{2 \cdot (T_{\text{SR}} \cdot P_{\text{B\_SR}} + T_{\text{LR\_1}} \cdot P_{\text{B\_LR\_1}} + T_{\text{LR\_2}} \cdot P_{\text{B\_LR\_2}}) \cdot \text{SFC}_{\text{engine}}}{1000} \quad (\text{R.1})$$

$\text{Fuel}_{\text{con\_trip}}$	= fuel consumption per trip	[kg]
$T_{\text{SR}}$	= time spent on the small waterway	[h]
$P_{\text{B\_SR}}$	= power needed to sail on the small waterway (if chosen)	[kW]
SFC	= specific fuel consumption	[g/kWh]
$T_{\text{LR\_1}}$	= time spent on the large waterway (condition 1)	[h]
$P_{\text{B\_LR\_1}}$	= power needed to sail on the large waterway (condition 1)	[kW]
$T_{\text{LR\_2}}$	= time spent on the large waterway (condition 2)	[h]
$P_{\text{B\_LR\_2}}$	= power needed to sail on the large waterway (condition 2)	[kW]

The time spent on one or more selected waterways will be the summation of the total time spent on all the selected waterways. So if two different routes are selected, then the time spent on both waterways is taken into account.

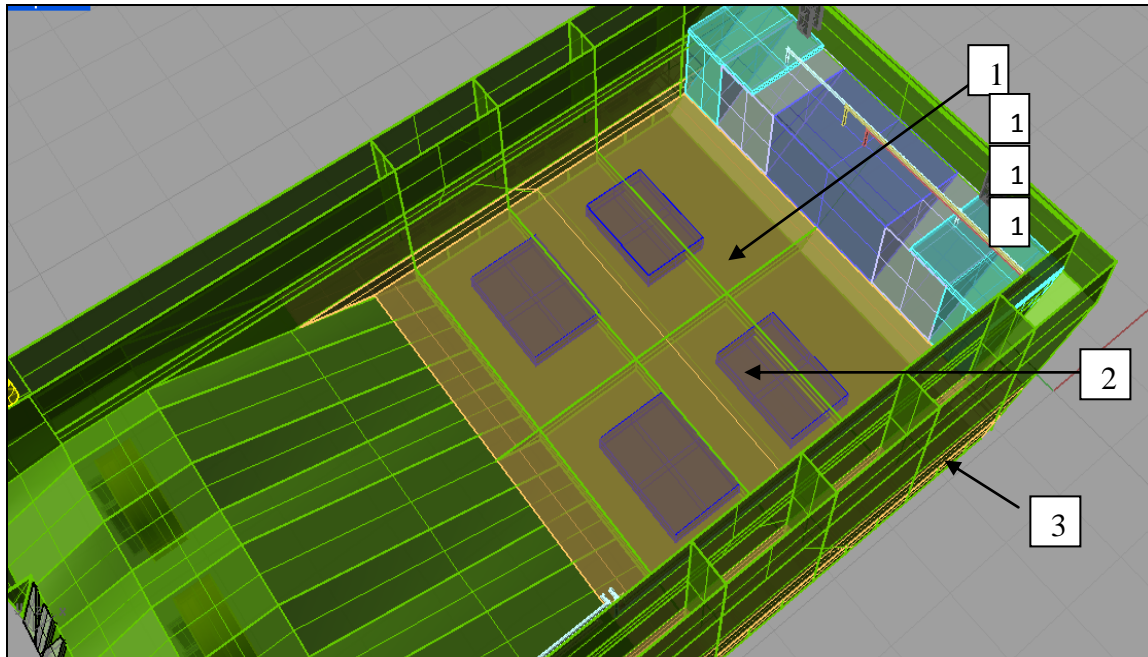
When a diesel electrical option is opted for, the values of SFC will change if the propulsion lay-out are designed for two different conditions then there will be two different SFC. In case of the diesel direct system there will be only one SFC. Formula 7.16 shows that the fuel consumption depends on the sailed speed in two different ways. The first way is that an increase in speed will lead to an increase in required power. The other way is that by a change in speed also the time will change. If the speed is increased the sailed time is decreased and vice versa. Therefore a reduction in speed will not automatically imply a reduction in fuel costs

The total amount of fuel that needs to be allocated in the tug will be determined by the given range of the tug. If one defines the range at 2, then the tug has to sail two times from the selected destinations in the seaport to the selected inland destination and back. The fuel oil is allocated in the double bottom of the tug. It is assumed that 25% of volume of the double bottom cannot be used to accommodate the fuel tanks. This space is taken by the construction parts of the double bottom. If more fuel needs to be placed in the tug, then the side tanks of the tug are filled up. If the side tanks are also completely filled, then the 3D model will show that the fuel tanks are sticking out of the tug. The, there are two different options: or he must reduce the range of the tug or he must redefine the main dimensions of the tug.

The fuel in the fuel tanks will be placed in a "normal" fuel tank, which will be used to allocate the fuel oil. In the same tank separate flexible tanks will be installed which will separate the ballast water from the fuel oil. This flexible tank will be similar to a balloon. If it is empty, the ballast tank will be small and when it is full with ballast water, it will expand in the fuel tank. The amount of ballast water that needs to be taken in will be determined by

the amount of fuel that is consumed. This will be done by a control system that will monitor the fuel consumption of the installed engines. In figure R.1 an overview of this system is given.

Figure R.1: Double tank layout with 4 different tanks in the double bottom and side tanks



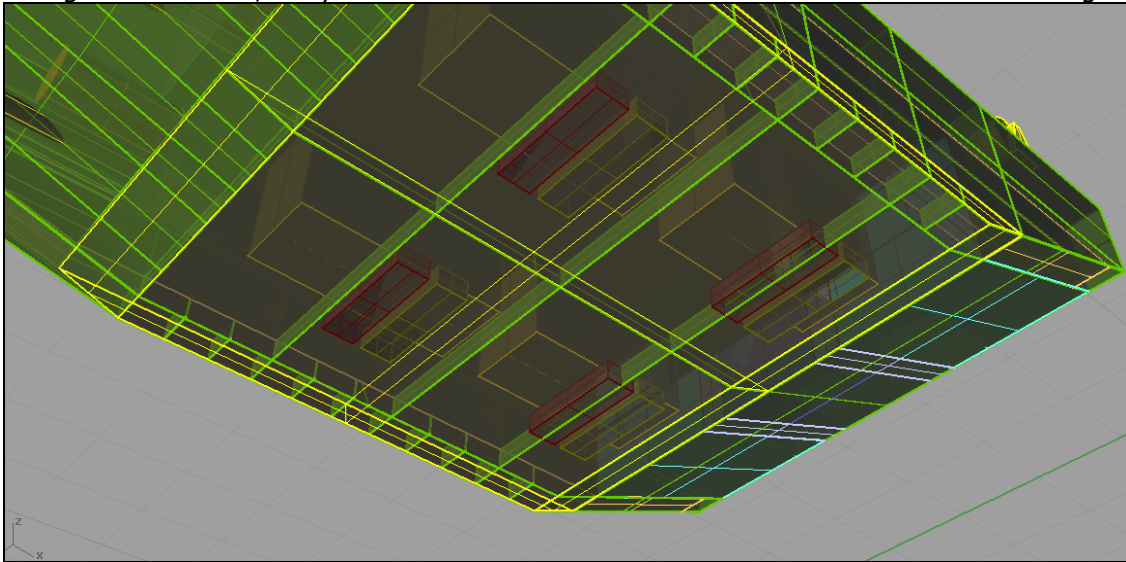
- 1) "Normal" fuel tank
- 2) Inflatable ballast tank located in the fuel tank
- 3) Side tank

By applying this double fuel tank concept, the fuel tank and ballast tank are combined into the same space so no additional space is required. An additional advantage is that the stability of the ship will not be affected because the ballast water will be in the same place as where the fuel oil was placed. So the ship in design condition and the same ship in ballast condition will have (almost) the same stability.

### *Dirty and lubrication oil tanks*

Besides the fuel tanks, also the dirty oil and lubrication oil tanks are taken into account in the design model. The amount of lubrication oil is taken from an example ship and the amount of dirty oil is set to be equal to the amount of lubrication oil. The tanks are also allocated in the double bottom of the tug and are located under the installed engines. The total available space for the fuel oil in the double bottom is diminished by the volume of the lubrication and dirty oil tanks. In figure R.2 the tank allocation is given in the double bottom of the tug.

Figure R.2: Fuel, dirty and lubrication oil tanks in the double bottom of the tug



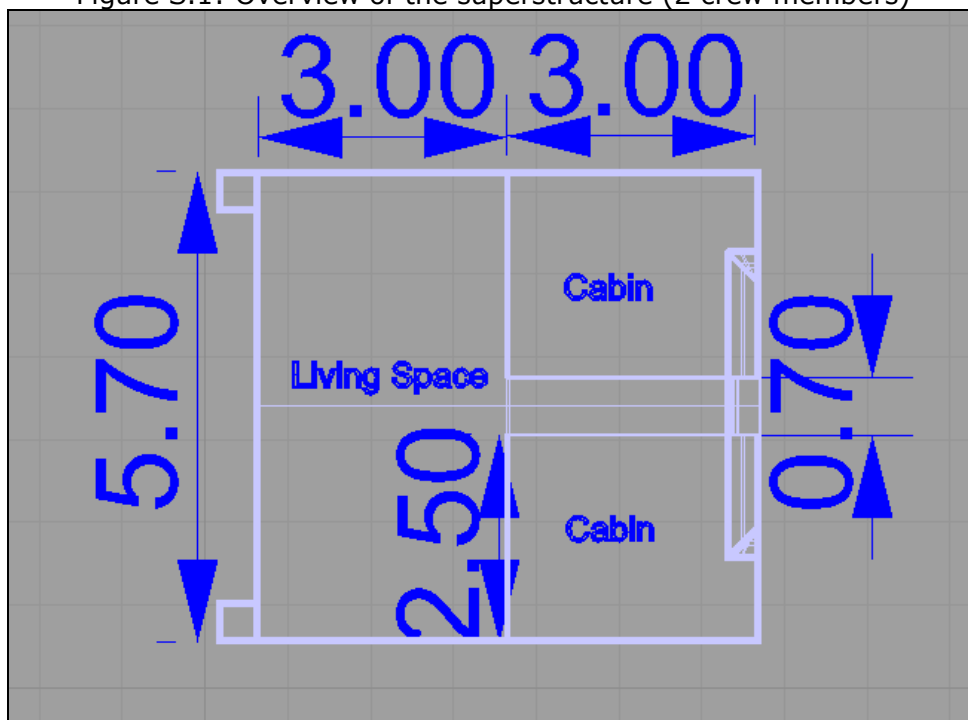
## Appendix S: Accommodation design

In the accommodation captains and quartermaster will have a single cabin, while the other crew members have to share a cabin if that is necessary. In those crew cabins a bunk bed will be placed.

The total width of the accommodation will be determined by the double width of two cabins plus an extra 70 cm. That extra 70 cm will be the width of the hall way between the cabins. At the end of the hall way a door will be placed, which will connect the accommodation with the wheelhouse when it is in the lowered position.

Besides the space that is needed for the cabins there is also space needed for the galley and a common space for the crew. The required space will be determined by the rules of the shipping inspection and is again a function of the number of crew members. The width of that space is set at the total width of the accommodation, where the length is a function of the required available space. A schematic overview of the superstructure is given in figure S.1. In this overview 2 crew members can be accommodated in the superstructure.

Figure S.1: Overview of the superstructure (2 crew members)



The weight of the accommodation is determined with the method of Watson (1998). This relation is given in formula R.1, in which the effect of choosing to construct the accommodation from aluminium is already taken into account.

## Appendices

$$W_{ss} = (0,36 + 0,09 \cdot \frac{B_{ss}}{H_{ss}}) \cdot 0,5 \cdot L_{ss} \cdot H_{ss} \cdot (0,68 + (0,068 + 0,3 \cdot \frac{T}{D}) \cdot (\frac{L_{tug}}{100})^2) \wedge L_{ss} < 0,15 \cdot L_{tug} \quad (S.1)$$

$$W_{ss} = (0,36 + 0,12 \cdot \frac{B_{ss}}{H_{ss}}) \cdot 0,5 \cdot L_{ss} \cdot H_{ss} \cdot (0,68 + (0,068 + 0,3 \cdot \frac{T}{D}) \cdot (\frac{L_{tug}}{100})^2) \wedge L_{ss} \geq 0,15 \cdot L_{tug}$$

$W_{ss}$  Weight superstructure [tonne]

$L_{ss}$  = length superstructure [m]

$B_{ss}$  = width superstructure [m]

$H_{ss}$  = height superstructure [m]

$L_{tug}$  = Length of the tug [m]

It is assumed that the calculated weight of the superstructure is the total weight inclusive of the total equipment such as tables, beds, the galley, etc.

## Appendix T: Stability and trim calculations of the tug

### Initial stability

In order to calculate the GM-value first the centre of buoyancy in height needs to be determined with the following relation.

$$KB = \frac{(\text{Displ}_{\text{mid}} \cdot \frac{T}{2} + \text{Displ}_{\text{fore}} \cdot \frac{2}{3} \cdot T + \text{Displ}_{\text{aft}} \cdot \frac{2}{3} \cdot T)}{\text{Displ}_{\text{Tot}}} \quad (\text{T.1})$$

$\text{Displ}_{\text{mid}}$  = displacement of the mid part of the tug [m<sup>3</sup>]  
 $\text{Displ}_{\text{for}}$  = displacement of the for part of the tug [m<sup>3</sup>]  
 $\text{Displ}_{\text{aft}}$  = displacement of the aft part of the tug [m<sup>3</sup>]  
 $\text{Displ}_{\text{tot}}$  = displacement of the tug [m<sup>3</sup>]

The moment of inertia of the waterline can be calculated with the following relation.

$$I_t = \frac{L \cdot B^3}{12} \quad (\text{T.2})$$

The value of KB can now be determined with  $I_t$  and the displacement.

$$KB = \frac{I_t}{\text{Displ}_{\text{total}}} \quad (\text{T.3})$$

The value of KG of the tug has been calculated with calculated weight data of all the components that are placed in the tug including the hull of the tug. The value of GM can now be determined with:

$$GM = KB + BM - KG \quad (\text{T.4})$$

The values of GZ (up to 20 degrees) (angles of inclination) can be determined with the formula of Scrabanti and is given in the next relation:

$$GZ = (GM + \frac{1}{2} \cdot BM \cdot \tan(\phi)^2) \cdot \sin(\phi) \quad (\text{T.5})$$

### Trim

Besides the KG of the tug also the longitudinal centre of gravity (Lcg) of the tug will be calculated in the model. Also the Lcb of the hull of the tug will be determined. The difference between those two values is the trim of the tug.

$$\text{trim} = Lcg - lcb \quad (\text{T.6})$$

When the trim of the tug is not equal to zero, then the model will add ballast to the tug. The amount of ballast needed to trim the tug can be calculated with the following relation:

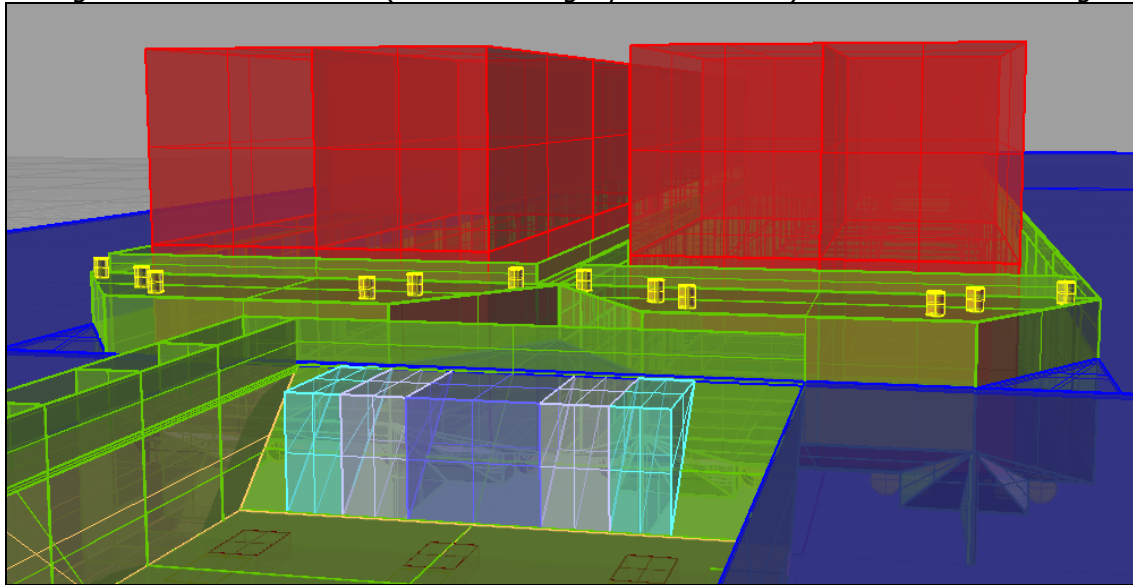
$$\text{Weight}_{\text{Ballast}} = \frac{\text{trim} \cdot [\text{total\_Weight}_{\text{tug}}]}{\text{Lcb} - \text{Lcg}_{\text{ballast}}} \quad (\text{T.7})$$

$\text{Lcg}_{\text{Ballast}}$  = longitudinal centre of gravity of the ballast [m]

$\text{Total\_weight}_{\text{tug}}$  = total weight of the tug, without the weight of the ballast [kg]

In order to perform this calculation, it is necessary to predefine the Lcg of the ballast. Therefore the location of the ballast is set to be in the bow of the tug. The ballast in the tug below the waterline is given in figure T.1.

Figure T.1: Fixed ballast (and fresh + grey water tanks) in the bow of the tug



Due to the hull shape of the tug, the tug will have a negative trim, i.e. the tug will be trimmed backwards; therefore ballast in the bow is necessary. Because this trim is due to the hull shape of the tug and is always present, it is chosen to use steel as fixed ballast material. The tug could also be trimmed with ballast tanks filled with water but that would take too much space compared with the fixed ballast. Another disadvantage of using water filled ballast tanks is that the ballast tanks will have to be filled all the time. Therefore there is no need for them to be empty. In order to fill the bow, the ballast is split up into two different parts, a part below the waterline and a part above the waterline. To have a constant Lcg of the ballast below the waterline, the ballast space will be filled sideways instead of from bottom to top. There is a maximum amount of ballast that can be installed due to space restrictions. A part of the bow will also be used to allocate the fresh and the grey water tanks.

If more ballast is needed to trim the tug, more ballast will be installed above the waterline. Because of the rectangular shape (and therefore constant Lcg) this ballast is filled from bottom to top. Not all the space in the bow of the ship will be used to allocate ballast tanks. A part is not used because the hydraulic equipment for the movable wheelhouse and winches will be placed there. To calculate the amount of ballast needed above the waterline, a new trim calculation will be done where also the reduced trim (also including the ballast below the waterline) is used.



If there is more ballast needed than that there can be installed in the bow of the tug, the model will give the value of the trim for maximum ballast instalments. It is then to be decided if that trim is accepted or that the design of the tug must be adjusted. The total weight of the ballast will also have an effect on the total weight of the tug (and also on the displacement) and the stability of the tug.

## Appendix U: Waiting time in the port

Waiting times in the port of Antwerp and Rotterdam



Minimum waiting time Antwerp = +/- 7 hours

Minimum waiting time Rotterdam = +/- 7 hours

Source: www. Rhinecontainer.nl visited in 2009

## Appendix V.1: Design data case I

Design data: tug and barge convoy to routes one (2 barges), route two (4 barges) and route 3 (2 barge).

Main DATA Barge			Main DATA Push Ship		
accept design solution	[-]	<b>ok</b>			
L	[m]	50.00	L	[m]	12.71
B	[m]	6.80	B	[m]	6.80
T	[m]	1.90	T	[m]	1.45
D	[m]	2.66	D	[m]	2.11
Displ	[m³]	597.57	Displ	[m³]	76.25
LW	[kg]	99,689	Weight_total_Tug	[tonne]	76.03
TEU	[-]	28	V	[m/s]	3.50
Weight Payload	[kg]	498,033	V_2	[m/s]	3.50
<b>AirGap</b>	<b>[m]</b>	<b>3.72</b>	Pb_2	[kW]	0.00
<b>GM</b>	<b>[m]</b>	<b>0.78</b>	Pb_1	[kW]	705
<b>GM_LW</b>	<b>[m]</b>	<b>11.16</b>	Pb_Elec	[kW]	150
# Batt	[-]	174	Pb_Batt	[kW]	98.79
Fuel tank	[m³]	0.00	Diesel electric	[-]	0
Pb_Barge	[kW]	169	<b>GM</b>	<b>[m]</b>	<b>3.39</b>
Thruster_margin	[%]	94.16	<b>trim</b>	<b>[m]</b>	<b>0.00</b>
New building Costs	[EUR]	446,094	Rudders	[-]	6
Independend sailing	[-]	Yes	New building costs	[EUR]	1,229,372
One captain per barge	[-]	Yes			

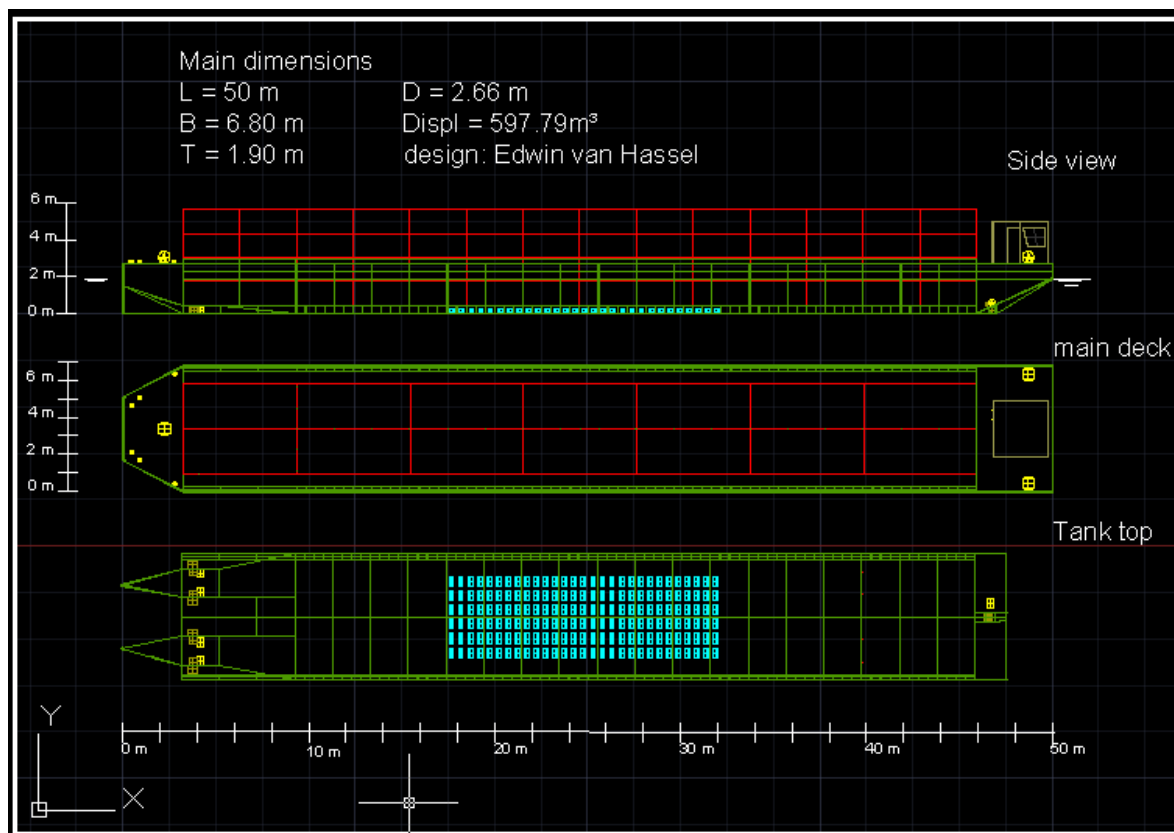
## Appendix V.2: Design data case II

Design data: Tug and barge convoy to route two (4 barges) and route three (4 barges) while two barges are pushed to the ICTs on the selected routes

Main DATA Barge			Main DATA Push Ship		
accept design solution	[-]	<b>Ok</b>			
L	[m]	50.00	L	[m]	12.12
B	[m]	6.80	B	[m]	7.20
T	[m]	1.90	T	[m]	1.35
D	[m]	2.66	D	[m]	2.17
Displ	[m³]	597.59	Displ	[m³]	73.02
LW	[kg]	99,806	Weight_total_PS	[tonne]	73.30
TEU	[-]	28	V	[m/s]	3.50
Weight Payload	[kg]	498,033	V_2	[m/s]	3.50
<b>AirGap</b>	<b>[m]</b>	<b>3.72</b>	Pb_2	[kW]	0.00
<b>GM</b>	<b>[m]</b>	<b>0.77</b>	Pb_1	[kW]	1017.00
<b>GM_LW</b>	<b>[m]</b>	<b>11.15</b>	Pb_Elec	[kW]	150.00
# Batt	[-]	168	Pb_Batt	[kW]	247.99
Fuel tank	[m³]	0.00	Diesel electric	[-]	0
Pb_Barge	[kW]	169.20	<b>GM</b>	<b>[m]</b>	<b>4.06</b>
Thruster_margin	[%]	94.26	<b>trim</b>	<b>[m]</b>	<b>0.00</b>
New building Costs	[EUR]	444,368	Rudders	[-]	6
Independed sailing	[-]	Yes	New building costs	[EUR]	1,318,953
One captain per barge	[-]	Yes			

## Appendix V.3: General arrangements barge and tug

### General arrangement of the barge



# General arrangement of the tug

